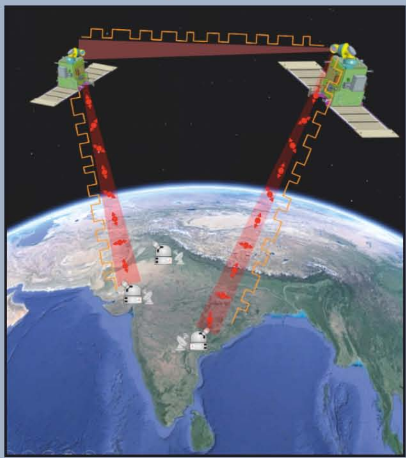
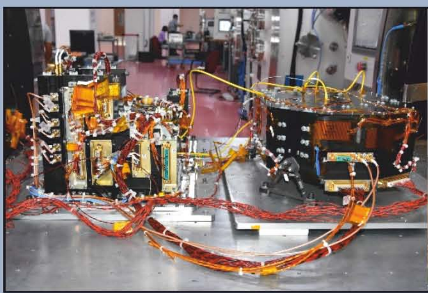
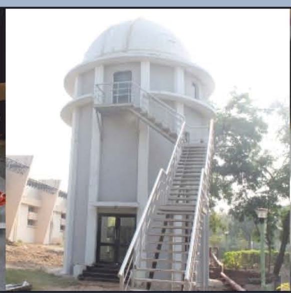
Research Areas of SAC

-A compendium of Themes for Sponsored Research

May - 2025





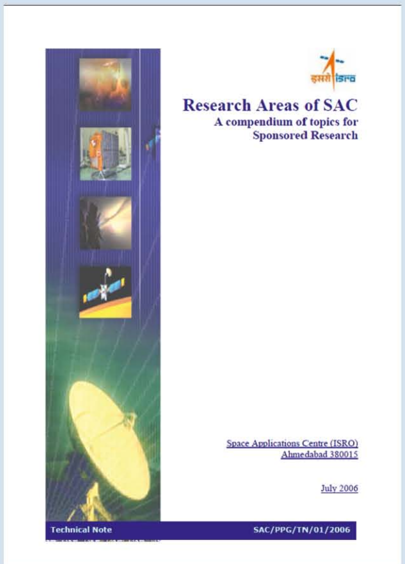


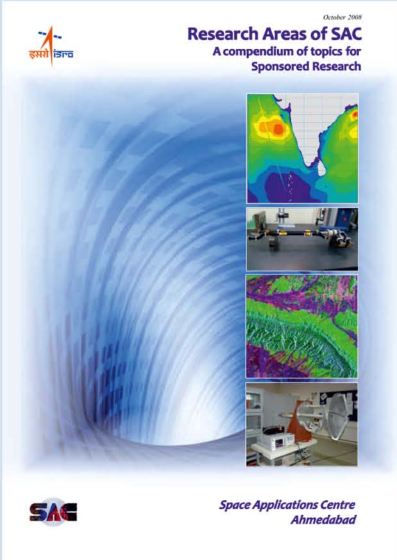
Marching Towards Quantum Leap : For a Connected, Secure Future

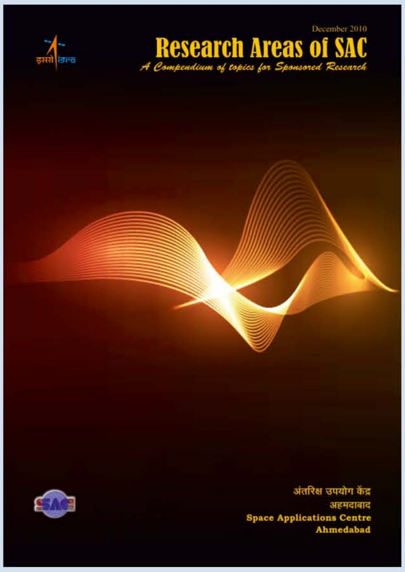
अंतरिक्ष उपयोग केंद्र, इसरो, अहमदाबाद

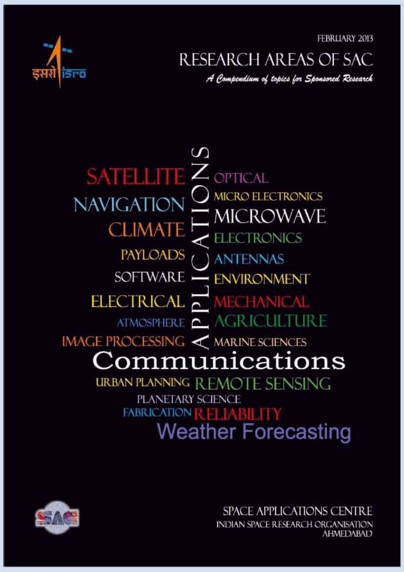
Space Applications Centre, ISRO, Ahmedabad

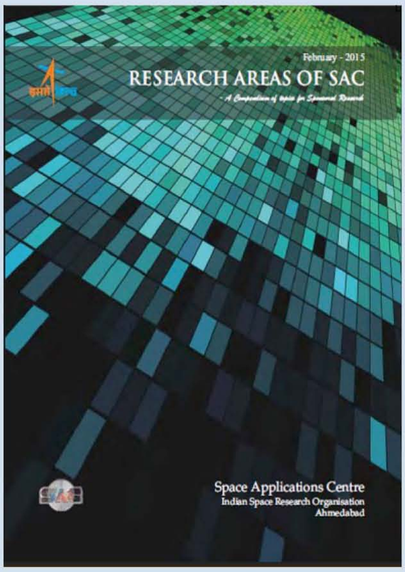
Proactive approach for Research Solicitation From Academia

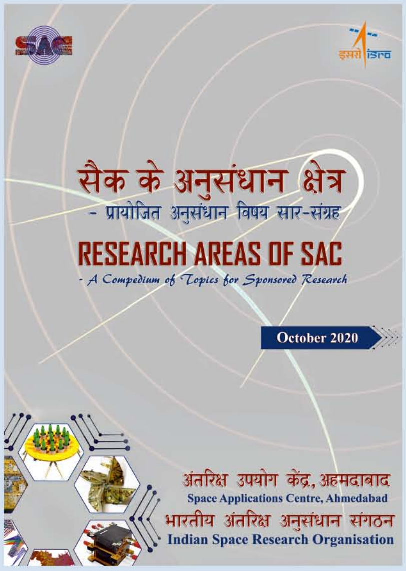


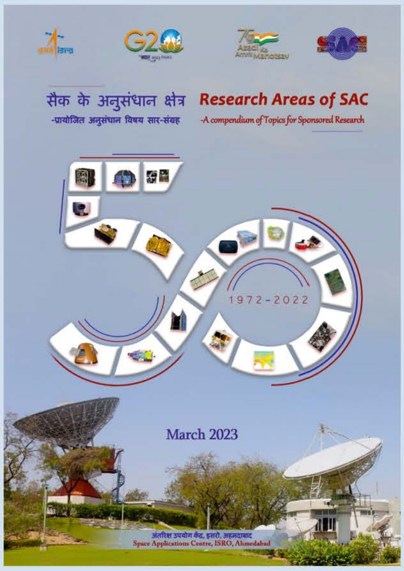












सैक के अनुसंधान क्षेत्र

प्रायोजित अनुसंधान विषय सार-संग्रह

Research Areas of SAC

A compendium of Themes for Sponsored Research

Soliciting proposals from Academia

May 2025

अंतरिक्ष उपयोग केंद्र, इसरो, अहमदाबाद

Space Applications Centre, ISRO, Ahmedabad

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जय हिन्द
एन एम देसाई / N M Desai
विशिष्ट वैज्ञानिक/ Distinguished Scientist
निदेशक / Director

सत्यमेव जयते

भारत सरकार GOVERNMENT OF INDIA
अंतरिक्ष विभाग DEPARTMENT OF SPACE
अंतरिक्ष उपयोग केंद्र
SPACE APPLICATIONS CENTRE
अहमदाबाद AHMEDABAD - 380015
(भारत) / (INDIA)
दूरभाष / PHONE:+91-79-26913344, 26928401
फैक्स / FAX : +91-79-26915843
ई-मेल / E-mail: director@sac.isro.gov.in

FOREWORD

Space Applications Centre (SAC) is one of the major multi-disciplinary R&D Centre of ISRO. Since it's inception fifty-two years back, SAC has been significantly contributing to Indian Space Programme for national development. Evolving with the technological advancements and applications driven approach, SAC has proven it's core competence in the development of space and air borne instruments/payloads ranging from remote sensing, satellite communication to meteorology, navigation, planetary exploration as well as Country's future Human Spaceflight Programme '*Gaganyaan*'.

It gives me immense pleasure to present the **'Research Areas of SAC 2025: *A Compendium of Themes for Sponsored Research*'**, a well curated document prepared by our Research Management Team to inspire, invite, and engage with the vibrant academic and scientific community across India. ***The year 2025 holds particular significance, being declared 'International Year of Quantum Science and Technology', by United Nations.*** As a ***lead Centre of ISRO contributing towards National Quantum Mission, we are working to harness the transformative potential of quantum technologies across communication, sensing and computing.*** This document presents an overview of our Centre's activities with information on our EO applications driven web portals, glimpses of recent payloads developed at SAC, Sponsored Research at SAC and details on promising research themes in each of the thirteen entities of the Centre. Aligned with the national priorities, SAC's proactive commitment to pioneering quantum-driven space applications is also reflected on the cover page of the document. The document also informs about all procedures and necessary guidelines to academia for submitting research proposals under different capacity building avenues of Sponsored Research at SAC.

I envision this document not merely as a solicitation, but as an invitation to brilliant minds in various academic and research institutions across the country, who are eager to contribute, while working hand-in-hand with us towards advanced R&D and technology developments in new frontiers of space research. I believe our collaborations with academia continue to be a cornerstone of innovation, enabling knowledge exchange and capacity building for ensuring a quantum leap in Space frontiers and contribute to the ***country's vision and aspirations of 'VIKSIT BHARAT: 2047***. I may add that the scope of R&D is not limited to research themes mentioned in this document and academia are encouraged to propose further research in related areas to strengthen Indian Space Programme.

(निलेश एम देसाई) / (N M Desai)
निदेशक/Director

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Contact Details

This compilation is based on inputs from constituent entities of SAC who can be contacted for consultation related to their areas of research activities:

SAC:			
Director, SAC	Shri Nilesh M Desai	director@sac.isro.gov.in	3344*
Associate Director, SAC	Shri Sumitesh Sarkar	s_sarkar@sac.isro.gov.in	3349
Area Specific:			
SATCOM & Navigation Payloads	Dr. S C Bera	scbera@sac.isro.gov.in	8351/8350
SATCOM & SATNAV Applications	Dr. K K Sood	kksood@sac.isro.gov.in	3608
Antenna Systems	Dr. M B Mahajan	mb_mahajan@sac.isro.gov.in	2114/2115
Electro-Optical Sensors	Shri Somya S Sarkar	sssarkar@sac.isro.gov.in	3853/54
Microwave Remote Sensors	Dr. Ch V N Rao	cvnrao@sac.isro.gov.in	5220/5221
Human Spaceflight & Advanced Technologies	Dr. M Senthil Kumar	senthil@sac.isro.gov.in	2238/2239
Signal & Image Processing	Shri Debajyoti Dhar	deb@sac.isro.gov.in	4148
Earth, Ocean, Atmosphere, Planetary, Space Sciences & Applications	Dr. Rashmi Sharma	rashmi@sac.isro.gov.in	4024
Electronics, Microwave & Microelectronics Design & Fabrication	Smt. Punam Pradeep Kumar	punam_tyagi@sac.isro.gov.in	2334/ 2355
Mechanical Engineering Systems	Shri. Arup Kumar Hait	akh@sac.isro.gov.in	3306/3305
Systems Reliability Safety & Human Rating	Kum Shilpa Pandya	shilpa@sac.isro.gov.in	5027/26
Cyber Security and Information Technology	Shri D K Patel	dk@sac.isro.gov.in	5135
Management & Information Systems	Shri Vivek Singh	dd-misa@sac.isro.gov.in	3312
RESPOND @ SAC, Ahmedabad:			
Group Director, RTMG	Dr. Dhani Ram Rajak	gd-rtmg@sac.isro.gov.in	3339
Head, RESPOND & Research Management Division & Coordinator, RESPOND	Dr. Abha Chhabra	research_sac@sac.isro.gov.in	3333
RESPOND @ ISRO HQ, Bangalore:	respond@isro.gov.in	080- 23415269, 22172269	

Four digit Numbers xxxx at SAC, Ahmedabad can be reached by dialing 079-2691XXXX

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7.	Abstract	This document highlights key research themes from each of the thirteen entities of the centre. It helps in soliciting research proposals from Academia for relevant sponsored research R&D activities at SAC. The document also informs all procedures and necessary guidelines to academia for submitting research proposals under different capacity building avenues of ISRO under Sponsored Research at SAC.
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SAC is a unique Centre of ISRO with multidisciplinary technical areas and R&D pursued in each technical areas by passionate Scientists/Engineers. This document is a compilation of valuable inputs generated from each of the technical areas as a result of several brainstorming and reviews by senior management.

We express sincere thanks for all the inputs received from all Deputy Directors, Group Directors, Group Heads, Division Heads, Scientists/Engineers and other technical personnel in preparing this document and bringing it to academia.

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Abha Chhabra
Ankita Vishal Patel

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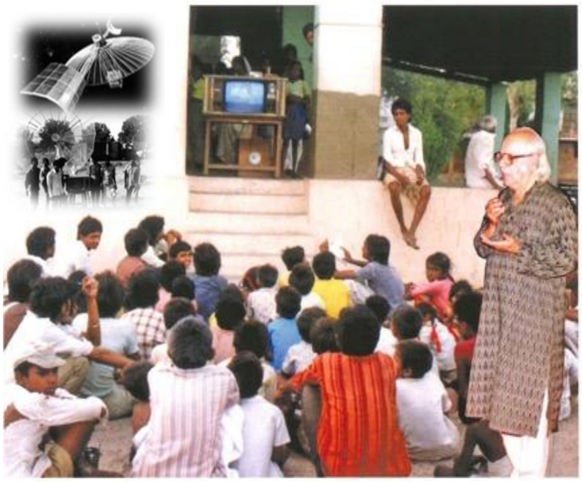
1. INTRODUCTION

Space Applications Centre (SAC), Ahmedabad is a major R&D Centre of the Indian Space Research Organisation (ISRO) with focus on the design of space-borne instruments for ISRO missions and development and operationalisation of applications of space technology for societal benefits. Driven by the vision laid down by Late Dr. Vikram A Sarabhai, *Father of Indian Space Programme*, SAC has been significantly contributing towards Indian Space Programme for National development. During it's Golden Journey of Excellence of 52+ years, SAC has delivered more than 100 payloads for various ISRO Missions and over 100 applications for various users. Today, SAC stands high in each of its endeavour with its strong R&D capabilities and continues to deliver world-class technologies and applications for various national, strategic, societal and technology demonstration missions of ISRO. These applications are in diverse areas and primarily meet the communication, navigation and remote sensing needs of the country.

The genesis of this Centre dates back to 1966 when first Experimental Satellite Communication Earth Station (ESCES) was established, it's formal existence came into being in 1972. The different units of ISRO in Ahmedabad pursuing research in applications of space technology were merged to form Space Applications Centre (SAC). The success journey of SAC/ISRO started with Satellite Instructional Television Experiment (SITE) during 1975-76 under the esteemed leadership of Late Prof. Yashpal, the first Director of Space Applications Centre. The year 2025 marks the Golden Jubilee anniversary of SITE Programme, a landmark initiative that revolutionized satellite-based communication for education and development in India. SITE showcased the power of space-based communication but also laid the foundation for India's present-day satellite broadcasting and tele-education systems. SITE was conceptualised

First Experimental Satellite Communication Earth Station (ESCES), Ahmedabad in 1967



SITE programme initiated in 1975 under leadership of Prof. Yashpal, first SAC Director

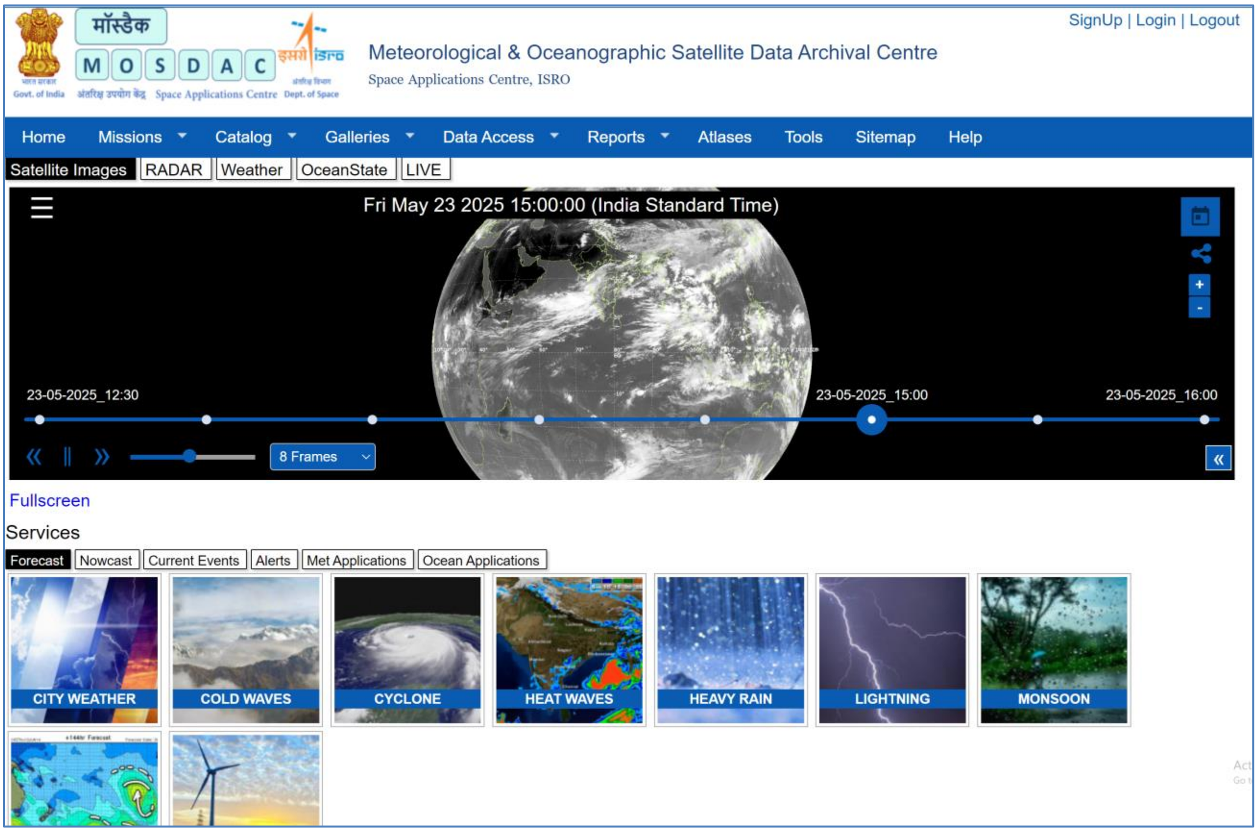
1.1. Overview of SAC Activities

Currently, SAC is spread across three beautiful, green eco-friendly campuses having multi-disciplinary activities. The lush green main campus in satellite area is spread over 90 acres area has rich biodiversity and marked with legendary Ahmedabad Earth Station. The other two campuses i.e. SAC Bopal Technical Campus and New Bopal Campus are spread over 14.7 and 39.9 acres, respectively. SAC also operates and maintain Delhi Earth Station at Delhi.

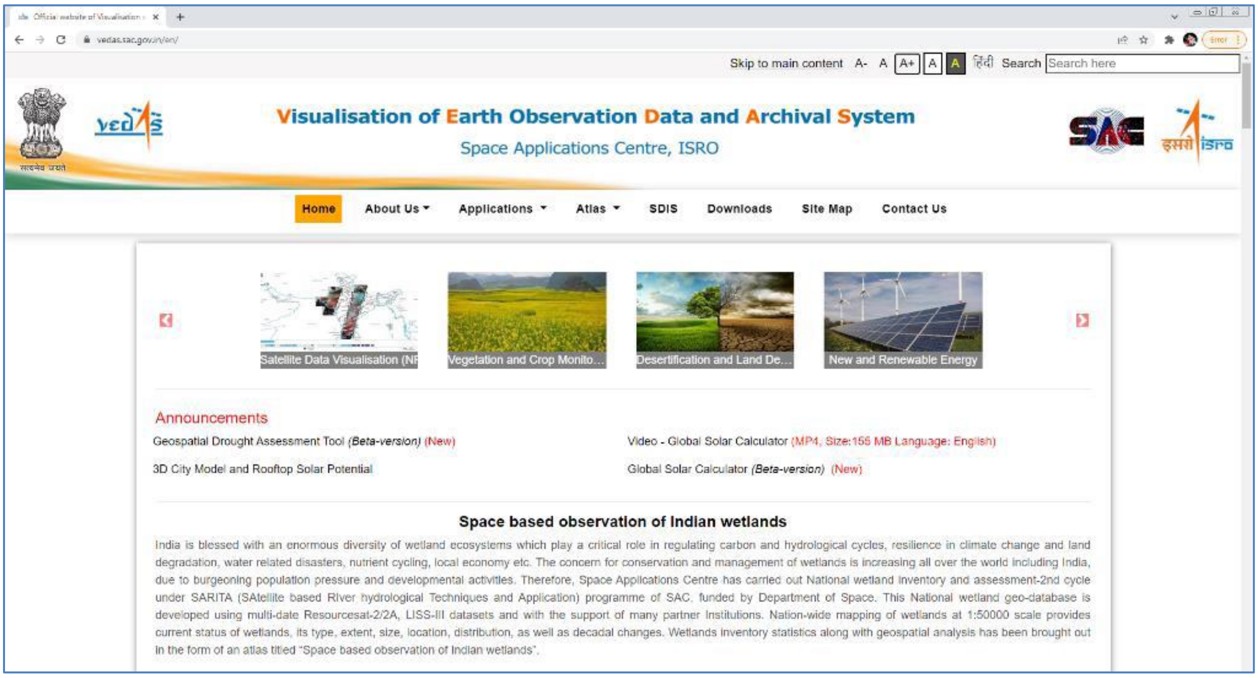
SAC focuses on the design of Space-borne instruments for ISRO missions and development and operationalisation of applications of space technology for societal and national development. The communication transponders developed at this centre for Indian National Satellite (INSAT) and Geo Synchronous Satellite (GSAT) series of satellites are used by government and private sector for VSAT, Direct To Home (DTH), internet, broadcasting, telephony etc. These satellites are instrumental in establishing communications in remote parts of the country as well. The payloads for major navigation systems of the country-Indian Regional Navigation Satellite System (IRNSS) and GPS Aided Geo Augmented Navigation (GAGAN) have been developed at SAC. This centre designs and develops the optical and microware sensors for the satellites, signal and image processing software, GIS software and many applications for Earth Observation (EO) programme of ISRO. These applications are in diverse areas of Geosciences, Agriculture, Environment and Climate Change, Physical Oceanography, Biological Oceanography, Atmosphere, Cryosphere, Hydrosphere etc.

Meteorological & Oceanographic Satellite Data Archival Centre (MOSDAC) is a data portal of SAC and has facility for satellite data reception, processing, analysis and dissemination. MOSDAC is operationally supplying earth observation data from Indian meteorological and oceanography satellites, to cater to national research requirements.

Visualization of Earth observation Data and Archival System (VEDAS) is a web platform developed for archival and dissemination of thematic data and data products generated by SAC or in collaboration with other participating agencies. The derived information is used to develop custom crafted geo-spatial applications which can feed into or support the decision-making system. VEDAS provides a platform (data, infrastructure and guidance) for utilisation of information derived over land using mainly Indian space-borne sensors to develop custom crafted geo-spatial applications which can feed into or support the decision making system. It is expected that with such a handshake between data generators and potential analysts, newer and innovative ways will emerge which will facilitate identifying hot-spots and discovering hidden patterns in the spatio-temporal data. VEDAS motivates and encourages talent pool of analysts such as students, researchers and academia to use these data to showcase their spatio-temporal analytical skill. To achieve this goal, VEDAS provides necessary training to familiarize with the data and processing that has taken place to generate thematic layers.

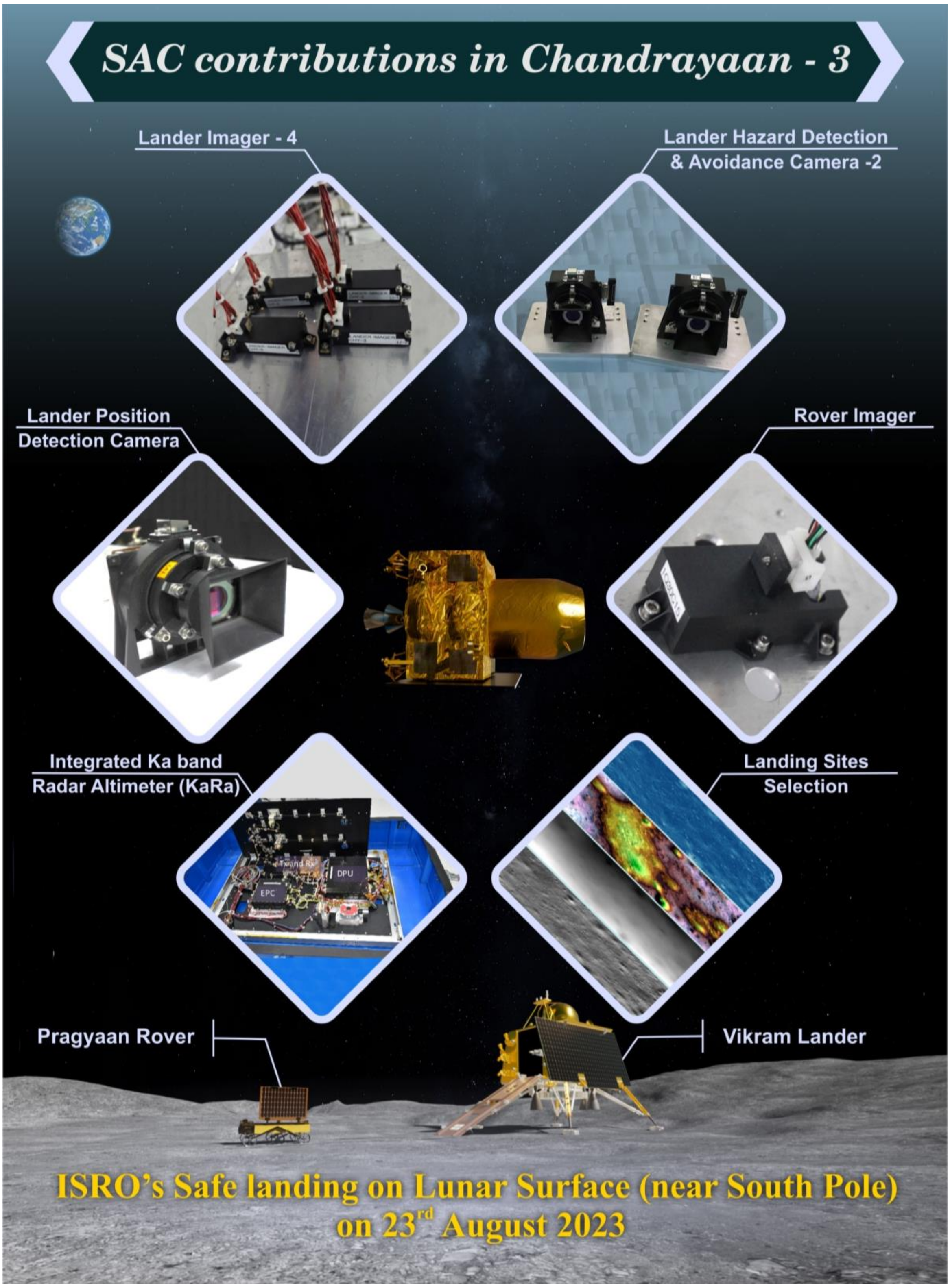


MOSDAC web Portal: https://www.mosdac.gov.in



VEDAS web Portal: https://vedas.sac.gov.in/

SAC also continues to significantly contribute to the scientific and planetary missions of ISRO and Advanced R&D for critical technologies development needed for future space missions. One of the recent milestones of ISRO include the success of ***Chandrayaan-3 mission. SAC realized 11 critical technologies for India's 3rd Lunar Mission,*** which contributed to successful soft-landing on South Pole of the Moon. It included Lander and Rover Cameras, Radar Altimeters, Hazard Detection and Avoidance Systems etc. SAC continues to contribute towards ISRO's future lunar Missions.



Marching ahead, in recent times, SAC has been actively contributing for conceptualizing system configuration and integration activities related to Crew Cabin and Communication Systems for Gaganyaan mission and associated technology developments, simulators and ground segment elements. There is a strong thrust in R&D for streamlining futuristic advance technology developments in the field of free space Optical Communication, Atomic Clock, Microwave TWTA, Terahertz technologies, Quantum Frontiers (Quantum Communication & Quantum Radar) & associated photonics technologies as well. ***Some of the recent payloads are shown in picture below:***

SAC is leading the development of Quantum technologies for future Space Based Quantum Communication and Quantum Sensing. SAC has already made an important breakthrough with demonstration of free-space Quantum Key Distribution (QKD) over 300m, which happens to be India's first-ever end-to-end free space Quantum communication link experiment. Further, a QuantESS (quantum entanglement studies in space) payload has been realised. SAC is leading the development of payloads for SAQTI Mission (Opto-Quantum Communication), under National Quantum Mission (NQM).

The payload related development are shown below and also showcased on the document cover page.

SAC also has state-of-the art laboratory facilities including highly sophisticated payload integration laboratories, electronic and mechanical fabrication facilities, environmental test facilities, GIS and image processing and analysis facilities. Systems Reliability Area provides formulation of quality systems, procedures and guidelines, ensuring their compliance for the realization of highly reliable systems used in satellite payloads for communication, optical & microwave remote sensing, planetary missions, as well as ground based systems.

The technical areas are supported by a well-structured Management and Information Systems Area, responsible for streamlining the activities related to Project Planning, Budgeting, Human Resource Development, RESPOND & Research Management, Training and Outreach and Technology Transfer and Industry Interface. RESPOND & Research Management is responsible for coordination and management of various In-house Technology Development, Advanced R&D activities as well as Sponsored Research with academia through diverse Capacity building avenues of ISRO.

SAC lays lot of The Centre also conducts nine-month post graduate diploma courses for students from the Asia Pacific region under the aegis of the Centre for Space Science and Technology Education (CSSTEAP) in Satellite meteorology, Satellite communication and Global Navigation Satellite Systems. Specialised training programmes like SMART (Satellite Meteorology and Oceanography Research and Training) and TREES (Training and Research in Earth Eco-System) are also conducted to promote and encourage graduate and post graduate students, professionals from academia and researchers across the country to pursue research in the field of satellite meteorology & oceanography and Earth ecosystems, respectively.

SAC has active collaborations with industry, academia, national and international institutes and space agencies for research and development. The industry portal provide opportunities for technology transfer/consultancy between SAC and private/public/MSME sector industries with the objective of faster industrial growth.

Centre has a well-stocked library with vast collection of knowledge resources and innovative information services.

SAC also has state-of-art in-house Vikram Sarabhai Space Exhibition and mobile exhibition to propagate space technology and applications amongst students and public and outreach to rural and remote areas of the country. SAC also organise special outreach events viz. World Space Week, National Space day, National Technology day and during special launch missions, astronomical events etc. Various competitions for different age groups are organised during these events. These competitions range from panting competition for primary students to hackathons and other challenges for professional students as well as interactions with senior scientists and engineers.

Vikram Sarabhai Space Exhibition at SAC Ahmedabad

Space on Wheels : Vikram Sarabhai Mobile Space Exhibition of SAC Ahmedabad

2. SPONSORED RESEARCH PROGRAMME

Cutting-edge research and innovation are core ingredients for national development with science and technology. The world is witnessing an exponential growth of technology in every domain of life. Research and Development (R&D) activities form the engine for futuristic technical advancement. Indian Space Research Organisation (ISRO) started the Sponsored Research (RESPOND) programme in the 1970s, with the primary objective of encouraging academia to participate and contribute in various space related research activities. This is one of the flagship programme of ISRO with an aim to establish strong links with academic institutions to carry out quality R&D projects of relevance and derive useful deliverables to support ISRO's ongoing and future missions. It also facilitate enhancing academic base and capacity building through human resources and laboratory infrastructure at the academic institutions across the country to support the goals and objectives of Indian Space Programme.

Sponsored Research which was initiated as RESPOND program way back in 1970s, has grown manifold under several Capacity Building initiatives by ISRO. These include RESPOND, RESPOND Basket, Space Technology Cell (STC) at premier Indian Institutes of Technology (IITs), IISc Bengaluru and Savitribai Phule Pune University (SPPU), ISRO's Regional Academic Centre for Space (RAC-S), Space Technology Incubation Centres (S-TIC), Centre for Nanoscience and Engineering (CeNSE), IISc Bangalore, Advanced Space Group at Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram.

SPONSORED RESEARCH AT SAC

SAC is in forefront of ISRO's Sponsored Research programme. '*Sponsored Research at SAC'* with academia across the country is an integral part in it's journey. A large number of academic institutes and universities have been participating in Sponsored Research at SAC being carried out under RESPOND, RESPOND Basket, STC, RAC-S, S-TIC. In addition, SAC is also actively participating in R&D projects under national mission like Uutachar Avishakar Yojna (UAY) programme of Ministry of Education (MoE) and partially funded by ISRO.

SAC has a proactive approach for research solicitation from academia. So far, thirty five Interest Exploration Meetings (IEMs) have been organised with academia institutions across the various geographic regions of the country to encourage and promote academia towards space research activities.

Special efforts have been taken to organise Interest Exploration Workshops at Regional level inviting academia across the region. One such example is ISRO's RESONANCE Space Technology Interest Exploration meet at Gauhati University on 8 August 2024 involving all academia in north east region of the country.

Interest Exploration with Academia

These IEMs & IEWs resulted in a well-distributed geographical spread of the ongoing Sponsored Research projects in East, North-East, North, North-West, West and Central regions of the country.

2.1. RESPOND BASKET

ISRO is embarking upon many new areas of Science and Technology by taking up challenging technological assignments incessantly. In this significant task of National Importance, ISRO is looking for wider participation and contributions from academia in a focused manner for timely accomplishment of its goals. RESPOND under Capacity Building Programme Office (CBPO), ISRO HQ bring out a “RESPOND BASKET” of Space comprising of urgent and most important research topics with a brief write up about the topic, scope and expected deliverables so that interested academia can prepare and submit detailed proposals in discussion with ISRO experts.

2.2. Space Technology Cells (STC)

ISRO has set up Space Technology Cells (STCs) at premier institutes of the country to carry out thematic research activities in the areas of space science, space technology and applications in support of Indian Space programme. Currently, Space Technology Cells are established at IIT Bombay, IIT Kanpur, IIT Kharagpur, IIT Madras, IIT Roorkee, IIT Guwahati, IIT Delhi, IISc Bangalore and Joint Research Programme with Savitribai Phule Pune University of Pune, Pune.

2.3. Regional Academic Centres for Space (RAC-S)

Regional Academic Centres for Space (RAC-S) is a regional level new initiative to pursue advanced research in the areas of relevance to the future technological and programmatic needs of the Indian Space Programme and act as a facilitator for the promotion of Space Technology activities in the region. Currently, four RAC-S have been established by ISRO at National Institute of Technology (NIT) Kurekshetra, Malaviya National Institute of Technology (MNIT) Jaipur, IIT (BHU), NIT Patna, Guwahati University, NIT Surathkal for Northern, Western, Central, East, North-East and Southern regions of the country, respectively.

2.4. Space Technology Incubation Centres (S-TICs)

Space Technology Incubation Centres (S-TIC) have been set up by ISRO to attract and nurture the students at graduation level with innovative ideas / research aptitude for carrying out research and developing the Academia-Industry ecosystem for space technology. ISRO has setup Space Technology Incubation Centres across six regions of the country viz. NIT Jalandhar (North), VNIT Nagpur (West), MANIT Bhopal (Central), NIT Rourkela (East), NIT Agartala (North-East) and NIT Trichy (South). The outcome of the research from these S-TICs will be transferred to the group of Indian industries within that region, capable of productionising them and utilising them into several spin-off products thereby identifying new business/job opportunities as ‘start-ups’ on Space technologies and related systems.

2.5. Centre for Nanoscience and Engineering (CeNSE), IISc

Considering the requirements of ISRO in nanotechnology and nanoscience, an MoU was signed between ISRO-HQ and CeNSE, IISc Bangalore on February 2, 2021. The scope of the MoU includes the R&D activities by the various centres of ISRO with faculties at CeNSE IISc. A Programme Review and Advisory Committee (PRAC), Chaired by Scientific Secretary, ISRO and Co-Chaired by Chairman, CeNSE with senior scientists/faculty from ISRO and IISc has been constituted to review and monitor the ongoing research projects/ activities and to provide overall policy guidance and research directions to the CeNSE. In addition, a rate contract for utilization of the state-of-the-art nanofabrication and characterization facilities as well as training/capacity building at CeNSE by various centres of ISRO was agreed on March 25, 2024.

2.6. Advanced Space Research Group (ASRG)

Advanced Space Research Group (ASRG) at Indian Institute of Space Science and Technology (IIST), Thiruvananthapuram has been established for all collaborative research activities of IIST with all R&D centres of ISRO. An Empowered Overseeing Committee (EOC) which comprises of members from all research centres of ISRO is the apex body to ASRG. IIST Link Unit at ISRO Centres is also established to have effective coordination of the joint research programmes.

A brief outline and possible set of topics for various research themes solicited from Academia under Sponsored Research is given in subsequent chapters. Research Areas of SAC is also available at www.sac.gov.in/respond/ .The website is updated regularly.

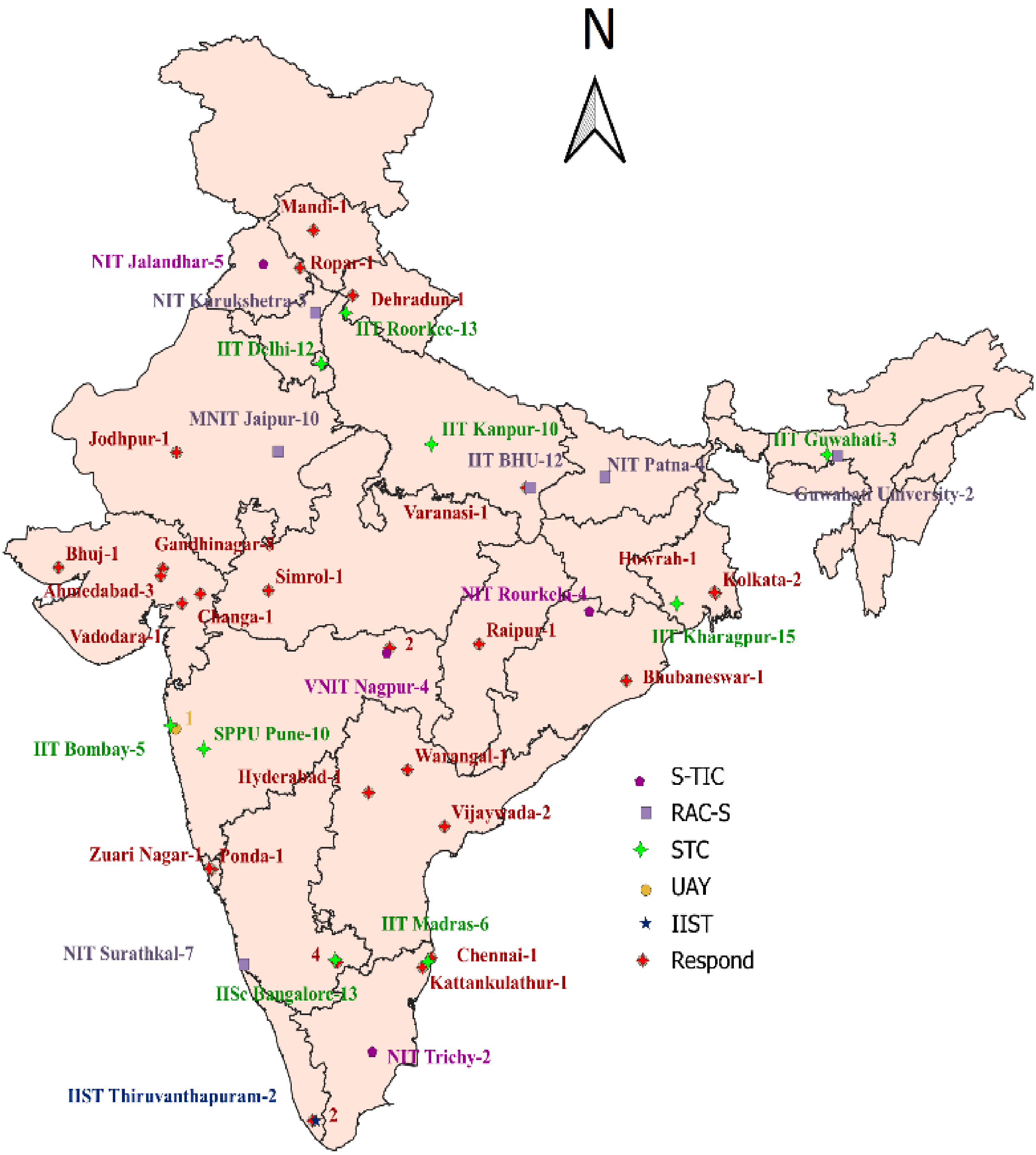
Annexure : *Kindly refer to Annexures of the document for guidelines and formats for new research proposal submission, terms and conditions of ISRO research grants, general rules for fellowships, etc. under various schemes of ISRO's Sponsored Research.*

For further details, please visit website: https://www.isro.gov.in/academia.html , https://www.isro.gov.in/SponsoredResearch.html

The snapshots of previous '***Research Areas of SAC'*** document (from the period 2006 to 2023) are provided in inner cover page of this document.

This ***Research Areas of SAC-2025'*** document is ninth in the series.

The geographic distribution of Sponsored Research at SAC with Academia is shown in Figure below.



Geographic distribution of Sponsored Research at SAC with Academia (as on May, 2025)

SAC's all Sponsored Research activities with academia under various avenues are reviewed annually at SAC. The glimpses of SAC Annual RESPOND Review (ARR), Annual STC Review (ASR), Annual Sponsored reseArch Review (ASAR) are provided in the back cover pages.

www.sac.gov.in/respond/

3. SATCOM & NAVIGATION PAYLOADS

One of ISRO's major tasks is to provide space-based assets, applications and services related to telecommunication, broadcasting and navigation. Satellite Communication (SATCOM) & Navigation Payload Area (SNPA) is responsible for the designing and development of the satellite payload.

SNPA deals with satellite communication and navigation system engineering, designing, fabrication and payload assembly and integration of the payload. Also, SNPA designs and develops various payload filters and amplifiers. There area of activity also includes digital signal processing.

Research Areas in the field of SATCOM and Navigation Payloads

3.1. System Engineering

3.1.1. LEO Constellation for Regional Coverage

Advance technological changes in satellite communication has led to reduced payload manufacturing cost & launch cost per kg to Low Earth Orbit (LEO) orbit which has made LEO orbit a popular choice for broadband connectivity from space. LEO orbit has major advantage of lower latency and ability to cater smaller user terminals. Broadband LEO constellation can complement the terrestrial networks by serving unserved and improving Quality of Service (QoS) in underserved region. Such networks can be integrated with future technologies like 5G, 6G & Internet of Things (IoT) where connectivity between the devices is a prime requirement, which is major concern for devices located in extreme topography with no terrestrial connectivity.

The research areas in this field includes:

- Development of algorithm for inter-satellite link dynamic routing/handover for data downlink/uplink to/from gateways
- System studies on integration of LEO broadband constellation & future terrestrial 6G technologies
- Development of on-board resource management algorithm based on user demand
- System study and algorithm development for LEO-GEO & LEO- Medium Earth Orbit (MEO)-GEO multilayer constellation routing
- Development of single aperture multi-beam , compact and light weight antenna integrated with compact lightweight trans-receiver module
- Development of compact ISL terminals for LEO-LEO and LEO-GEO communication
- Compact ISL terminals for LEO-LEO, LEO-GEO communication: compact optics, pointing and tracking system, optical modulators etc.
- Development of translucent/transparent on-board processing digital system based on commercial processor/FPGA technology

3.1.2. Software Defined radio based Satellite architectures for Future Satcom systems

In present scenario, low cost small satellites (Micro or Nano Satellites) are being launched or planned for launch son LEO orbit to provide communication services over the Globe. Small satellites provide an efficient and cost effective solution to different communication services as compared to bigger satellite platforms targeted for GEO orbit. Due to their low mass, power and volume envelope, the payload also has to be designed considering these constraints. Software defined radio (SDR) based payload architectures can provide solution for compact/miniaturized design which requires low mass, low DC power consumption & less volume. Present SDR systems can receive/transmit signals directly at RF level up to C-band. This will eliminate the requirements of the complex frontend hardware which in turn provides savings in mass, volume and DC power consumption. SDR based communication payload architecture is well suitable for Indian Nano Satellite Bus (INS) and Indian Micro Satellite Bus (IMS). SDRs will also be useful for future communication payloads for GEO/LEO satellite.

- Common RF transceiver (single chip/module) having RF front end and Digital subsystems (direct sampling based ADC and DAC modules) to operate from UHF to Ku band frequencies.
- Studies and implementation of different signal processing algorithms for regenerative processing and flexibility in terms of channelization and bandwidth.
- Development of integrated wideband RF front end with LNA, Bandpass Filters & Precautionary and Liquidity Line (PLL) on RF Transceiver module
- Development of Direct Sampling based ADC and DAC modules which can be integrated with wide band RF front end.

3.1.3. Hybrid Satellite/Terrestrial networks and their compatibility with 5G cellular system

As the spectrum resources are becoming limited and trend is towards delivering high speed data rates in both satellite and terrestrial mobile communication. Hybrid network of terrestrial and satellite systems complementing each other shall be developed for ubiquitous coverage, seamless connectivity and high data rates.

Research areas in this direction are:

- Studies on Satellite - Terrestrial system architecture compatible with 5G Networks
- Channel modelling considering both land-mobile and earth-to-space channels
- Investigation of Multiple-Input Multiple-Output (MIMO), precoding and other signal processing techniques for enhancing capacity of mobile satellite systems and ensuring coexistence of terrestrial and satellite systems.
- Protocol level integration of satellite and terrestrial system and development of satellite-5G testbed.
- Investigations on satellite platforms and terminal architectures complementing terrestrial 5G networks.

3.1.4. Development of signal processing and resource allocation algorithms for multi gigahertz on-board processors

With the advancement in signal processing capabilities, the trend is towards channelization and processing of wideband signals covering gigahertz bandwidth. Similarly, the necessity to dynamically and efficiently allocate a communication payload’s on-board resources such as power and bandwidth over the desired coverage requires the development of algorithms for beamforming-precoding, beam-hopping etc.

Research areas in this direction are:

- Development of signal analysis algorithms for wideband signals (multi-gigahertz bandwidth). Sparse signal analysis/compressed sensing based algorithms can be targeted.
- Development of translucent processing algorithms which bridge transparent and regenerative payloads through partially decoding packets on satellite.
- Development of algorithms for beam-hopping, digital beamforming, and precoding for efficient spatial allocation of on-board resources.
- Satellite system design and architecture for multi-gigahertz signal processing payload.

3.1.5. Studies on Advanced Navigation systems

Satellite navigation has become a key infrastructure element worldwide, enabling numerous applications along with great economic activity. These systems have been conceived as cornerstone of the national security and playing that role effectively. The significance of these systems is evident from the fact that currently there are six global navigation satellite systems (GNSS) which are either operational, under deployment or modernization. The system capability is evolving in both civil and defence domains. Indian Regional Navigation Satellite System(IRNSS) system is now a full-fledged operational system which is providing navigation services over Indian region. The evolving user requirements and global scenario will certainly require continuous research and development to acquire and utilize newer technology in this field. Few such potential areas are enlisted below:

- Use of IRNSS signals for navigation with “signals of opportunity” of terrestrial networks.
- Systems studies for autonomous satellite navigation for MEO constellation.
- Development of simulation tools for situation awareness for navigation end users supporting their mission planning. Such tools will consider the complete navigation systems and provide the information about the system accuracy, availability, integrity and reliability for any operational situation.
- System studies on provision of standalone Positioning, Navigation and Timing (PNT) services for the missions on extra-terrestrial bodies like Moon/Mars.
- End-to-end performance analysis of IRNSS signals in LMS channels using software/hardware simulation platform.
- Research on security features of navigation signals such as anti-spoof and message authentication.

- Studies on navigation signal generation, multi-level signal/sub-carrier design and multiplexing using multicarrier constant envelope modulation schemes.
- Studies of various signal modulation schemes like Minimum Shift Keying (MSK), Gaussian Minimum Shift Keying (GMSK), Orthogonal Frequency-Division Multiplexing (OFDM), etc. as potential candidates for the future navigation signals. Studies should also include overall receiver performance analysis for such signals.
- Studies of interference mitigation techniques like wavelet based de-noising or other compressive sensing methods on receiver performance.
- Research in utilizing space service volume capability of GNSS signals.
- Clock ensemble algorithm development for improvement of on-board timing system performance.

3.1.6. Space based Automatic Dependent Surveillance-Broadcast (ADS-B) and Automatic Identification System (AIS)

Automatic Identification System (AIS) is a universal ship-borne terrestrial system used to improve the maritime safety and efficiency of navigation by enabling ship to ship and ship to shore communication. Automatic Dependent Surveillance-Broadcast (ADS-B) is the aircraft surveillance technology in which aircraft provide data such as position, velocity, and identification from on-board aircraft systems.

AIS and ADS-B both rely on message transmitted by users regarding their navigation status/location. Space based AIS and ADS-B augment the surveillance capability beyond the terrestrial system range with global coverage (remote, polar and oceanic areas), unrestricted by location. AIS & ADS-B payloads, hosted on low earth orbit (LEO) platforms receive AIS/ADS-B messages, process them and relay them back to ground for usage by service provider to end user.

Satellite receives the message from multiple AIS and ADS-B terminal at a same time which causes on-board message collision or messages may get garbled. Since, this is an upcoming area, there are several challenges:

- Development of On-board algorithm for detect, de-collision and decode of AIS and ADS-B message in low SNR (<9 dB).
- Development of low-size, weight and power (SWaP) digital processor.
- Development of low noise sensitivity (<-105 dBm) AIS and ADS-B RF front end.

3.1.7. Next Generation Data Relay Satellite System (NexGen-IDRSS)

ISRO has conceived and is developing a Data Relay Satellite System i.e. IDRSS primarily to provide Data Relay Services to Gaganyaan mission. In addition, it is also capable of providing TM/TC services to LEO satellites as well as high data rate relay link from Antarctica. However, IDRSS first generation of satellites are targeted for specific missions. In addition to the services provided by the IDRSS 1st generation satellites, next generation of IDRSS satellites will have enhanced capabilities to provide higher data rate services to a variety of users. Some of the services, which will be targeted through these satellites, are:

- High Data rate relay link from Antarctica station
- Audio/Video/data relay to Human space flight mission.
- High data rate relay from LEO imaging satellites.
- Audio/Video/Broadband Internet services for Bhartiya Antariksh Station.

The payload will require following technologies to be developed to cater to these services:

- Large Deployable Antennas of the order of 4.5 mts in foldable configuration for better G/T and EIRP performance in S-band
- Advanced Phased Array Antenna for targeting multiple LEO satellites for TM/TC operation
- Microwave/Optical Intersatellite links for High Data rate optical communication between satellite to satellite and satellite to ground operation.
- Advanced single channel Mono-Pulse Tracking system.

3.1.8. Interplanetary Communication System

The recent increase in lunar missions, like landing, manned lunar mission and returning on the South Pole region and demonstration of technologies related to robust thermal systems for the operation of spacecraft for more than one lunar day (~14 Earth days) for exploration of the lunar South Pole region, paves the way for planning future lunar missions. Further, interplanetary missions like Venus and Mars landing missions are also planned by ISRO. The planned lunar and interplanetary missions would require interplanetary communication system for supporting a moon habitat, high resolution imagery, interplanetary exploration and safety-of-life service for manned missions. The interplanetary communication system requires constellation of small satellites, deep space data relay satellite network and RF beacon system for establishment of high data rate connectivity, local network, connecting with International Mobile Telecommunication (IMT) systems and search & rescue system in emergency situation. A typical lunar communication system architecture is shown in the following figures.

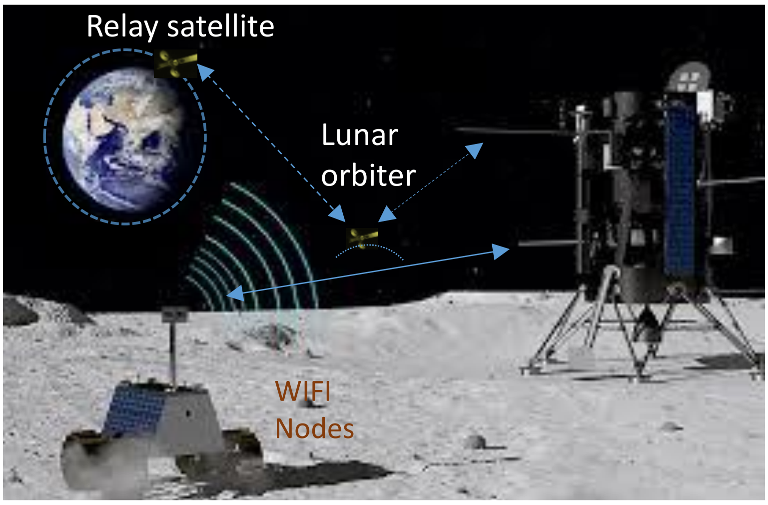


Figure: Lunar Surface WiFi Network Architecture

Interplanetary Communication System Network:

Utilization: Support for future human missions to moon and future interplanetary missions with high-speed data communication.

Technologies:

- New waveform, network protocol design as per existing terrestrial standard
- Interoperable communication system design
- Re-configurable, miniaturized antenna/RF/Digital subsystems, advanced one/two-way ranging, orbit determination, and autonomous operation
- Tolerance to extreme temp. variation, radiation, vibration, shock, etc.
- Satellite aided search & rescue system based on position estimates using Doppler tracking
- RF beacon deployment mechanism on the moon or Mars surface
- Reliable and continuous communication among lander, rover and orbiter for long-term exploration

3.1.9. Millimetre-wave Satellite Communication Systems

The ever increasing demand for data and the proliferation of digital communication devices has led to a spectrum crunch in conventional satcom bands. To increase the available bandwidth for user terminals in Ku and Ka bands, it is proposed to shift the hub frequencies in Q/V bands or W band. While there are several challenges such as limited technological readiness and severe atmospheric impairments, the advantages obtained from freeing a large section of Ku/Ka spectrum are quite significant. Similarly, it is also proposed to have LEO constellations in Q/V bands offering high data rate broadband using small user terminals. Towards this several technologies and studies can be carried out:

Research areas in this direction are:

- Channel modelling and availability analysis for Indian land and Indian ocean regions in Q, V and W bands.
- Design of phased array based multibeam transmit/receive antennas for high data rate communication incl. development of beamforming core chips.

3.2. Digital Systems for Future Communication Satellites

Introduction: - The current success of satellites is primarily in the fixed satellite services, broadcast satellite services and broadband/internet-related satellite services. In the satellite communication business, the trend for ever-increasing capacity, flexibility and availability of service, as well as increasingly more affordable, more compact, lighter, and even more stylish and ergonomic ground and personal terminals, has become need of the present. It is also believed that satellites in future still play a key role in providing mobile services despite the setbacks that came with early market failures. Onboard digital signal processing has potential for offering innovative satellite services. Availability of space-qualified high-capacity high-speed Field Programmable Gate Array (FPGAs), availability of high-speed Analog to Digital Converters (ADCs) / Data Assimilation Converters DACs and development of specialized-function Application Specific Integrated Circuits (ASICs) have made advanced services a reality. Managing mass, power, complexity, functionality and reliability for such payload is of paramount importance for offering services at acceptable cost. The emphasis worldwide is on:

- Increasing the performance (i.e. service availability)
- Quality of experience (i.e. less delay)
- Reducing cost/bit of information
- Efficient use of spectrum
- Network integration with terrestrial system
- Flexibility (i.e. reconfigurable payloads)
- Integration with navigation and observational satellite systems
- Security of communication
- Resistance to interference and jamming

The accomplishment of above tasks would require developing techniques for:

- Innovative and efficient spectrum processing and sensing algorithms
- Innovative techniques, protocols and architecture
- Innovative business models

The satellite technology is divided in to two major category

1. Communication satellite related technology
2. Navigation satellite related technology.

3.3. Communication Satellite Related Technology

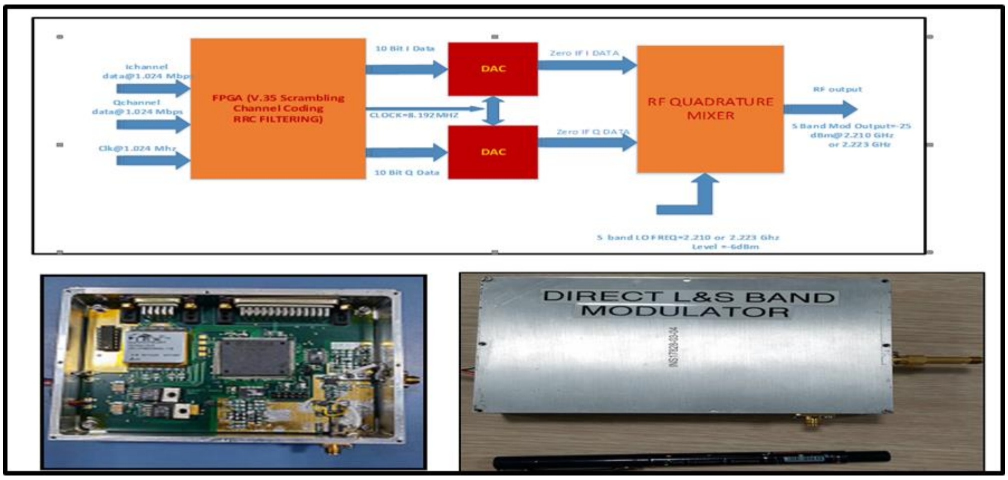
3.3.1. Advanced Coding and Modulation for Satellite Communication

Recently the terrestrial communication system of fiber optical cables has grown tremendously. In order to develop a harmonious infrastructure with terrestrial communications systems, the speed of satellite communications must be increased to meet the speed of terrestrial communications system. It is useful to consider a so-called Internet satellite and its development.

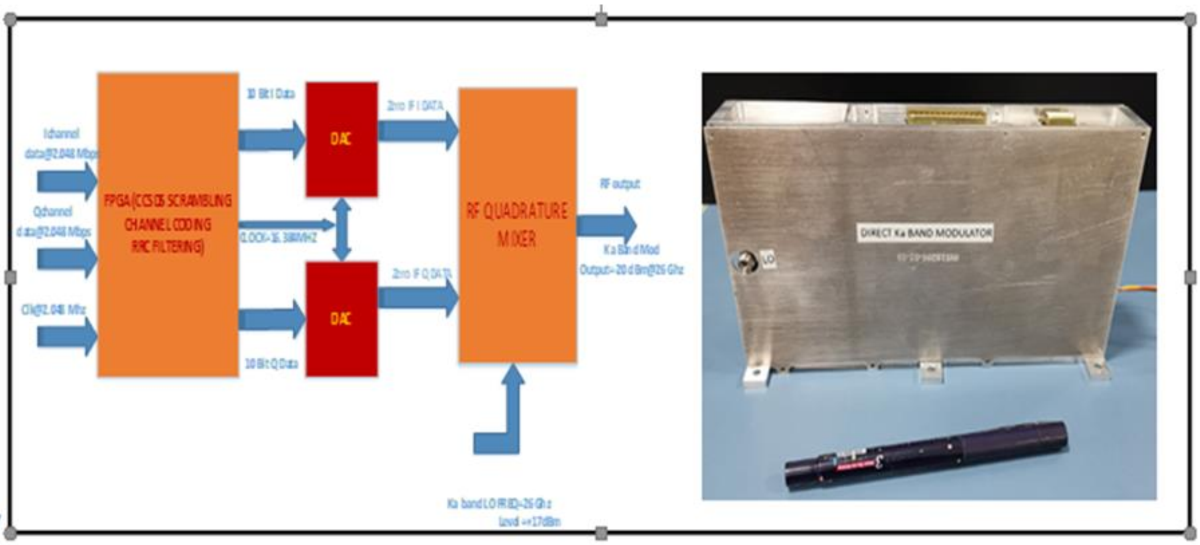
One generation of 10 years may be long, but it must be reasonable because it may be about a generation of infra structure. An Internet satellite is meant one that provides fixed, broadcast and mobile satellite communications

Current Situation and challenges

Most of the communication satellite in ISRO like Indian National Satellite (INSAT) and Geosynchronous Satellite System (GSAT) class of series satellites used mostly Quadrature Phase Shift Keying (QPSK) and Binary Phase Shift Keying (BPSK) modulation system. The reason of using these modulation systems, because of their simplicity and better performance compare to other modulation systems in satellite communication scenario. They are still the popular choice, even in worldwide satellite communication scenario. There are two major approaches for modulator design heterodyne and homodyne. Heterodyne approach basically involves two level of up conversion i.e. the first modulation at Instruction Fetch (IF) label and then up conversion to desire Radio Frequency (RF) frequency. In homodyne approach involves direct conversion from zero IF to desired RF frequency. Till now mostly all major modulator design is based upon heterodyne based approach. But now current state of art design is based upon homodyne approach. Following figures shows direct S and Ka band modulator design for Gaganyaan project. The challenges are left in these modulation are to handle high data rate, where the hardware or component used earlier design will not be useful. The other challenges are reduction of size and power consumption of such system. So, high data rate system using our current modulation scheme with reduces size and power is the current challenges.



Block Diagram and DVM model of S Band Modulator



Block Diagram and DVM model of Ka Band Modulator

3.3.2. Channel coding for satellite communication

The large distance between the transmitting spacecraft and the receiving earth station and the limited transmitting power result in a very poor signal- to-noise ratio at the receiver side. The consequence is a large amount of transmission errors. At the same time, the data bits are highly compressed before transmission to allow as large as possible a number of images to be transmitted in the limited data rate. But especially compressed data bits are very sensitive to transmission errors. Therefore, channel coding method is also one of the most important technologies.

Current Situation and challenges

Currently most of the satellite made by ISRO used convolutional code with different code rate 1/2, 3/4, 7/8 in concatenation with Reed-Solomon (RS) code in some of the satellite. This type of channel codec works well since last 20 years in satellite communication world. However due to increasing in demand of quality of service and several upcoming deep space explorations, it is now essential that change channel codec for future mission. The Consultative Committee for Space Data Systems has suggested few of the channel code for future satellites and deep space explorations. The current state of the art channel codec is

- Turbo convolutional codes(TCC)
- Turbo product code(TPC)
- Low density Parity check code(LDPC)

New channel coding Scheme

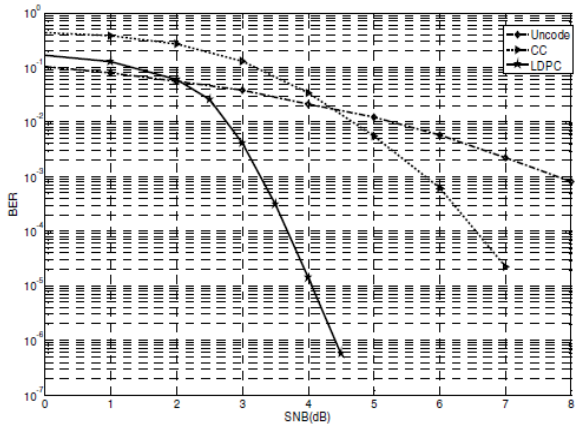
For our satellites and deep space mission Turbo convolutional code and LDPC code are the two main area of thrust for future mission.

- **Turbo Convolution Code**

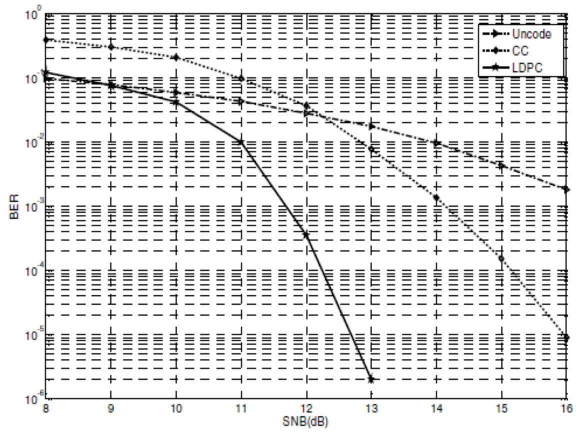
Parallel-Concatenated Convolutional Codes (PCCC), known as turbo codes, allows structure through concatenation and randomness through interleaving. The Consultative Committee for Space Data Systems (CCSDS) Telemetry Channel Coding Recommendation establishes a common framework and provides a standardized basis for the coding schemes used by CCSDS Agencies for space telemetry data communications. This standard traditionally provides the benchmark for new and emerging coding technologies Turbo codes have an astonishing performance of bit error rate (BER) at relatively low Eb/No. Turbo codes were chosen as a new option for this standard in 1999, only 6 years since their official presentation to the international community: this was the first international standard including turbo codes. The reason was the significant improvement in terms of power efficiency assured by turbo codes over the old codes of the standard. In Chandrayan-1 mission of ISRO, we have used Turbo convolutional code as per CCSDS standard 131.0-B-1 for low data rate telemetry application. We have also planning to use this turbo code for human space program.

- **Low density parity checks code (LDPC)**

The another important error correcting code, whose performance close to Shannon limit know as low density parity check code. The LDPC code is also a close contender of turbo code. LDPC codes have a remarkable performance with iterative decoding that is very close to the Shannon limit. When compared to the decoding algorithm of convolution code, LDPC decoding algorithm has more parallelization, low implementation complexity, low decoding latency, as well as no error-floors at high Signal-to-Noise Ratio (SNR) as turbo code. The next generation satellite communication systems e.g. digital video broadcast satellite/terrestrial (DVB-S2/T2) have readily adopted LDPC code for Forward Error Correction (FEC), mostly due to its near Shannon performance at very low signal to noise ratio. However, the channel code performance also depends upon the modulation scheme, figures shows the performance of LDPC codec and convolutional code with respect to BPSK and 16 Quadrature Amplitude Modulation (QAM) modulations.



BER comparison under BPSK modulation



BER comparison under 16 QAM modulation

The use of advanced channel coding techniques (e.g. TC and LDPC codes) is the state-of-the-art technology used in current satellite systems to provide broadcasting services to fixed terminals in the Ku/Ka frequency bands into two-ways (i.e. Digital Video Broadcasting - Second Generation (DVB-S2) in the forward link and Digital Video Broadcasting - Return Channel via Satellite (DVB-RCS) in the return link, respectively), in which the Additive white Gaussian noise (AWGN) channel is usually assumed. In particular, DVB-S2 considers irregular LDPC codes of either 16200 or 64800 bit code words and 11 coding rates (i.e. ranging from 1/4 to 9/10). With respect to DVB-RCS, double-binary turbo codes are assumed with 12 frame sizes (i.e. ranging from 48 to 752 bit couples) and 7 coding rates (i.e. ranging from 1/3 to 6/7).

Sync word less Concatenated RS and convolutional code encoder and decoder development

The recommended concatenated coding system in satellite communication consists of a Reed-Solomon outer code and a convolutional inner code (which is Viterbi decoded). In typical scenario there is requirement of sync word for synchronization for RS decoder, which lead to reduce the overall efficiency of data transmission and also the overall throughput. The proposed activity will remove the requirement of sync word in each data packet which will improve the overall data efficiency. The proposed activity will be useful for future payload like Gaganyaan etc.

Digital Processors for High Throughput Satellites.

Conventional high throughput satellites employ limited, RF based processing due to unavailability of wideband signal processing hardware. For future high throughput satellites, it will be necessary to employ processing techniques to distribute the on-board resources in an optimal fashion and extract the maximum possible throughput. The relevant research areas would be:

1. Development of system on chip with integrated wideband, direct sampling data converters and RF transceivers.
2. Development of on-board partially or fully reconfigurable, failure tolerant, Multi-core Processor based signal processing system
3. Development of multi-channel wideband adaptive signal processing system for digital beamforming and channelization in broadband multi-beam communication payloads.
4. Data compression algorithms for inter-board data communication.

Precoding for V/High Throughput Satellites

Precoding is to counteract the multibeam interface when high/full frequency reuse is employed in V/HTS so that noncomplex UTs can maintain a high Signal to Interference plus Noise Ratio (SINR), even the same carrier frequency is used by adjacent beam. To achieve this precoding employs the channel state information (CSI) toward each UT to mitigate the interference. Signal processing for optimization of precoding matrix and implementation of Precoding function in next generation V/HTS. Some research areas are calculation of Precoding Matrix, and Efficient Implementation of Precoding Matrix in satellite.

3.4. Navigation Satellite Related Technology

3.4.1. Modulators for Navigation Satellites

This Satellite Navigation has revolutionized the navigation world, opening new opportunities in an increasing number of sectors that require high precision. ISRO has taken up the project for the implementation of an independent regional navigation system currently known as Navigation with Indian Constellation (NavIC). The project Indian Regional Navigation Satellite System (IRNSS) envisages establishment of regional navigation system using a combination of Geostationary Orbit (GEO) and Geosynchronous Orbit (GSO) spacecraft's. NavIC is already providing two types of services restricted and unrestricted services or public domain services in L5 and S Band. Binary offset carrier (BOC) and Binary phase shift keying (BPSK) is use for these services. In NavIC, we are using different method for combining these two modulation scheme in order to get constant modulation envelope i.e., the total transmitted power does not vary over time. So that the transmitted information is not contained in the signal amplitude and the transmitted signal amplitude becomes less critical. However, in future NavIC satellite we are going to transmit L1 band signal also for better interoperability and compatibility. In L1 band, we need comply the power spectral density of Multiplexed binary offset carrier (MBOC) modulation. There are other navigation players, who are transmitting their own custom modulation scheme in L1 band. These are mention below.

- **CBOC:** The Composite BOC is the solution adopted by Galileo for the Open Service in E1/L1.

- **TMBOC:** The Time-Multiplexed BOC is the solution adopted by GPS for L1C.
- **Quadrature Multiplexed BOC**: Adopted by compass.

  A suitable modulation scheme, which comply MBOC power spectral density may design and develop to complete the future requirement.

3.4.2. Coding Scheme

Like other wireless communication signals, navigation signals are subject to noise, multipath and shadowing effects which may induce errors in the received data. Modern navigation signals employ some techniques to detect and correct these errors.

Galileo, modernized GPS as well as space-based augmentation systems (SBAS) (e.g. Wide Area Augmentation System (WAAS), European Geostationary Navigation Overlay Service (EGNOS)) messages make use of FEC. In the following the various error protection techniques used by these systems are described and some details are given for the encoding and decoding processes. The fundamental principle of channel coding is to add redundancy to the navigation message, which is used by a receiver to detect or correct possible errors in the received symbols. The redundant bits added by the encoder are a function of the original information. The original bits may or may not be directly visible in the encoded message. In the first case the encoding is called systematic while in the second case it is called non-systematic.

Channel coding techniques can be further divided into block codes and convolutional codes. Block codes operate on fixed sized blocks of data, each of which are encoded separately, while convolution codes operate on a continuous stream of input data. Both kinds of codes are employed in Global Navigation Satellite System (GNSS), a few of which are detailed in following Table.

Table

CODING SCHEMES USED IN GNSS SIGNALS

System	Signal	Message	Coding
GPS	L1 C/A	LNAV	none
	L1C	CNAV-2	block: BCH & LDPC
	L2C	CNAV	½-rate convolutional
	L5	CNAV	½-rate convolutional
Galileo	E1-B	INAV	½-rate convolutional
	E6-B	CNAV	½-rate convolutional
	E5a	FNAV	½-rate convolutional
	E5b	INAV	½-rate convolutional
SBAS	L1	SBAS	½-rate convolutional

Recently china (Compass) is also transmitting signal in L1 band having own custom Bose-Chaudhuri-Hocquenghem (BCH) and LDPC codes. In NavIC signal, we are also planning to transmit L1 band signal for better interoperability and compatibility. So there will be a need to develop custom channel coding of navigation signals.

3.4.3. Optical Interconnects for High Speed Signal and LO distribution

There is a need for High bandwidth (BW) serial data transmissions. Optical Interconnects are required to minimize power consumption, mass and volume. They are practically lossless propagation in an optical fiber within a Digital sub-systems module. The other significant advantages are Immunity to Electromagnetic Interference (EMI) and Electro Magnetic Compatibility(EMC), are mechanically flexible and galvanic ally isolated and provides low phase noise degradation.

3.4.4. High-Performance DSP for Software Defined Payloads

To meet the requirement of high speed and reconfigure software defined payloads, a high performance Digital Signal Processors (DSP) processor which can meet space electronics quality guidelines are required. Their performance should be benchmarked for following applications

1. DVB-S2 modem: 2 Gb/s transmit, 1 Gb/s receive
2. Fast Fourier Transform FFT (complex 16 bit fixed-point): 150 GOPS (Giga Operations per Second)

3.4.5. Digital Cancellation Scheme for High-Order Passive Intermodulation Interference

Passive intermodulation (PIM) is a phenomenon that additional signals at new frequencies (not only the harmonic frequencies) are generated when signals containing two or more different frequencies are processed at the passive devices, such as duplexes, cable connectors, waveguides and antennas. PIM would worsen the antenna gain-to-noise-temperature (G/T) value, thereby further disrupting the whole system. A full-digital PIM canceling adaptive scheme can be explored based on Least Mean Square LMS algorithm.

3.4.6. Onboard Clock Ensemble for clock anomaly handling

To improve the clock accuracy in future navigation payloads it is required to generate the output frequency signal based on an ensemble of input clocks with optimized performance and improved robustness by clock anomalies handling. Following three algorithms can be developed: Measurement Filtering (MF), based on a cascade of low-pass recursive filters with exponential window functions. Clock Fault Detection and Correction (CFDC), with associated logic based on MF outputs, onboard Clock Ensemble (ONCLE), based on weighted averaging according to filtered frequency information covering clock anomaly handling

3.4.7. On-board Autonomous Orbit Determination of Navigation Satellites using inter-satellite ranging

Autonomous orbit determination of a navigation constellation is the process by which the orbit parameters of navigation satellites are autonomously calibrated onboard the satellites without the need for external aids. It commonly uses a satellite onboard data processing unit and a filtering method to process the measurements of inter-satellite ranges. The onboard data processing unit is the main module of autonomous navigation systems.

3.4.8. FPGA/ASIC Design Methodology

Following areas for research in FPGA/ASIC Design for onboard signal processing:

- 28 nm Fully Depleted Silicon On Insulator (FD SOI) to be evaluate for low power Application-Specific Integrated Circuit (ASIC) development for future high speed Digital Subsystems
- Formal Verification to Verify Single Event Upset (SEU) Mitigation Techniques for increasing design reliability
- High Level Design Methodology for faster design rollout
- Linux Operating system for space applications.

3.5. Development of Ferrite Material for Space Use

Microwave circulators and isolators are used in communication payloads to improve impedance matching and to avoid multiple reflections. Ferrite material is used in the waveguide junctions because of its non-reciprocal properties, resulting in circulation when magnetized.

Understanding the structure of the ferrite material requires knowledge of chemistry, theory of magnetism in ferrites, the non-reciprocal characteristic of ferrite junction at microwave frequencies due to gyromagnetic effect, which involves physics and advanced mathematics.

The important properties of a ferrite are:

Saturation Magnetization, Ms: This property is related to the spontaneous alignment of electron spins parallel to the applied magnetic field.

Gyromagnetic Line width, ΔH: It is a measure of ferrite magnetic losses in the vicinity of ferromagnetic resonance.

Effective line width, ΔHeff: It is a measure of ferrite magnetic losses for off-resonance operating points (below and above resonance).

Spin wave line width, ΔHk: It is a measure of attenuation factor of spin waves excited above a power level.

Magnetization temperature coefficient, α: It is a measure of relative change in magnetization with respect to temperature.

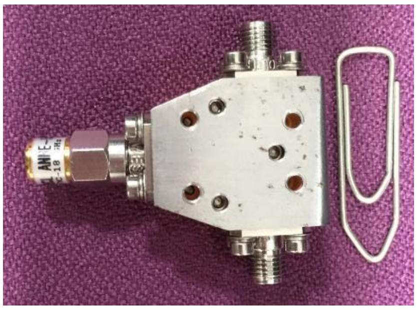
Curie Temperature, Tc: Temperature above which ferrite material has no magnetic properties.

The table below shows the ferrite material properties sought for to be used in circulators for space use:

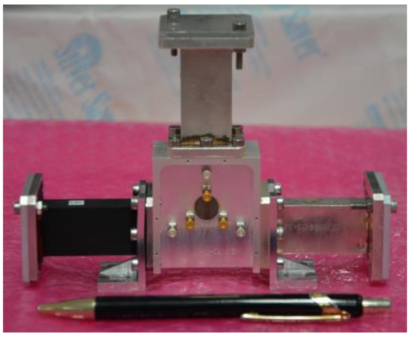
Application	Requirement	Material Property
Low Power Circulator/Switch	Low Insertion loss, Wide Bandwidth, Compact	Minimum **ΔHeff, α** Maximum **ε** **Ms** as per the frequency
High Power Circulator/Switch	Low Insertion Loss, High average and peak power handling	Minimum **ΔHeff, ΔHk, α** **Ms** as per the frequency High **Tc**

Research undertaken/to be taken up in Ferrite Devices at SAC

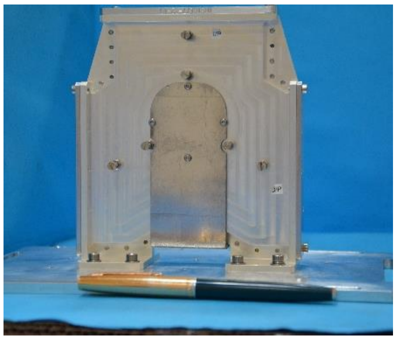
1. Low power and High power Wideband Coaxial circulator
2. High power waveguide circulator at Q-V band and millimeter wave
3. Ferrite Phase shifter
4. High power and low power Ferrite switches



a) Ku Band Stripline Isolator



b) Ku Band HP WG Circulator



c) S Band HP WG Circulator

Developed Isolator/Circulators at SAC

3.6. Amplifier Technology

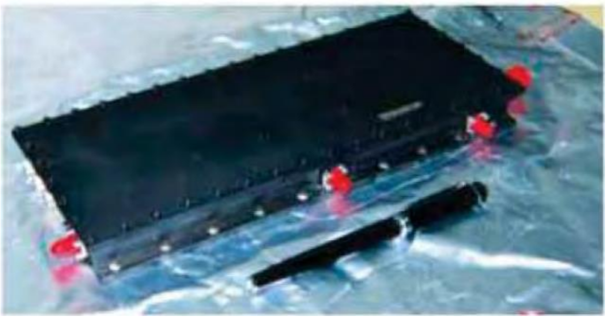
Amplifier Technology

The microwave and RF amplifiers present in various communication and navigation payloads includes low, medium and high power amplifiers over different frequencies ranging from UHF to Q/V-bands. III-V group (Gallium Arsenide (GaAs) and Gallium Nitride (GaN))based semiconductor technology in the form of discrete RF transistors and Monolithic Microwave Integrated Circuits (MMICs, packaged & unpackaged) are being utilized for the design and realization of high performance solid state amplifier circuits and subsystems.

The next generation satellite communication systems require high output power amplifiers with high efficiency and linearity in small size, low weight having better reliability. To meet the desired performance from amplifier subsystems, control circuits like digital attenuators, phase shifters, voltage variable attenuators, switches etc. are also designed, realized and successfully used in various payloads in the development of channel amplifiers and Solid State Power Amplifier SSPAs. At the lower end of frequency spectrum, at UHF to C-band, availability of GaN technology is offering newer breakthrough in realizing the power amplifiers which may even be replacing Travelling Wave Tube Amplifier (TWTA) in future satellites.

The Indian Regional Navigational Satellite System (IRNSS) provides regional navigation satellite system using a combination of GEO and GSO spacecraft over the Indian region. GaN based SSPA are emerging as a viable alternative to TWT amplifiers especially at L and S-band used in these navigation satellites.

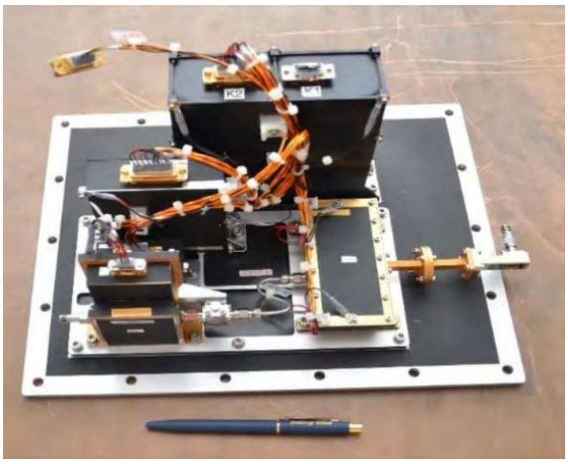
150 Watt L5-band GaN Power Amplifier



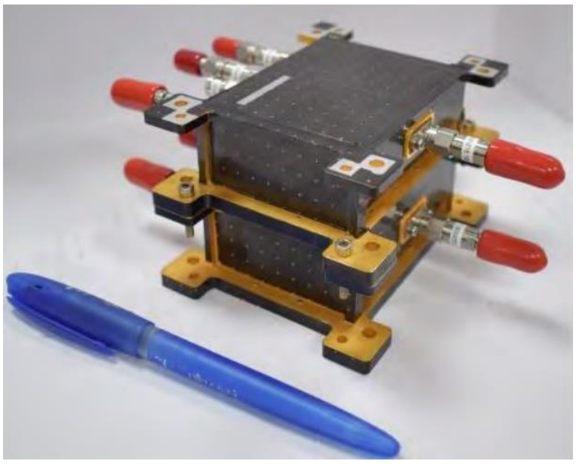
250 Watt S-band GaN Power Amplifier

Scope of the work exists in the area of simulation and design of medium to high power compact SSPA with size comparable to TWTA or even smaller. ISRO had already designed, developed and successfully demonstrated communication at Q/V-band in one of its mission. High throughput satellites are being proposed at millimeter wave band in future, requiring further technology development utilizing state-of-the-art techniques in the development of miniaturized driver amplifiers and high power SSPAs with highly efficient RF power combining techniques. There is a requirement of wideband, high power MMIC power amplifier designs upto V-band. To achieve higher power, low loss combining techniques and development of planar or 3D miniaturised RF power dividers and combiners are required at these frequencies.

ISRO had also designed and developed a 2-channel Switch Matrix at Ka-band utilizing high isolation Single Pole, Double Throw (SPDT) switch MMICs and split block assembly. There is research scope in developing state of the art packaging technique for preserving high isolation from such RF switches. There is also research scope in development of thermal modelling and thermal management techniques for high power amplifier MMIC. Multi-function MMIC design & development for driver amplifiers and multi-channel transmit modules are also new areas of research.



Q/V band SSPA



Ka-band Switch Matrix (stacked)

L1-band Driver Amplifier

Ku-band 4-channel Transmit Module

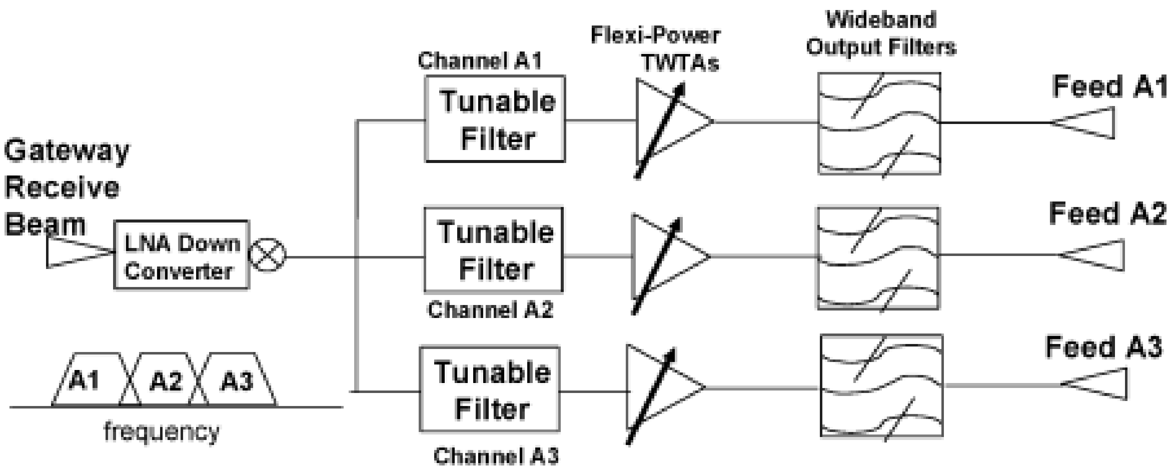
Areas of research are:

- Wideband, high power SSPA & Channel amplifiers in UHF, L, S, C, Ku, Ka and Q/V-band.
- GaN based high power compact SSPAs at UHF, L and S-Band.
- High power amplifier GaAs and GaN MMIC designs.
- State-of-the-art technology for design & development of compact SSPA at Q/V-band with waveguide RF interfaces.
- Spatial power combining techniques at millimeter wave frequencies.
- High efficiency Continuous Waves (CW) SSPAs with associated thermal & power management.
- Implementing Efficiency enhancement techniques in S, C, Ku-band Power amplifier.
- Thermal modelling & thermal simulations of MMIC power amplifiers.
- Modelling & simulation of entire amplifier module consisting of MMICs for the effects of bondwires, package cavity etc. on RF performance at Ku-band & beyond.
- Design & development of ASIC for the tele-command interface control circuit for channel amplifier & SSPAs.
- Design & development of high isolation switches and voltage variable attenuators at Ku & Ka-band.

3.7. Reconfigurable Filters for Satellite Communication

Introduction:

The use of reconfigurable payloads in satellite provides significant advantage over current state-of-art satellite configurations. Re-configurability of payload allows for multimode and multifunctional operation. Agility opens the way for reconfigurable payloads that can be tuned during mission time while in orbit. The ability to reconfigure the operating frequency band offers key advantage to adapt long-lifetime satellites to rapidly evolving user requirements.



Flexible Payload Configuration

A switchable filter bank can act as alternative solution to a tunable filter where discrete flexibility is required. One such approach, used in the past, employs multiple IMUX and OMUX units, addressing different frequency plans, with extra RF switching functionality to change between them. This solution, however, is costly both in terms of added component costs and the increased mass and volume of the satellite.

Reconfigurable Filters:

Microwave Filters used in the communication payload have very stringent in-band and out-of-band requirements. If Tunable/Reconfigurable filters are used to replace these filters in payloads, they must meet these stringent requirements. In particular, they must have High Q, maintain required bandwidth, must have reasonable return loss and should provide required rejections at specified frequency points. These filters should also be able to meet average and peak high power requirements. High Q filters presently used in the satellites are primarily made from 3-Dimenssional Waveguide Cavity Resonators, Dielectric Resonators or Coaxial Resonators. Filters made from these resonators meet all the stringent requirements of the payload including high power handling. Depending upon the application, frequency of operation and power handling requirement, one of the above resonator technology is chosen for realizing payload filters. Tunable/Reconfigurable filters required for the satellites will also be required to be realized using these 3D resonator technologies to meet payload requirements. Most of the present day research has been focused on micostrip based tunable filters or SIW based tunable filters. The important constraints related to High power, High Q applications makes these reconfigurable technologies unsuitable for payload applications.

Recently, some progress has also been made in the tunable 3D high Q filters using mechanical motors, piezoelectric actuators and micromechanical switches for aching desired tenability. Some of the major challenges involved in the development of such 3D high Q tunable filters are:

- Maintaining required bandwidth and reasonable Return Loss over wide tuning range. Non-uniform variation in resonant frequency of various resonators of the filter and variation in coupling values (External & Internal) of the filter with frequency could lead to degradation in Return loss of the tunable filter.
- Maintaining High Q over wide tuning range. Tuning of resonator over wide tuning range could lead to significant reduction in its Q-factor.
- Ensuring High average power handling capability and required Multipaction margin of 6dB. Implementation of tuning mechanism should not lead to degradation in power handling capability of the filter.
- Qualification of Tunable filter for Space Application. Tunable Filter along with its tuning mechanism, should endure QM level environmental tests.
- Ensuring required Reliability of the tunable filter and its tuning mechanism over its operating life. Reliability of the tunable filter could be impacted due to wear and tear of moving parts or due to increase in the number of parts.
- Minimizing the power consumption and complexity for the tunable filter.

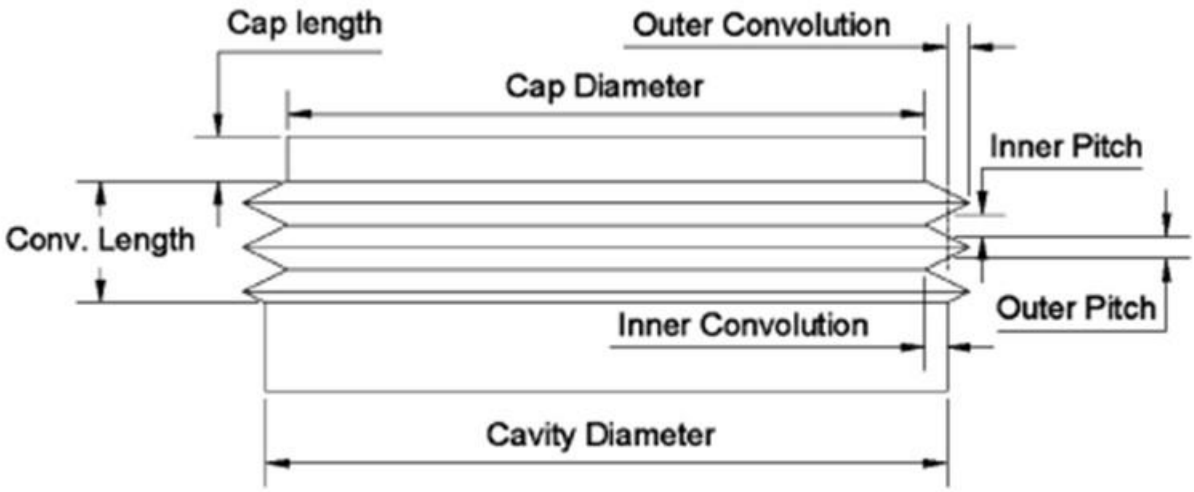
Recent Advances in Reconfigurable Filters:

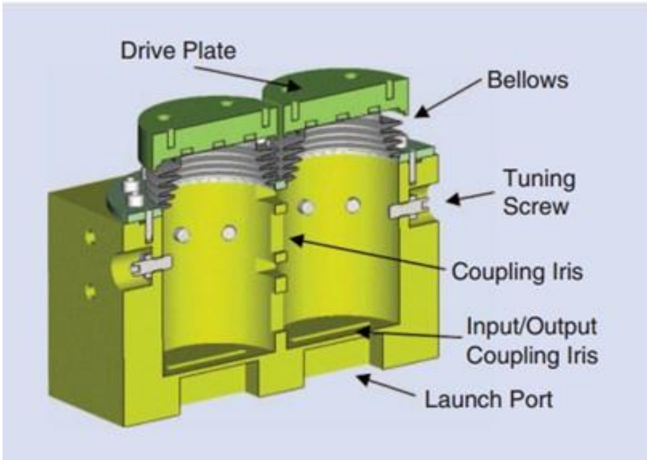
Though, the optimal design of Tunable/Reconfigurable microwave filter suitable for payload application is yet to be developed, many researchers around the world are at work with this goal in mind. To obtain a tunable cavity filter and thus a tunable mux, the resonant frequencies of the resonators that comprise the filters must be reconfigured. Depending on the resonant mode and its electromagnetic field distribution used in the cavities, this can be achieved by different approaches. These approaches have led to various results in terms of achievable unloaded Q factor, spurious-free tuning range, or mechanical simplicity. Tuning can be performed using mechanical, magnetic, or electrical commands. Some of the recent advances in the field of 3D tunable filter are given below:

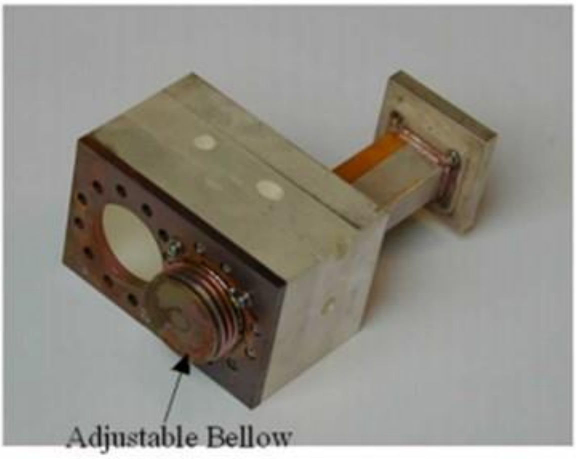
3.7.1. Mechanically Tunable waveguide cavity filters

a) Bellow-Mounted Tunable Filters

Waveguide cavity filters have been widely used in satellites, due to the high-Q and high-power handling capability. In addition, cross-coupled circular-waveguide dual-mode filters, typically operating in TE113 mode, offer mass and size reduction and excellent RF performance. Mechanically tunable waveguide cavity filter maintains both High-Q and high-power-handling capabilities. A mechanically tunable waveguide filter can be implemented using bellows. The bellows is a flexible electroformed copper structure which acts as a tuning element. It is a thin-walled (nominally 0.002-in thick) metallic closed-end piston with a designed profile and specific number of convolutions. The bellows-mounted tunable filter offers a very low loss performance over a wide tuning range. A very stable transmission response over a very wide tuning range is also a distinctive feature of this technique. However, there is a tradeoff between RF and mechanical performance when designing a bellows profile. Mechanical operating characteristics are maximized by increasing the number and amplitude of convolutions, whereas RF performance relies on bellows with fewer convolutions.



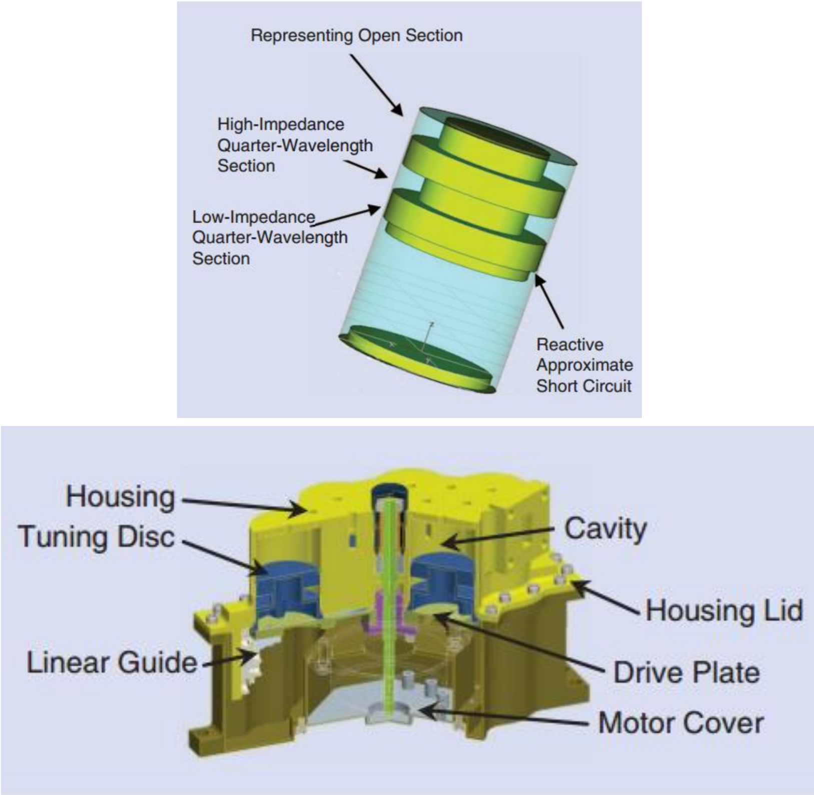




Bellow mounted tunable cavity filter

b) Fully Tunable TE011 Cavity Filters

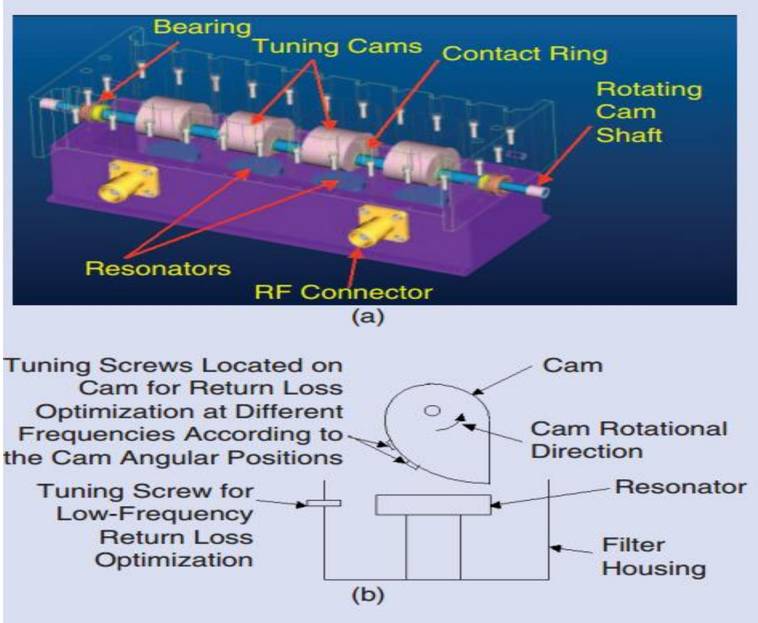
A fully tunable filter for a completely flexible transponder requires tunability of both the bandwidth and center frequency of the filter. RF performance of the filter should be maintained over wide tuning range. In cylindrical cavity filter operating in TE011 mode, electric field strength and current distribution approach zero at the edge of the cavity end walls making it possible to use tuning discs without Q degradation, which in turn leads to the potential for incorporating small and low power consumption motors due to the contactless tuning feature. A movable plunger with diameter smaller than or equal to that of the cavity is used for filter tuning. The A contactless plunger is used to provide a reactive short-circuit condition at the back of the metal disc ensuring good electrical contact, creating a near shortcircuit condition. This type of plungers consists of quarter-wavelength transformers. The three-section plunger incorporates two low-impedance sections and one high-impedance section. Providing an RF enclosure to the resonator prevents unwanted modes from interfering and degrading the operating TE011 mode. The achieved Q of approximately 10,000 for a Ku band filter is reported in the literature. This design, however, has narrow spurious free window due to presence of low-Q TM111 mode.

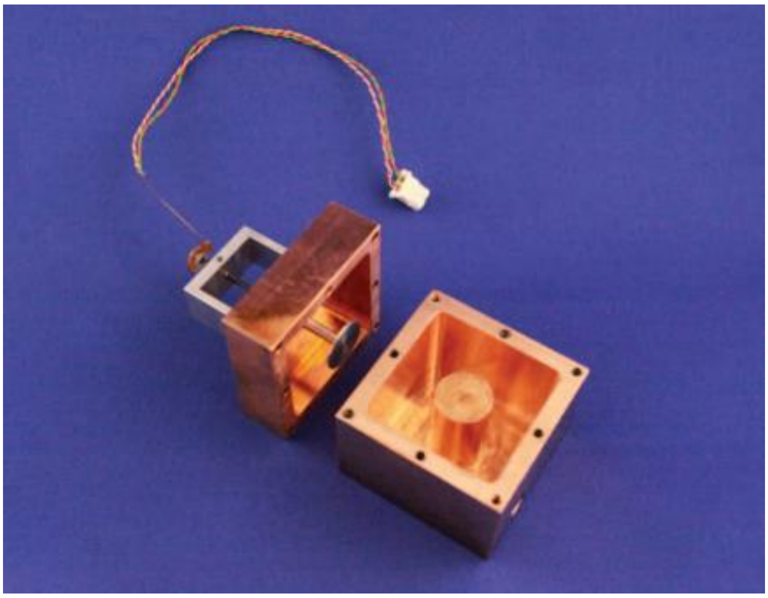


Fully tunable TE011 cavity Filter

3.7.2. Coaxial Tunable Filters

Coaxial resonators offer moderate-Q and have been implemented for satellite channel-filtering applications. Coaxial technology is suitable for tunable filter applications because of the ease of tuning, which is a well-known characteristic of coaxial resonators. A design of a manually tunable coaxial filter is shown in following figure. In this design, Tuning is achieved by rotating a shaped cam above the resonator post which in turn changes the capacitive loading of the resonator. Variation in capacitive loading required for tuning resonant frequency of coaxial resonator can also be achieved by varying the height of tuning disk used at the top of the resonator.





Tunable Coaxial Filter

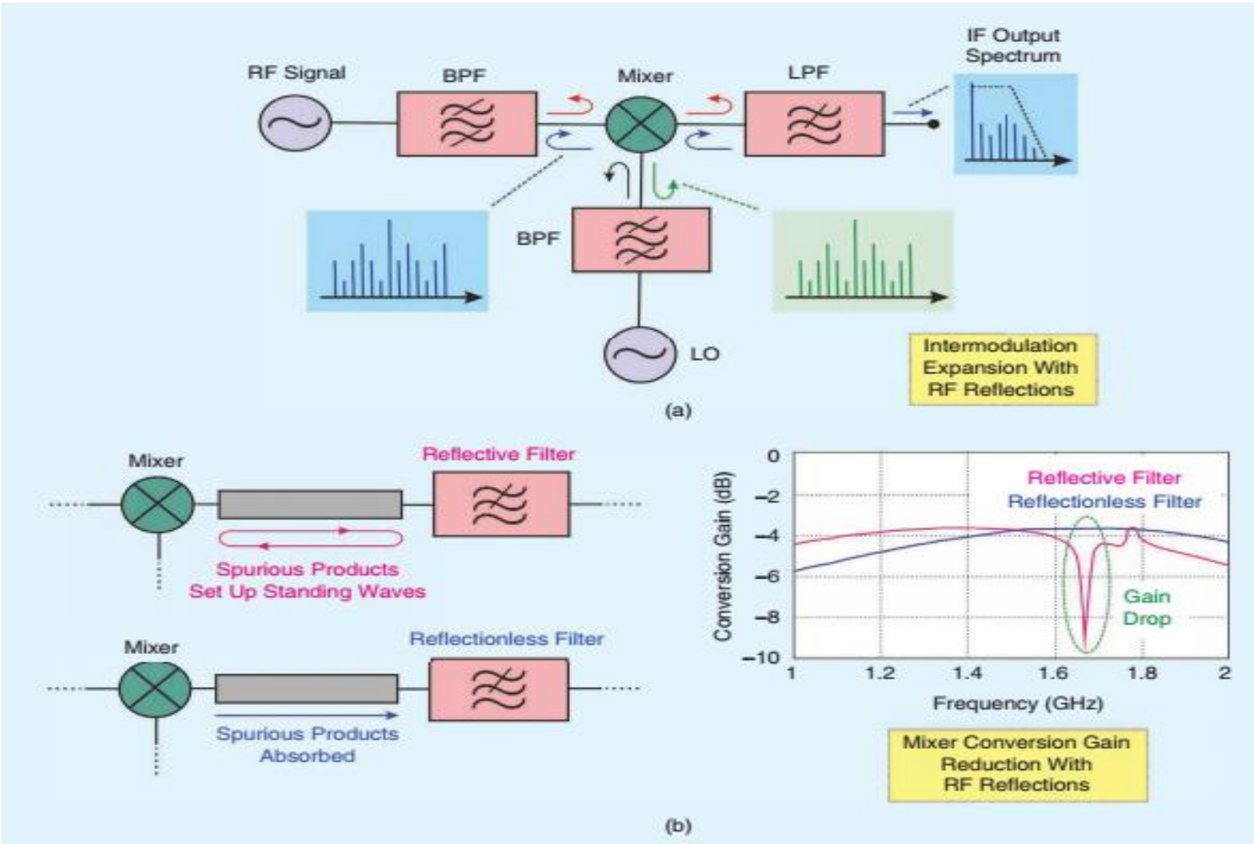
3.8. Synthesis and Analysis of Microwave Filters Based on Available Computational Methods

To design a microwave filter, synthesis of electrical circuit is required. Synthesis generates complex polynomial for filter transfer function. Coupling matrix synthesis is a popular approach for extraction of the electrical parameters from the complex polynomials. The extracted parameters of coupling matrix are the circuit building blocks for a required filter response realization.

The coupling matrix can be configured/modified for any desired topology of the filter and its corresponding (transmission/Reflection) response. Methods for direct optimization of the coupling matrix for desired transmission/reflection response are also available in literature. Prospective and retrospective use of the coupling matrix for any desired RF response for adaptive resonator topology can be very helpful for time efficient and better electrical performance designs.

Software development for numerical electromagnetic analysis and optimization of standard geometries like rectangular, circular, coaxial resonator based microwave filters with GUI will initiate efforts towards indigenization of Electro-Magnetic (EM) solvers. The scope of software development can be further expanded to more complex geometries. Numerical electromagnetic techniques like Mode matching, Finite Element Method (FEM), Finite-difference Time Domain (FDTD) can be used depending the nature of geometry. The existing Commercial EM tools are highly expensive and hence good amount of foreign exchange can be saved after successful completion of this activity.

3.8.1.1. Reflectionless Microwave filter



The problems of (a) intermodulation expansion in a receiver's low-conversion stage due to multiple out-of-band RF signal power reflections produced by reflective-type filters and (b) mixer conversion gain reduction resulting from generated standing waves in interconnection transmission lines. LPF: low-pass filter; IF: intermediate frequency.

A long-overlooked opportunity to enhance the signal-to-noise ratio (SNR) and dynamic range within a signal chain and to reduce harmonics/spurious content within these circuits is to address a seemingly innate property of filters: their out-of-band reflective behaviour. Reflectionless filters utilize a novel circuit topology to effectively eliminate the standing waves created by traditional filters without additional components (such as pads). This unique property gives designers a new way to improve the system performance of a wide array of broadband circuits, or any circuits suffering from out-of-band impedance mismatch. The typical performance of conventional filters (reflective filters) only exhibited a matched impedance at its ports within the filter's pass-band. The stop-band regions of these filters are intentionally designed to have very poor impedance match. As a result, undesired stop-band signals, including harmonics, interference, and noise, are all reflected from the filter ports back through the signal chain. If these unwanted signals are reflected back to another reflective device, a standing wave effect emerges. This standing wave will persist and build on itself until the attenuation of the transmission path between the two reflective components dampens and absorbs the unwanted signal energy. The reflectionless filter is a set of filter topologies and designs that inherently exhibit a broadband matched impedance. The major advantage of reflectionless filter topology is that these filters are readily cascadable, so sharper roll-off and greater stop-band rejection may be achieved by adding filters as modular building blocks. The figure above shows the improvement of the receiver chain with the introduction of reflectionless filter.

Recent Advancements

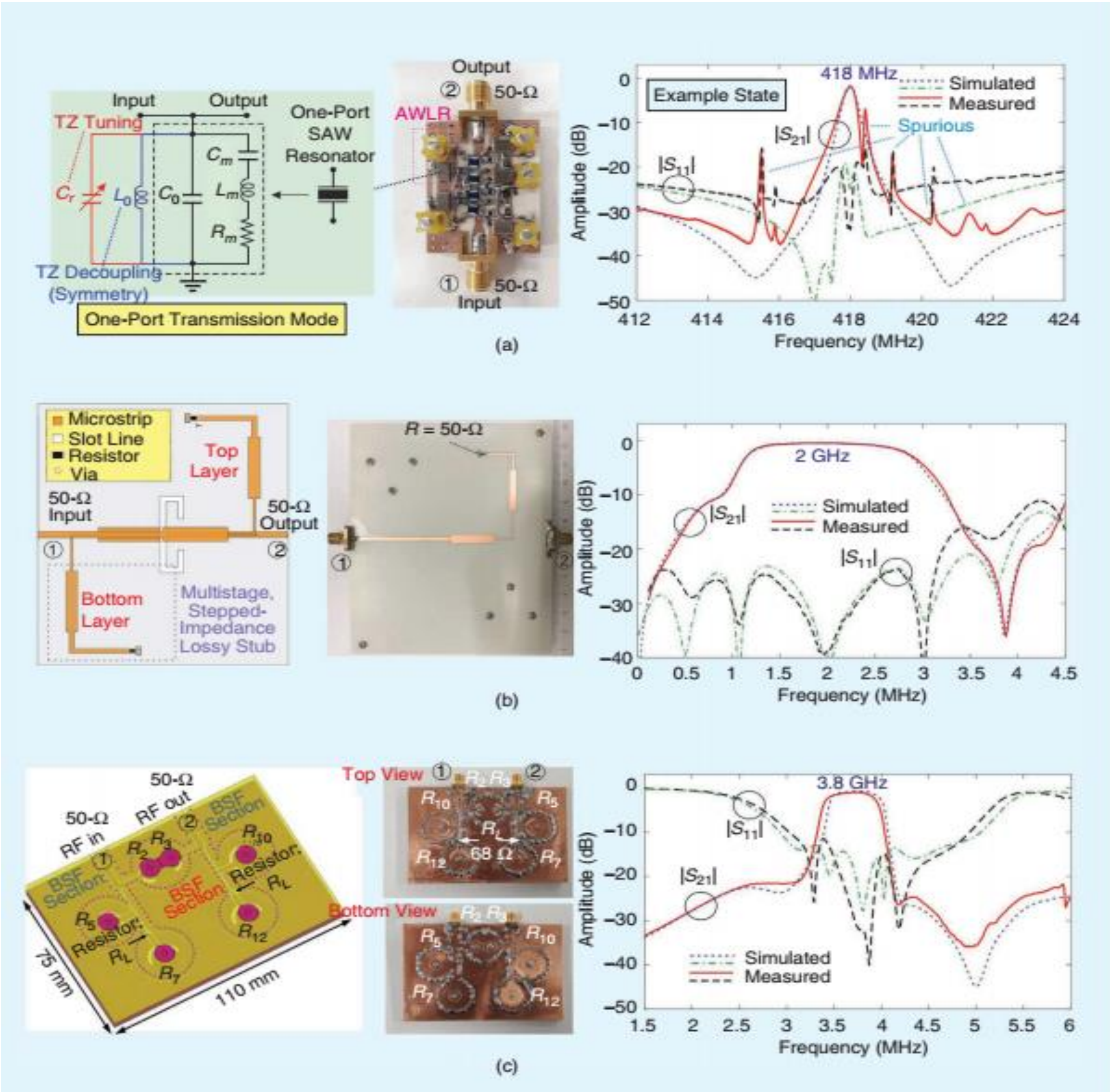
Reflectionless Bronchopleural Fistula (BPF) devices developed mostly in planar realizations. However, to much lesser extent they are also have been demonstrated in other technologies. Below are the technologies where nonplanar reflectionless BPF components have been demonstrated are shown in figure:

1. **MMIC and low-frequency technologies**: Reflectionless BPFs in MMIC technologies are demanded for modern, energy-efficient, compact RF front-end chains .A theoretically perfectly matched symmetrical BPF network with even- and odd-mode subcircuit compensation, an integrated, passive, two-port absorptive BPF is developed. This prototype exhibits a quasi-elliptic-type bandpass filtering response centered at 2.5 GHz with return loss levels above 15 dB from dc to 10 GHz for a chip area of 1 mm^2. It should be noted that commercial counterparts of this solution are already available showing promise for deployment in future RF transceiver modules. On the other hand, although, thus far, they are used only in low-pass filtering components (which can be easily extended to BPF ones after appropriate lowpass-to-bandpass frequency transformations), the novel classes of reflectionless filters for very low-frequency applications. The future need is to demonstrate and extend this concept for Ku and Ka-band.

2. **Acoustic wave technology**: BPFs in acoustic wave realizations are leading frequency-selective devices in mobile communications systems, due to their high quality factor (Q) and compact footprint However, most show some major limitations in terms of their very narrow operational bandwidth and frequency-static filtering transfer function being mostly of the reflective type and because of their spurious mode creation. By efficiently combining the acoustic-wave lumped, element resonator

(AWLR) concept presented in for enhanced-bandwidth, quasi-elliptic-type BPF realization with the complementary diplexer approach. AWLR-based BPFs with reconfigurable out-of-band TZs are shown in figure 1.2.

3. **Multilayer technology**: The exploitation of microstrip-to-microstrip vertical transitions with slot line resonators in multilayer schemes has proven its potential in the development of ultra-wideband BPFs aimed at broadband and RF receivers. Using this concept and the lossy-stub-loading philosophy for reflectionless BPF design, new ultrawideband BPFs that simultaneously exhibit a very broad, symmetrical, reflectionless behaviour can be developed shown in figure 1.2.



Examples of reflectionless BPFs in nonplanar technologies. (a) An input reflectionless AWLR- based BPF using a complementary diplexer approach for TZ tuning. (b) A symmetrical, reflectionless, wideband BPF on multilayer technology using input/output multistage lossy stubs. (c) A symmetrical reflectionless BPF with substrate-integrated coaxial resonators using a two-port complementary diplexer approach.

3.8.1.2. Ceramic filters

As the name implies, RF & IF ceramic bandpass filters are manufactured from ceramics that exhibit the piezo-electric effect. One of the most common ceramics used is known as Lead Zirconate Titanate (PZT), lead zirconium titanate. The ceramic element uses its very high Q mechanical resonances to provide the resonant feature. They have bandwidths that are typically measured between 0.05 and 20% of the operating frequency. Often the Q levels range between around 500 up to 10 000

Ceramic filters are electronic components that are widely used in IF and RF bandpass filter applications for RF circuit design in radio receivers and transmitters and the like. They may also be used as resonant elements in a variety of electronic circuit designs

3.9. Receiver & Frequency Sources Technologies

Compact, low power consumption and small volume are the system requirements of all times. In this direction a major emphasis and thrust has been provided over the years for development of miniature Low-Noise Amplifier LNAs, Receivers and Frequency converters over frequencies ranging from UHF to Q/V band. MMIC technologies combined with advance packaging techniques are being utilized for various communication and navigation payloads. Higher operating bandwidths and gain requirements combined with stringent spurious performance poses a challenge for development of compact systems as stringent filters are also to be incorporated.

Areas of Research are:

1) Beam Forming Receiver
2) Receiver Design for Doppler Shift
3) Flexible Receivers in terms of frequency and bandwidth
4) Design and development of RF switches, Variable Valve Actuation (VVA) and Video Graphics Array (VGA) upto Q/V band
5) Fully integrated Receiver (RF, Local Oscillator (LO) & DC/DC in single package)
6) Medium Power Beacon Sources
7) Design of Synthesizer Integrated Circuit (IC)s

3.10. Electronic Power Conditioners

Electronic Power Conditioners designed to supply power in wide range for RF (Transmit and receive section) and Digital Processors of communication and navigation payloads. EPCs are designed with efficient power conversion topology, high switching frequency, EMI mitigation, low output noise, output voltage sequencing, load sharing, temperature compensated output voltages and categorized as miniaturized low power for RF front end, highly efficient high power for power amplifiers and high peak current channelizer for digital processors. EPC from 1 W to 650 W output power designed and developed for space applications are modular HMC based EPC card embedded in Receiver package, EPC for dynamic load switching of digital processors, EPC for pulsating load of iRAFS, EPC for Modulators, high power EPCs for 250 W SSPAs etc.

New EPC development emphasizing the high frequency miniaturized EPCs, advance noise mitigation techniques in compact footprint of EPC, very low voltage (~0.8V) and high peak current EPCs for digital processors, efficient very low noise modular supply for digital devices. to meet the requirement of subsystems of upcoming digitized SDR, HTS and LEOCOM communication payloads

3.10.1. GaN FET based EPCs

Wide bandgap semiconductors such as the Gallium Nitride (GaN), and Silicon Carbide (SiC) are promising transistor technologies for future generations of power electronics circuits. GaN FET-based DC-DC converter is useful for space applications in that GaN FET has a high immunity and it becomes less susceptible for any false turn-on due to ionizing radiation.

GaN FET EPC for LEOCOM The present EPC (40W-50W output power) design using Teledyne GaNFET TDG650E60BEP as power switching element is realized to power 15W C-band SSPA. All the components are available in space grade except the GaNFET which is a plastic package and hence, qualified only for LEO applications. In an effort to miniaturize EPC size while increasing efficiency, it becomes challenging task in high power EPCs to achieve required goal. The figure 1 below shows the card level design meeting all electrical specifications during lab testing. Switching frequency of converter is 500KHz and efficiency is around 86%.

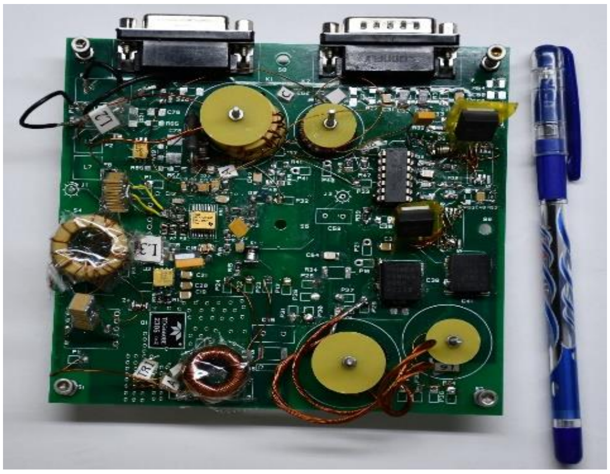


Fig 1: GaN FET based 50 W triple output EPC

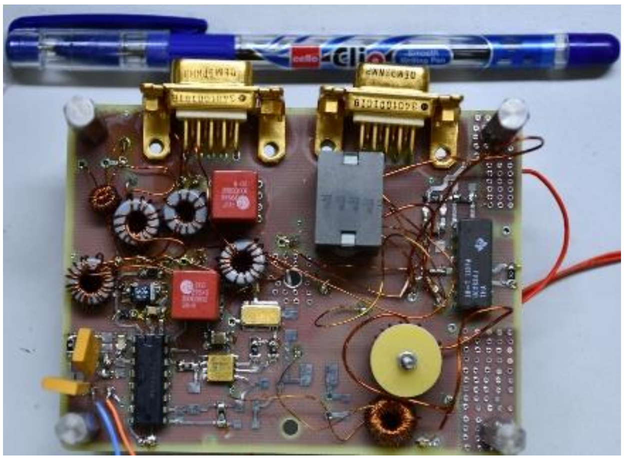


Fig 2: GaN FET and Planar transformer- based 10 W EPC

GaN FET EPC for GEOSAT: The present EPC (10W output power) design using Intersil GaN FET ISL70024 (Intersil Driver ISL70040) as power switching element is realized to power low power RF subsystems. All the components are available in space grade. Achieved efficiency of the converter is 70% at 10W output power and 400KHz switching frequency. Further increase in switching frequency (above 500 KHz) with high frequency PWM controller is being designed and development is in progress. EPC is featured with no wall mount components, can be integrated in same package with RF subsystem.

3.10.2. Active EMI Filter

With increase of switching frequency of dc-dc converter reduces the size and weight of the power supply on the one hand, and leads to more serious EMI problems on the other hand. Conventionally, a second-order passive electromagnetic interference (EMI) filter is used to mitigate the conducted EMI noise generated by the power converter. These passive LC filters tend to be bulky and could occupy up to 30% of the system volume. Active EMI filters, on the other hand, offer dynamic and adaptive filtering capabilities, enabling precise control over the attenuation of EMI across a broad frequency spectrum.

The presently designed AEF has been tested with two EPC boards having switching frequency of 110KHz and 230KHz. AEF was able to attenuated the switching frequency noise around 37 dB and 20 dB respectively.

Fig 3a: Higher ripple when AEF disabled

Fig 3b: Lower ripple when AEF enabled

3.10.3. 15 W HMC Module for low power RF subsystem

With the advent of advanced high-throughput communication satellites, requirement of RF front end subsystem will be in larger number, hence the development low power HMC dc-dc converters that can cater power supply requirement of all types of low power RF subsystem is very essential. This low profile HMC module can be used as embedded card in package of with RF subsystem. It will improve EMI performance and compactness of package.

Hybrid DC- DC converter is realized by implementing the ICs chip and wire technology, by increasing the switching frequency which drives the ability to use smaller magnetic components. Most of the low voltage DC to Dc converters Module available is operating at internal switching frequency up to 500 Khz for space use, few of them are design for 1MHz.

The present Triple output 15W HMC at switching frequency 510 KHz is designed by using flyback converter topology along with post regulators for better cross regulation with turn -ON/OFF voltage sequencing between positive and negative supply lines. Protection features are ULVO, current protection with primary as well as secondary side current sensing circuit at positive voltages and foldback at negative output voltage line. HMC includes TM and TC interface circuit. Efficiency of HMC is around 65 % at max load condition. This low profile HMC is suitable for all types of low power RF subsystem i.e., Rx, DA, LNA, converters and other sub systems. Size of the HMC is 75 * 105 * 16 mm^3.

Fig 4: 15W HMC Module for low power RF subsystem

3.10.4. 90W HM-EPC module along with post regulators

The evolution of new generation FPGAs demands highly efficient and reliable power management systems to meet their growing performance requirements. EPC along with post regulators need to be designed in well-coordinated manner to manage number of output power rails required by digital subsystems.

The EPC is designed with active clamp forward converter with synchronous rectification. A low power flyback converter is also implemented to derive low power output and generating housekeeping supplies. The Substrate level testing is completed. Size of HMC is 3.2"x 3.2" x 0.7".

Whereas post regulators are designed with advanced POL and LDO regulators. HMC with three tunable outputs (0.8V-1.9V @9A, 1.8V to 2.5V @4.5A, 1.8V to 5V @1A) is to be designed.

Some of the post regulators demand PMBus controlled low voltage and high current output like 0.8V @45A. Droop control, fast dynamic response, capacitive loading, low PARD and stringent load regulation; are the major challenges. GaN based Synchronous buck converter is tested for the application.

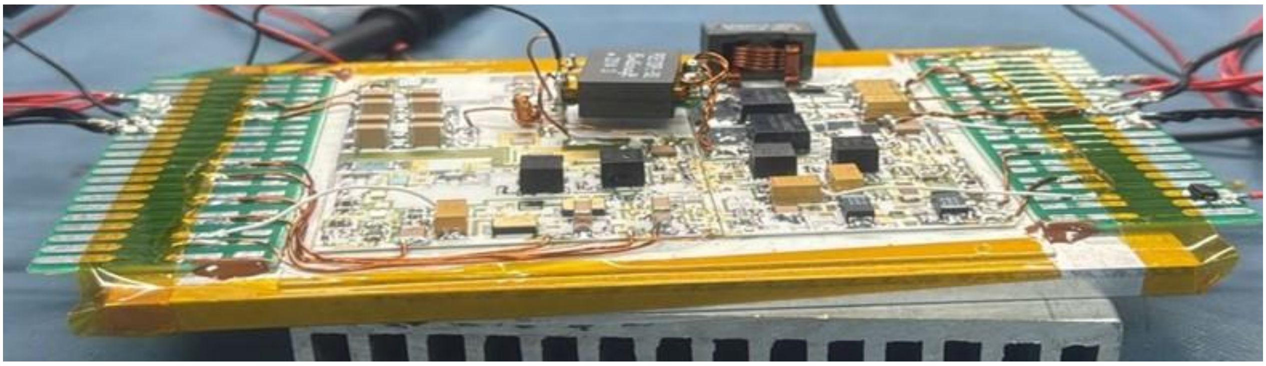


Fig 5: 90 W HMC Module with Post regulators for Digital Processors

3.10.5. Planar Technology Development

Towards the self-reliant, in-house Planner technology development will put thrust to low profile miniaturized DC to DC converters for payloads. Developed single output Transformer for 100W EPC, Vin: 70 ±5V, Vout: 5V ±1V OR 3.5V ±1V @ 10Amp.

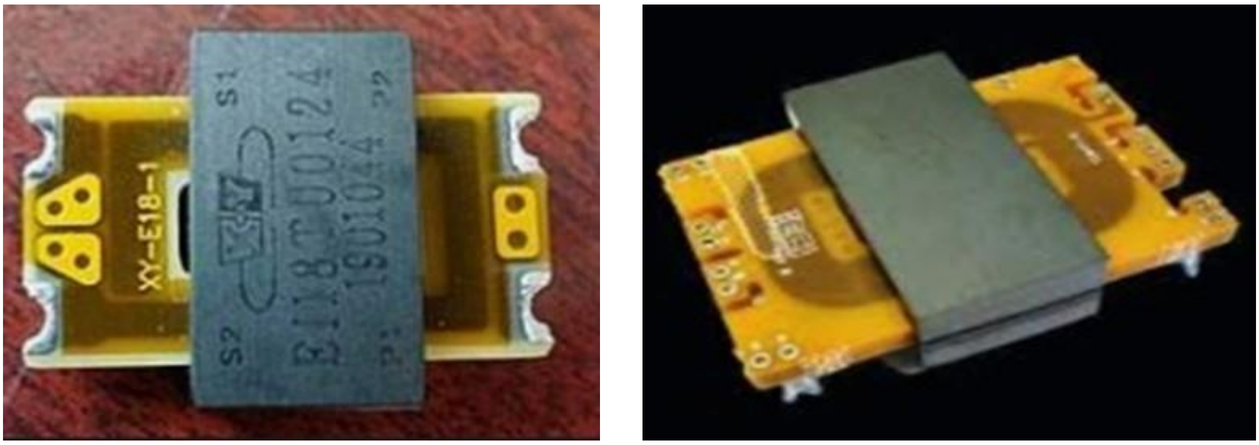


Fig 6: 100 W Low profile power transformers

3.10.6. Development of Digital controller simulator for EPC realization

Development of software and hardware toolkits shall be carried out, that allow fast prototyping of any power controller.

Digitally Programmable controller reference kit can be developed, which is a hardware board that contains DPC chips and auxiliary circuits along with all its signal interfaces. Once connected to PC and power components, it allows designer to program power controller algorithm that will help faster implementation and realization.

Scope of research proposal:

- Complete theoretical analysis of EPC including modelling and simulation with suitable topology selected.
- Simulation and circuit optimization for dual& four phase controllers

- Incorporation of advanced techniques to miniaturize the size and increase the efficiency of the EPC like low magnetic loss, synchronous rectification etc.
- Miniaturize the design with high frequency operation and use of GaN switching device.
- Designing of efficient HMC layout maintaining signal integrity while reducing board size and obtaining higher switching frequency above 500 kHz up to 1MHz. Implementation of planar magnetics within the HMC.
- Low loss Turn -On sequencing circuit for multiple high power output voltage lines in a single converter.
- Loss breakup analysis to maximize EPC efficiency.
- Complete theoretical analysis of AEF with EPC including modelling and simulation.
- Implementation of AEF in higher switching frequency converters above 500 kHz up to 1MHz.
- Designing of efficient Printed Circuit Board (PCB) layout maintaining signal integrity while reducing board size and obtaining higher switching frequency above 500 kHz up to 1MHz.
- Further optimization of compensation network to achieve desired attenuation over wide range of frequency.
- Realization and delivery of AEF + EPC with compliance of electrical specifications.
- Realization and delivery of EPC with compliance of electrical specifications of all of the subsystems

3.11. RF characterization of communication and navigation payloads

Communication payloads include bent pipe, SDR based and spectrum processing configuration. Navigation payloads have data transmitter type configuration, which provide Position, Velocity and time solution to user. These payloads are characterized for different parameters such as IO transfer curve, frequency response, group delay, noise figure frequency conversion error, 3rd order intermodulation, spurious etc. for communication payloads & Error Vector magnitude (EVM), BER, phase noise, carrier suppression, magnitude/phase imbalance (IQ imbalance), absolute delay, code/carrier coherency etc. for navigation payloads. These parameters are characterized using an Automated Test System (ATS). The ATS is an interconnection of stimulus and measurement equipment to test a transponder (communication/navigation) in an automated fashion. The data is processed on a controller to provide the parametric results, which needs to be complied with the payload specifications. The processed data is displayed and stored in variety of formats such as excel, pdf, text, database etc. The ATS is generally developed on platforms such as LabVIEW, Matrix Laboratory (MATLAB), and Python etc.

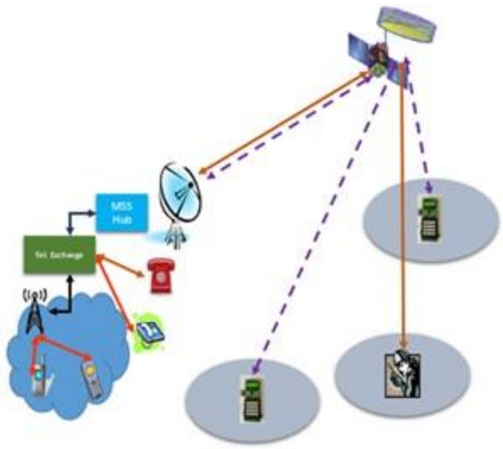
ISRO is actively involved in development of payloads for variety of user applications for which high speed ATS development is required to test payloads in production mode as well as applying suitable DSP algorithms for estimation of various parameters.

Payload testing also requires design and development of various ground components (low power and high power) such as Switching & Interconnect Network, switch matrix, waveguide/coaxial adaptors, couplers, dividers, high power waveguide terminations etc. to enable realization of ground test setup for communication and navigation payloads. Future research scope exists in ongoing activities:

- Development of web based Miniaturized ATS to characterize payloads from UHF to Q/V band and above, having very narrow to very wide bandwidths (5 KHz to 500MHz), using DSP techniques.
- Development of fast phase array antenna (PAA) measurement technique (in near/far field conditions) for LEO payloads
- Design of PAA test setup as well as qualification in thermovac & compact antenna test range (CATR) chamber.
- Characterization of multiple transponders in parallel using DSP techniques.
- Mismatch Fault isolation analysis using time domain techniques.
- Design and development of very high power waveguide terminations (> 2KW) at Ku and Ka band
- Design and development of high power pressure windows at S, C, Ku and Ka bands (quartz or alumina based).
- Design and validation of stimulus for various scenarios for communication, navigation, ADS-B, AIS, Radar, spectrum processing.
- Development of efficient technique for ground setup RF calibration setup for wideband multibeam/communication payloads.
- Feasibility analysis of Artificial Intelligence and Machine Learning (AI/ML) concepts application in analysis of payload test data generated during multiple phases of testing
- Query based trend analysis on centrally stored payload test data, generated at different geographical locations.
- 5G NTN testbed design & development
- Array antenna diagnostics & practical phase shifter uncertainty demonstration using deep learning approach
- Measurement of nonlinearity with memory effects
- Test methodology for characterization of multi-beam payload with reduced test interfaces
- G/T measurement in ALC mode
- Characterization & calibration of multi-port amplifier
- Document processing & information retrieval using large language modelling
- Near field characterization of payloads having phased array fed reflectors

4. SATCOM & SATNAV APPLICATIONS

Satcom & Satnav Applications Area (SSAA) of SAC is entrusted with the development of technologies and devices that leverage the installed capabilities of two major categories of ISRO satellites *viz.* communication and navigation satellites. Various applications for both commercial and special usage are developed as per requirements of user agencies and / or vendors who are then enabled for further commercial or operational roll-out through a combination of transfer of technology (ToT) and build-to-print or -spec models with handholding provided. SSAA also builds and operates satcom networks through provision of hub / gateway stations along with associated baseband technologies to route and manage the traffic. Navigation-related developments comprise three major segments of GAGAN / NavIC utilization. These are development of GNSS receivers, GNSS application devices that provide value-added services based on positioning information and GNSS simulators to aid in development of these as well as performance validation of both NavIC payloads & developed receiver / application hardware.



SPS (IRNSS + GPS + GAGAN) Receiver

In House IRNSS Simulator

SSAA comprises of two Groups based on the above broad domains of applications activities.

The Communication Technology and Applications Group (CTAG) is focused towards development of various state-of-the-art baseband technologies, establishment of ground segments and applications development towards the effective utilization of space-based resources. The Group has its primary focus towards building satcom networks / ground infrastructure (Technology Development, Terminal & Hub Station etc.) to support different mobile satellite service (MSS) applications, fixed satellite services (FSS)Broadband Communication using up-coming High Throughput Satellite (HTS) and synergistic applications using a combined 'Com-Nav' approach for commercial / special user group.

Of late, the Group has successfully developed and demonstrated four types of MSS services namely Reporting Service for one-way small message & position reporting, low bit-rate two-way voice communication service (Satellite Phone), two-way multimedia communication *viz.* video conferencing and broadcast service using personalized gadgets. The Group has also established Ka-band interconnected gateways to support broadband HTS applications using the country's first high throughput satellite. CTAG also supports the communication network for national disaster management to cater to emergency communications. Also, we are entrusted the propagation studies experiments for higher frequency bands like Ka, Q and V-bands.

The Navigation Technology and Applications Group (NTAG) within SSAA is responsible for developing various critical technologies related to ISRO's satellite navigation programme in general and Navigation with Indian Constellation (NavIC), in particular. Various types of receivers *viz.* IRNSS Payload-Test receiver, IRNSS SPS-User receiver, IRNSS RS-User receiver, GNSS Receiver, SBAS Receiver, Messaging Receiver and IRNSS Simulator have been successfully developed. Also, Reference receiver, Software-based receiver and ASIC chipset-based solutions for NavIC are currently being developed.

The Navigation Group has provided IRNSS encryption scheme and its implementation in payload besides PRN codes and its analysis for the NavIC programme. Data analysis of Ka-band propagation experiment and GAGAN-TEC network as well as IRNSS Secret Intelligence Service (SIS) performance analysis is also carried out. Other activities include development of applications related to IRNSS/GNSS/Augmentation systems and simulation studies related to digital signal processing for baseband applications relevant for ground-based applications systems. NTAG is shouldering the major responsibility to conduct the prestigious Centre for Space Science and Technology Education in Asia Pacific (CSSTEAP) programme under the aegis of the United Nations. A nine-month course on GNSS is offered to meritorious nominees from developing nations in the Asia-Pacific region under this.

In the following; a list a major areas of research respectively in satellite-based communication and navigation are provided wherein the Indian academic institutions can potentially contribute through RESPOND programmes.

4.1. SATCOM Applications and Technology Development

Space Applications Centre, ISRO, Ahmedabad is responsible for SATCOM Applications and Technology development for eventual use of Societal and Strategic users of the country. Besides meeting the application needs, the Centre continues to work on development of state-of-the-art technologies for SATCOM with an intent to indigenise technology and product development.

In the last two years, the Centre has been into the establishment of more than 25 SATCOM Gateway stations in Ku/Ka band to meet national enterprise VSAT communication demand using upcoming HTS class of satellite. In the Mobile Satellite Service domain, the Centre has developed applications like Real-time Train-tracking Information System (RTIS), MSS Network for Tracking of Sub-20m boats, Real-Time Aircraft Tracking System etc. to meet the custom requirements of user ministries. Besides these efforts, the centre also focuses on development of technologies like SATCOM baseband ASIC development, MMIC development for RF Sub-systems, Signal Processing algorithms for SATCOM baseband technologies to enable communication on the move (COTM) for Airline, Maritime and Land Applications. The Centre specializes on baseband technology development pertaining to FSS and MSS. The Centre is working on development of advance technologies for miniaturization (Satcom Baseband ASIC), cost and power efficient battery operated MSS terminal development to support voice communication, IoT and M2M communication using MSS satellites. The Centre is also exploring the opportunity to promote development of RF and baseband sub-system technologies indigenously by collaborative efforts.

While efforts are ongoing to achieve self-reliance, there are many new technologies still that need development in the domain of Satellite Communication Ground Systems like more powerful processors/ASICs, new source/channel encoding-decoding capabilities, user terminal miniaturization and baseband algorithms that can enhance user mobility, versatility, performance in a cost effective manner.

This document incorporates research areas relevant to the satellite communications ground segment and application development to meet the near future requirements.

4.1.1. Baseband Technology Development

4.1.1.1. Non Orthogonal Multiple Access (NOMA) based Multi-beam High Throughput Satellite /Ultra High Throughput Satellite System

Researchers are invited to explore the potential of Non-Orthogonal Multiple Access (NOMA) technology in Satellite Communications (SATCOM) systems. To submit a proposal, researchers should provide mathematical analysis and explain how NOMA can be integrated into existing satellite systems from a system-level perspective. Specifically, they are encouraged to propose methods for combining NOMA with pre-coding techniques, outline an implementation plan, and demonstrate the effectiveness of NOMA in low signal-to-interference (C/I) conditions.

Additionally, researchers are invited to develop and evaluate receiver algorithms that can handle multi-user detection and successive interference cancellation (SIC) at the receiving end. The goal is to improve spectrum utilization efficiency and reduce co-channel interference in SATCOM networks. Researchers should propose innovative solutions for NOMA-based systems in various application scenarios.

4.1.1.2. Algorithm and Implementation of real-time Wideband Spectrum Sensing (WSS) and Automatic Modulation Recognition AMR system for Blind Signal Detection

Blind Signal Detection (BSD) relies on sophisticated algorithms to efficiently analyze wideband signals and identify modulation types in real-time. To further enable its practical application, researchers are invited to propose novel approaches for automatic spectrum sensing and modulation recognition systems. These proposals should also address the challenges of identifying communication streams, demodulating signals, and monitoring interference.

In addition, BSD systems can benefit from advanced techniques such as carrier-in-carrier (CIC) or PCMA-based methods for more accurate identification. Researchers are encouraged to submit their ideas for efficient spectrum sensing and modulation recognition systems that include:

- Interference detection and mitigation strategies
- Signal demodulation plans with implementation details
- Methods for identifying blind scramblers and channel coding techniques

By tackling these challenges, researchers can contribute to the development of reliable BSD systems that enable more efficient and effective use of communication resources.

4.1.1.3. Advance Baseband Technologies for Vocoderless audio communication for Satellite Phone

In the Ongoing research of efficient datarate communications, vocoderless audio communication is provided through satellite link in ultra low datarates. This unique choice of vocoderless audio communication and the ultra-low data rates allows and paves the way for miniaturized low power satellite terminal with voice and data communication. It will also allow massive number of devices to be supported simultaneously due to efficient utilization of bandwidth. This novel research development will help providing voice and data communication in existing low bandwidth channels. This research is aimed at realizing the low power Miniaturized Satcom Voice and Data terminal with two-way communication capability for strategic applications aimed at ultra-portability.

4.1.1.4. Baseband Technology for Search And Rescue (SAR) systems of ISRO

ISRO operates INSAT satellite(s) equipped with a 402-MHz Search and Rescue payload as well as 406 MHz Data Relay Transponders that are being used for SAR operations using different types of distress beacons of maritime, aviation and land users.

- Researchers are encouraged to submit their proposal for development of MEO-SAR emergency locator transmitters with requisite Letter of Undertaking (LUT) processing algorithm.
- Data Relay Transponders are usually of 200 to 350 kHz bandwidth and being non-regulated band suffer from interference from users .The nature of interference being non-time dependent and sweeping nature causes the communication loss .Researchers are encouraged to submit development proposal in interference resistant waveform for sensor data reporting in burst mode of transmission that can offer better quality of service.
- Proposal on development of Mixed signal ASICs for SAR user terminals are encouraged.

4.1.1.5. MSS/DRT Network for data collection from Oceanic Platform

ISRO has already established a network with multiple GSAT satellites carrying MSS transponders & INSAT satellites carrying Data Relay Transponders (DRT) transponders. Also more next generation satellites with advanced MSS/DRT transponders & larger antenna will be coming up in future. This network can be potentially utilized for data collection & relaying applications from oceanic platforms. This network can facilitate the data collected by different oceanic sensors deployed at different locations to be communicated to control centre in near real-time. The network can have hybrid reconfigurable terminals which can communicate in both MSS & DRT bands & provide unified interface with sensors.

Researchers are encouraged to innovate and propose design of ASICs, low-profile planar antenna system with beam-forming capability and suitable waveform for robust communication and leading to low power miniaturized system realization. A very low bit-rate (25-300 bps), fast acquisition, spectrally efficient spread spectrum burst demodulator design will add value to the proposal.

4.1.1.6. Baseband Sub-systems of Ground Network with multi-homing capabilities for Gaganyaan

ISRO has been working on the Gaganyaan Project, which will also include development of audio/video processing system for ground segment. All ground stations are connected to Master Control Centre (MCC) through multiple ground links to achieve failsafe transmission reliability and service quality. For real-time multiplexed streams comprising audio, video and data, the reliability requirement is different for each type of data stream. So there is a need of an efficient transmission technique for such multiplexed streams with different reliability parameter settings for each stream over a multi-homed networking environment. It is also required to have a suitable handoff mechanism in case of link failover with minimum handoff latency.

Researchers are encouraged to propose a custom protocol stack for seamless multimedia communication over multi-homing network.

4.1.1.7. Design and Simulation of digital beam-forming /electronic beam steering-techniques for high frequency COTM/SOTM (Communication on the Move / Satcom on the Move applications)

The Indian Space Research Organisation (ISRO) has designated specific frequency bands for its satellite services, including the S-band for Mobile Satellite Service and Ku/Ka band for aeromobile broadband services. To optimize performance and support critical communication protocols, researchers are sought to develop advanced technologies.

Specifically, proposals are invited for the design and development of efficient electronic beam steering systems that can mitigate interference in the S/Ku/Ka frequency bands used by ISRO's satellite services. The proposed systems should also ensure seamless switching between different communication modes (COTM/SOTM).

Additionally, researchers are encouraged to submit proposals for:

Compact mechanically steerable antenna systems suitable for aero-mobile applications

Hybrid systems that combine mechanical steering with electronic beam control for improved efficiency and reliability

The goal is to develop cutting-edge technologies that can enhance the performance and effectiveness of ISRO's satellite services.

4.1.1.8. Development of baseband signal processing elements for aero-mobile terminals

The demand for in-flight broadband connectivity is on the rise, driven by increasing expectations for high-performance services from aircraft operators. As a result, more airlines are investing in on-board broadband systems, leading to growing demands for reliable and efficient connectivity.

To meet these demands, ISRO's satellite-based broadband network uses Ka-band satellites and ground equipment to provide high-throughput services to aircraft in flight. However, the challenge lies in offering affordable, low-cost terminals that can support a multi-beam network with high-performance capabilities.

Researchers are invited to submit innovative designs for Ultra-High Throughput Satellite (UHTS) class modem technology, which must enable: Wide and fast acquisition capabilities, Support for large drifts in satellite position and velocity, State-of-the-art access schemes, such as mobility management techniques for aero-mobile broadband

These advanced technologies will be essential in enabling low-cost, high-performance terminals that can provide reliable broadband services to aircraft in flight.

4.1.1.9. Design & Simulation of physical-layer waveform for high mobility wireless channel (high Doppler-delay channel)

Providing reliable wireless communications for high mobility terminals remains one of the main challenges faced by satellite high-mobility communication systems. because the high Doppler frequency offset, Doppler rate & delay caused by the high-mobility nature of the mobile terminal, and low signal-to-noise ratio (SNR) circumstances caused by limited satellites' link budgets degrade the system performance seriously. This is a very challenging aspect in LEO broadband communication. Most of algorithms mainly focused on the estimation and compensation of Doppler frequency rate and Doppler frequency offset, rather than reducing the influence of Doppler effect in the communication system. To solve such a problem in high-mobility satellite communications advance physical layer waveform may be proposed which is insensitive to Doppler & delay.

Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.

4.1.1.10. Generation and performance evaluation of candidate waveforms for NB IoT and NTN

With the evolution of Internet of Things (IoT), education, healthcare, commerce, and energy has put strong pressure on current generation of wireless networks to improve their services by including Non Terrestrial Networks (NTN) for better coverage and seamless connectivity. The explosion of smart devices and applications has resulted in the largescale use of the IoT requiring huge data rates, latency, frequent sensing, and computation that can exceed the capabilities of current networks. As the requirements in these applications continue to increase, NTNs will have to offer good energy efficiency, improved spectral efficiency, very low latency, and high mobility. To meet these requirements, the radio interface of NTN will have to be flexible and improvised. Therefore, new modulation methods, access techniques and waveforms capable of supporting these technological changes need to be generated and evaluated. Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.

4.1.1.11. Design & Simulation of baseband technologies for LEO Broadband communication

The LEO Broadband Communication Network consist of Ka/Ku band user terminal, Space segment & Ka-band Satellite Gateway. Satellite Orbit propagation & Scheduling, automatic antenna pointing/beam steering, beam acquisition/ switching, Space resource management, Satellite handover & security are the major technology challenges.

Researchers are encouraged to propose innovative efficient solutions/algorithms for above challenges.

Researchers may also propose detailed hardware & software architectures of various baseband systems in User Terminals & satellite gateways.

4.1.1.12. Design & Simulation of waveforms for Extremly Low SNR Satellite communication

The satellite communication industry is experiencing a surge in demand for mobile broadband and Internet of Things (IoT) applications. These emerging use cases require the development of compact, low-cost, and energy-efficient user terminals that can operate reliably at extremely low signal-to-noise ratios (SNR) (-30dB or lower), while maintaining high bandwidth efficiency.

Researchers are encouraged to submit innovative proposals for:
Efficient waveforms that can effectively transmit data in adverse channel conditions Advanced signal processing algorithms that enable robust acquisition, synchronization, and reliable operation of receivers under dynamic channel conditions, including extremely low SNR and high Doppler frequencies Furthermore, researchers are invited to propose efficient multiple access schemes and signal processing technologies that can maximize capacity in satellite communication networks, ultimately enabling the widespread adoption of mobile broadband and IoT applications.

The goal is to develop novel waveforms and signal processing techniques that can overcome the challenges of operating at extremely low SNR, while maintaining high bandwidth efficiency and reliability.

4.1.1.13. Geolocation of interference using terrestrial technology

To disrupt satellite-based communications, it is observed that an interference signal is being transmitted at the same operating frequency by some unknown source. This interference signal makes it difficult for the intended receivers of the ongoing communication to demodulate the received signal. The location of such malicious transmitter that is transmitting the interference signal is unknown. This research proposal is therefore aimed at processing the interference signal to estimate the location of such malicious transmitter.
This research proposal envisages the use of multiple ground based receivers to receive the signal transmitted by a malicious transmitter and process this signal to estimate the geo-location of the transmitter. The work/ algorithm must not use any aerial borne receiver platform and should only consider ground-based receivers that are receiving the transmitted signal. Researchers are encouraged to offer innovative solution in form of algorithm, simulation model as part of their proposal.

4.1.1.14. Optimizing PQC for resource constrained IoT Devices

The emergence of Internet of Things and cyber security for spacecraft applications are two important areas that demand the adoption of an increasing number of security standards which in turn requires implementation of a diverse set of cryptographic primitives. This poses tremendous challenges in the design and implementation of PQC standards in a single embodiment. The implementation of standards should handle large key sizes and at the same time should not be too expensive in terms of speed and energy. This requires optimization of cryptographic primitives implemented in hardware. The hash module, NTT and multiplication processes, compression and decompression and sampling need to be implemented with minimum number of resources. The design should also ensure that the security in not compromised with such optimization.

4.1.1.15. Enhanced Spread Spectrum Aloha Technology Development

Enhanced Spread Spectrum Aloha (E-SSA) is an asynchronous access protocol especially conceived to provide messaging services over the satellite return link. Protocol is slightly modified version of the robust 3GPP Wideband Code Division Multiple Access (W-CDMA) random access waveform (asynchronous burst transmission). The absence of synchronization mechanisms simplifies deployment and activation of the terminals. A wide range of applications based on burst transmissions not significantly capacity-demanding have been envisaged, such as telemetry, environment and traffic monitoring, emergency alerts, fleet management, highway tolling, forecast predictions.

Researchers are encouraged to submit their proposal for ESSA system simulation and Receiver design and implementation plan.

4.1.1.16. IoT enabled terminal development

Implementation of IoT/M2M via satellite deals with mainly two issues: First, the physical layer level: terminal related constraints (limited in power, energy, and antenna size), channel (potentially with masking and multipath) and the space segment to ensure proper link budget allowing the communication. On the other hand, the need to provide access to the resource to a large number of terminals. The access layer should also be able to interface with larger networks architectures.

There are two possible ways of realizing IoT/M2M via satellite. The first scenario involves the use of a satellite relay terminal that interfaces with terrestrial access technology sensors (backhaul communication link). The second scenario is based on direct communication with sensors / objects via satellite constellation.

Research proposals are invited for implementation of low power, low cost terminals, waveforms and other sub-system technology to support IoT over Satellite & Terrestrial networks.

4.1.2. Ground Segment Network and Hardware Technology Development

4.1.2.1. Indigenous VSAT sub-systems technology development

In today's scenario, there is an increasing need to indigenize the baseband subsystems of Very Small Aperture Terminals (VSAT) due to their stringent power, size, and operational requirements. To meet these demands, researchers are encouraged to submit innovative proposals for designing and developing indigenous solutions for VSAT technology.

Specifically, researchers are invited to propose:

Efficient, low-cost designs for RF subsystems commonly used in VSAT terminals, such as:

- Battery Disconnect Unit (BDC)
- Block upconverter (BUC)
- SSPA (Supervisor Security and Privacy Assurance)

Rapidly deployable VSAT terminals that can quickly establish communication links in emergency disaster situations. These designs should feature advanced antenna and RF technologies, supported by state-of-the-art baseband technology for:

- Quick antenna pointing
- Establishing reliable communication links from mobile platforms with limited power/space availability

Extending interfaces to terrestrial devices for providing backhaul connectivity through the satellite
The goal is to develop innovative solutions that can meet the complex requirements of VSAT terminals, while promoting indigenization and reducing dependence on imported technologies.

4.1.2.2. Development of Low Profile Ku/Ka band terminal for Mobile Satellite Service

ISRO is aiming at realizing the mobile satellite service in Ka-band .Researchers are encouraged to submit their proposal for Ka-band Mobile Satellite Service system solutions with their feasibility and recommendations; Proposals for terminal design, Proposal for protocol stack development for seamless overlay with existing MSS services, in case needed .Innovative ideas are encouraged from researchers towards providing reliable MSS services in Ka-band along with sub-system design proposals .

4.1.2.3. Portable HUB baseband system development (ESIM)

Earth stations in motion (ESIM) address a complex challenge - how to provide reliable and high-bandwidth Internet services to what are - literally - moving targets. They provide broadband communications, including Internet connectivity, on platforms in motion. There are currently three types of ESIM: ESIM on aircraft (aeronautical ESIM), ESIM on ships (maritime ESIM) and ESIM on land vehicles (land ESIM). Earth Stations in Motion (ESIMs) are the result of the most modern satellite technological developments and are designed to be used on aircraft, ships and land vehicles. They are small size terminals, with high-precision tracking capabilities, associated with state-of-the-art Ka-band satellites providing high-power multiple spot beam coverage, allowing transmission rates in the order of 10-50 Mbits/s.

Recognizing that there is a need for global broadband mobile-satellite communications and that part of this need could be met by allowing ESIMs to communicate with fixed-satellite services (FSS). The advances in satellite and earth station technology make ESIMs the best solution for users on the move and bring the benefits of high performance FSS networks to communities that have yet to benefit from true broadband offerings.

Researchers are encouraged to submit their proposal for design, development and implementation of different ESIMs.

4.1.2.4. Internet Protocol for Satellite Network

In recent years, many routing algorithms have been proposed for LEO satellite networks. Routing Internet traffic over satellites can be addressed using two alternative approaches. We can simply consider each satellite as a node in the Internet and use a traditional protocol stack. However due to the long round trip time (RTT) delay between the satellites and the terrestrial infrastructure, problems such as routing instability and slow convergence will be even worse than only using the terrestrial Internet. On the other hand, we can consider the satellite network a separate autonomous system (AS), with its own protocols. In this case, an IP packet will be encapsulated in a suitable way when entering the constellation, and rebuilt when inserted back in the terrestrial network at destination. The routing problem is divided into two sub problems: Up-and-Downlink (UDL) routing and Inter satellite link (ISL) routing.

Again, to ensure quality of services, research in this field is growing and there are various open issues and research areas in the field of Satellite Networks like -

- Reducing the routing overhead of a dynamic QoS routing in a different traffic is a challenge
- GEO satellites have advantage of technological maturity and good coverage but due to high delay and attenuation limits, transmitting real time information becomes a problem .A single layer LEO satellite network has poor performance on transmitting long distance .How to combine advantage of both the satellite to improve network performance

Multicasting datagram in the satellite networks to achieve larger coverage area on the terrestrial infrastructure is also a potential research area.

4.1.2.5. Adaptive protocol

To cope with the highly dynamic behaviour associated with the wireless environment and mobility, it is widely recognized that protocols should be able to adapt to a wide variety of situations. While protocols in the wired network also adapt to different conditions in a very limited way, usually at connection-setup time. Once a connection in a wired network is established, the underlying conditions will remain relatively stable, other than occasional congestion. This is often not so in wireless mobile networks. The wireless link experiences a range of conditions e.g., fading, transient service outage, high error rates, burst error patterns, and highly unpredictable traffic on shared links. Furthermore, mobility exacerbates the situation by introducing handovers, motion-induced effects, rerouting actions, and limited battery life.

Adaptive protocols provide productive ground for advanced protocol research. As nearly all protocol research has been done on relatively static protocol architectures, there is much to learn about how to select a different protocol on the fly when the original one no longer provides the required level of service. Protocol adaptation may be realized in several ways. Active networking, in which packets may contain executable instructions (in addition to headers and data), provides one approach to implementation. The efficient implementation of adaptive protocols in both hardware and software present interesting research problems. Some of the challenges are listed below:

- End-to-end protocol design that dynamically switches from one interface to the other, transparently to the application and its user
- Protocol stack development to support adaptiveness
- Development of principles to allow on-the-fly protocol selection in wireless mobile networks . Identify techniques for deciding when to select a new protocol, for switching protocols, and for efficiently implementing this feature in software and hardware .

4.1.2.6. SATCOM in Non-Terrestrial Network (NTN) of 5G

With the advent of 5G terrestrial network, Satellites are being proposed as an integral NTN component. ISRO is keen on extending its reach to be a part of next generation 5G communication, especially in the light of new satcom policy of the Govt of India.

Researchers are encouraged to submit their research proposal for system and sub-system design for facilitating NTN component in 5G using SATCOM.

4.1.2.7. Q/V Band Propagation Study

Presently Alphasat is the only satellite operating in Q/V band for European region available for such studies. Recently with GSAT-29, ISRO had established a limited capacity communication system for experimental purpose between Ahmedabad & Delhi. Due to congestion in higher band and bandwidth availability & demand, a very strong push for Q/V band is expected in future. Very high signal impairments and no availability of validated models for the Indian Region indicate a need to investigate this hereunto neglected area. These will serve as vital input for future satellite designs and deciding QoS and availability figures. Modelling and associated mathematical studies, development or realization of RF subsystems, beacon from satellite, pan-India study; Academia & Foreign Collaboration may be explored.

4.1.3. ASIC Technology Development

4.1.3.1. Design and Development of miniaturized, multiband S, L, UHF band / (S-band Low Power Wideband Transceiver Mixed Signal ASIC for SATCOM terminal

The mixed signal ASIC will comprise of comprise of front-end LNA, filter, transceiver with built-in LO for full duplex operations, gain& filter blocks, ADC-DAC etc. The selected architecture should have all imbalance measurement and compensation techniques built into it. The device calibration feature will be an added advantage.

The research proposal should address the development of low power, low cost custom RF wideband transceiver ASIC in S/L/UHF-band to support communication using miniaturized handheld and battery operated SATCOM terminals. The proposal should include all specifications of each sub-block, the reconfiguration parameters etc.

4.1.3.2. Design and Development of RF-ASIC to support implementation of low-power, cost-effective electronic beam steering capabilities for aero- mobile communication in Ka/Ku band.

Aero-Mobile terminal in Ku-Band/Ka-Band with beam steering capability could be miniaturized using RF-ASIC .

Researchers of this domain are encouraged to submit their proposal for design and implementation of RFIC for miniaturized, power and cost efficient terminal implementation.

4.1.3.3. Development of low cost terminal with Commercial-off-the-shelf (COTS) ASICs for RF front-end (MMIC and LTCC based RF Frontend for miniaturization)

The important aspect of any terminal is it being hand held and light weight this trend we have observed in terrestrial mobile phones as day by day they are becoming light and small. If we consider the Satcom terminals, the miniaturization is current necessity of the situation as to be better usable and appealing for the consumers. The miniaturization is happening on the baseband front by the development of Application Specific IC's and single board setup where whole baseband is being included. Hence, the miniaturization on the RF part needs to be done in order to decrease the weight and the size so that the whole terminal can be small and light.

There are a few techniques to reduce size & weight of the RF section. One of the most-utilized techniques is MMIC design in place of discrete microwave circuits where discrete active and passive components are integrated using either transmission lines on different substrates chosen according to frequencies. Monolithic Microwave Integrated Circuits (MMICs) contain active, passive, and interconnect components all on single wafer and can operate at frequencies from hundreds of MHz to hundreds of GHz. The size advantage obtained is very drastic as MMIC are of size of um to mm whereas the Microphone MIC circuits are in range of cm. Most of today's MMICs are fabricated on III-V compound substrates such as GaAs, InP, and GaN. This new technique enables us to make the circuits like LNA, Mixer, Power amplifier etc on a single Silicon doped chip, which are instead made using discrete components.

Another miniaturizing technique lies in a type of packaging technology named Low Temperate Co-fired Ceramics (LTCC) where the technology is used for robust assembly and packaging of electronic components.

It also offers may features like embedded components like capacitors resistors and inductors, as the passive components are available they can be utilized to make filters. The technology also allows us to make Substrate Integrated Waveguide filters. Further as the MMICs are bare dies, they need packaging, and interconnection LTCC proves to be the best option, which results in an integrated on a single RF module, which is very space efficient, and light weight. Furthermore, Antennas can also be made in order to make a more integrated space efficient and lightweight RF module which contains everything from Antenna to the IF signal.

The utilization of all these techniques can yields us miniaturized RF frontend, which can be of similar size of that of a compact baseband card thereby yielding us a small, and light weight hand-held terminal, which can be comparable to modern day mobile phones.

- **Modem ASIC development for Ultra High Data Rate System 100 Mbps -2 Gbps**
- **Mixed Signal ASIC development with built-in low cost SATCOM transceiver for various low-power IoT applications.**

4.1.3.4. Power Saving technique Backend ASIC design of ultra-low power Software Defined Modem (SDM) ASIC

Satcom baseband modem ASIC is being developed for various Satcom ground applications. Typical application of Modem ASIC, which are battery, operated & demands low power consumption. The Modem ASIC supports multiple mod-code & wide range of data rate. Based on application ASIC is configured by Serial Peripheral Interface (SPI)/ Universal Asynchronous Receiver-Transmitter (UART) interface. Currently even when a simple configuration is running, the power of entire core is ON and the clock is active.

Idea is to implement various power saving technique in frontend/backend ASIC design to suspend functionality of partial design or full design based on applications. Following power saving modes can be thought of considering nature of applications:

a. **Fully sleep mode** :This mode is very useful in case of burst transmission & reception .Device will consume minimal power when not active .In this case, only configuration core is always active . Modem core is enabled whenever required & kept shut for rest of the time.

   Typical applications :Reporting Terminal,

b. **Partial sleep mode:** This will be useful in almost all applications .This mode will disable the non-functional block for a particular configuration .In only Viterbi is used is active then other decoder should be shutdown .Entire receiver chain can be turn off in case of transmit only terminal & vice-versa .

   Typical applications :Two way MSS Vessel tracking terminal

   Sleep mode can be implemented using following methods

   - **Clock gating**
   - **Power gating**
   - **Multi-Voltage level**

4.1.4. Applications and Tools Development

4.1.4.1. Development of Hybrid Network for Real-time Person or Asset Tracking using Machine to Machine Communication Technology and Indian Navigation System.

Currently, ISRO has developed satellite-based solution for tracking of personnel and assets like vehicles and fishing boats. Although this solution is extremely useful in remote locations where terrestrial, network coverage is sparse or not existing at all, there is similar need for such solutions in areas, which are widely covered by terrestrial networks. A hybrid solution is proposed which can enable communication of mobile terminals using both SATCOM and terrestrial networks. This will greatly save the satellite resources and enable us to serve more number of users.

The network will consist of terminals having the ability to communicate their location and other significant information with the hub via satellite and terrestrial networks. The terminal will be equipped with NavIC receiver to detect its location. It should have the intelligence to detect the availability each of this network and switch between them as and when required.

As an extension of this functionality, the terminal should be intelligent enough to detect the presence of similar neighbours (terminals) around it. This may be achieved via point-to-point communication using Bluetooth/Wi-Fi. The Hub can also assist in finding neighbours. The terminal can find its neighbours and can directly contact them in emergency. A smartphone may interface with the terminal for visual representation of location and other information. Mobility management and interface for interaction between terminals also needs to be developed.

- Development of Spectrum and Waveform Analysis tool using low cost SDR platforms.
- Hub No Man's Sky (NMS), Network Control Program (NCP) and Web-based tools for effective Decision Support System
- Propagation studies, Advance Fecal Microbiota Transplantation (FMT) development and inclusion for improved QoS
- SATCOM System definition, Unified protocol stack and Test Bed development of 5G with Non-Terrestrial Networks (NTN) element
- NTN standardization efforts and Capacity Development Activities

- Development of mobility management algorithm and Hub Network Management System for different application

4.1.4.2. Satellite Communication On The Move (SOTM)

Satellite communications-On-The-Move (SOTM) is a communication capability used for high speed satellite connectivity in moving vehicle. SOTM terminal with vehicle mounted automatic tracking antenna will provide two-way, high-speed communications on the move under various operational conditions using HTS

(High Throughput Satellite). Using SOTM terminal, it is possible to provide high speed satcom connectivity for aero-mobile, land or marine applications. ISRO has developed prototype Ku band SOTM receive terminal with 0.6m antenna using 2 axis (Az and El) stabilized servo based system and demonstrated it for live DTH reception in moving vehicle.

Research proposals are invited for

- Mechanism and Control system design for 3 axis/4 axis automatic antenna steering and tracking of targeted satellite within +/- 0.1 degree accuracy for Ku band transmission.
- Solutions for estimating highly accurate heading information by INS (Inertial Navigation System)/ Sensor in dynamic magnetic environment. Magnetometer is not providing proper heading under dynamic magnetic field condition.
- Technology for Low cost INS with GNSS without compromising performance
- Compact and light weight Ku/Ka band flat panel/planner array antenna/ Carbon Fiber Reinforced Polymer (CFRP) reflector for mechanically steered transmit-receive SOTM system
- Design and development of efficient electronic beam steering system for Ku/Ka band operations as well as hybrid scanning system (electronic + mechanical)
- Design and development of system to test pointing accuracy of SOTM in lab environment and algorithms to find out misalignment.

4.1.4.3. Satellite Network Simulator (SNS)

The project's main objective is to develop a Satellite Network Simulator, which is used to generate and collect data-driven insights into the satellite network-level planning and design activities. The simulator will allow an estimation of bandwidth and power requirements to attain a target system-level capacity. The simulator will model the Variable Coding and Modulation (VCM), Adaptive Coding and Modulation (ACM), and Uplink Power Control (ULPC) systems that will be executed in an operational satellite network. Using the simulator, the system engineer will determine the attainable data rates attained in the clear sky and the rainy conditions and gather insights into the potential avenues of removing or reducing the bottlenecks so that the overall system capacity is improved.

Home Page of Simulator

Link budget Page

SNS is being developed in Python language with features viz. to carry out the forward and return link budget calculations, rain fade modelling, capability of providing DR site suitability recommendation, ULPC/ACM simulations, selectable DVB-S2 and S2X modcods in both forward and return link and evaluation of system availability. It will be useful for System engineering, network planning, throughput evaluation at different fading levels of existing & future High throughput satellites in higher frequency bands.

4.1.5. New Frontiers in SATCOM

4.1.5.1. Development of High Data Rate (HDR)/ Ultra High Data Rate (UHDR) modems for Home broadband service

SATCOM based Home broadband service is one of the emerging field .Ultra High Data Rate Modems will be essential component of this technology .These modems should be capable of supporting upto 1Gbps receptions capability for offering broadband services equivalent to terrestrial broadband, to remote users .The major design challenges for such UHDR modems include reconfigurable hardware platform & high-speed data processing subsystems including demodulation loops, high throughput advanced FEC Encoder/Decoders & multi-core baseband data processing engines.

4.1.5.2. Indigenization of Future HTS Gateways

ISRO is inclined towards providing Direct to Home Broadway connectivity using HTS Satellites. This will require Gateways & antenna system in large quantities. Aim is to bring down the overall cost with indigenization efforts. Today, across the globe three major market players are operating and have maximum market share. The trend is to implement gateways in frequency band of Ka or higher band.

Researchers and Industry partners are encouraged to innovate and propose efficient design of 9/11m antenna system, RF-sub-systems, NavIC based TFGU, Hub Monitoring and Control System, Antenna Tracking System etc. which can reduce design and production lead time, be cost effective and mass producible design.

4.1.5.3. Device and method for fragmenting virus/microbe using RF radiation

A non-thermal method of virus inactivation (in-vitro) especially SARS-CoV-2 by physically fracturing the viral outer envelope using microwave radiation at its precise natural frequency has been developed at SAC. A generic theoretical approach has been identified to calculate the natural frequency of any spherical virus. Nanoparticle Tracking Analysis (NTA) & real time Real Time Polymerase Chain Reaction (RT-PCR) analysis was performed to test the efficacy of the developed prototype on Severe Acute Respiratory Syndrome Coronavirus 2 (SARS-CoV-2). On detailed analysis of test results it was found that the device was efficient enough to eliminate up to 99% of SARS-CoV-2 upon one minute of exposure. Antiviral efficacy of developed prototype is successfully tested for various virus contaminated surfaces such as glass, metal, ceramic and laminate and achieved up to 99.99 % SARS-CoV-2 viral elimination within five minutes of radiation exposure time. Patent granted **(patent no. 465801)** for the invention titled "Method and Device for fragmenting virus/microbes using RF radiation at resonance frequency" by the Indian Patent Office (IPO).

Experimental test setup using Satcom subsystems to validate the concept of viral fragmentation upon microwave exposure at its natural frequency.

Miniaturized device prototype developed by SAC/ISRO for corona virus fragmentation using microwave radiation.

Research Areas include:

- Design and development of miniaturized decontamination system which removes airborne contaminants -- such as biological (virus/microbes) and chemical impurities.
- Implementation of the technology for destruction of mosquito larvae at an early stage.
- Sanitization of spacecraft using resonance frequency technique to avoid spread of microorganism during interplanetary travel.

4.1.5.4. SATCOM based solution for Early Warning Disaster Management for extreme weather conditions

To enhance the efficiency and reliability of the EWS at unmanned Glacial locations in events like GLOF (Glacial Lake Outburst Flood), an all-weather SATCOM solution is envisaged to provide reliable communication links for data transmission. In extreme low temperatures and remote sites, providing power with proper backup for communication setup is challenging, due to non-availability power grid and continuous power requirement of the equipment and limitation of battery backup. Also, even light rain and snow/ice accretion on antenna surface can form a water film causing signal degradation during outdoor operations especially at remote unmanned locations where the power available is restrained to solar generation. Hence, VSAT solutions with heater and/or manually clearing the deposited snow/water film from the antenna surface is not feasible. Therefore, there is a need for low cost, durable water/snow repellent coating/materials which can facilitate un-interrupted VSAT operations at unmanned remote locations.

4.1.5.5. Passive flat panel antennas for Ext. C band operations

The flat panel antennas offer several advantages over traditional parabolic antennas including compact size, light weight design and ease of installation. The development is required for passive flat panel antenna in ext. C band covering the transmit frequency range from 6.725 to 7.025 GHz and receive frequency range from 4.5

to 4.8 GHz. Keeping in mind the advantages of flat panel antenna, the scope of this research is to design and develop passive flat panel antenna in ext. C band covering the transmit frequency range from 6.725 to 7.025 GHz and receive frequency range from 4.5 to 4.8 GHz. The desired antenna gain should be more than 26 dBi and power handling capacity of up to 5W. The panel size should be restricted to sub 1-meter range preferably around 0.6-0.7 m.

4.1.5.6. SATCOM Based Beyond Visual Line of Sight (BVLOS) Operations

SATCOM Based Beyond Visual Line of Sight (BVLOS) Operations refers to the use of SATCOM technology to enable drones or Unmanned Arial Vehicles (UAVs) to operate beyond the pilot's visual line of sight range. BVLOS operations are essential for long range missions especially in areas where traditional line of sight communication is impractical or disaster stricken areas where terrestrial infrastructures are not available. Currently SAC ISRO is developing SATCOM solution for telemetry and control of UAV to enable BVLOS connectivity. SAC is developing MSS terminal and customized MAVLink protocol for low data rate & high latency GEO satellite communication link. In future, Ku band SOTM terminal is to be developed to support high data rate video communication.

Research proposals are invited for

- Latency and throughput optimization techniques for MSS channel
- Hybrid communication system which combines all other possible communication link with SATCOM link to ensure seamless connectivity
- Electronically steered antenna for video, telemetry and control data communication
- Multi-constellation integration into a single unified system for uninterrupted coverage across different geographic locations
- Cybersecurity protocol for SATCOM to protect against hacking, spoofing or jamming attempts.

4.1.5.7. IoT and AI-enabled Remote Healthcare Monitoring in Tele-Medicine

The integration of Internet of Things (IoT) and Artificial Intelligence (AI) has the potential to revolutionize the healthcare industry by enabling remote monitoring, early disease diagnosis, and proactive treatment. This research proposal aims to explore the application of IoT and AI in tele-medicine, leveraging wearable devices and sensors to continuously collect patient data, which can be utilized for improved treatment outcomes and faster disease diagnosis.

Research Objectives of this proposal are as under:

- To design and develop an IoT-based tele-medicine system that integrates various wearable devices and sensors (e.g., accelerometer, altimeter, digital camera, electrocardiogram, electromyograph, electroencephalogram, electrodermograph, location GPS, microphone, oximeter, Bluetooth proximity, pressure and thermometer) to collect patient data.
- To develop an AI-powered analytics platform that can process and analyze the vast amount of data generated by IoT devices, identifying patterns and anomalies that may indicate potential health risks or disease progression.

- To investigate the application of machine learning algorithms in predicting disease diagnosis and prognosis based on IoT-collected data.
- To evaluate the efficacy and feasibility of the proposed tele-medicine system in improving patient outcomes and enhancing overall quality of life.

To implement the mentioned proposal, a comprehensive review of existing research on IoT, AI, and tele-medicine will be conducted to identify gaps and areas for improvement. The IoT-based tele-medicine system will be designed and developed, incorporating various wearable devices and sensors. Patient data will be collected from the wearable devices and sensors, which will be transmitted to a centralized server for processing and analysis. Machine learning algorithms will be applied to analyze the collected data, identifying patterns and anomalies that may indicate potential health risks or disease progression.

Expected Outcomes of this project are as under:

- Development of an IoT-based tele-medicine system that integrates wearable devices and sensors for continuous patient monitoring.
- Creation of an AI-powered analytics platform that can process and analyze vast amounts of data generated by IoT devices.
- Identification of machine learning algorithms that can accurately predict disease diagnosis and prognosis based on IoT-collected data.

4.2. Satellite-Based Navigation (SATNAV) Technology & Applications

India has developed its own navigation system named NavIC (Navigation with Indian Constellation). The NavIC constellation is a combination of GEO and GSO satellites which are presently transmitting L5 (1176.45 MHz) & S (2492.028 MHz) band signals that are received by the user devices equipped with NavIC receivers. In receiver segment, various types such as User Receiver, Reference receiver, Timing Receiver and messaging receivers are being developed by SAC and through transfer-of-technology (ToT) and other collaboration modes, by private companies. These receivers are capable of providing pseudo-range (Code phase) and carrier phase measurements which can be processed to provide metre- to cm-level position accuracies. Real Time Kinematic (RTK) solutions based on differential positioning concept and Precise Point Positioning (PPP) are techniques used to provide very high accuracy positioning upto cm-level accuracy. Receivers equipped with these capabilities are usually dual frequency equipment and use very precise carrier phase measurements. These receivers have very wide applications in the field of survey & land records, geodesy, 5G, testing driverless / autonomous cars and precision agriculture. Also, NavIC chips as well as NavIC-in-mobile platforms are coming up and may be used for ubiquitous location-based services etc.

Furthermore, there are various scientific and technical applications which can be addressed by using NavIC and other GNSS receivers, Inertial Navigation System (INS), ground-based navigation system such as Pseudolite system developed at SAC etc. Different algorithms are required to process these multi-constellation receivers equipped with INS and other navigation aids. Therefore, new algorithms, software and solutions are required to be developed. This document highlights various research areas in Satellite Navigation to cater applications in various fields. Use of GNSS measurements has also been very promising in meteorological applications such as estimation of Integrated Water Vapour (IWV) which is ingested in Numerical Weather Prediction (NWP) models etc. Space weather is also one of the very important aspect which is being addressed using GNSS signals.

This section relevant to applications deriving from ISRO's navigation satellites constellations is broadly divided into two major segments of technology development and GNSS applications which largely include scientific applications also.

4.2.1. Technology Development

NavIC signals in general may be prone to interference with other GNSS satellite signals such as GPS, Galileo and Beidou. The NavIC S-band signal in particular may experience interference from commercially used S band spectrum by Wi-Fi and WiMax services. Therefore, interference/jamming detection and mitigation algorithms and techniques need to be vitally developed.

4.2.1.1. Joint optimization of signal waveforms, spreading codes, and multiplexing scheme

Many existing constant envelope multiplexing (CEM) design approaches rely on the assumption that the spreading sequences of different component signals are perfectly orthogonal. However, in real-world scenarios, the imperfect orthogonality of these sequences can cause slight distortions in the correlation function following multiplexing, which may lead to an inherent bias in code tracking. A promising direction for future research involves the integrated design of spreading sequences, chip waveforms, and CEM. An initial attempt was made to address this, where the symmetry of the code sequence was incorporated as a constraint in the optimization framework, resulting in a notable reduction in the inherent bias of code tracking.

4.2.1.2. Constant envelope multiplexing for general modulations

The constant envelope multiplexing (CEM) discussed so far for GNSS are primarily designed for memoryless DSSS signals with multilevel chip waveforms, where instantaneous waveform value transitions are assumed. This assumption implies that the components being multiplexed maintain sufficient side lobes outside their main spectral lobe. Since the multiplexing operation occurs in the digital baseband using digital logic, and the envelope constancy must only be preserved up to the high power amplifier (HPA) input, the assumption of instantaneous transition remains approximately valid, provided that the bandwidth of the up-converter before the HPA is sufficiently wide. Consequently, envelope distortions caused by chip transitions have not been a major concern for a long time. However, as spectrum resources become increasingly scarce, more complex chip waveforms with higher spectral efficiency, such as the prolate spheroidal wave function (PSWF) waveform, are being proposed for future satellite navigation signals, particularly in the C-band. Additionally, advanced modulations, such as continuous phase modulation (CPM) and chirp spread spectrum (CSS), are being considered as alternatives to DSSS. For signals with continuous transitions in their waveforms and memory-based modulation, existing CEM techniques are not directly applicable. Therefore, the development of CEM techniques capable of accommodating signals with more general spreading waveforms or even non-DSSS signals presents an area of promising research. Preliminary results are emerging in this domain, such as the combination of two components into a CPM signal.

4.2.1.3. Lunar-PNT Systems for Autonomous Navigation

This research focuses on designing and developing PNT systems tailored for autonomous lunar exploration. Traditional Earth-based GNSS systems are not feasible for the Moon due to the lack of infrastructure, so a lunar-specific PNT system needs to be developed. This includes studying the Moon's gravitational environment, using lunar landmarks for positioning, and leveraging celestial navigation methods. The research would explore potential integration with lunar orbiters to provide continuous coverage, as well as solutions to address challenges such as lunar terrain-induced errors, dust storms, and the absence of a global positioning network. It also involves examining the integration of advanced sensors, like altimeters and gyroscopes, with the PNT system for precise navigation on the lunar surface.

4.2.1.4. Impact of Lunar Environmental Conditions on PNT Signal Integrity

This research examines how the unique environmental conditions of the Moon—such as extreme temperature variations, dust storms, and radiation—impact the performance and reliability of PNT signals. It would explore the effects of these factors on radio signal propagation, system accuracy, and signal degradation over time. The research would propose solutions to mitigate these effects, such as the use of low-frequency or high-frequency signals that may be less susceptible to lunar environmental disturbances. Additionally, it would investigate the potential for signal interference from the Moon's regolith or interactions with solar and cosmic radiation. Ultimately, this topic aims to ensure robust, reliable, and accurate PNT performance for future lunar missions and long-term lunar bases.

4.2.1.5. Impact of LEO Satellite Dynamics on Time Synchronization and PNT Accuracy

This research addresses the effects of the unique orbital dynamics of LEO satellites on time synchronization and overall PNT accuracy. Due to the high velocities and rapidly changing orbits of LEO satellites, precise synchronization of their onboard clocks with the ground or other satellites is challenging. The study would focus on the impact of these dynamics on time error propagation, clock drift, and potential signal interference, and propose advanced algorithms for time synchronization across satellite constellations. The research would also consider the challenges of maintaining synchronization over long durations and during rapid orbital manoeuvres, which can lead to varying signal delays. The goal is to develop robust methodologies to ensure accurate timekeeping and PNT performance for LEO satellite-based services, essential for applications like remote sensing, real-time navigation, and global communication.

4.2.1.6. Configurable GNSS Universal Correlator Architecture ASIC for various NavIC Applications:

Development of NavIC + GNSS Baseband ASIC (NavASIC v3) @ 28nm node is carried out at SAC to cater the requirements of high performance, low power and small size navigation receiver for civil and strategic users. It has massive correlator based fast acquisition engine for direct acquisition of NavIC Authorised Long-codes; thereby achieving the critical Time to First Fix (TTFF) requirement of the order of 10-15 sec. It consists of 100 tracking channels to process all-in-view open GNSS civilian signals along with NavIC SPS and authorised signals. It also has external code generator interface so that same ASIC can also be catered to future Navigation signals. The chip is targeted at 28 nm technology node for optimized power, performance and area (PPA). ASIC design consists of ~50 Million NAND2 equivalent gates. SAC carried out ASIC Architecture design, FPGA prototyping, Front-end design (RTL and gate level netlist synthesis) & verification whereas Back-end design and fabrication through MPW run was outsourced to Indian vendor.

ASIC architecture is designed such that it is having a lot of configurability for usage in variety of applications with different operating modes. 32-bit dual core processor is used along with GNSS hardware correlators, timing and measurement modules for Baseband signal processing & Navigation solution computation.

ASIC has state-of-the-art Partial Matched Filter with FFT based acquisition engine for fast and direct acquisition of optimized Long code with time assistance from RTC along with support for acquisition of open NavIC & GNSS signals. ASIC also has four 2046 tap matched filter based acquisition modules which support epoch to epoch integration required for acquisition of signals having same PRN code duration and data-bit period along with support for BPSK(10) signals.

This ASIC has total 100 tracking channels, which are configurable for processing of NavIC-SPS, Short/Long signals, and open GNSS signals, which are having different modulations, PRN code rate, length and data rate. The configurability is achieved by universal acquisition & tracking correlator design for processing of different types of signals. ASIC can also process Pseudolite signals.

ASIC can accept digitized IF inputs either in real or complex format from multiple GNSS RF signal bands such as L1, L2, L5 and S. This ASIC also has external code streaming interface for accepting PRN codes from an external chip. ASIC has inbuilt anti-jamming module for CW and Pulse interference mitigation. ASIC also has clock-gating and power-gating feature for power savings in different operating scenarios.
The design is partitioned in multiple blocks (total 20) & each block is synthesized separately (hierarchical synthesis) with UPF flow (for power gating) & were connected through top module with wrapper logic. On-chip PLL IP is used for generating different processor clock frequencies depending on the application requirement. RTL and netlist design has been thoroughly verified by Design & SQA teams using different test vectors & verification strategies. FPGA prototype & emulation of ASIC has been carried out & tested with simulated scenarios of NavIC and GNSS signals using GNSS simulator. The chip peripherals include three UARTs, one SPI core with multiple slave selects, one I2C core along with dual MIL-1553B RT core. The gate-count of this ASIC is ~50 million with 6.5mm x 6.5mm die size & 15mm x 15mm flip-chip BGA package.

Initial board bring-up & testing is carried out and first cut Positioning is obtained successfully in intermediate 64 pin CQFP package. Power consumption of this ASIC is 180mW to 600mW range in different operating modes. Thorough testing in final BGA package is under way.

This ASIC has dual core Sparc V8 processor, so that for various applications like vehicle tracking, RTK, DGNSS operations; there is no need to have external processor in addition to this ASIC. New Algorithm development can run in any one of the core, while other core will continuously do PVT positioning.

4.2.1.7. Development of CMOS /BiCMOS RFIC

SAC is involved for design and development of NavIC based receiver for broad range of applications, like Civil, Military and Space applications. It is required to develop Complementary Metal-Oxide Semiconductor (CMOS)/BiCMOS Bipolar Complementary Metal-Oxide Semiconductor, Radio Frequency Integrated Circuit (RFIC) to have multi-chip module solution along-with indigenous baseband ASIC and to have miniaturized NavIC Rx. for various applications.

Commercial and space grade RFIC is required with the following blocks:

- Tri band integer PLL/ Fractional PLL.
- Triband / wideband LNA
- Image reject Mixer Narrow band and wideband
- Variable gain amplifier
- Low drop out regulator
- Complex filter for IF range
- SPI interface to control the overall receiver block
- Multibit ADC: Multibit low power ADC is required to meet high Anti-jamming capability.

  ADC specifications:

  a. Bit resolution: 16 bit
  b. SFDR: 86dB
  c. Sampling clock: 50MHz
  d. ENOB: >14 bits

- MEMs based Temperature Compensated Crystal Oscillator (TCXO):

  Satellite application of space-grade NavIC receiver required high acceleration sensitive TCXO. MEMs based TCXO can meet the 0.5 ppb/g acceleration sensitivity. MEMs based capacitive resonator is suitable choice for space application and piezo resistive resonator can meet ground application.

4.2.1.8. Construction and selection of balanced and near balanced Pseudorandom Sequences with lower correlation values and large linear complexity

Spreading PRN codes are utilized in satellite navigation for ranging, spectrum spreading and satellite identification in Code Division Multiple Access (CDMA) based GNSS systems. Considering future navigation signals, there is an increasing demand of spreading codes families of various Length, family size, and correlation properties PRN sequences to be used in communication and satellite navigation should have certain statistical and correlation properties. While designing a sequence for satellite navigation, it is desirable for sequence to be balanced, have low value of out of phase auto-correlation and cross-correlation, have well behaved distribution of one and zeros and should be easily implementable in hardware. Since the sequences in sequences in the field of satellite navigation are also modulated by data or overlay codes thus, it is also desirable the sequences have low values of out-of-phase odd auto-correlation and odd cross-correlation as well. Sequences with longer length or time-period greater than few milliseconds are often partially cross-correlated in a navigation receiver. Large linear complexity sequences are a potential candidate for signals with anti-spoofing capability. This work involves designing of a PRN code family where each PRN sequence of the code family should have the properties of randomness. The code family set should have sufficient number of codes to satisfy a global constellation of satellites and enough for supporting the augmentation system, if any. It also involves selection criteria determination and to compare the performance of a set of codes against the performance parameter matrix to find optimum codes. Performance parameters for code selection include sequence balance; run length, orthogonality, auto- and cross-correlation histograms at various Doppler offsets, excess line weight and values for the low auto-correlation functions.

4.2.1.9. Design and Development of True Random Number Generators

Random numbers are of paramount importance in field such as cryptography, Monte Carlo simulations, randomized algorithms etc. In contrast to Pseudo Random Number Generator, physical (true, hardware) random number generators extract randomness form physical processes that behave in a fundamentally nondeterministic way, which makes them better candidates for true random number generation. TRNG are useful for key generation in field of encryption and authentication of satellite navigation signals. This work objective is to develop a true random number generator, which produces random numbers that passes through the criteria of randomness, which is given by a series of statistical tests of National Institute of Standards and Technology NIST Test suit, Diehard battery of randomness tests etc. In general, TRNG suffers with unequal probability of occurrences of one and zero which is known as bias. Thus, the developed TRNG should also include the post processing mechanism of bias removal. Some of the RNG constructions are as follows-

- Noise-based RNGs
- free running oscillator RNGs
- chaos RNGs
- quantum RNGs
- The resources utilized by TRNG, its throughput and frequency of operation are some of the design criteria which needs to be considered while choosing an architecture. The generated random numbers should pass through randomness property measured using statistical tests.

4.2.1.10. Multi constellation and multi frequency GNSS positioning algorithms

Owing to the complementary nature of the various GNSS signals / services, there is a worldwide trend for deriving position solutions of more than one GNSS signal. Known as multi-GNSS, this has the potential of providing an accuracy superior than any of the GNSS signals when used singly; complementing the number of satellites in case of lower availability and / or blockage and extension to the space service volume (SSV). Employing more than one frequency (multi-frequency) to obtain the positioning solution offers the advantages of enhanced accuracy, resolution of ionospheric effects, etc.

Potential research areas in these two domains may be satellite selection, triple-frequency for ambiguity resolution, inter-system/signal/frequency bias estimation, etc.

4.2.1.11. GNSS Security, Vulnerability, Encryption, Authentication

- Key exchange Algorithms: IRNSS RS service for authorized users involves encryption and to improve security, encryption keys are changed regularly to avoid brute force attack and cryptanalysis from unauthorized users. IRNSS RS receivers deployed in field will have to be communicated with changed keys.
- Key Distribution/Key management for GNSS strategic applications
- RAIM, Advanced RAIM and TRAIM Algorithms
- Spreading Code Encryption for very long code using stream/block ciphers
- Block-chain technology for authentication/security of GNSS services
- Geo-encryption
- Message Authentication Techniques for NavIC

4.2.1.12. Precise Satellite Relative Location Estimation System for Tandem Satellites operation

Design & development of "precise Baseline/Orbit determination system" for Tandem Satellites operation. Following are important research area in this topic:

- High-precision GNSS receiver
- Precise orbit & Baseline determination
- Implementation Dynamic Force Models
- High-precision orbit propagation

4.2.1.13. Navigation Simulators

The design and development cycle of GNSS Receivers is highly dependent on the signals provided by GNSS Simulators right from conceptualization to product development cycle. Following are important research areas in Navigation Signal Simulation:

- Low-cost NavIC Simulator
- Handheld GNSS Simulator
- Interference Simulator for GNSS bands
- Low-cost Navigation Educational Kit
- Seamless indoor/outdoor navigation with NavIC and other Signals of Opportunity/Technologies
- LEO GNSS and NavIC + LEO GNSS Simulators

4.2.1.14. Software Defined Radio (SDR) based NavIC system Development

SDR is a popular trend that allows the configuration of generic receivers that may be customized based on specific user requirements. Potential domains for research proposals in this area may be:

- NavIC-GNSS receiver
- NavIC-GNSS simulator
- SDR for RTK and PPP
- SDR for Pseudolite-based navigation System.
- SDR for GNSS + Pseudolite System

4.2.1.15. Pseudolite-NavIC-GNSS receiver algorithm Development

Pseudolite System is ground-based navigation system which may provide very accurate position within a localized area. These are low-cost systems and can be easily integrated with other GNSS systems. Following topics may be taken for development of new algorithms:

- Successive Interference Cancellation to mitigate near-far problem in Pseudolite
- Pseudolite-NavIC-GNSS hybrid user position algorithm /Extended Kalman Filter) EKF /(Unscented Kalman Filter) UKF (based algorithms
- Time synchronization algorithms with GNSS
- Signal acquisition & tracking in pulse-CDMA mode
- Pseudolite indoor-positioning algorithms
- Multipath mitigation algorithm
- Algorithms for bi-directional Pseudolite based system for interplanetary scenario like Mars, Moon etc .
- Pseudolites for landing application at Indian airports

4.2.1.16. LEO GNSS:

Position, Navigation and Time (PNT) services can be provided by mega-constellations in LEO orbits, which are otherwise primarily meant for providing communication and broadband internet services across the globe. Following are the research areas in this domain:

- System engineering aspects
- Doppler Positioning and Velocity Algorithms
- New navigation processing algorithms for acquisition and tracking
- GNSS+LEO constellation designs and algorithms

4.2.1.17. Differential Positioning & RTK Receiver Algorithm Development for NavIC

Differential positioning is a technique which provide cm-level accurate position and transmits corrections from a base or reference receiver at accurately known location to a rover receiver through UHF/VHF link. This technique assumes that both base and rover receivers are observing common set of satellites. Differential positioning is performed using both pseudo-range and carrier-range measurements. Following algorithms may be developed:

- Integer Ambiguity (AI) resolution in carrier-phase measurements
- Carrier Phase-Based Positioning
- Low-cost single frequency RTK receiver algorithms
- RTK correction generation & dissemination module in RTCM format
- GNSS Corrections: RTK, RTK-PPP, PPP
- Network RTK for India
- NTRIP based interface for NavIC
- High-accuracy Post-processed RTK positioning algorithms

4.2.1.18. Precise Point Positioning (PPP) Receiver Algorithms

Precise point positioning (PPP) is a technique using Global Navigation Satellite System (GNSS) satellites to achieve decimetre level or better position accuracy using a single receiver. This technique relies on the availability of highly precise ephemeris and clock products from a network of reference receivers without using a base station. PPP also requires a dual-frequency receiver with precise carrier range measurements. However, nowadays single frequency-PPP is also being attempted by researchers. Precision usually in this case means a horizontal position accuracy of 10 cm or better.

- Precise ephemeris & clock product generation & dissemination
- EKF-based PPP algorithms
- Low-cost single-frequency PPP algorithms
- Multi-constellation PPP
- PPP-AR (Ambiguity Resolution) algorithms
- High accuracy Post-processed PPP algorithms
- PPP-INS positioning algorithms
- PPP-RTK positioning algorithms
- PPP with Pseudolite or GNSS + Pseudolite system

4.2.1.19. Atmospheric Studies

NavIC L5 and S Band signals along with other GNSS signals can be used for estimation of better ionospheric TEC and relevant model development. These signals are useful for ionospheric scintillation studies and also for tropospheric model development.

- Ionospheric studies over the Indian Region

a. Real-time ionospheric Total Electron Content (TEC) & scintillation map generation
b. Ionospheric tomography model development

- Tropospheric Studies
    a. Tropospheric model development for Indian region
    b. Tropospheric mapping function development
- Weather Monitoring and forecast through NavIC S-Band
    a. Thunderstorm detection using Machine Learning/Deep Learning Techniques
    b. Multipath and Soil Moisture model development using AI/ML/DL

4.2.1.20. Other Topics

- Short delay Multipath Mitigation Techniques in GNSS Receivers
- S band interference in Satcom and Satnav applications
- Spoofing Detection: Using Multiple antennas, Signal time of arrival
- NavIC data processing in RTKLIB
- Robust positioning with Civilian GNSS signals.
- Ground Testing of Rubidium Atomic Clocks.
- Navigation Solution with Multi-Constellation.
- Ground Characterization of On-board Atomic Clock performance.
- Effect of Wi-Fi, 3G/4G/5G on NavIC/GNSS Signals.
- Design of Global Indian Navigation constellation.
- Cooperative & peer to peer positioning
- Positioning for Autonomous systems (robot, drones, marine vehicles)
- Time to First Fix (TTFF) reduction in GNSS receivers
- Assisted NavIC
- Design and development of NavIC Data Post-processing Tools (GAMIT, Berneze, RTKLIB like s/w)
- Design of NavIC Advisory generation and dissemination (like GPS's NanU)

4.2.2. GNSS Applications

4.2.2.1. Precision Agriculture:

India is an agricultural country. Produce of agricultural products can be optimized using GNSS techniques such as RTK and PPP. This entails significant savings of equipment usage, fuel consumption, potential for manual error, etc. and can significantly enhance productivity. Following algorithms/solutions may be developed:

1) RTK-based precision agriculture solutions
2) PPP-based precision agriculture solutions
3) Low-cost or community-based solutions (e.g. village-level)

4.2.2.2. Mobile Application Development

- The availability of NavIC-enabled mobile phones will provide improved accuracy and availability as these mobile phones use all-in-view (multi-constellation) based processing. Besides GNSS, other sensors in the mobile phones can aid in improving accuracy as well as availability of position solution in the places with weak or blocked GNSS signals. Mobile applications can be developed for fusion of GNSS and sensor data for location-based services.
- NavIC-GNSS mobile App for location based services using GIS map
- Mobile-based train tracking App for Railways including paperless ticketing
- NavIC/GNSS based Navigation App for blind/physically impaired person
- Android Studio based positioning using raw NavIC/GNSS observables
- NavIC/GNSS anomaly reporting

4.2.2.3. Scientific Applications

The following research activities may be suggested for scientific applications of GNSS. One may extend this work in future for finding the cloud dynamics and even for hydrology. This, however, is possible when the measured data is highly dense in nature. With more precision in measured data, it may also be utilized for finding the cyclonic condition and movements. Especially, NavIC S-band signals may be very useful for weather studies. Also, networked GNSS data may be utilized for earthquake research and hazard mitigation. Data from available network over India, may be collated, in one hand to find the crustal movements, while the post-earthquake signatures on ionosphere may be studied, on the other hand, to identify and index the strength of the earthquake and its extent.

1) Modelling Equatorial TEC perturbation
2) Forecasting of ionospheric scintillation
3) Integrated Water Vapour (IWV) estimation using GNSS
4) Cyclone tracking & Precipitation prediction
5) Seismic studies using TEC

4.2.2.4. Other Applications

1) Marine Applications
2) Disaster Management using GNSS & GAGAN
3) NavIC/GNSS-based navigation for UAV
4) GIS application involving NavIC/GAGAN and ISRO's geospatial database Bhuvan
5) GNSS based spacecraft attitude determination
6) Application/software for vehicle parking system including automatic toll collection
7) NavIC based biometric bracelet
8) Low-Cost Surveying and Land Record Mapping using NavIC & GAGAN Receivers
9) GNSS for Smart City applications
10) IRNSS Messaging based Applications
11) Timing Applications of NavIC

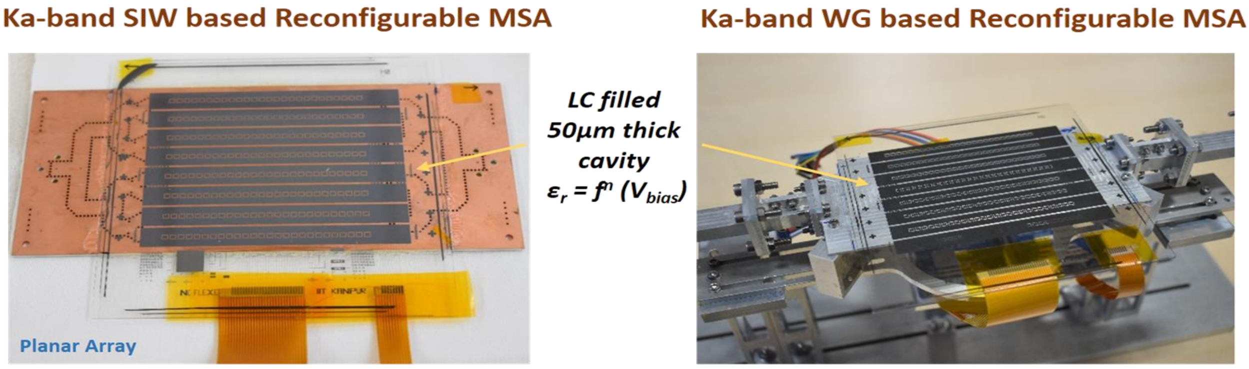
5. ANTENNA SYSTEMS

Antenna Systems is involved in the design and development of antenna systems for satellite (communication, navigations and microwave remote sensing, human space missions) and ground applications. Few of the antenna technologies recently developed and used in different missions of ISRO are listed below,

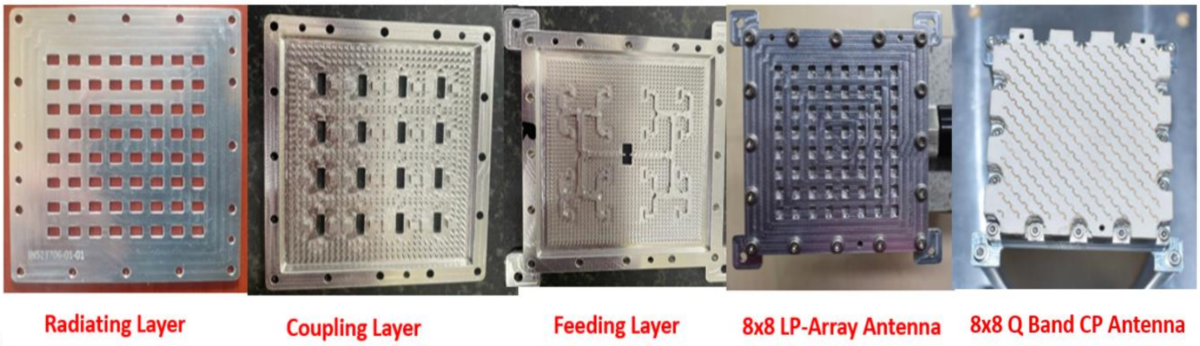
- Shared Aperture Tri-band Antenna (L1/L5/S-bands) for navigation payload,
- Active phased array antennas at Ku-band, X-band and C-band etc. for communication and
- Earth observation programs,
- mm wave scanning reflector antenna for humidity sounder,
- Altimeter antenna for chandrayaan-3 and Gaganyaan missions,
- Cassegrain multiple beam unfurlable antenna for radar imaging payload,
- Ka-band Multiple beam antennas with different size beam from common antenna for HTS
- Frequency selective surface (FSS) based S/Ka band Cassegrain antenna for data relay
- communication payload,
- THz Quasi optical Beam Waveguide (BWG) antenna for 3m /6m telescope,
- Active integrated GNSS band antennas for Geodetic applications.
- Antenna for SOTM applications,
- xi)Multi Feed per beam Multi-beam reflector antenna System at Ka-band for HTS missions
- Meta-surface based Ka-Tx and Rx planar antenna for SOTM
- Gap Waveguide array antenna at Q-band
- S/Ka- dual band shared aperture feed system for Data Relay Satellites
- Feed chain for Ka-band 9.3m Hub station Antenna

Apart from these antenna technologies, ASA has also developed various advanced technologies under R&D activities. Some of these antenna technologies viz. flat panel liquid crystal based reconfigurable antenna, meta-surface antenna, multi-feed per beam antenna for HTS using single reflector, shared aperture S/Ka band feed, quad band active radar calibrator antenna, GNSS reflectometry antenna, P-band SAR antenna, Q-V band Gap waveguide based array antenna etc. are developed. Currently few other technologies still under development are ultra wideband antenna (2-14 GHz) for Very-long baseline Interferometry (VLBI) applications, digital beam forming based antenna at S-band for interference mitigation, SDR payload multi beam antenna, multilayer board based active integrated phased array antenna, planar man pack terminal antenna etc. ASA has developed few technologies for antenna measurements like planar near field test range, antenna diagnostic tool and quiet-zone scanner, antenna phase-centre measurement tool, Technique of time domain based antenna pattern measurement, Microwave Holography technique for reflector profile measurement etc.

Some of the development of SAC are show cased below.

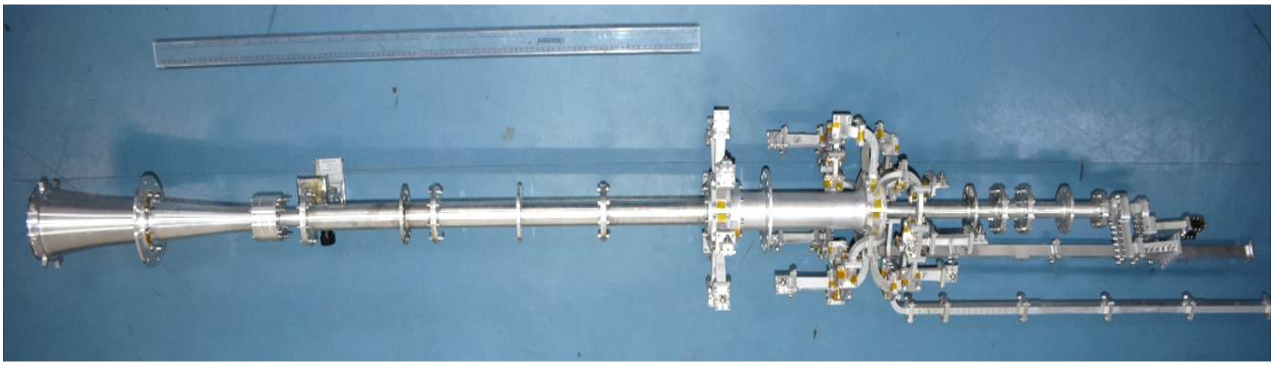


Ka-band Rx Reconfigurable MSAs

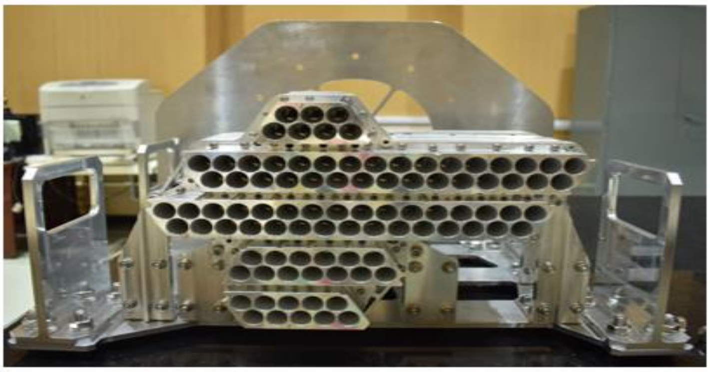


Ka-band Tx/Rx Ultrathin High Gain Circularly Polarized Meta Surface Antena

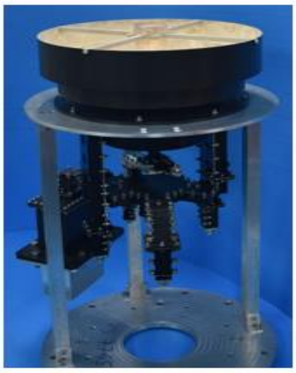
Gap Waveguide Based Array Antenna in Q-band



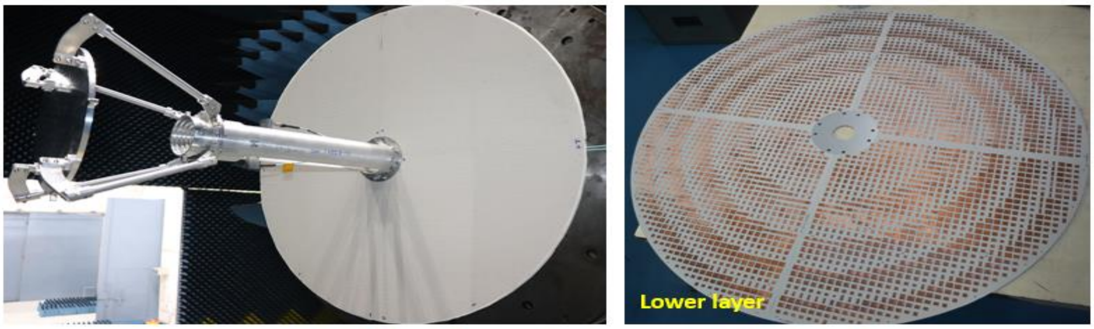
Indigenous Development of 9.3m Ka-band Hub Station Antenna Feed System



Ka-band Tx/Rx Multi-feed per beam feed cluster for generating 29 Beams

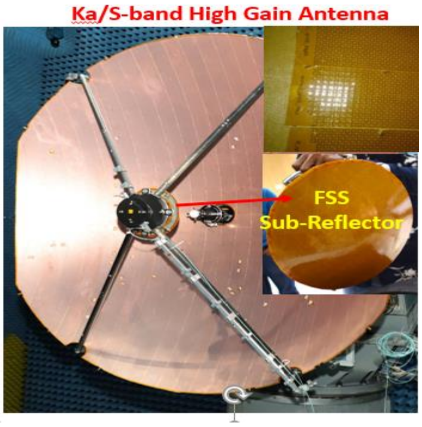


S/Ka feed Chain

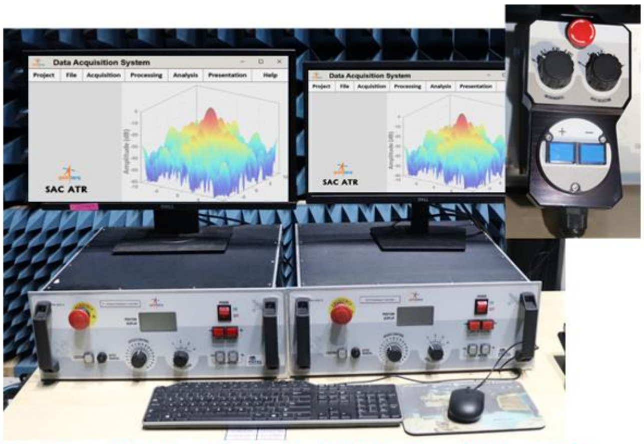


Reflect-Array Antenna in Ku-band

Ka/S-band High Gain Antenna



Active Radar Calibrator at L,S,C & X Bands



Developed Motion Controller & Data Acquisition Software

Indigenization of NFTR facility

Following are the research areas in the field of antennas on which research proposals are sought from Indian academia:

5.1. Multimode Vortex Beam Generating Common Aperture Antenna for future OAM based communication systems

Orbital Angular Momentum (OAM) communication offers a promising solution by utilizing the unique properties of vortex beams. This research topic aims to investigate the design and implementation of multimode vortex beam generating antennas to enhance the capacity and efficiency of future OAM-based communication systems. Vortex beams can carry multiple OAM modes simultaneously, increasing the data throughput significantly. However, effective generation, control, and reception of multimode vortex beams requires advanced antenna designs and signal processing techniques.

5.2. Controlled Radiation Pattern Antennas for Anti-jamming GNSS Terminals

Jamming and interference can drastically degrade the GNSS position, navigation and time availability even to the extent of complete cease in service. The low power GNSS signals from space are overpowered by the excessive noise generated by the jammers, which consequently saturates the user GNSS receiver front-end. The anti-jamming terminals have the capability to find the direction of interference and have the ability to mitigate this interference by creating nulls in the antenna pattern in the direction of the interference. Generally, these terminals are capable of mitigating interference from multiple jammers. The number of simultaneous nulling direction depends on the number of radiating elements used in the terminal. This generally creates a compromise between the size of the terminal and the number of simultaneous nulling possible.

5.3. Design & Development of Terahertz Array Antennas for Space and Ground applications

The proposed research work will be catering THz communications and imaging systems. Developing antenna systems at these frequencies will help in solving many problems related to antenna realization, integration and characterization. Design and development of terahertz array antennas involves selection of suitable radiating elements (Horn, slots, patch etc.) and design of appropriate feeding mechanism (waveguide, SIW, Gap WG etc.). Emphasis to be on the antenna realization technology also (silicon micro machining, metallization, CNC fabrication etc.) as it forms an important step. The RF design has to take care of all the limitations arising from the realization methodology. The design should also address the scalability of antenna architecture to achieve higher antenna Gains. Suitability of material selection for space missions to be addressed.

5.4. Development of Graphene-based Flexible Wearable Antennas

The research aims to develop a graphene-based flexible wearable antenna for UHF (300 MHz - 900 MHz) and L&S-band (1-3 GHz) communication. Graphene's exceptional electrical, mechanical, and thermal properties make it an ideal candidate for next-generation antennas that need to be flexible, lightweight, and capable of high-performance under diverse environmental conditions. The research scope includes. Investigating the electrical conductivity and RF performance of graphene in comparison to traditional materials like copper.

5.5. Curved reflectarray for dual band dual circularly polarized Ka-band multiple beam antenna missions with reduced apertures

HTS missions at Ka-band are achieved by utilizing multiple beam antenna technology using multiple apertures. The objective of present technology is to reduce the number of apertures by illuminating a curved reflectarray with a dual circularly polarized feed. The dual band reflectarray so designed may have the capability to reflect the LHCP beam positively offset by half beamwidth and RHCP beam negatively offset by half beamwidth thus generating a beam lattice. Two such reflectors can give dual frequency/polarization four colour scheme for achieving high throughput. Complete study to achieve desirable gain and carrier to interference ratio (C/I) with prototype development may give confidence for further study to expose to harsh space environment conditions and qualification

5.6. Design and development of dual polarized low profile metallic lens antenna

Recently, with emerging application at microwave, mm waves and THz frequencies the antennas must necessary be low-profile, lightweight and high gain systems with wide-angle-scanning/multi-beam capabilities. Traditional solutions for the said constraints are reflectors antennas and planar arrays. Reflectors antennas are bulky, whereas array antennas are lossy. Lens antennas, which are not popular at low frequencies due to their large size, offers a better solution in this context, due to their wide-scanning capability, broadband behaviour and focusing properties.

The lens antennas can transform various type of divergent electromagnetic waves into plane waves if their geometry is properly designed and right material is used. Lens antenna can be made from either dielectric material or purely metal. Both materials are capable of collimating the incoming spherical electromagnetic waves by correcting the phase differences.

At high frequencies, metallic Lens antenna have attractive electromagnetic properties such as high directivity, wide angle beam scanning, wide impedance bandwidth, low loss, high aperture efficiency etc. Therefore, at high frequency applications, metallic lens antenna is considered a more promising solution in comparison to phased arrays or other beamforming techniques. Also the structural complexity is less for this antenna category.

5.7. Plasma antenna

The plasma antenna is an emerging technology that partially or fully utilizes ionized gas as the conducting medium instead of metal to create an antenna. The key advantages of plasma antennae are that they are highly reconfigurable and can be turned on and off, which is good for stealth and resistance to electronic warfare and cyber attacks. The plasma can be freely moved to the desired geometry of the reflector by plasma diode which enables the beam to be steered quickly without the need for mechanical motion. When the gas is not ionized, it allows other antennas to transmit and receive without any interference which is a very useful feature.

6. ELECTRO-OPTICAL SENSORS

Electro-optical (EO) imaging systems for Earth and planetary observations have significantly evolved in the recent years. More than eighty state-of-the art EO sensors have been designed and developed by Sensors Development Area (SEDA) at Space Applications Centre (SAC), Ahmedabad for various high resolution, multispectral, and hyperspectral imaging missions. In the last five years (2019-2024) more than 25 payloads have been delivered and successfully launched for several Earth Observation and planetary missions and in coming 5 years (2025 to 2030) more than 60 payloads are envisaged. SEDA is engaged in EO sensor system design and engineering, design and development of focal plane detection system, electronics systems, assembly, integration, testing (AIT) and performance characterization of integrated imaging systems.

The system design and engineering discipline focuses on capturing user requirements, system configuration studies, EO sensor modelling and simulation studies, proto type development, spectral and radiometric characterization of subsystems and integrated imaging system, design and development of precision calibration sources encompassing visible to IR spectrum, in-orbit performance assessment, design and development of optical communication systems, data analysis and trouble-shooting during the development phase.

SEDA is actively engaged in design and development of advanced focal plane detection systems for various ISRO missions comprising long array Charge Coupled Device (CCD) detectors, area array detectors, multi-array Time Delay and Integration detectors, Active Pixel Service (APS) CMOS detectors, low noise scientific detectors, etc. In addition, many IR detection focal planes (IDDCA) have also been designed and developed for various ISRO missions. The research in this field involves studying device physics, designing various pixel architectures leading to custom design of detectors, interaction with foundries and fabrication of wafer scale devices, packaging of devices, electronics circuit designs to meet operational requirements of detectors, design and development of detector test benches, performing extensive EO characterization of detectors, design and development of flight model focal plane systems and testing, etc. There is a major thrust on indigenous design and development of detectors for upcoming ISRO missions with involvement of academia, national and global foundries.

The EO sensor image quality is primarily determined by the performance of optical system. The optical system of EO payloads have significantly evolved in recent years. SEDA has designed and developed high performance optical systems with primary apertures as high as 1.2 meters. SEDA is also engaged in indigenous design and development of metal mirrors, convex gratings, filters, opto-mechanical structures, etc. Tremendous research opportunities exist in the field of design and development of optical systems for spaceborne that include sparse aperture systems, high performance imaging interferometers, thin film development, volume holographic grating, aspheric and freeform optics, computer generated holograms, liquid mirrors, etc.

Electronics systems play a pivotal role in any spaceborne optical imaging chain. They cater to the requirements of detector drive, video processing, data handling, image compression, on-board control and bus management, active thermal management, power conditioning, interfacing with spacecraft mainframe elements etc. Robust design, miniaturization, usage of state-of-the components, programmability, on-board intelligence are some of the approaches adapted in the realization of sensor electronics systems. This field offers tremendous research opportunities in terms of design and development of generic electronics systems, system on chip based on-board computers, embedded processors, soft IP cores, standardized interfaces and Logic, memory, high speed data handling systems, on-board compression, soft IP core development, FPGA, ASICs, hybrid components, low noise, high efficiency power systems etc.

Assembly, integration and testing (AIT) of EO sensor is a very complex and involved process. AIT ensures a zero-defect imaging system hardware with high image quality performance. AIT calls for development of various systems and methods for performance estimation, optimization, characterization, in-orbit performance assessment, analysis of huge amount of data generated during various test phases, fault detection and prediction, test setups, interface characterization etc.

AIT requires sophisticated test setups for simulation of spacecraft mainframe elements, high speed data acquisition and analysis, support variety of interfaces such as Controller Area Network (CAN) bus, Camera link etc. , SEDA is engaged in design and development of precision ground checkout instrumentation for payload testing. Various research opportunities in this field to design and develop high end data acquisition systems, command and control systems, test protocols, generic setups, data analytics tools, etc.

SEDA looks forward to a very fruitful association with academia to work on many potential research and development opportunities in the field of EO sensor design, focal plane detection systems, optical systems, electronics, AIT and ground checkout instrumentation. Some of the research opportunities are discussed below:

6.1. EO Sensor System Design, Simulation and Characterization

6.1.1. Development of physics-based models for simulation of Electro-Optical Sensors

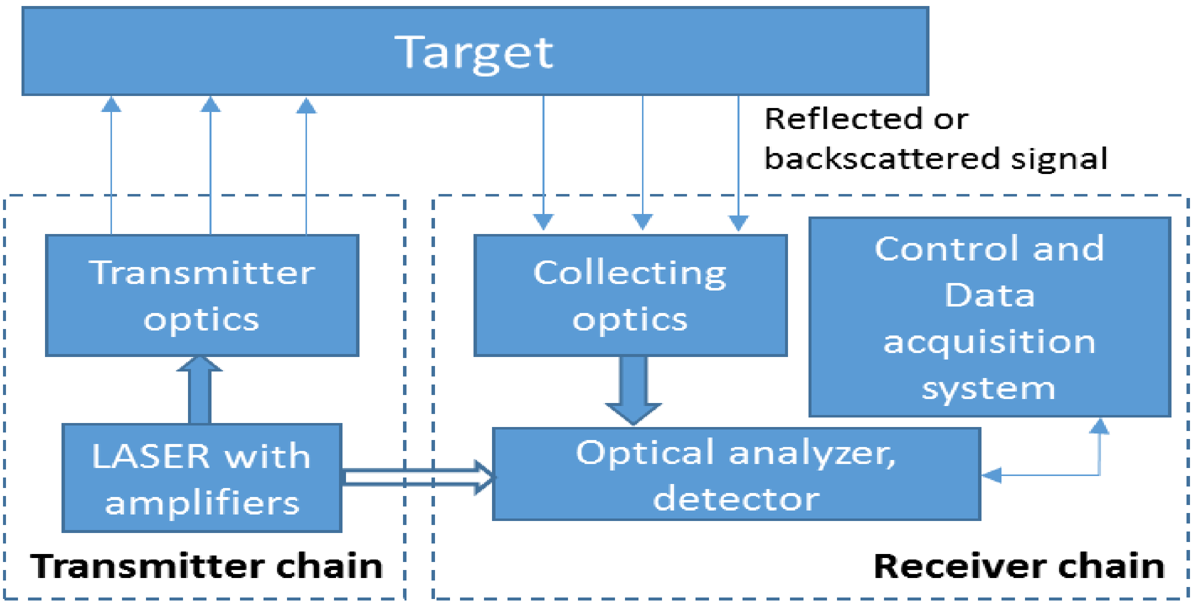
Design and development of EO sensors is a very complex process and requires a thorough understanding of the system behaviour and assessment of its possible outcomes before one embarks on the development of physical system. A physics-based model of EO sensors can significantly help in understanding and visualizing performance aspects and also extensive trade-off studies. The model shall capture the functional/behavioural characteristics of various subsystems such as optics, detectors, electronics and also shall account for various instrument effects arising due to their complex interplay at highest abstraction level. The model shall help in simulating final data/images for a proposed EO sensor configuration to enable visualization and quantitative assessment of instrument sensitivity to the design parameters/system, environment/on-board processing/viewing geometry, etc. Based on the model a software tool needs to be developed that should interface with COTS design software systems in Optical/Mechanical/Electrical domain and available RT models for atmospheric effect simulations. In other words, an end-to-end model shall be developed starting from simulation of ground targets, illumination conditions, observation geometry, intervening medium/atmosphere, at-sensor radiance, sensor characteristics, boundary conditions (under which the sensor is performing) leading to digital counts. The input scene to the sensor model can be typical laboratory targets, actual ground 3D targets or images acquired from the other sensors. This is an exciting research field and will help in the development of a comprehensive model and simulation tool for upcoming ISRO missions.

6.1.2. Design and development of on-board calibration system for absolute calibration of EO sensors

Extensive pre-flight absolute calibration of EO sensors are carried out in laboratory for establishing the transfer function of the EO sensors. However, due to launch loads, in-orbit operating environment, and natural aging process of its components, the sensor characteristics tend to change. This has significant impact on accuracy of Digital Number (DN) to radiance conversion process, which in turn affects the remote sensing parameter retrieval accuracies. Hence, it is important to design and develop appropriate on-board calibration system(s) for periodic calibration and updation of the sensor response function to ensure desired accuracy in DN to radiance conversion. The calibration system should ensure both radiometric and spectral calibration from visible to Infrared Radiation (IR) spectral region. These sources can be passive or active. Research is invited in the areas of design and development of on-board calibration sources e.g. Blackbody for IR calibration (high emissive nano-particle coating), diffuser plate for Visible/Near-Infrared (VIS/NIR) calibration, doped diffusers or active sources for spectral calibration. These systems are required to be compact and stable over long period of time. This can significantly help in improving the accuracy of payload data.

6.1.3. Design and development of a proto-type LIDAR system

Light Detection and ranging (LIDAR) measures distance or characteristics of the target by illuminating that target with a laser light. A narrow laser-beam can map physical features with very high resolutions. Typically, light is reflected via backscattering. LIDAR can be used for ranging, surface profiling and atmospheric studies (clouds, aerosol and wind). Suitable combinations of wavelengths can allow for remote mapping of atmospheric contents by identifying wavelength dependent changes in the intensity of the returned signal.



Typical LIDAR system

A LIDAR typically comprises of a transmitter chain, receiver chain and associated electronics. Critical components of LIDAR system are high power laser system (100mJ or more with pulse duration of ~10ns), large aperture collecting optics (>1m aperture size), detection system (time gated photon counting, interferometry, etc.). Research opportunity exists in design and development of high power continuous and pulsed lasers, large optical apertures, focal plane based on time gated detectors and interferometry systems leading to proto-type development of LIDAR system.

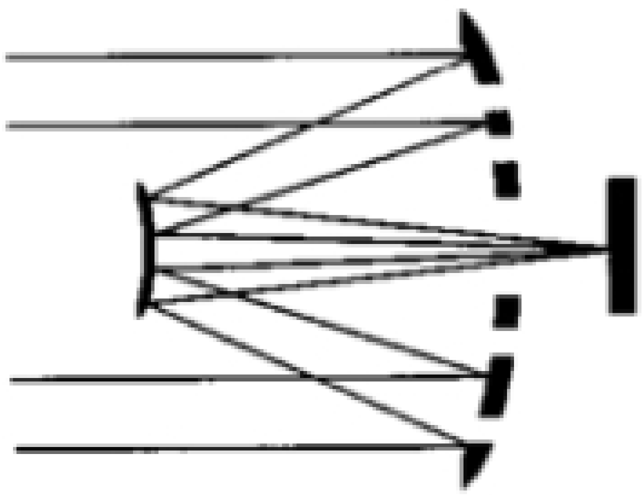
6.1.4. Image Simulators and Algorithms for Characterization of Imaging Sensors

EO sensors undergo extensive pre-flight testing and performance characterization to ascertain sensor behaviour and demonstrate performance compliance against specifications. Currently, static targets such as bar targets, slits, and flat field targets are used as input scenes for the EO sensor testing and characterization. However, this limits test capability in terms of temporal, spatial, and spectral variations in the scenes that an EO sensor sees in the actual remote sensing scenes. Research opportunity exists for design and development of synthetic scene simulators to generate dynamic scenes for EO sensor testing and characterization. Digital

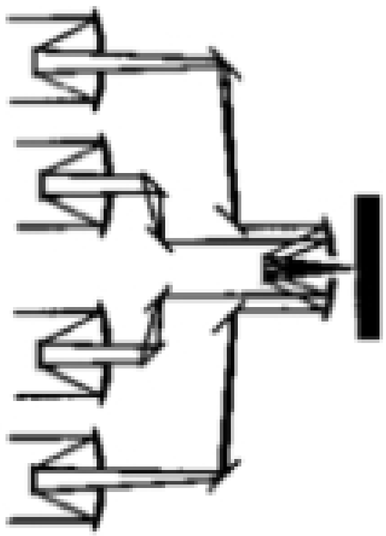
Mirror Device and Digital Light Processing can be potentially used for generating Multi-spectral and Hyper spectral scenes. The research in this field involves design and development of hardware and software system for generating suitable synthetic scenes having required dynamic variations, development of methods/algorithms for EO sensor performance estimation using the sensor output and evaluation in terms of image quality metrics, etc.

6.1.5. System configuration and simulation studies for Sparse Aperture telescope

The angular resolution of a traditional telescope is diffraction-limited and is given by $1.22\lambda/D$, where λ is the wavelength and D is the size of the optical system aperture. However, the optical system aperture is limited by the current glass-making technology and the cost involved. In order to overcome this limit, the technique of optical synthetic aperture have been reported in the literature. The optical synthetic aperture consists of several telescopes (as shown in figure below) with smaller apertures, phased in a manner to generate an equivalent large aperture.



Common Secondary Mirror



Multi Telescopes

This emerging field offers significant research opportunities in terms of studying feasible system configuration, perform extensive simulation studies, develop advanced processing techniques for generating improved resolution imagery from the acquired data, etc. The research will lead to development of a small-scale prototype for demonstration and validation of design and processing techniques.

6.1.6. System design, simulation studies and control system development for Segmented mirrors based EO sensor

A segmented mirror is an array of smaller mirrors designed to act as segments of a single large curved mirror. The segments can be either spherical or asymmetric. They are used as objectives for large reflecting telescopes. To function, all the mirror segments have to be polished to a precise shape and actively aligned by an active optics system using actuators built into the mirror support cell. In this research field opportunity exist to study feasible system configuration, develop simulation model, design and develop metering, actuation and control systems to maintain the segments in required shape and orientation to get the desired performance. This research aims to develop a small-scale prototype for demonstration and validation of the involved technology elements, and processing techniques.

6.1.7. Extending Super Resolution concept to Spectral Domain

Extraction of finer spectral resolution information from Hyper-spectral Imagery, given a large number of relatively coarser resolution images with overlapping spectrums. Similar to super-resolution imagery, if data is collected with a given spectral bandwidth, but with finer spectral sampling compared to the bandwidth, then it should be possible to generate images having narrower spectral bandwidth. The scope of the work includes development of models and simulation studies to demonstrate the concept and also develop a proto-type system to study hardware implementation aspects.

6.1.8. Design and development of Active cavity radiometers

Active cavity radiometers (ACRs) is one type of pyrheliometer used for measurement of direct beam solar irradiance. It is an electrically self-calibrating, cavity pyrheliometer used to measure total and spectral solar irradiance. They can be suitably tuned for measuring radiation from UV to IR spectral region. These radiometers remain stable over long duration and thus can be used as a calibration standard for relative calibration of uniform illumination sources or spectro-radiometers. Various research opportunities in the field includes studying active cavity radiometers, define feasible system configuration, perform extensive simulation studies and develop a proto-type model for demonstration.

6.1.9. Long range 3D imaging using flash LIDARs

3D Flash LIDARs have emerged as a potential imaging sensors for real time terrain mapping, 3-D measurements, guidance and navigation to support in rendezvous and soft landing missions, etc. A 3D flash LIDAR provides depth information of objects in the scene in addition to their 2D spatial distribution. The technological elements in 3D flash LIDARs involve Laser head, receiver optics, focal plane unit and electronics system with embedded image processing techniques for 3D measurements etc. This research envisages design and development of a proto-type 3D flash LIDAR imaging systems that involves system configuration studies, simulation studies, realization of small scale proto-type with COTS components, development of electronics system with embedded processing capabilities, performance characterization and field studies.

6.1.10. Design and development of high-resolution imaging system with active optics correction elements

High resolution imaging system generally employ large aperture optical systems and are generally affected by launch loads and orbital environmental conditions, which induces large amount of aberrations effects leading to loss of MTF in the acquired images. Active optics correction systems enable corrections of these deformations using an actively controlled optical surface in the telescope chain. The proposed study aims to design and develop an active optics correction based EO sensors for future missions.

6.2. Focal Plane Detection Systems

6.2.1. CCD and CMOS sensor fabrication process modelling and simulation studies

CCD and CMOS image sensors are mainstay sensor technology employed in spaceborne imaging systems. State-of-the-art imaging systems require custom development of these sensors. Sensor fabrication process and device modelling and simulation studies are very important milestone in the development of these sensors. SEDA has developed a dedicated modelling and simulation lab for design of these sensors as it allows more leverage to meet custom requirements. The lab is equipped with various simulation tool kits such as Technology Computer-Aided Design (TCAD) and MATLAB etc. The research opportunities include modelling of CMOS and CCD based optical image sensor fabrication process to estimate key performance parameters such as quantum efficiency, cross talk, sensitivity, dynamic range, charge handling capacity, etc.

6.2.2. Modelling and simulation studies on Superlattice structure-based SWIR and MWIR sensors

Infrared imaging detectors are increasingly being used in the focal plane of spaceborne imaging systems as it offers unique opportunities for variety of remote sensing applications. SEDA has taken up modelling and simulation activities for design of exotic sensors operating in Short-Wave IR (SWIR), Medium-Wave IR (MWIR) and Low-Wave IR (LWIR) spectral range. Research opportunities in this field includes TCAD and MATLAB modelling of Type-II superlattice structure for sensitivity in IR ranges, development of methodologies for higher temperature operation by suitably modifying stack to reduce dark current and development of techniques for enhancement of Quantum efficiency beyond 50%.

6.2.3. Design and development of high power NIR and SWIR LASER modules

Spaceborne LIDAR systems are gaining attention of the remote sensing community as it offers variety of applications in surveying, geodesy, geomatics, geomorphology, seismology, forestry, atmospheric physics, laser guidance, and laser altimetry etc. One of the important elements in the LIDAR system is high power Light Amplification by Stimulated Emission of Radiation (LASER) system. Currently SEDA is exploring design and development of the of high-power NIR & SWIR laser modules. The research opportunities include design and development of laser head, amplifier circuits, pump sources, drivers, diffractive optical elements, cooling system etc for long distance 3D measurement and flash LIDAR applications.

6.2.4. Thermal Background modelling for integrated IR detector cooler assembly (IDDCA)

Thermal background is one of the major sources of noise and offset in the IR detector system. Hence, it is important to estimate thermal background flux in the IDDCA to implement effective thermal control system. The research opportunities include development of physics-based model for estimation of thermal background in a given IDDCA configuration using various software tools such ray-tracing tool, thermal analysis tool, result visualization and quantitative estimation in Labview/Matlab etc. These modelling efforts will help in understanding the source of thermal background and enable improved design of IDDCA and the imaging system.

6.2.5. Design and development of drive circuits for CCD sensors

The research opportunity exists in design and development of CCD based image sensor drive circuitry for minimization of noise floor and clock induced charges. The design shall adopt different circuit design techniques for shaping CCD clocks (-10V to +15V, drive capacitance: 500pF, frequency: 10MHz) for maximization of stable video and reference sampling zones.

6.2.6. Design and development of Photonics Integrated circuits (PIC) based system on chip

System-on-chip significantly helps in integrating various image sensor circuit function in a very small footprint, thereby saving resources on payload/spacecraft. The research focuses on design and development of integrated circuits for clock and data multiplexing / demultiplexing, modulation/ demodulation, laser driver, laser and photodetector, packaging of imaging detector with PIC based chipset to miniaturize focal plane detector proximity electronics.

6.2.7. Design and development of High speed Event detector

The research focuses on design and development of CMOS image sensor pixels for automatic thresholding, target detection and tracking applications. Fast occurring events could be observed by identifying them within the pixel at analog level by using programmable thresholding circuitry. The pixel level circuitry initiates readout by raising appropriate flag. Such flags help row - column circuitry to readout events of interest at high frame rate, up to 50kHz. Once of the possible application could be automatic detection and radiometry of lighting events.

6.2.8. Development of process flow for CMOS chip debug

The research opportunities exist in the de-processing, micro-surgery, hot electron imaging active micro-probing, and IR microscopy, etc for debugging of CMOS chips. After we fabricate any chip, it is quite challenging to debug possible problems areas (design, fabrication, assembly, integration, packaging and testing) if it does not meet the desired performance. We have to develop some of the chip debug tools to be able to debug complex chips. These sort of tools and technologies would also help to identify possible reasons for yield reduction.

6.2.9. CMOS pixel process development at 180nm

The research opportunities exist in Pinned photodiode-based pixel (7 to 50micron pitch) development to meet charge handling requirement from 30ke to 3Me. This research will lead to development of pixel process for TDI CMOS focal plane arrays.

6.2.10. Packaging of Infrared detector arrays for multispectral application

This research focuses on development of techniques using industry for butting of smaller arrays to form large arrays, integration of filter / cold shield / lens, assembly of detector onto cold table mounted with flexible thermal link for cooling down to 50K and minimization of thermal load by utilizing new interconnect materials.

6.2.11. Design and development of Ultraviolet detectors based on wideband gap semiconductors

Photon detectors based on wide band gap semiconductors have recently garnered considerable attention due to its suitability in development of highly sensitive ultraviolet detectors. The scope of research includes comprehensive review of literature in the field, understand the mechanism of these sensors, inherent advantages and disadvantages of those detectors, explore suitable materials for producing these detectors, etc.

6.2.12. Development of curved sensors

Curved image sensors have emerged as novel technology that can decouple the traditional constraints between field-of-view (FOV), resolution and image quality. Usage of curved sensors relaxes the stringent imaging performance requirements on the optical systems at extreme fields. Many research groups are working on the device fabrication technologies. The scope of the research in this field is to explore various fabrication process technologies, carry out design and simulation studies for pixel architecture for curved sensors, address issues/challenges in the field and attempt to develop proto-type curved sensor for characterization studies. This research will lead to adaption of such curved sensors in the future spaceborne missions.

6.2.13. Metamaterial based absorber surfaces for image sensors applications

Metamaterial structures have attracted substantial attention due to their ability to obtain desired effective permittivity and permeability by carefully designing its structure. It has resulted in the discovery of exotic phenomena such as negative refraction, cloaking, perfect absorption etc., which are not possible with ordinary materials. Broadband metamaterial absorber shows a promising prospect in applications such as controlled reflectors, solar cell, infrared detection. Junyu Li, Haoran Zhou et al have developed deep subwavelength plasmonic metamaterial absorbers for infrared detection (Conference on Laser and Electro-Optics (CLEO)

2019 © OSA 2019). In this study, a metal-insulator-metal based infrared plasmonic metamaterial absorber consisting of deep subwavelength meander line nano-antennas(MLAs) based array was fabricated and experimentally demonstrated the absorption from 11 μm to 14 μm with a pixel pitch of 1.47 μm. Plasmonic metamaterial absorbers (PMAs) are arrays of subwavelength-spaced metallic nano-objects (also termed as optical antennas) whose primary function is to concentrate the propagating light into regions much smaller than the wavelength and efficiently dissipate the optical energy into heat via localized surface plasmon resonances (LSPRs). The proposed research aims to explore CMOS compatible metamaterial absorber structure, simulation of absorption characteristics of these materials, explore fabrication feasibility, etc.

6.2.14. Dilute Magnetic Semiconductor (DMS) material synthesis for spintronics applications

A new class of materials known as dilute magnetic semiconductor (DMS) are semiconductor materials that exhibit both ferromagnetism (and a similar response) and useful semiconductor properties. If implemented in devices, these materials could provide a new type of control of conduction. Whereas traditional electronics are based on control of charge carriers (n- or p-type), but magnetic semiconductors would also allow control of quantum spin state (up or down). DMS have been a major focus of magnetic semiconductor research. These are based on traditional semiconductors, but are doped with transition metals instead of, or in addition to, electronically active elements. Due to their novel properties of change and spin control, they have generated huge interest among the scientific community as a strong candidate for the fabrication of spin transistors and spin-polarized light-emitting diodes.

6.2.15. Optical Beam Steering Photonic Chip for Lidar

In a Lidar, a laser beam is formed to concentrate the optical power within single pixel instead of the whole scene, which makes it a point-wise measurement system. To form an image, the beam is scanned through the FOV Namely, a beam scanner. Scanning LiDAR achieves higher signal-to-noise ratio (SNR) at the cost of lower points per second (i.e. point throughput) and slower frame rate, and more importantly, at the cost of having a beam scanner. Beam scanner is often realized through mechanical actuation of either the source itself or the discrete optics around the source. While mechanical optical beam scanner design is already an established domain of engineering, there is a fundamental challenge associated with achieving good control precision and reliability goals for automotive vehicles using a low-cost mechanical system. To reduce the unit cost of a scanner module and make it feasible for consumer electronics, various solid-state beam scanning solutions are the preferred option. There are many approaches to realize a photonic chip for Optical beam steering like MEMS Switch based array of grating coupler, Optical phased array, true time delay based beam steering, etc. The beam steering chip shall define the beam width of less than 0.2 degree and shall steer the beam within 20 degrees in both axes.

6.2.16. On-chip nano wire grid fabrication for polarization sensing

Traditional imaging systems have focused on capturing and replicating the imaged environment in terms of colour and intensity. One important property of light, which the human eye is blind to and it is ignored by traditional imaging systems, is polarization. Polarization of light caused by reflection from materials contains information about the surface roughness, geometry and other properties of the imaged environment. Polarization-contrast imaging has proven to be very useful in gaining additional visual information in optically scattering environments, such as target contrast enhancement in hazy/foggy conditions, depth map of the scene in underwater imaging, presence of ice in clouds or non-spherically shaped dust particles and in normal environmental conditions, such as classifications of chemical isomers, classifications of pollutants in the atmosphere, and non-contact fingerprint detection among others. In addition, polarization of light has found a niche in many biomedical applications, such as imaging for early skin cancer detection, cell classification and retinal surgery.

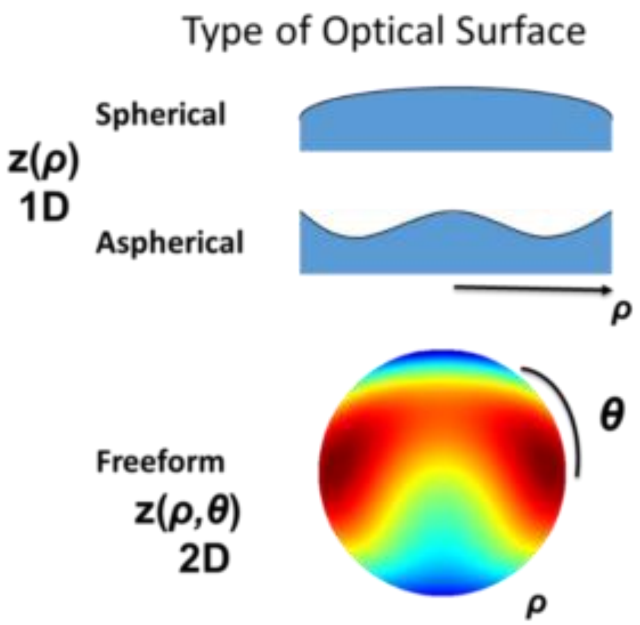
Wire grid polarizer is compatible with complementary metal-oxide-semiconductor (CMOS) technology, and it can be fabricated monolithically by using metal layers for wiring. Using deep-submicron CMOS technologies, which allow the design of metal patterns finer than 100 nm. The angle (0, 45, 90 and 135 degree) of the polarizer on each pixel can be designed.

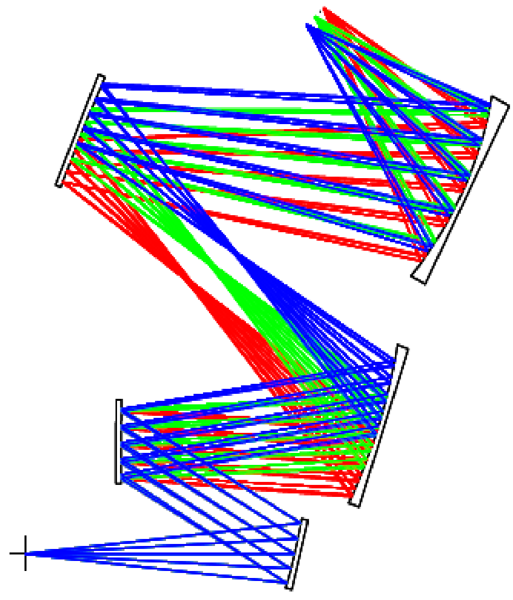
6.3. Design and Development of Optical Systems

6.3.1. Optical systems using freeform surfaces

Freeform optics offers more degrees of freedom to optical design that can benefit from a compact package size and a large field of view for imaging systems. The introduction of freefrom optical surfaces in a space instrument offers the possibility to improve its performance, its volume and weight or a combination of both. Motivated by the advances in modern optical fabrication and metrology, freeform optics has found place in many applications. The freeform mirrors are manufactured by diamond turning based on a feedback modification strategy.

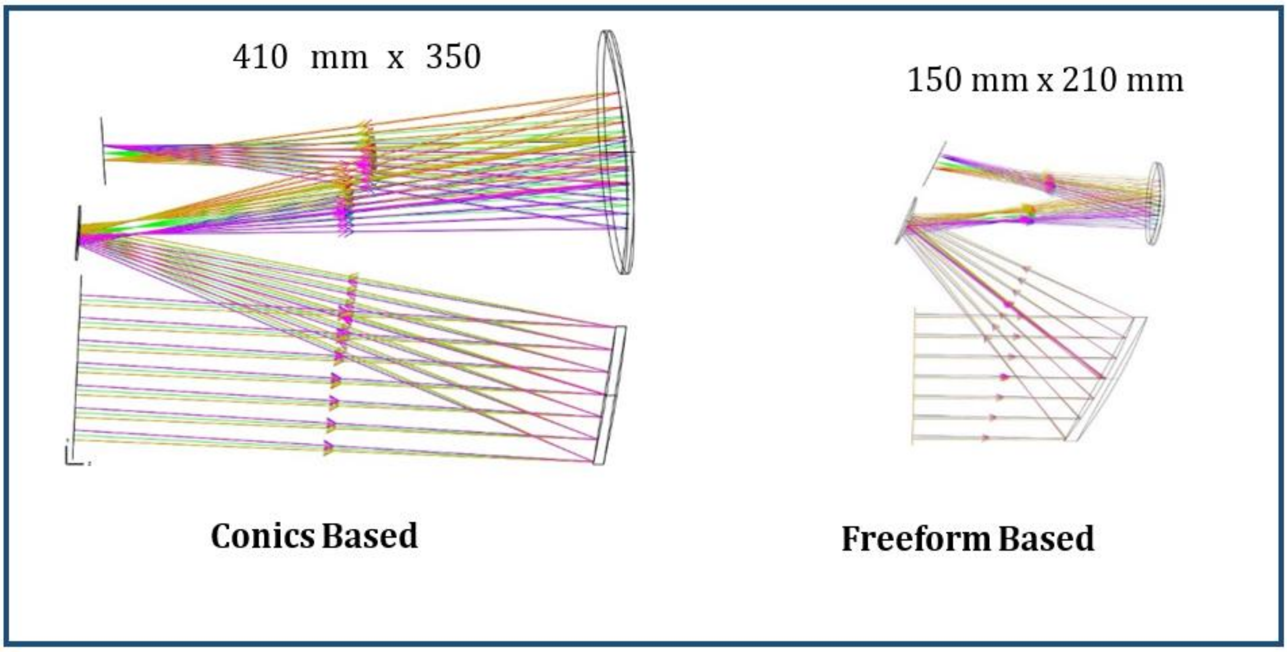
Freeform optics involve optical designs with at least one freeform surface which, according to the International Organization for Standardization (ISO) standard 17450-1:2011, has no translational or rotational symmetry about axes normal to the mean plane. Integration of freeform optics and surfaces into imaging systems remains a major challenge. However, the new degrees of freedom introduced by freeform optics designs are the driver to overcoming these challenges. These additional degrees of freedom enable many potential advantages, including system miniaturization, reduced component count and even entirely new optical functionality that will have a profound effect on the optics industry.





Example of optical system using freeform optics

Research activity that can be taken up is to utilize freeform surfaces to design future telescopes with wide field of view. One particular study can be carried out to show how the freeform optics can be used to miniaturize/improve the performance of an optical system. Another interesting research activity is the fabrication and testing of free form surfaces (IR/ Visible range). One such example of miniaturization using freeform optics (XY polynomial) is shown in the following figure.



6.3.2. Chalcogenide optics in dual-band IR Applications

The development of dual-band IR sensors that image both MWIR and LWIR on the same image plane challenges the optical designer to create refractive lens systems with one aperture. In the past, classic materials such as Ge and ZnSe have been combined with more exotic materials such as barium fluoride (BaF2) and gallium arsenide (GaAs) to focus light across a wide range of IR wavelengths. Material limitations create unique challenges for wideband chromatic correction. Existing and new formulations of chalcogenide glasses provide additional indices of refraction and dispersion characteristics for chromatic correction as well as thermo-optic properties for athermalization. Chalcogenide glass is an increasingly important tool for the optical designer, providing a versatile material for many applications—from thermal imaging to hyperspectral imaging. The properties of these amorphous glasses are useful over a broad spectral range, from the near-infrared (NIR) at 700 nm well into the LWIR spectrum.

Chalcogenide glasses consist of mixtures of the Group 16 elements selenium (Se), sulphur (S), and tellurium (Te), and various Group 14 and 15 elements such as arsenic (As), germanium (Ge), tin (Sn), and others. These glasses are well suited for imaging in the IR regime because of their high transmission, low dispersion, and low refractive-index change with temperature. By changing concentration ratios, glass properties can be tailored for index of refraction, dispersion, glass transition temperature, and other properties. This gives the optical designer or the lens manufacturer more freedom than traditional IR materials. As traditional IR materials such as Ge and zinc selenide (ZnSe) rise in cost, the use of chalcogenide glasses is becoming more widespread. Chalcogenide materials offer substantial savings today in both the raw material cost and in fabrication methods such as molding technology. They also provide numerous benefits to systems with stringent specifications. There are many sources for chalcogenide glasses, including Vitron GmbH (Jena, Germany), SCHOTT North America (Duryea, PA), and IRradiance Glass (Orlando, FL), which produces a number of glass types along with custom melts.

Rochester Precision Optics developed moulded micro- and nanostructures in chalcogenide glasses. The optical properties of chalcogenide optics can be altered by nanoscale surface textures. Antireflective structures that reduce reflectance significantly reduce glare and improve transmission.

Unlike a thin-film coating that creates interference effects, nanostructures are not bandwidth-limited. Hybrid structures have demonstrated performance over dual-band regions (3-12 μm), showing promise for future applications such as high damage threshold for lasers, super hydrophobicity, and antifogging. While these functionalities have been shown on the development scale, there are still great challenges in developing industrial fabrication methods that can reduce the cost of such nanostructured materials.

This rapidly evolving world of high-volume, low-cost IR optics, along with the expansion of extremely demanding dual-band IR applications, has created a requisite for use of chalcogenide glasses. Chalcogenide materials have the ability to be altered and provide optical and systems designers many more options than historic IR material offerings without compromise.

The scope of the proposal is as follows:

- Study of feasibility for use of chalcogenide glasses for spaceborne remote sensing application.
- Design of dual band IR common optics using chalcogenide glasses that will image both MWIR and LWIR on the same or different imaging sensors.
- Collaboration with indigenous industry and universities for realization of Chalcogenide optics via. Fabrication, assembly and testing for achieving the desired performance goals.

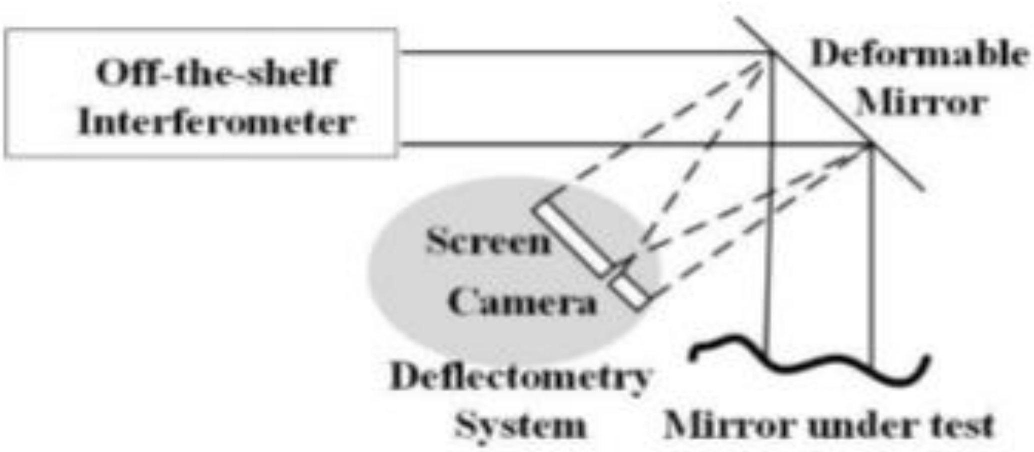
6.3.3. Adaptive test techniques for Aspherics and Freeform surfaces

During the manufacturing of optics, the in-process (i.e., not-yet-completed) optical surface must be accurately measured to correctly guide the iterative fabrication process. The customized null element makes the process time taking and costly.

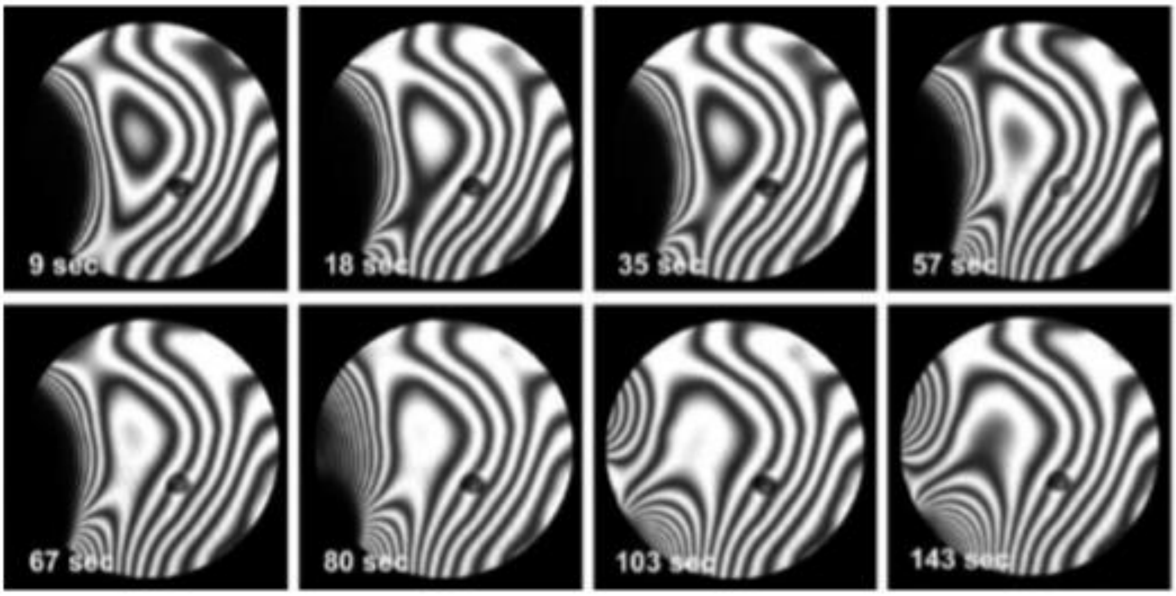
Also, for interferometric surface form measurement of final freeform surfaces the measurement is limited by the Nyquist criteria, which is often encountered due to large slope of freeform surfaces.

To overcome this, one of the current techniques is Adaptive interferometric null testing method
The adaptable null component may be a Spatial Light Modulator or Deformable Mirror.

1) **Test set-up using deformable mirror**



When an unknown test optic is first inserted into the metrology system, non-ideal (e.g., partial) interference fringes could be observed.



Next, the DM is driven based on the results from the algorithm recovering near-null interference fringes. This creates an online null condition for the freeform surface. The interferometer measurements, along with the results from the Deflectometry System are combined to produce the final surface shape data.

The algorithm, that is used for fringe restoration will be heavily influenced by the merit function which is provided as the required target. A smart choice of this merit function will result in a quicker and more efficient convergence (to the ideal or threshold value).

Limitation of the method: DM has limited range of stroke of actuators and can only compensate mild free form departures.

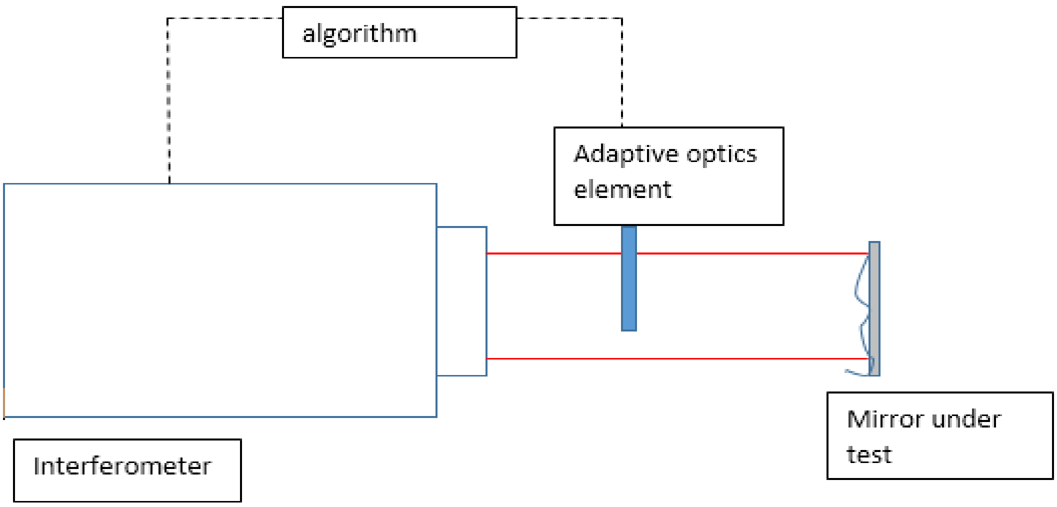
The DM will be developed and characterised by industry/academia, which can further be integrated in to the test set up at SAC. The other important part of the test set up i.e. Deflectometry system used to monitor the DM surface can be developed jointly by SAC & academia.

6.3.4. Test set up using Spatial Light Modulator

The DM-based null test is adaptive and economical compared to CGH; however, DM has limited range of stroke of actuators and can only compensate mild free form departures.

A high-definition (i.e., >1080 pixels, <5 µm pitch) spatial light modulator (SLM) circumvents the limitation of the DM.

The phase conjugation algorithm is additionally utilized for turning resolvable fringes into null ones. Finally, local severe surface figure error is extracted from the SLM phase and the null test result by reverse optimization based on ray trace model.



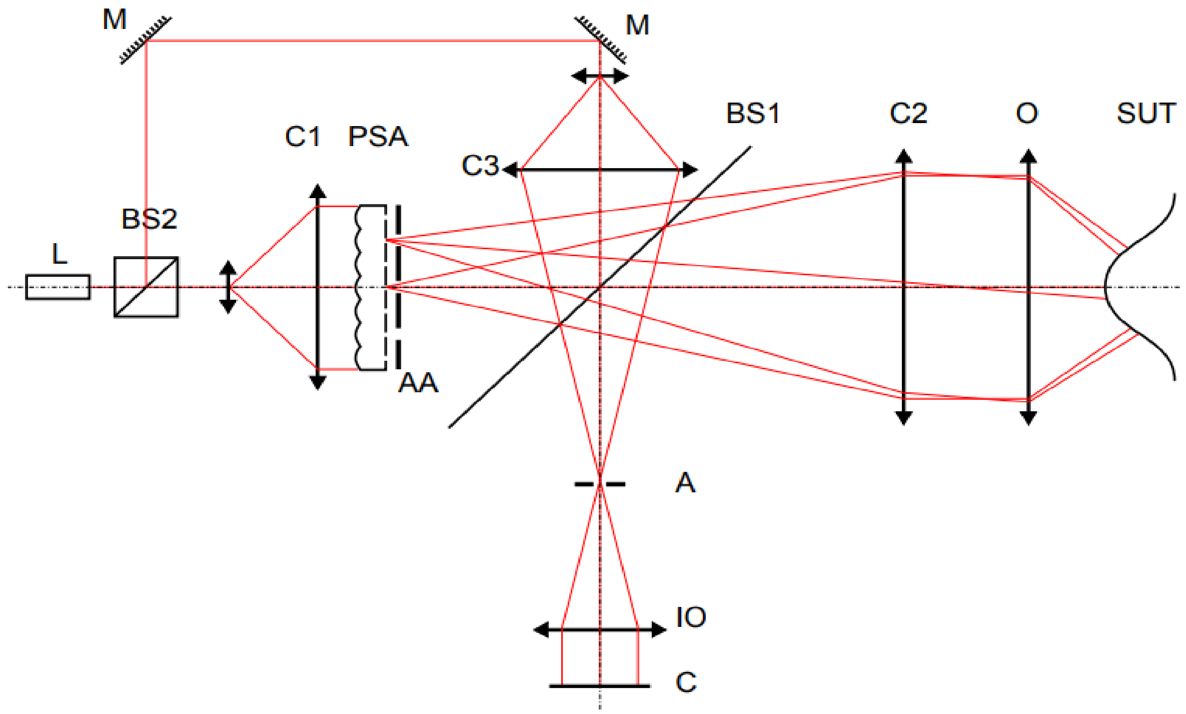
TDP is already going on. Collaboration may be sought on development of algorithm. The commonly used algorithms for such applications are widely used in Machine Learning applications. Some of the algorithms are

- Stochastic Parallel Gradient Descent
- Simplex Optimization
- Genetic Algorithm
- Simulated Annealing

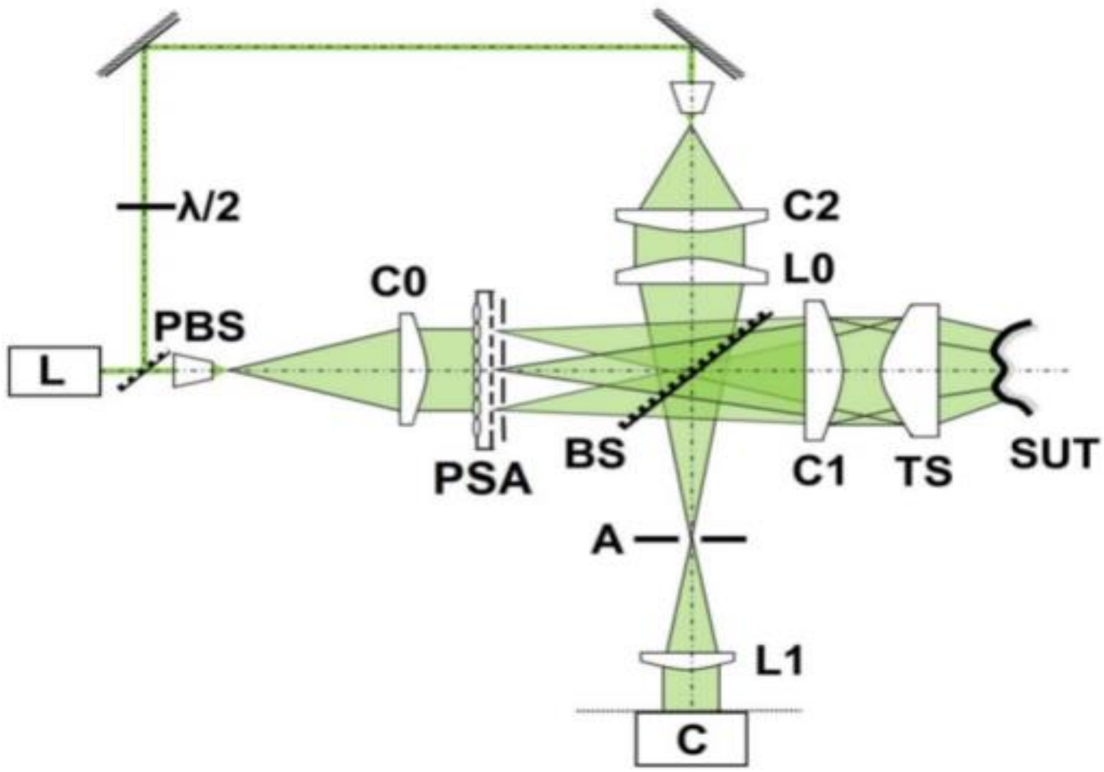
Simulation can be carried on supplied data and later verified experimentally at SAC.

6.3.5. Tilted Wave Interferometer

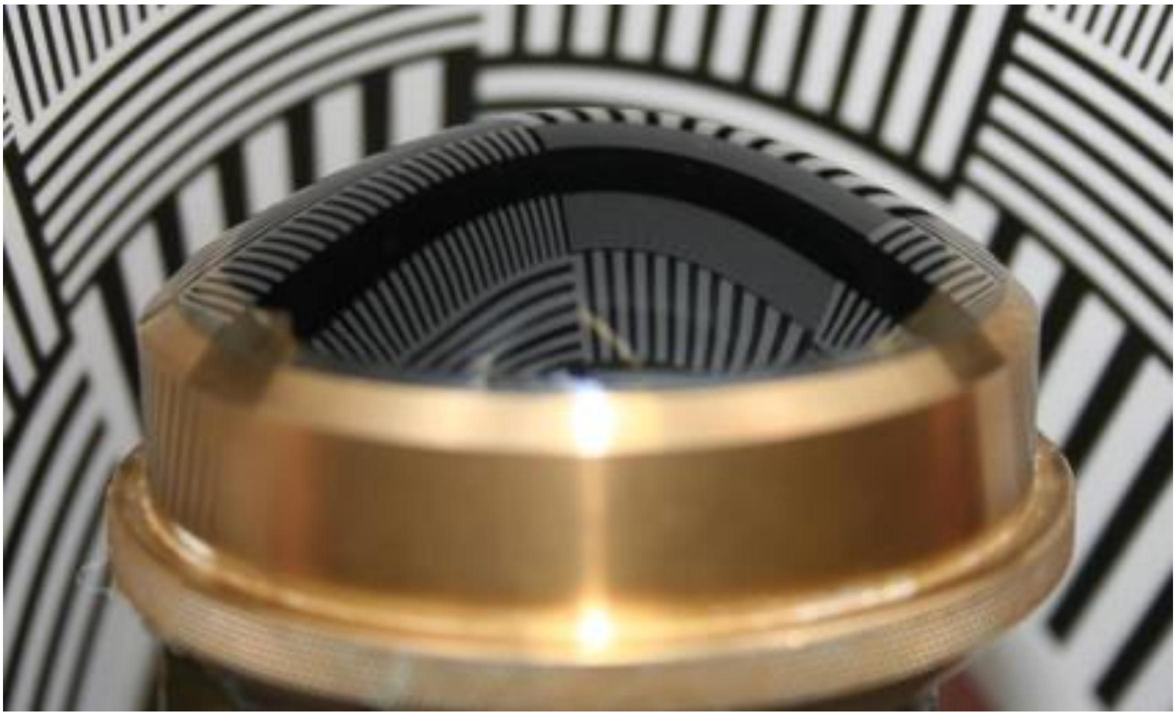
The use of aspheric and freeform surfaces becomes more and more important in the design of modern optical systems. These surfaces offer additional degrees of freedom to the optical design, allowing to improve the optical imaging as well as to reduce the number of surfaces needed for an optical design. However, testing of such surfaces is still a difficult task. This issue can be addressed using the technique of Tilted Wave interferometer. TWI is non-null, full-field interferometric measuring technique for aspheric and free-form surfaces with a new degree of flexibility. The interferometer uses a set of tilted wave fronts to locally compensate the deviation of the surface under test from its spherical form. Also since its non-null technique, hence the costly optics is not required for testing. The main difference of this approach to the scanning type interferometers is that the acquisition of the data is highly parallelized, since all test wavefronts are applied to the surface in only four steps. Further, the surface under test (SUT) does not have to be moved during the measurement process. Both these advantages lead to a very short measurement time of far under a minute.



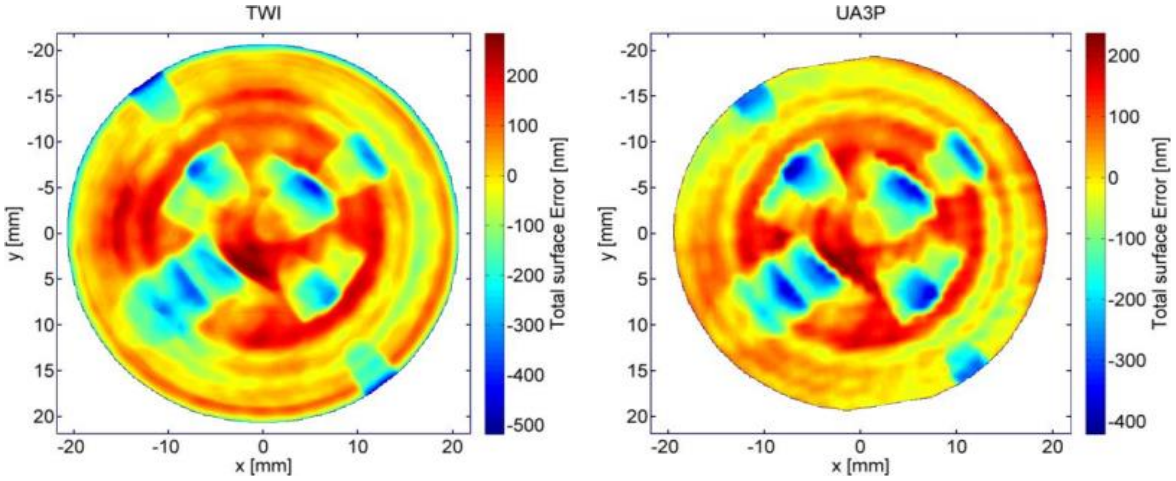
Schematic setup of the interferometer. L: Laser source; BS1, BS2: Beam splitter; C1, C2, C3, Lens; PSA: Point source array; AA: Aperture array; M: Mirror; O: Objective; SUT: Surfaces under test; A: Aperture; IO: Imaging optics; C: Camera.



Tilted Wave Interferometry



Aspheric surface with clear aperture of 40mm and 800µm / 5° deviation of the best fit sphere.



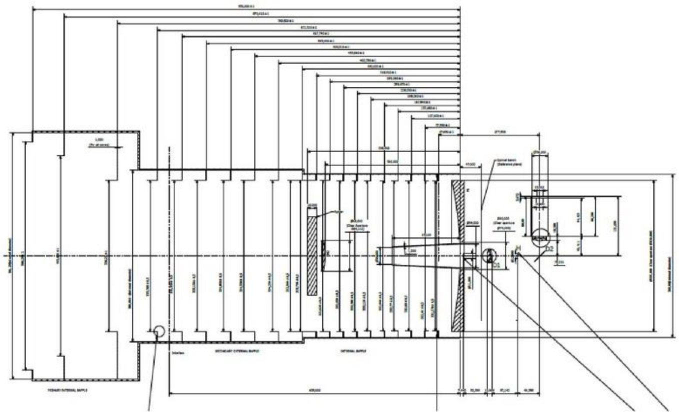
Measurement of aspheric surface by TWI (left) and comparison measurement by CMM (right)

The surface has a strong astigmatic shape of about 1mm deviation from the spherical form. The marks from the diamond-turning tool are clearly visible in the measurement.

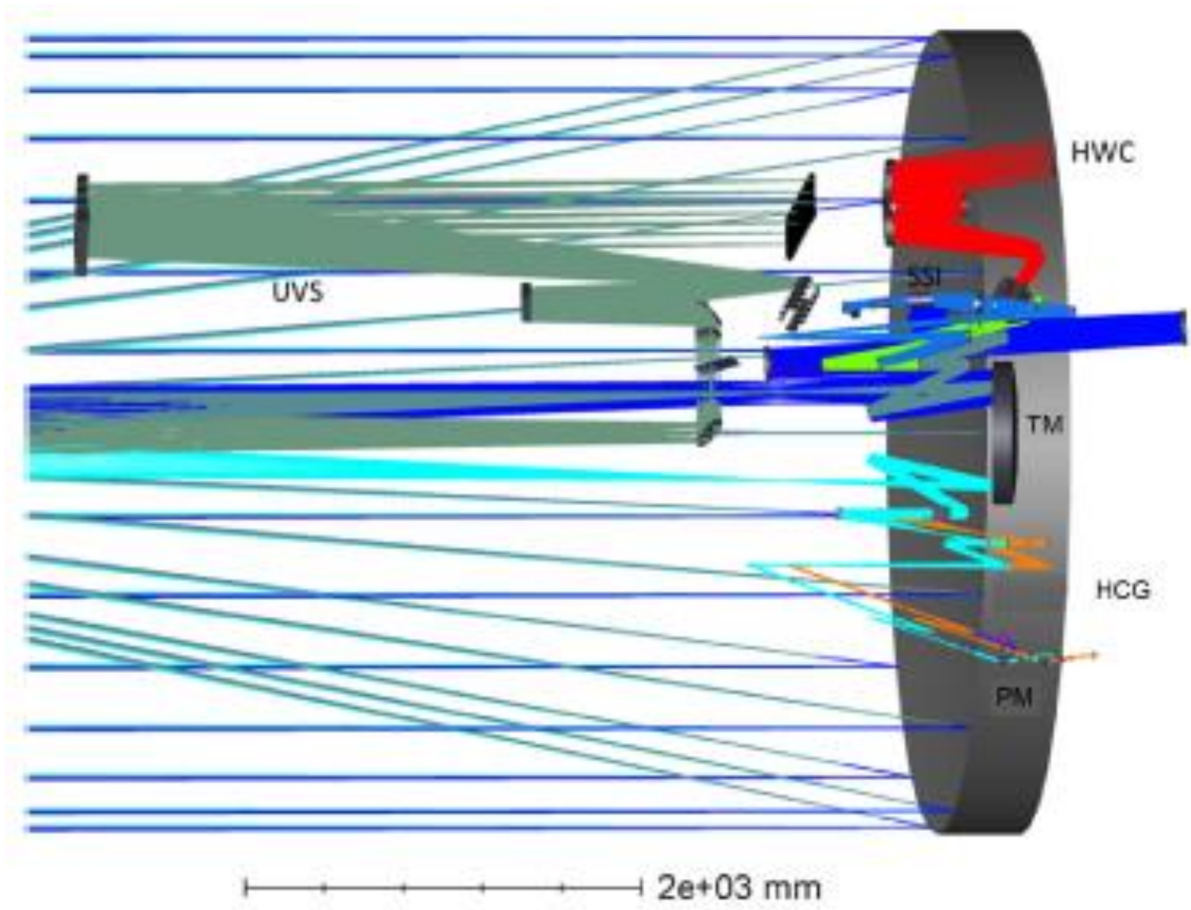
6.3.6. Optical Design of telescope for space observatory for study of Exoplanets

Planets that orbit around other stars are known as Exoplanets. Exoplanets are very hard to see directly with telescopes. They are hidden by the bright glare of the stars they orbit. Therefore, indirect methods such as radial velocity, transit photometry/spectroscopy and timing variation methods are used to detect exoplanets. In some cases, direct imaging method is also used to find exoplanets.

The telescope to study exoplanets can consist of a single instrument (eg. Characterising ExOPlanets Satellite (CHEOPS) of European Space Agency (ESA)) or a cluster of instuments (eg. Habitable Exoplanet (HabEx) of National Aeronautics and Space Administration (NASA)). The design options include Ritchey-Chritien (RC) or a three mirror anastigmat (TMA) design followed by science instruments. The spectral range of these telescopes generally include ultraviolet (UV), visible and near-infrared (near-IR), shortwave infrared (SWIR) and sometimes midwave infrared (MWIR) regions. The telescopes include both imaging and spectroscopic capabilities. Stray light suppression using effective baffling is very important as the faint light from exoplanets should not be suppressed by any other light coming from earth or stars. Research in this field is invited for the development of optical systems for upcoming exoplanet missions.



Comprehensive baffling system to suppress straylight (CHEOPS)



Optical schematic of telescope assembly with instruments (proposed in HabEx)

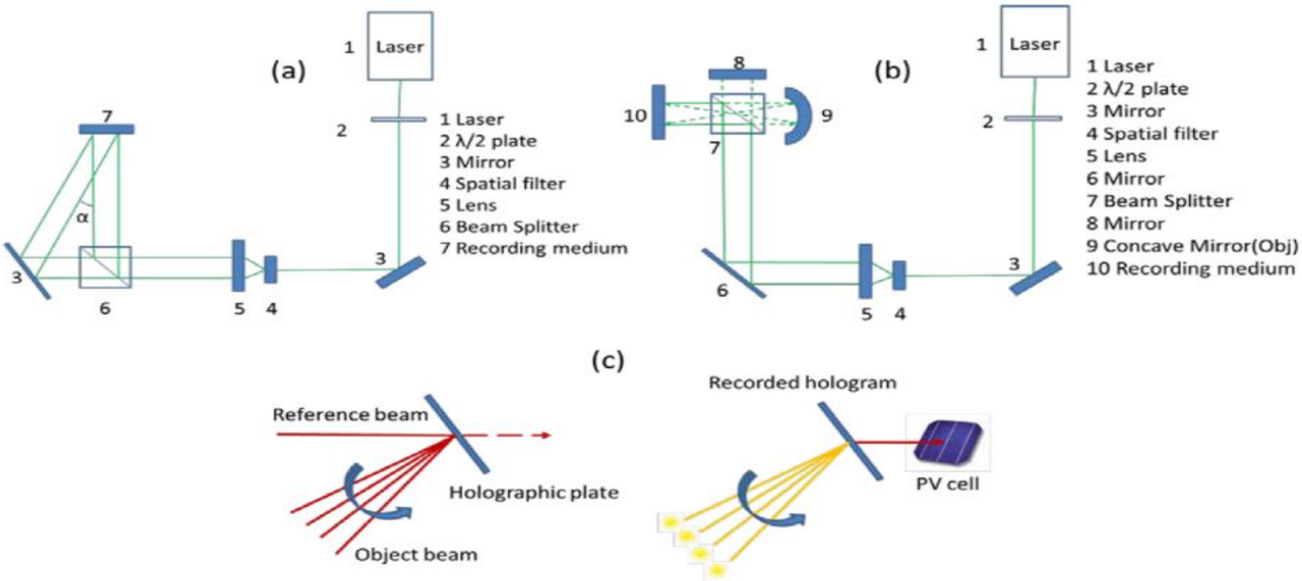
6.3.7. Design and development of Volume Holographic Grating (VHG)

VHGs are widely used in ground based astronomical spectrometers with moderate to large diameter telescopes ranging anywhere between 8 meters to 10 meters. These have also been extensively used in gas sensors where spectral peaks with very narrow bandwidths are required to match with gas absorption spectra. They are suitable for both ground and spaceborne applications. Considering the major advantage of higher number of grooves/mm and consequently finer spectral bandwidth of few picometer, the VHG have been used in multiple global space missions like Sentinel 3A and Rosetta etc. This research proposes design, fabrication and characterization of a plane/curved VHG for spaceborne imaging spectrometers for astronomical observations and environmental monitoring.

The fabrication of VHG basically involves writing of a typical pattern by optical interference between two coherent laser beams (reference and object beams) superposing in a photosensitive material making fringes in the material by means of a periodical variation of the refractive index (i.e. a sinusoidal profile) throughout the volume of the photosensitive material. The technique enables writing 600 to 6000 grooves/mm on a substrate diameter upto 850 mm.

Scope of the research

- Modelling of the grating with peak efficiency at required wavelength mainly catering to VNIR and SWIR, fabrication and characterization.
- Indigenous/ in-house development of the holographic exposure system to record fringe pattern of desired frequency and orientation using photo-polymer coated plane/curved glass substrate.
- Indigenous / in-house development of photo-polymer or gelatin like films.
- Development of a suitable processing technique so that modulation pattern is accurately reproduced after a wet-dry processing cycle.
- Exploring feasibility for space usage and carrying out related testing.



The interferometric techniques, c) recording material

6.3.8. Computer Generated Holograms (CGH)

Aspheric and freeform optical surfaces are frequently used in spaceborne/airborne sensing instruments as they help in reducing the number of optical components in the system, thereby reducing the size and weight of the sensing instruments. Aspheric surfaces are usually tested using null interferometric testing methods: either refractive (null lens) or diffractive (Computer generated Holograms). A Computer Generated Hologram (CGH) is produced via computer synthesis, where the object does not exist physically but it is expressed in mathematical terms. CGH's can generate any shape of wavefront including freeform. Two types of CGH's are used: Amplitude CGH (chrome pattern on glass) and Phase CGH (Pattern etched on glass). High precision and high resolution CGH's can be fabricated using microlithography technologies like electron beam lithography and laser beam lithography. These microlithographic techniques are common in semiconductor industry for integrated circuits (IC) fabrication.

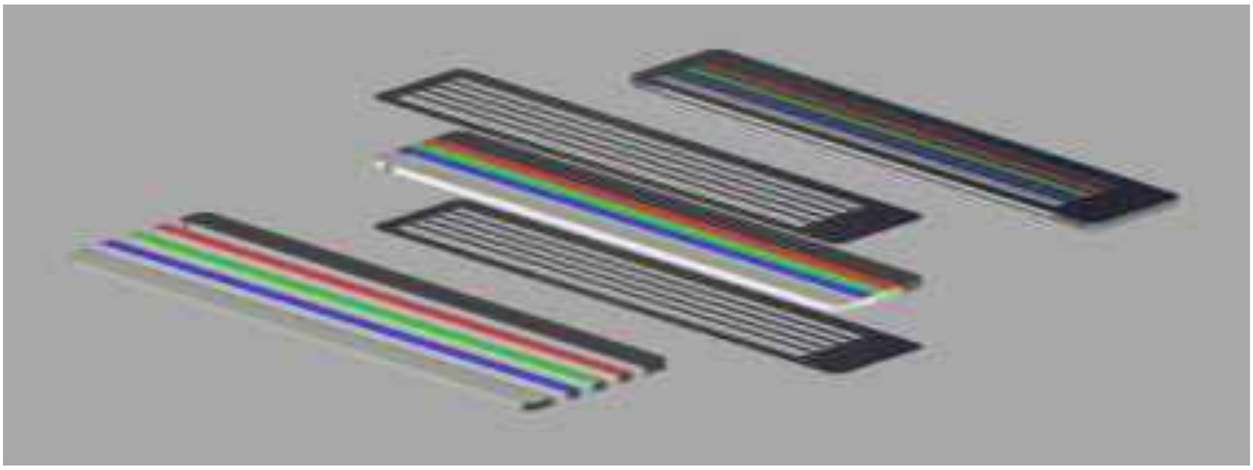
Scope of the Research:

- Resist (e-beam or photo resist) coating,
- Electron beam / Direct Write Laser (DWL) Lithography for resist patterning,
- Resist development, Metallization (E-Beam evaporation),
- Lift-off or Wet Chemical Etching for Amplitude CGH and Glass dry etching for Phase CGH.

6.3.9. Design and development of Strip Filters in VNIR spectral range.

Strip filters are interference filters. The strip filter assembly can be developed using butcher block technique. In this the filter strips catering to different spectral bands are glued together to form an array. Using the coating facility (SYRUSpro1110) at thin film lab SEDA, the required band pass filter (B1-B4) coatings will be developed. These filters are then diced into strips of required widths using the dicing facility in the lab. Four filter strips belonging to different bands (B1-B4) will then be glued together to form the filter arrays. These activities can be carried out at SAC.

In order to use it on board, one needs to block the stray radiations at the junction of the strips, for which masking coating needs to be applied, which also defines precisely the clear aperture of each filter strip. For this purpose, we need to use lithography followed by masking coating deposition followed by dry etching. At present these facilities are not available in the lab, hence the facilities available at other institutions can be utilized for this purpose.



6.3.10. Development of band pass filters with controlled thickness variation across the filter length

The interference band pass filters are sensitive to angle of incidence. Not only the central wavelength shifts due to angle but also the shape and transmission changes at higher incidence angles. This becomes more significant in case of narrow band pass filters. In optical payloads with large field of view, it becomes almost mandatory to design the tele centric optics in order to minimize this effect. This in turn makes the design very complicated and may require aspheric components, which are difficult to fabricate. In order to reduce spectral shifts due to large angles, a band pass filter can be design to compensate for this shift by introducing controlled variability in the filter thickness. The variability can be introduced by designing the appropriate masks, which will be filter specific. By replacing conventional filters by these variable filters, the optical design can be made very simple. The design of these filters will be done in house. Development of the controlled thickness variation of the coating across the filter will be taken up in collaboration with Academic institutions.

6.3.11. Development of IR filters

For payloads, involving IR imaging we need filters catering to the spectral range from 3 - 15 microns. The proposal is to design the filters in house and get it coated with the help of institutions within India. At present, the thin film lab does not have the facilities to develop the coatings in the IR spectral range. These activities can be taken up with the help of other institutions within India.

6.3.12. Development of Rugate Notch Filters

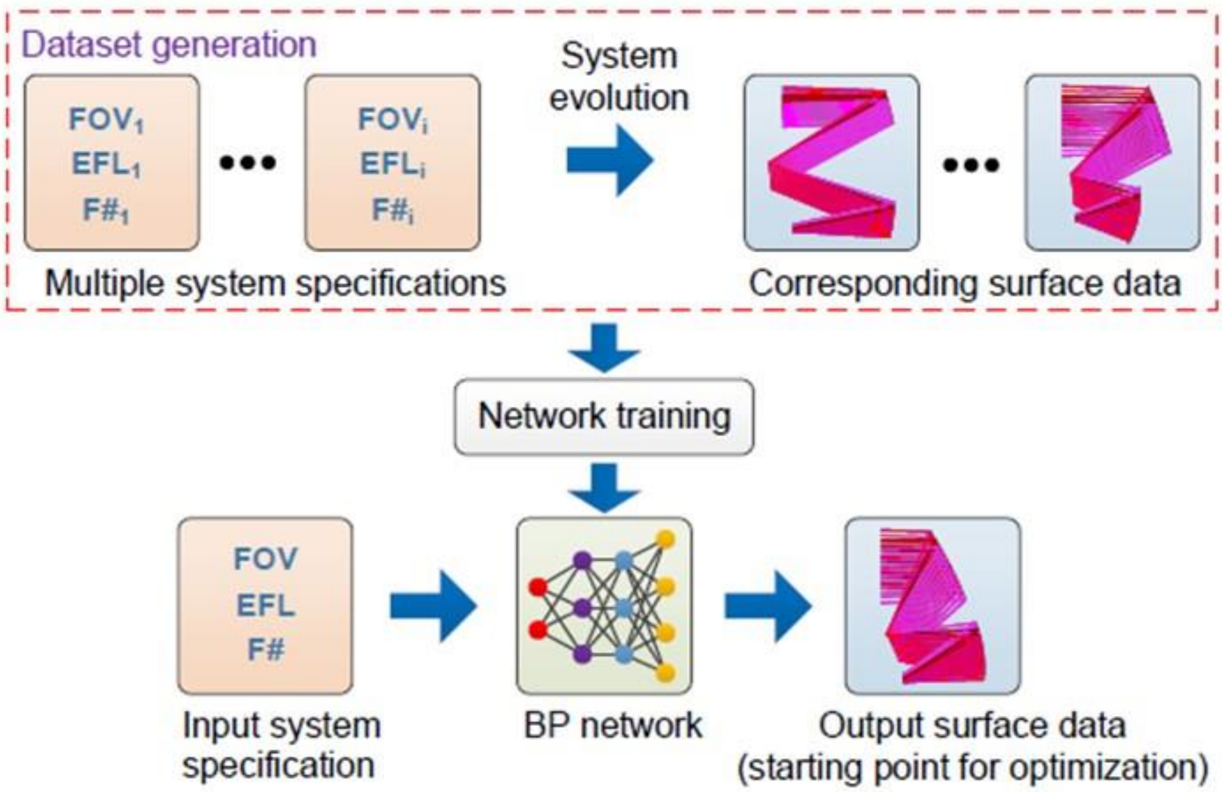
Notch filters are optical filters that selectively rejects a portion of the spectrum, while transmitting all the other wavelengths. Notch filters based on the principle of optical interference can be fabricated using Rugate dielectric stack, which provides high reflection in a narrow wavelength region and high transmission outside.

These filters act as mirrors for a narrow band of wavelengths. In the free space optical communication as well as in space based detect ability and identification of submersibles. In this high energy, LASER pulse is transmitted from ground based station towards a space based mirror that scans over a specific oceanic area looking for returns from underwater objects. These filters can replace the reflectors. This will reduce the background noise, as they will only reflect the narrow band of wavelengths around the LASER wavelength. They are also useful in the RAMAN spectroscopy and fluorescence based imaging.

6.3.13. AI enabled design of next generation optics/optical systems

The traditional design method for imaging optics is to first find a starting point, and then perform optimization. However, for freeform system design, proper starting points with similar system specifications and special nonsymmetrical configurations are very rare, which greatly increases the possibility of using extensive human effort.

Use of Deep learning algorithms (Artificial Neural Network (ANN) in particular) can significantly aid in finding optimized starting points for imaging system design. This research work envisages development of an intelligent framework where the entire design process need not be repeated again and will result in faster development of EO payloads. A typical AI enabled design framework is shown in Figure below:



This approach offers several advantages, particularly in the situation where there are limited existing designs and patents and knowledge is limited. The intelligent framework developed can be used to learn from the previous added designs. Moreover, designers do not have to manage the starting point exploration or analytical/numerical design process.

6.3.14. Zerodur, Silicon Carbide, Schott Glass blank development

Zerodur, Silicon Carbide, Schott Glass blank materials are required for the fabrication of Optics (reflective/Refractive telescope). Zerodur is glass ceramic and its CTE is nearly zero and used for reflective optics development. Schott glasses are used for refractive optics development. Indigenous development of these blanks will significantly aid in payload design and developmental activities for future ISRO missions.

6.4. Electronics System Design and Development

6.4.1. Development of Integrated Circuits for Harsh Environment Operation

Harsh Environments are defined as environments, which are characterized by high/low temperatures, extreme vibration loads, harsh chemical environment, high radiation etc. The electronics or systems required to operate under such harsh/extreme conditions have application such as in aircraft engines, automotive, oil-well drilling and space exploration like near to Sun and planets like Venus where the surface temperature is appx. >400°C. Hence there is a requirement of development of electronics and sub-systems (both commercial and space) which can operate under extreme environments.

Present technology used in development of integrated circuits are mostly Silicon which is suitable for reliable operation when the temperature is <150°C. The other technology Silicon-On-Insulator (SOI) can operate upto temperatures <300°C. Hence, these ICs are susceptible to damage in high temperature and radiation environment and hence require additional distancing and shielding, thereby putting restrictions to where these circuits can be placed.

Recent developments have shown use of wide bandgap (WBG) semi-conductors like Silicon Carbide (SiC), Gallium Nitride (GaN), diamond etc. These materials have shown tremendous resistance to harsh temperature and radiation. Development of an integrated (like SiC-CMOS) circuit technology enables development of integrated circuits which are stable in harsh environments.

The benefits are improved reliability, reduction in size / weight and power for cooling systems (which are typically required when conventional electronics (Si or SOI) is used) and possibility of direct sensing and control systems in harsh environment.

6.4.2. System Modelling and Controller Development for IR Payloads

Various control systems are used in IR payload for controlling the temperature of various Opto-mechanical elements. IR detector requires temperature control of IDDCA cold tip, detector window, Blackbody and other elements within few mK accuracy and stability.

There is a need to develop an executable model of the system including the plant using first principle methods or other methods (using experimental data). MATLAB or other modelling tools can be used for developing the executable model.

Methodology:

- In first principle method, equations governing the working principle of the plant are developed. Consideration to material properties and interfaces are given to develop accurate relationships between controlling variable and controlled variable.

  If information related to operation of some blocks are not available, field data (experimental data) can be used to model these blocks.
- Above models are simulated and Controller is tuned and optimized for best performance in terms of overshoot, rise time, settling error and stability.
- Additional logic e.g. safety logic can be included for protection against over current / voltage.
- Controller architecture algorithm should be selectable / programmable.

- This PID controller is to be implemented in Micro-controller/FPGA. To achieve this translation from the system level model to HDL or C language is required. This can be achieved using C Code or HDL coder toolboxes or similar tools/ methods.
- Generated HDL/C Code are simulated and compared against the results from system level model.
- Final validation is done by doing Hardware in loop tests with the actual FPGA/Micro-controller.

6.4.3. ASIC: Design, Simulation, Fabrication and Modelling

The scope the activity covers Analog, Digital and Mixed signal ASIC design, simulation, verification, layout, tape-out and fabrication. The main motivation is miniaturization and indigenization of electronics in the form of low power ASICs and Readout Integrated Circuits (ROICs) with objective of integrating multiple functionality in a single device. The ultimate goal is to integrate individual blocks to realize System on Chip (SOC). Some of the ASICs, but not limited to, are multi-channel Analog Front end device for detector signal processing, High data rate Serializer-deserializer, High precision low noise multi-output voltage reference, programmable bias generator and regulators (negative and positive), Bipolar high speed high capacitive CCD clock drivers, IR detector ROICs, multi-channel temperature controller, switches etc. Design and development of radiation hardened library covering standard cells and devices is also covered under the scope. ASIC modelling either software or based on implementation in FPGA/microcontroller of various ASICs to be part of various system level simulations and optimizations is also envisaged.

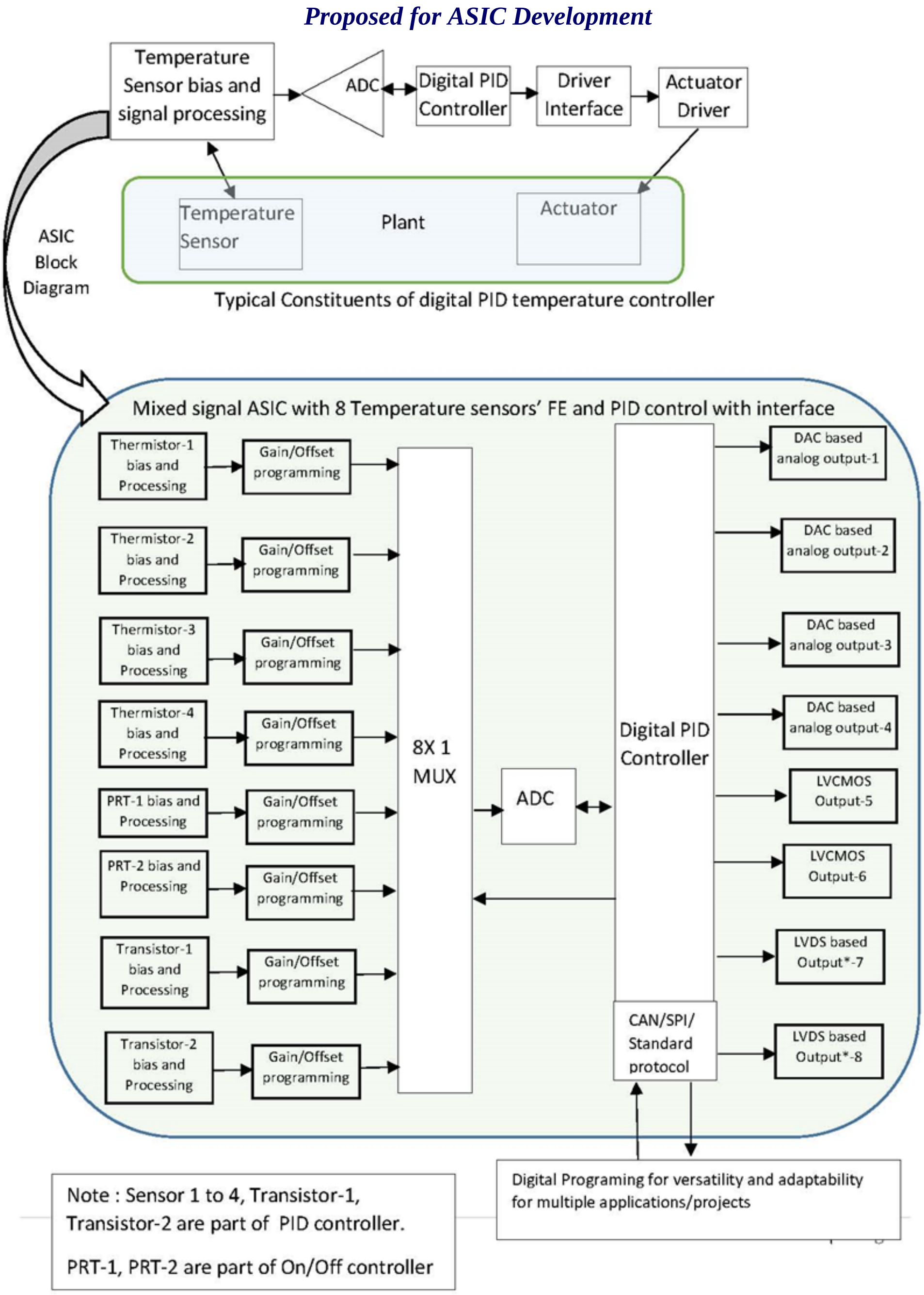
6.4.4. Modelling of Special Components, Interfaces, Hardware

Modelling of various state of the art mixed signal devices, detectors, interfaces etc is envisaged. Font-End design (detector proximity electronics) of an electro-optical payload faces lot of constraints w.r.t system requirements, detector used, real estate availability, harness routing, mechanical design, optical ray diagram, thermal requirements, grounding scheme, hardware in the vicinity etc. Also almost all electro-optical payloads are unique for each mission w.r.t above constraints and it becomes impractical and non-optimal to use a common standardized design for front end electronics. Hence development of various models of components, detectors, interfaces taking into account mechanical constraints, layout, routing, signal integrity, thermal issues, pcb size, circuit topology, grounding scheme, hardware in the vicinity etc needs to be developed. The development of this kind of integrated model will help in better understanding of the system performance at early stage and faster realization of the hardware.

6.4.5. Generic Multi-Channel Front-End and Digital Proportional-Integral-Derivative (PID) Controller with actuator interface ASIC for Temperature Control

Electro-optical payload cameras have many elements like detector, calibration source and optical elements etc. which need stabilized temperature for proper functioning. Range of temperature depends on system engineering, physics involved in device working and overall mission performance specification. Passive cooling is popular and simpler method for temperature control. Cooled object (achieved through deep space radiative coupling) is heated using close loop system to maintain defined temperature. In this scheme, Thermistor or Platinum Resistance Thermometer (PRT) are used as temperature sensor. Foil heater of required capacity are used as actuator. Control is either based on On/Off method or PID method. Other type of temperature control uses active cooling where very low temperature (<200K, cryo-temperature) is to be achieved. This approach uses transistor Vbe to sense cryo-temperature. Linear or Brushless Direct Current (BLDC) motor is used to achieve cooling. Actuator drive signal is 50Hz AC sine wave or Two/Three phase pulses.

In general, any digital domain based temperature controller has (a) Temperature Sensor (b) Signal conditioner (c) Digitizer (d) PID or On/Off control logic (e) Interface control signals for actuator driver (f) Driver for actuator excitation. ASIC proposed for blocks (b), (c), (d) and (e) is multi-channel (typically eight) independent temperature signal conditioning channel ASIC, with versatile and generic design, planned to support multiple application of temperature control. Offset and gain control in signal conditioner blocks is required to allow temperature control using PRT and Thermistors. 3 PRT, 3 Thermistor and 2 Transistor based channels are planned. Digital interface (Low Voltage Complementary Metal Oxide Semiconductor (LVCMOS)/ Low-Voltage Differ-ential Signaling (LVDS)) is planned for actuator driver control. 2 On/Off actuators control, 4 PID actuator control and 2 motor actuator control are planned. Digital PID controller should be programmable using CAN or any other interface for adaptability to multiple applications.



6.4.6. ASIC development of Generic N-channel MOSFET drivers and PWM generator with integrated Current and Hall Effect sensing mechanism and sigma delta ADC

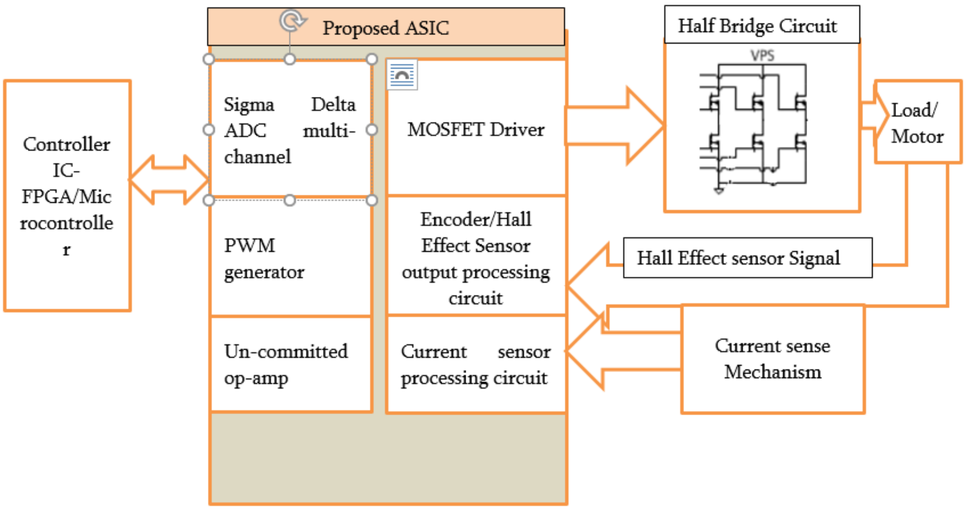
The main objective of development of this ASIC is complete indigenization of space grade motor drive electronics. Generic design of Metal-Oxide Semiconductor Field Effect Transistor (MOSFET) driver is aimed for half bridge control. The ASIC envisaged also has integrated current sense amplifier, hall effect sensing, Pulse-width modulation (PWM) generator and ADC. N-channel MOSFET drivers are mainly used in N-channel Metal-Oxide Semiconductor (NMOS) based drive circuits of stepper motors, BLDC motors, Cryo-coolers etc. A MOSFET driver is a type of power amplifier that accepts PWM signals and produces a high current (>1A) / high voltage (>10V) drive input for the gate of a high-power transistor (such as power MOSFET) with fast switching frequencies (>100KHz) and dead time (~500ns).

Current sensor amplifies a small differential input voltage developed by the current flowing in a sense resistor at the load side. The processing circuit processes the electrical signal generated by Hall Effect sensor or resolver output. Modern Sigma-delta converters offer high resolution, high integration, low power consumption, and low cost, making them a good ADC choice. Multi-channel delta sigma ADC is required for processing control parameters e.g. Load current, voltage etc. The Independent PWM Generator (switching frequency > 100KHz) block is required to generate pulses for carrier-based pulse width modulation converters. The block can be used to fire the MOSFETs of single-phase, two-phase, three-phase bridges. PWM resolution of >10 bit is preferred. PWM generator shall provide internal or external reference input for modulation and shall have a bypass option for providing input from external FPGA/uC. An uncommitted (low bandwidth, precision) op-amp is required, so they can be tuned based on the application. The gain resistor of op-amps should be external to allow the buffer and filtering of required signals. Typical specifications and block diagram of the ASIC is as below.

Typical Specifications:

- 4 High and 4 Low side outputs
- >1A drive per output
- High side voltage/bootstrap voltage > 50V
- Programmable dead time up-to 500ns
- 3 Current sensors
- 4/8 channel sigma delta ADC, >12 bits, >100ksps
- 6 bi-level inputs for Hall sensors
- Resolver interface (optional)
- Optional Buffered PWM inputs (3.3V or 5V)
- In-built PWM Generator with bypass option
- PWM resolution: better than 10 bits
- PWM frequency > 100KHz
- Duty cycle range: 5% to 95%
- Un-committed Op-amp (BW- 1MHz, typical)
- Serial programming

Block Diagram:



6.4.7. Reconfigurable System-On-Chip based solution for satellite on-board computing

High speed computing has always played an important role in on-board data processing and control. On-board computing has been represented mainly by the on-board computer (OBC), which is the kernel of the On-Board Data Handling (OBDH) system that is central to the overall satellite design and its operations. The OBDH system is an integral part of the satellite platform and in many missions extends to comprise various elements of payload electronics. In future missions, there is need for advance technologies that can be achieved via miniaturized multi- System-on-Chip (SoC) processor designs.

Now a day, the increasing requirements of on-board reconfiguration and on the fly programming capability, system-on-a-programmable-chip (SoPC) designs has emerged as a major enabling technology. It is envisaged that the application of the SoPC concept to on-board computing will result in radical improvements and unleash new capabilities. In addition to the benefits of SoC design, such as reduction of size, complexity and cost, it can provide the means to build flexible and modifiable on-board computing systems. The SoC platform can be configured to meet different mission requirements.

The SoC on-board computer (SoC-OBC) consists of mainly soft IP cores, programmable gate arrays including the LEON/ Advanced RISC Machine (ARM) processor and multiple peripheral devices. A purpose-built Direct Memory Access (DMA) controller handles the data transfers between the peripheral cores and the main memory. The AMBA AHB and AXi buses is for interfacing of high-performance system modules. The Advanced Microcontroller Bus Architecture (AMBA) Aadhaar Payment Bridge (APB) bus supports peripheral functions with minimal power consumption and reduced interface complexity. The CAN, High-level Data Link Control (HDLC), SpaceWire and space fibre network interface controllers and the EDAC block are typical components and interfaces for use in space.

Designing On-board Computer consisting of programmable system on chip hardware is really challenging and this will provide the common miniaturized hardware platform for multiple missions along with providing seamless solutions and flexibility of programming, controller, data processing and standard interfaces.

Scope of Research:

- Design and development of On-board computer hardware encompassing mainly Programmable System on chip(PSOC), Rad hard FPGA, high end memories and all standard interface CAN/Spacefibre/Serdes/LVDS interfaces along with SI and PI analysis with industry collaboration.
- Soft cores IP design for standard interfaces and Logic
- Standard Memory DDR2/3, ONFI controller designs.
- External peripheral interfaces design &development.
- Embedded processsor/LEON/ARM processor interface with FPGA.
- Onboard partial n selective configuration.
- Space fibre codec n network design and development.

6.4.8. Real time image processing in on-board Space systems

Target detection and tracking has gained significant importance in many applications, including optical communication, inter-satellite communication, motion detection, reconnaissance and surveillance in which the major is to reveal trajectories of the targets. Considering the recent developments, many electro-optical systems are in need of full automation for achieving this task. Therefore, many multi-tracking algorithms include two fundamental stages as the automatic, time independent detection of tar-gets; and association of the detections in the temporal space. Problems remains to be challenging mainly due to unknown and changing number of targets; noisy and missing observations; interaction of multiple targets. Moreover, all these challenges are needed to be solved in a time efficient manner for real-time applications in space systems.

Scope of Research:

- Study and implementation of object detection algorithm for low SNR targets and its real time implementation in on-board FPGA hardware
- Tracking algorithm development: Kalman for tracking and trajectory prediction.
- Study/development of Optical Flow algorithm for planetary landing.
- DSP based real /near real time data processing for signal analysis and image processing.
- Real Time decision making for Landing System.
- Machine learning techniques along with computer vision techniques need to be studied and implemented for the targets required for obstacle detection, landing site and surveillance.
- Real Time Operating System (RTOS) optimisation for on board I

6.4.9. Power supply systems for Space missions

Payloads for Remote sensing and planetary exploration missions require state of art Power Supply electronics to cater to various requirements of Camera Electronics sub systems. These Power Supply Electronics requires to meet several stringent requirements such as multi-output voltage lines in range 3.8V to 24V, very low noise (□20mV), high efficiency (>70%), EMI 461E complaint, inbuilt input power protection and output short circuit protection.

The following technologies are of particular interest in future Power Supply electronics development

- Very Low noise (□5mV), Low power (<10W), highly efficient (>80%) complying with EMI 461E standard, space grade isolated power supply /module.
- Multi-output (3 to 4 voltage lines in range 3.8V to 24V), high efficiency (>80%), Medium Power (25W - 100W), Low noise (□15mV) complying with EMI 461E standard isolated space grade power supply
- Development of Hybrid Micro Circuit (HMC) based miniaturised dual output (+3.8V and +5.6 V) DC-DC converters with high efficiency (>75%), medium power (> 30 W), inbuilt EMI filter and having EMI/EMC compliance to MIL-STD-461E.
- Development of housekeeping and protection circuitry in the form of HMC to monitor and protect power supply electronics from various fault conditions such as Overvoltage and under-voltage protection, Over temperature protection, Overcurrent protection and Output Short circuit protection
- Development of Rad-hard non-isolated synchronous buck converters for wide input voltage (10-30VDC), adjustable output voltage (from 3V to 80% of Vin) and high output current (>10A).

6.4.10. Optical data transmission system for Nano/micro payloads

High resolution wide swath imaging typically requires payloads and satellites of large dimensions & weight. Huge amount of data requires to be transmitted to ground requiring multiple transmitters further increasing the mass and size. Cost of such satellites is too high. Development time is large and penalty associated with any component under performing/ malfunctioning is large. Alternative approach is to develop a constellation of Nano satellites to cater to above requirements. However traditional Nano satellites suffer from low data transmission capability and poor pointing accuracy. To overcome this problem it is proposed to develop a Nano satellite utilizing optical data transmission. However incorporating a traditional Optical Communication Terminal (OCT) is not feasible in the mass and power constraints of a Nano platform. It is therefore proposed to develop & demonstrate a miniaturized Optical data transmission system to enhance the capabilities of ISRO's small satellites.

6.4.11. Single Board Controller based Payload & Mainframe Electronics for High Resolution Nano Satellites

Traditional ISRO Nano satellites (~10Kg) are capable of providing ~20m resolution from LEO orbits. However higher resolution & lower mass is desirable for future Nano missions. A Nano Satellites consists of following subsystems:

- Payload sub-systems (Sensor, Electronics, Optics, Mechanical)
- Mainframe subsystems (Attitude Control system ,OBC, RF system)
- Electrical Harness
- Mechanical Frame/Housing for Payload and Mainframe
- DC-DC for payload
- DC-DC for Mainframe

Present approach has dedicated electronics for various functions of the payload and satellite mainframe e.g.

- Sensor Bias, Sensor Control, Sensor data processing, Compression , Data Formatting, Data Transmission is managed via 2-3 Boards.
- Payload DC-DC Electronics Board
- Satellite mainframe OBC Board, ADCS Board, RF Board.
- Mainframe DC-DC Electronics Board

For reducing the overall satellite mass (<5kg) while improving payload performance (resolution, swath, SNR), miniaturization & integration of various Electronics is proposed. A Single Board High Performance Controller along with a bus structure shall be developed carrying out functions of Sensor Bias, Sensor Control, Sensor data processing, Compression, Data Formatting, Satellite mainframe OBC, ADCS, RF Data Transmission.

6.4.12. Space qualified flexible EMI Shielding and Radiation resistant coatings and enclosures for Onboard Electronics

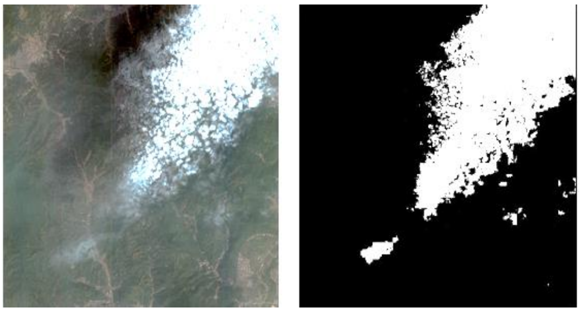
High speed electronics systems, miniaturization of PCBs, Electronics packages, small payloads and other such advanced capabilities, electronic sub systems requires highly populated PCBs / Packages / harnesses to support their functionality and performance requirements. Such compact/dense packaging causes EMI effects. Traditional metal EMI shields take too much space thereby reducing the overall competitive functionality of electronic devices and increases the size as well. Therefore, more recently, the research focus is on flexible coatings and enclosures developed from nanocomposites. Therefore, we feel the requirement of the development of MIL-STD-461E compliant flexible EMI shielding and radiation tolerant enclosure, which can be easily applied and adapted onto a PCB design and very sensitive signal lines. The required composites should suite the needs of ISRO especially like space-qualified material, high thermal stability, flame retardant and durable for mission life of more than 10 years. These composites can be explored for designing materials that can shield radiation and protect PCBs and harnesses without much overheads. The qualification of these composites, but not limited to, should include Thickness measurement test, thermal shock test, thermos vacuum test, humidity test, coating peel test, outgassing test etc. The design of enclosures should be in a way that they don't need to be electrically grounded to the PCB, thus simplifying or eliminating masking. This should also be able to address EMI issues on the PCB, in between tightly packed semiconductor devices and can be tuned to absorb EMI at specific required frequencies. The design must also take care that they could be applied at the end of a product design cycle. These enclosures should not affect the electrical performances and sub system functionality at ground and at onboard. The shielding performance also need to be brought out for frequency range up to 1GHz with respect to the material thickness.

6.4.13. Gigabit Interfaces for Spacecraft data flow

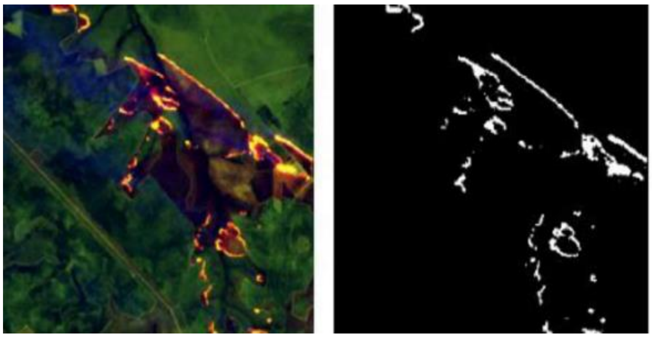
Next generation payloads will have a suite of cameras and measurement systems. The capability to cater to more than 50 million pixels aggregate for processing, formatting, storage and distribution prior to near real time compressed data transmission calls for Gigabit interfaces to handle Terabyte data volumes. This has to be handled by three major methods, (a) Gigabit physical data interfaces between FPGA, memory, data serializer and lane drivers, (b) high end FPGAs to meet throughput and capability, (c) design of high bandwidth PCB traces and characterization of transmission cables, (4) reliable data interface protocol. New components have been identified to provide low jitter clocks, GTY interface for > 1Gbps data interface and matched connectors to meet SI. New in-house protocols based on SpaceFibre which is compliant to ECSS-E-ST-50-11C for high speed serial data transfer between subsystems is being developed. This complex firmware will offer virtual channel buffer controller and flow control, integrated Quality of Service (QOS) based on priority, bandwidth reservation and scheduling for each channel, optional data scrambling, Control word generation and framing of the data packets, broadcast messages and Flow Control Token(FCTs), Generation and acquisition of broadcast messages, interleaving data, broadcast, Idle frames and FCTs based on precedence to generate a data stream along with Fault Detection Isolation and Recovery(FDIR) logic. This will push the serial link speed to greater than 6.25 Gbps.

6.4.14. Smart and efficient payloads with AI/ML

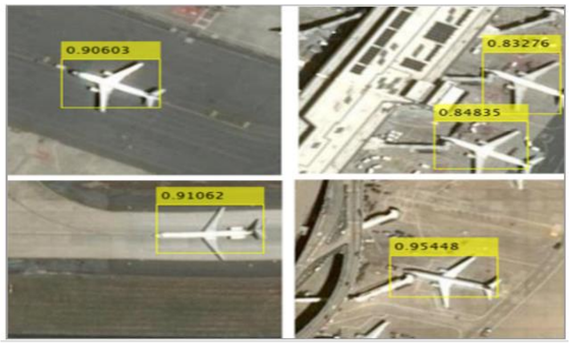
The traditional method in remote sensing is to transmit all the pixels to ground for offline post image processing. This consumes satellite resources in terms of bandwidth, complexity size and weight. A more efficient way is to define imaging areas in real time on-board and transmit useful data as demanded by users. This can be could-free imaging zones, class segmented objects like fire zones, or contextual binary data like quantitative presence or absence of user defined features. Artificial learning algorithms (AI) using Deep Neural Networks are used to train a suite of models for various features, multi-classification and contextual data with coordinates. These models, when implemented in FPGA based SoC enable control of on-board imaging, reduce bandwidth by data volume reduction and significantly aid the user by faster turnaround time. This research work envisages development of vast database, training, development intelligent framework and work-flow for FPGA porting, elaborate lab testing of real camera with real/ synthetic images. Outcomes of some AI enabled hardware framework is shown in figure below.



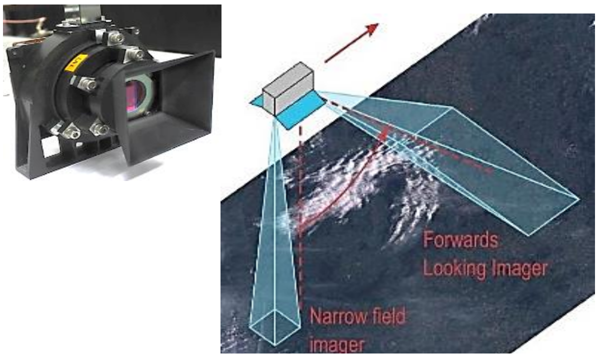
Cloud Detection



Fire detection



Object detection



Forward Looking imager for cloud detection, size: ~ 90 mm x 90 mm x 60 mm

6.4.15. Neuromorphic computing-Low complexity Artificial Intelligence

Present CNN network architectures are computationally intensive and consume high power compared to human brain. The human brain works on change detection and ends spikes of information. The Neuromorphic computing mimics the human brain more closely and is based on spiking neural network (SNN). This reduces the computational and power requirements significantly. Our goal is to deploy this SNN model inside FPGA and develop end to end system for feature detection, tracking application, etc. An intelligent flow based on Brainchip Akida is being developed. These involve training, quantizing, fine-tuning with Quantization Aware Training (QAT), and converting a model into a hardware-optimized format and performance evaluation to finally infer from images.

6.5. EO sensor System AIT and Performance Characterization

6.5.1. Design and development of smart test setups

Test setups help in simulating spacecraft mainframe interfaces, control and command of the sensor, and data acquisition for performance evaluation. Currently, test setups are custom developed for each EO sensor considering its interface, functional and operational requirements. However, in view of the upcoming demand for variety of EO sensors, there is a potential scope of research and development for smart test setups for EO sensor testing. The smart setups are easily reconfigurable to cater to variety of sensors, they have fault tolerant designs, and are self-calibrating to enable faster turnaround time and ensure precision measurements of EO sensor performance parameters.

6.5.2. EMI analysis and mitigation techniques

During AIT, various electronics subsystems, test setups and associated harness assemblies exhibit complex interplay and results in a complex EMI environment. This causes various random and fixed pattern noises in the EO sensor data, which can significantly impact radiometric quality of the imaging sensor. Hence, it is very important to identify the potential noise sources and develop suitable mitigation techniques. This offers a research opportunity for design and development of EMI analysis tool, which accounts for various noise sources in the sensor chain including electronics component level noise, crosstalk, signal coupling effects, ground noise coupling, engineering noise coupling, etc. and helps to analyse complex EMI scenario, identify the noise sources and help in developing suitable mitigation techniques. Available COTS software modules can be suitably used in the proposed analysis tool.

6.5.3. Development of new methods for EO sensor performance evaluation

SNR and MTF are two key performance parameters that are used as performance markers for comparative studies. Many methods exist for performance evaluation in terms of MTF and SNR, however, considering the stringent requirements of EO sensor performance in upcoming future missions, many new methods are required to be developed. This offers significant research opportunity in this field. We need to develop efficient, simple and robust methods for SNR and MTF measurements. Also, study shall identify new performance markers and develop suitable methods for its implementations.

6.5.4. Thermal analysis model of harness assemblies

Thermal analysis of EO sensors and spacecraft systems are carried out to evolve suitable thermal design and implementation approaches. Generally, thermal analysis of all electronics subsystems are carried out to evolve suitable thermal implementation scheme. However, thermal modelling and analysis of harness assemblies are generally ignored, although they are passive dissipating element in every spacecraft system. Thermal modelling of harness assemblies is very critical as it helps derive rerating specifications, avoid potential arching conditions, helps in improving performance of thermal control system.

6.5.5. Design and development of machine/deep learning methods for payload test data analysis

Large amount of data is acquired during ground testing of EO sensors. These data sets help in analysing EO sensor performance under various operating and environmental conditions. However, analysing huge data sets to bring out minute but potential performance degradations is very difficult with traditional approaches. There is an opportunity to develop machine learning techniques to analyse large amount of data acquired for various EO sensors.

6.5.6. Machine Learning Techniques for Fault Diagnosis using TM data

Complex EO sensors employ large number of interconnected subsystems to perform imaging task. The performance of all subsystems are monitored through the large number of telemetry (TM) channels such as voltage, current, temperature, timing information, configuration details etc. TM data is acquired during ground testing and also during in-orbit phases resulting in huge amount of TM data. These TM parameters allow designers to monitor the health of the sensor. Machine learning techniques can be developed to analyse the large amount of TM data to observe even subtle performance deviations that can help in diagnosing the faults in the operations of EO sensors.

6.5.7. Development of harness embedded panels for plug and play AIT

Interconnection harness constitute an integral and important part of the EO sensor and satellite system. Various electro-mechanical constraints in implementing the harness interconnection calls for significant efforts in the design and development of EO sensors. Literature survey shows innovative concept of harness embedded panels, which significantly helps in saving precious volume on resource constrained satellite systems. We envisage to develop such harness embedded panels for Indian remote sensing sensors. In this arrangement harness is run within the panel thickness and connectors are available on top and bottom surface of the panel as end points for package interconnection. The proposed research work involves exploring innovative design of harness embedded panels, structural analysis, usage of smart materials and proto-type development, etc.

6.5.8. Development of efficient algorithm for image reconstruction for compressive imaging sensor

Compressive imaging (Optical domain compression) is an emerging field that allows design and development of single pixel camera systems for imaging. Significant efforts have been reported in the literature for development of single pixel camera systems as an alternative to current commercial cameras. However, not much study has been carried out in exploring the feasibility of developing a spaceborne imaging system architecture based on optical domain compression. Currently, we are working on a single pixel camera architecture for spaceborne applications. The research opportunities exist in development of efficient algorithm for image reconstruction using the images acquired by a compressive imaging sensor and carry out extensive bench marking against available methods.

6.5.9. Development of robust image quality metric and suitable methods for its estimation using in-orbit images

In-orbit image quality evaluation of EO sensors is a continuous evolving research field. This research work envisages development of a robust image quality metrics and suitable methods for its estimation from in-orbit images.

6.5.10. Development of methods for accurate estimation of SNR and MTF from in-orbit images

EO sensors undergo extensive ground testing during development phase. However, post launch performance deviations are generally observed due to various instrument effects due to launch loads and orbital environmental conditions. On-board and vicarious calibration methods are employed to assess the in-orbit SNR and MTF performance of EO sensors. However, the achieved accuracies in deriving performance parameters always suffer from limitations either from measurements or the methods itself. The proposed research work will first study the available methods and suggest new approaches for accurate estimation of these performance parameters.

6.5.11. Development of techniques for quantitative estimation of MTF contributions from various elements in the EO imaging sensor chain

In-orbit images generally suffer from MTF degradations due to instrument behaviour in the orbital conditions, platform vibrations and jitter, and atmospheric conditions. Extensive characterization is carried out in laboratory using standard targets and also in-orbit using stellar and various calibration targets. It is important to quantitatively ascertain MTF contribution from each elements of the imaging instrument to understand anomalous behaviour (if any) of one or more elements using the laboratory data and in-orbit images. This research work envisages development of methods/techniques to quantitatively measure/derive MTF contribution from each element in the EO sensor chain. Also, extensive validation studies to be performed using available EO sensor data.

6.5.12. Design, development and characterization of Spacefiber interface-based data transmission board

Spacefiber interface is an emerging technology for transferring huge amount of data running up to 40 Gbps and can have multiple channels for increasing the data Tx rates. The interface protocol is based on Spacewire. The Spacefiber protocol has wires or fibres as physical layer for data transmission. This research work envisages comprehensive study of Spacefiber interface, design and development of a bread-board functional model and extensive characterization of the developed data transmission board.

6.6. Ground Checkout Systems for EO Payload Testing

6.6.1. Computer based Multichannel High Speed Digital Data Acquisition System

High Resolution EO cameras generate high speed data (of the order few Gbps). Evaluation of these cameras during various phases of testing, calls for design & development of High Speed Digital Data Acquisition System. Data Acquisition System receives incoming digital data from payload and transfers it to the computer. Data Acquisition System comprises of Data Formatter, Data Acquisition Modules installed in the computer and Data Acquisition Application. Data Formatter receives the digital data from payload over multiple chains with required electrical interface (LVDS, serializer/deserializer (SERDES)), formats it and transfers packed data to Data Acquisition Modules. Acquisition application acquires data from Data Acquisition Modules.

Out of different options for transferring the high speed data to computer, Camera link interface based transfer is one suitable option. Camera link interface supports high data transmission rates (2.04 Gbps for BASE mode, 5.44 Gbps for FULL mode & even higher for extended FULL mode configuration) & can be used to transfer very high speed data from Data Formatter to computer. Camera link's transmission method requires fewer conductors to transfer data. Hence it reduces the hardware components, interconnecting cables and simplify the Data Acquisition System configuration.

Design & development of High Speed Data Acquisition System which involves Data formatter (Data Input - Multi channel, SerDes interface) along with the Data Acquisition Application can be taken up for data transfer rate upto 4.0 Gbps using camera link i/f in-house which will be very useful during the testing of High Resolution EO cameras.

6.6.2. Comprehensive Automation of Test Benches

Automation of Spectral Response Measurement (SRM) test bench using a Bentham mono-chromator has been very successful and because of the same, the spectral characterization for all payloads works smoothly and effortlessly.

Complexity of the payloads have increased which demands more and more testing and that too repeatedly in different conditions. The 1553 bus based TC and TM systems simplify the tasks and have been implemented and are successfully working. Integrated testing becomes a laborious process when carried out by the test engineers and has chances of errors.

A scheme is proposed which has a generic architecture to combine instrumentation, data acquisition, parametric evaluation and a final output generation. The 1553 bus based instrumentation provides both the TC and TM functions. Tele-commands issued can be verified thru the telemetry for the confirmation. Synchronized data acquisition request can be made, followed by data processing to compute a set of parameters. This process is repeated for all modes of operations of the payload under a given test condition. At the end of execution of all operations, post-processing can be carried out over the data-set. Such instructions can be combined as a macro and executed as and when required.

For Microsat-2A (LWIR and MIR) payload calibration, there was a requirement to acquire and record the data of all seven exposures for different temperature settings ranging from 180K to 340K. To cater to this requirement, automation feature was developed for payload commanding to change the exposure, acquire and record the data and generate the results simultaneously. With the automation, the task could be completed with about a factor of three improvements in timings as compared to manual task.

This shall be an in-house development with the participation of focal persons from integration team, software and instrumentation developer for one test case project.

6.6.3. Knowledgebase Creation and Information Extraction

A huge database of information is available for all E/O payloads developed so far by SEDA. This information contains automatically archived test results, TM data, raw data, logs and manually uploaded documents. The information is structured at sub-system level and project level under categories such as Results, Issues, Discussions and Solutions. This will provide contents for to create a knowledge base for future generation projects. An interface on top of this, using Natural Language Processing (NLP) techniques can be developed. This interface shall accept the queries in human-understandable natural language and provide answers by processing the information.

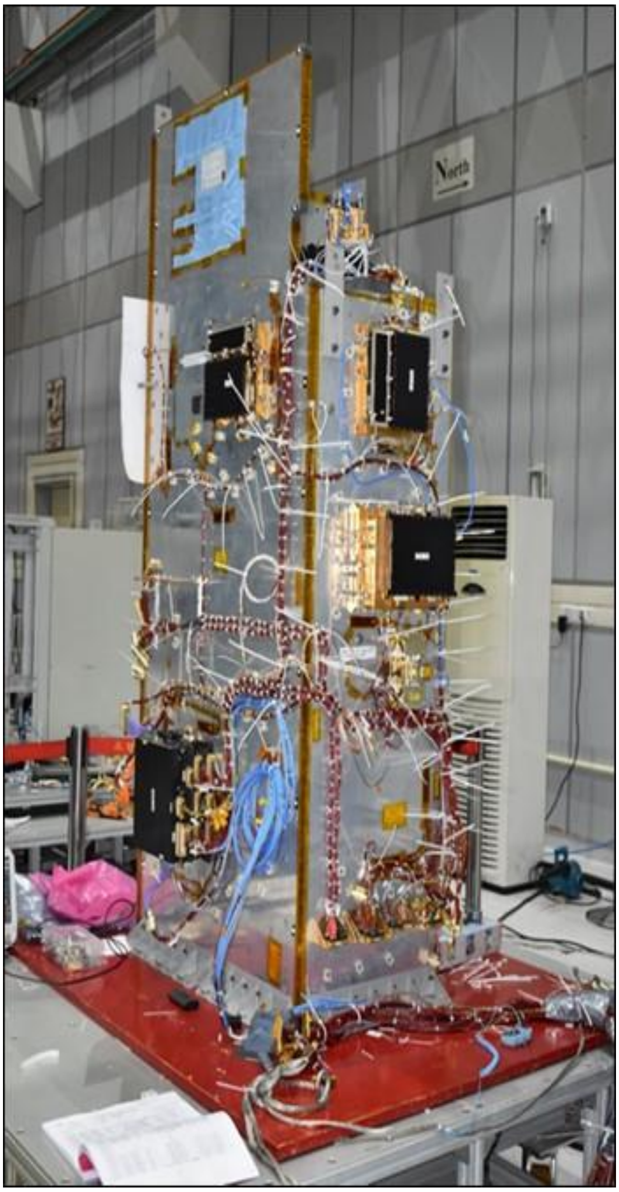
Academia has subjects related to Information Retrieval, Data Mining and alike under broad topic of Artificial Intelligence. Students from academia can be involved in the projects.

6.6.4. Development of learning algorithm for fault identification and recovery of EO payload by analyzing the video data, telemetry and commanding sequences

Electro Optical camera/payload consists of multiple subsystems i.e. Detector, Optics, Camera electronics and mechanical subsystems. To meet the performance specifications, it is required that all these subsystems operate to their best potential. During the course of integration and calibration of subsystems, lot of payload calibration data and payload telemetry is generated in response to the commanding sequences given to the payload. During this phase of payload integration, problems are observed which can be due to multiple reasons like faulty commanding sequence, improper cabling or faulty behavior of any subsystem. To diagnose these problems at the earliest, a learning algorithm needs to be developed which can continuously analyze the video data, telemetry and commanding sequences given to the payload and build a model of the payload over time. This algorithm will not only help during the payload integration phase but also during satellite integration and in-orbit operations of payload.

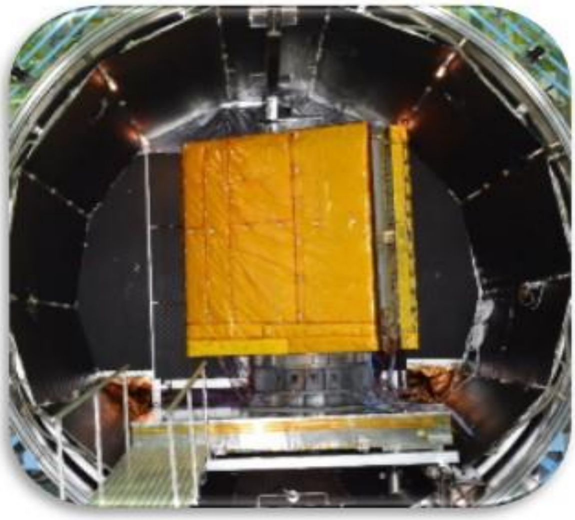
7. MICROWAVE REMOTE SENSORS

Microwave Remote Sensing Area (MRSA) of Space Application Center (SAC) is responsible for designing, developing and operationalizing microwave payloads used for earth observation, environmental monitoring, planetary missions and disaster management. MRSA involvement in microwave remote sensing dates to 1980s, when it initiated research on passive microwave radiometry for meteorological applications. From early studies in radiometry to the advancement of sophisticated synthetic aperture radars (SAR), scatterometers, velocity meters, altimeters, and sounders spanning frequencies from the UHF band to terahertz, it has played a crucial role in enhancing India's capabilities in earth observation, weather forecasting, and disaster management.

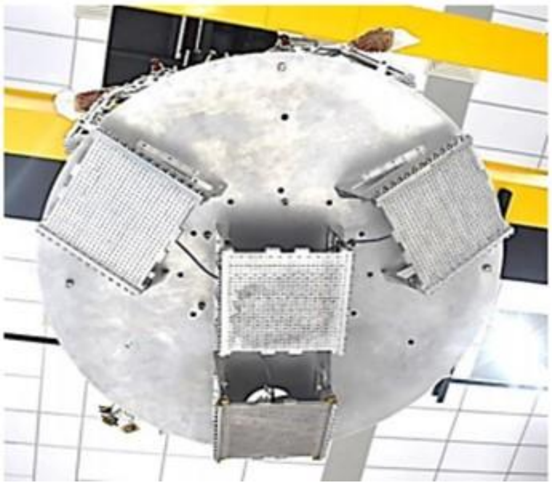


Integrated OS-3A Scatterometer Payload

6m x 2m Active Antenna for RISAT-1B

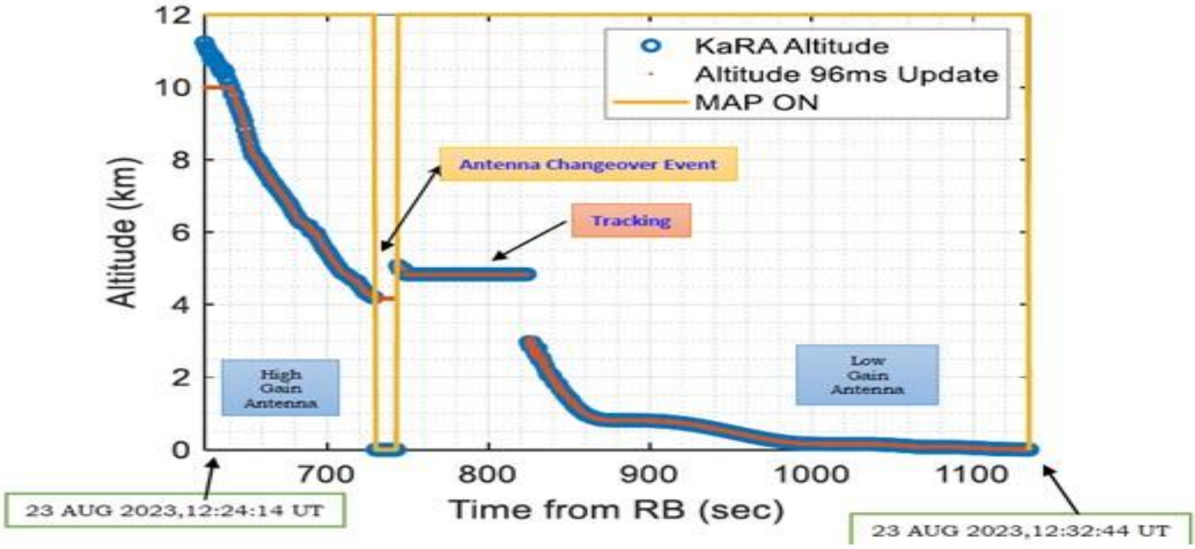


RISAT-1B Payload inside TVAC chamber



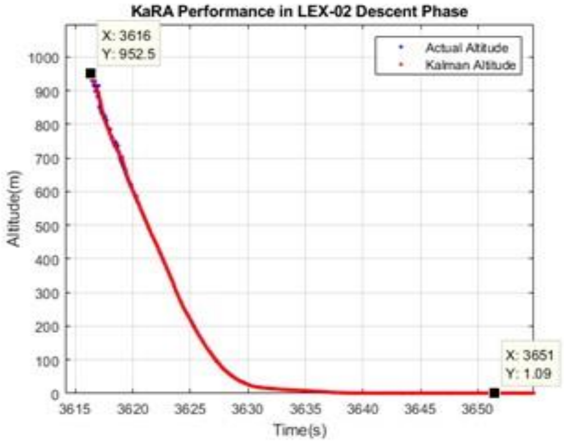

Radar Navigation Sensor (RNS)

In recent years, various advanced microwave payloads have been successfully developed to meet diverse user requirements. These include RISAT series satellites, an L & S-band polarimetric SAR, and a Ka-band radar (KaRa) altimeter designed for both the orbiter and lander of Chandrayaan-3. Additionally, an airborne dual-band L- & S-band SAR was developed for the ISRO-NASA joint air campaign (NISAR), along with SCATSAT-1 for global ocean wind vector measurements. The RISAT series satellites set a benchmark in radar imaging with the successful deployment of indigenous technologies, including ferrite switches, a Radial Rib Antenna system, high-power GaN-based pulsed switches, a Butler matrix, and high-speed digital acquisition processors. The Ka-band altimeter from Chandrayaan-2 has proven to be a technological breakthrough, leading to its adoption in Reusable Launch Vehicles (RLV), Gaganyaan mission, and the successful Chandrayaan-3 landing system.



Ka-RA performance during Chandryaan-3 landing

RLV LEX-02 Test with KaRa Altimeter



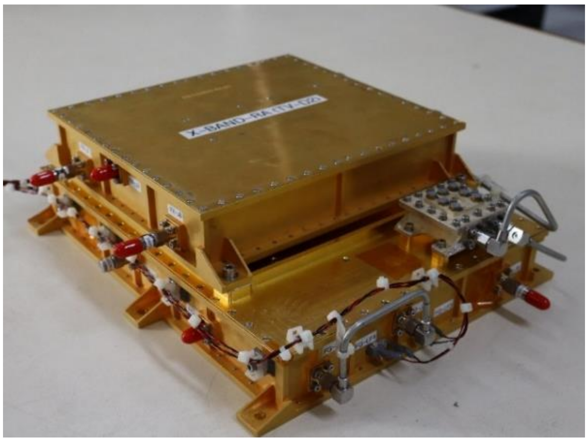
RA performance in LEX-02 test

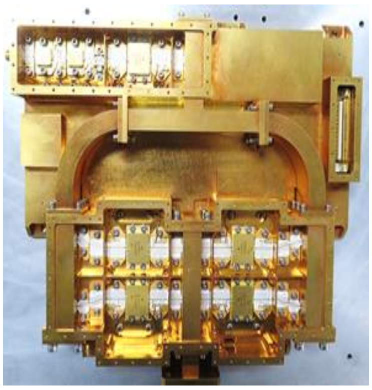
NASA-ISRO SAR (NISAR) is a Low Earth Orbit (LEO) observatory being jointly developed by NASA and ISRO. NISAR will map the entire globe in 12 days and provide spatially and temporally consistent data for understanding changes in Earth's ecosystems, ice mass, vegetation biomass, sea level rise, ground water and natural hazards including earthquakes, tsunamis, volcanoes and landslides. NISAR. This would be the first dual frequency radar imaging mission in L-band & S-Band using advanced Sweep SAR technique to provide L& S bnad space-borne SAR data with high repeat cycle, high resolution, and large swath, with capability of full-polar metric and interferometric modes of operation. This flagship partnership has major contributions from both agencies. NASA is responsible for providing the L-Band SAR payload system in which the ISRO supplied S-Band SAR payload and both these SAR systems use of a large size (about 12m diameter) common unfurl able reflector antenna.

Integrated NISAR Payload

Continuing advancements in microwave sensing, ISRO is now working on, Chandrayaan-4, LUPEX, Hy-MATHS for G20 satellite mission, Ground Penetrating RADAR (GPR) for VENUS, Lunar, Mars Landing Mission (MLM) and Venus Advanced Radar for Topside Ionospheric and Subsurface Sounding mission

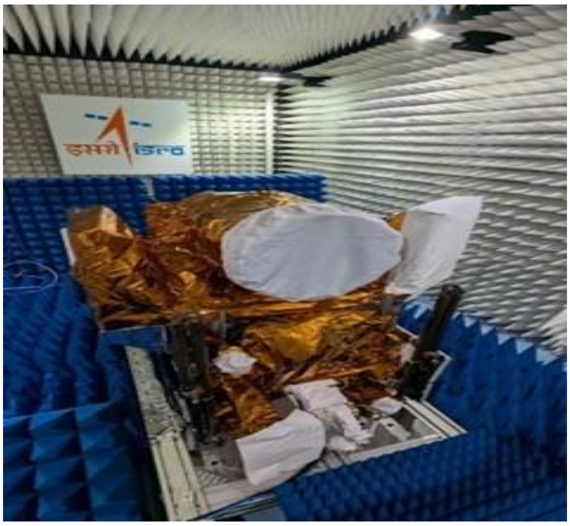
(VARTISS) etc., these developments reaffirm ISRO's leadership in cutting-edge microwave sensor technology for Earth observation and space exploration.

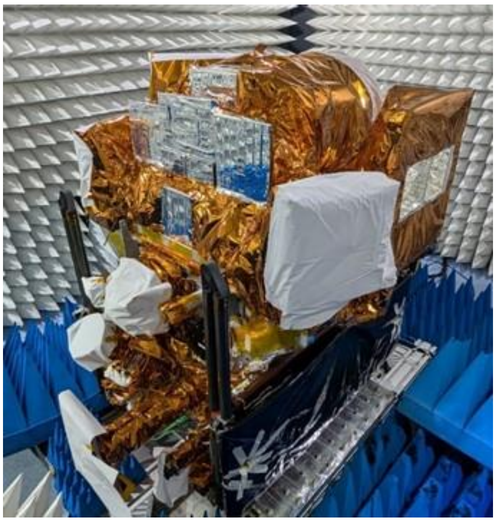




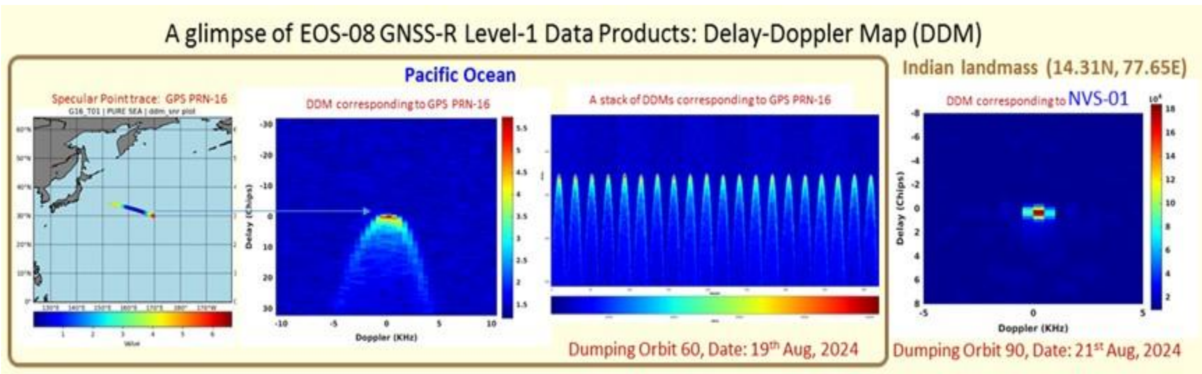
Integrated RF System Frequency Generator, Novel Spatial Combiner Receiver and Cavity Filter 350 X-Band SSPA

GNSS-Reflectometry (GNSS-R) instrument is one of the prime payloads of EOS-08. GNSS- Reflectometry paves a new mode of remote sensing which uses Global (& Regional) Navigation Satellite Systems (GNSS/RNSS) like GPS and NavIC constellations.





GNSS Reflectometry Payload Integrated with Spacecraft



Hyperspectral Millimeter-wave Atmospheric Temperature & Humidity Sounder (HyMATHS) payload is an Atmospheric Sounding payload, to be flown on G20 satellite along with other Earth Observation co-passenger payloads to enable space-based observations that affect environment and climate change. It's first-of-its-kind instrument from space-born platform for the observation, modelling and prediction of extreme weather events, climate-change monitoring. Proposed hyperspectral microwave sounder would provide a unique solution to global climate change studies by combining the benefits of cloud penetration, high vertical resolution and retrieval accuracy. Retrievals of temperature and moisture soundings are expected to be improved by as much as 50% by employing hyperspectral measurements that will be important to achieve the climate quality of the atmospheric profiles. This will greatly help the operational forecasting agencies by assimilating these hyperspectral microwave sounding observations into the NWP models to improve the weather prediction.

To enhance self-reliance and promote "Make in India" initiative, the MRSA is actively engaged in the indigenous development of advanced technologies. Efforts in this direction include the development of System-on-Chip (SoC) ASICs, onboard controllers, power ASICs, and digital and mixed-signal ASICs for various microwave remote sensing applications. Additionally, significant progress is being made in the development of wideband Active Radar Calibrators (ARC), ferrite switches, Gallium Nitride (GaN) and Monolithic Microwave Integrated Circuit (MMIC)-based transmit/receive core chips, frequency generators, and Low-Temperature Co-fired Ceramic (LTCC)-based compact T/R modules to enhance system capabilities. Furthermore, the Space Applications Centre (SAC) is venturing into complex and emerging technologies, including the development of a Terahertz Telescope and its associated subsystems for studying outer space and galaxies from both space-based and ground-based observatories.

Research Areas in the field of Microwave Sensors

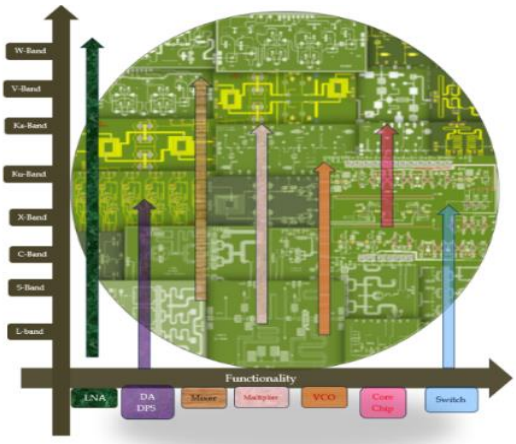
Electronics systems are fundamental to microwave remote sensing, supporting critical functions such as transmission, reception, power management, digital acquisition, data processing, and system control. They also facilitate data handling, compression, and formatting, onboard control, bus management, active thermal regulation, and seamless integration with spacecraft mainframe components. To achieve efficient and reliable sensor electronics, advancements focus on robust system design, miniaturization, utilization of state-of-the-art components, programmability, and onboard intelligence. This domain presents extensive research opportunities in the development of generic electronic architectures, system-on-chip (SoC) onboard computers, embedded processors, soft IP cores, standardized interfaces, high-speed data processing, onboard data compression, FPGA and ASIC implementations, hybrid electronic components, and high-efficiency, low-noise power systems.

We actively seek meaningful collaboration with academic institutions to explore a wide range of research and development opportunities in the fields of millimetre, submillimetre, and terahertz sensor design. Key areas of interest include advancements in transmitter and receiver technologies, digital control systems, data acquisition and processing systems, power electronics, and ground checkout instrumentation. Through these partnerships, we aim to drive innovation, enhance system performance, and develop cutting-edge solutions for next-generation remote sensing applications. The following sections highlight key research opportunities in these domains.

7.1. Microwave Frequency Generation and Receiver Technology

Brief Overview of the research done in SAC for the realization of frequency sources and receivers for various microwave remote sensing payloads is as follows.

For realization various multifunctional MMICs have been designed upto W band namely Low Noise Amplifier, True Time Delay Shifter, Digital Attenuator, Digital Phase Shifter, Sub-Harmonic Mixer, Voltage Controlled Oscillator, Multi Throw Switches, High Power Protection Switch, Multipliers, Driver Amplifier, Multifunction Core Chips which has been successfully utilized for the development of various systems.



MMIC details

PLL based Synthesiser up Ku band

SAC has developed frequency generators upto mmWave frequency either directly or indirectly through Phase Locked Loop (PLL). There is persistent effort to deliver higher performance, higher functionality, smaller size, lower power consumption designs based on latest technologies. The photograph of one such frequency generator system based on PLL technology upto Ku band has been developed successfully and appears below.

7.1.1. Development of Rydberg Atom Based Electric Field Sensors

A highly tunable, self-calibrated atomic sensors based on Rydberg atoms offer ground-breaking advancement in the microwave field sensing and quantum technologies .As atoms act as the basic sensing unit, the detection frequency can be easily tuned without further change in hardware .The system is self-calibrated in nature, owing to the invariability of atomic parameters .As these sensors use atoms to measure the filed amplitude, they barely distort the impinging field.

Atomic excitation to Rydberg state is achieved out by two highly stable and counter propagating lasers namely the probe and control laser .The frequency tunability is achieved by varying the control laser parameters . This research work deals in the development of highly tunable self-calibrated atomic sensors along with the necessary opto-mechanical components .

7.1.2. Design and Development of SiGe Based PLL-Frequency Synthesizers

Bi-CMOS SiGe based phase lock loops (PLL) can play a critical role in generation of highly stable (both long and short-term stability) and widely tunable frequency generation blocks. It consists of an integrated VCO, programmable or fixed frequency divider, phase frequency detector (PFD) and the loop filter.

The PFD must have dead zone of less than 300ps with an operating frequency up-to 200 MHz A differential charge pump along with the external loop filter provides the VCO control voltage. A multi capacitor bank based VCO enhances the Bandwidth of operation. The output frequency is dependent on the input reference frequency and the division ratio, a programmable divider helps in varying the operating frequency. This research work deals with the design and development of all the sub-circuits and its integration necessary for PLL based frequency synthesizer up-to 100GHz.

7.1.3. Design & Development of multifunctional mm-wave/sub-mm wave MMICs

This research area involves design and development of multi-functional mm-wave/sub-mm wave MMICs viz. low noise amplifiers, mixers, medium power amplifiers etc. using technology having InGaAs/ InAIAs hetero-structures with high Indium content/InP. The developed MMICs will be used in receivers for climatic study, weather forecasting and astronomical applications.

7.1.4. Schottky Barrier Diode (SBD) based sub-mm wave receiver front-ends

This research area caters to design & development of sub-mm wave SBD-based receivers for inter-planetary exploration missions. Receiver front end can either be mixer with IF LNA or RF LNA followed by mixer and IF LNA, depending on availability of RF LNAs at such high frequencies. Sub-harmonic mixer topology is preferred owing to difficulties in generation of high-power LO signals at high fundamental frequencies.

7.1.5. SIS-tunnel junctions based sub-mm wave/terahertz receiver front-ends

The superconductor-insulator-superconductor tunnel junction (SIS) based sub-mm wave receivers, operating at ~ 4K temperature, can achieve state-of-the-art noise performance of the order of 2-5 times the quantum limit. This research work involves design & development of cryogenically cooled (operating at ~ 4K) SIS based receiver front-ends at sub-mm wave and terahertz frequency bands.

7.1.6. mm-wave Single-Chip Receiver using RFIC technology

This research area involves design and development of miniaturized single-chip receiver core-chip at mm-wave frequency band using RF CMOS/ BiCMOS technology. This will lead to considerable reduction in size, weight, and power (SWaP) which is prime consideration for space-borne electronics.

7.2. Digital Controls, Data Acquisition, Processing

Microwave sensor digital electronics group is responsible for design, development and delivery of on board digital control sub-systems, on board ASICs, digital data acquisition, signal processing of sub-systems, near real-time SAR data processing system and ground checkout units for various digital sub systems.

Following research areas are identified for future microwave remote sensing payloads:

7.2.1. Payload Control and Tracking Unit (PCTU)

The development of a Payload Control and Tracking Unit (PCTU) involves designing a highly reliable and efficient system to manage payload operations in space. This includes hardware and software integration to ensure seamless communication, control, and data handling between the spacecraft and ground stations. Presently, PCTU is implemented to actuate scan mirror and fine scanning mirror (FSM) to bring the optical beam into line of sight with ground station.

This proposal is for development of future PCTU which takes input of spacecraft orbital parameters such as attitude, velocity etc. The orbital parameters can be used to predict errors in pointing and according a closed loop tracking can be initiated to bring payload in line of sight with accuracy of better than 10urad. These orbital parameters will also be used for computation of point ahead angles and point ahead mirror must be actuated in closed loop to align optical transmitter.

7.2.2. Time to Digital Converter (TDC) with 10ps accuracy

Time-to-Digital Converters (TDCs) are used for high-precision event time stamping. Currently, TDCs are implemented using FPGA carry chain delay lines, but they suffer from inaccuracies due to routing variations within the FPGA fabric. Various calibration techniques can be applied to enhance precision. Additionally, TDCs are highly sensitive to temperature fluctuations, making temperature compensation techniques essential for ensuring stable performance and improved accuracy. This proposal is for the design and characterization of TDC in FPGA/ASIC for 10ps accuracy. Following activities are required for this:

- Designing of Time to Digital Converter (TDC) using carry chain/buffers. Precise routing between inter element for minimal variation of sub clock period.
- Calibration of TDC through standard source with accuracy of one order better than requirement.
- Implementation of thermal compensation techniques for correcting response over temperature. Characterization of TDC over temperature for 10ps accuracy.

7.2.3. System on Chip with RISC-V processor and embedded FPGA for Space Application

This proposal focuses on the development of a reconfigurable fabric core (eFPGA) and its integration with a RISC-V microprocessor. The eFPGA will comprise an array of basic logic units (LUTs, flip-flops, etc.), a routing matrix, a custom DSP block, and onboard digital systems designed for interplanetary and small satellite missions, which require miniaturization, energy efficiency, flexibility, and sufficient computing resources.

A System-on-Chip (SoC) integrating a microprocessor soft core and an embedded FPGA (eFPGA) offers an optimal solution for applications demanding low power and high flexibility. The eFPGA core will be developed as a soft RTL core and interfaced with the microprocessor via the AHB/AXI bus. Users will have the ability to configure various parameters, including array size, I/O count, and memory size.

Additionally, the bitstream generation flow for the eFPGA core will be designed to be compatible with available open-source synthesis and place-and-route (P&R) tools. To ensure reliability in space environments, the eFPGA will incorporate fault-tolerant features, making it suitable for radiation-prone applications. The primary target application for this eFPGA is the implementation of control and signal processing functions for microwave remote sensing payloads.

7.2.4. Design and Development of Matched Filter Correlator ASIC

A Digital Correlator ASIC for Microwave SAR is a high-performance, low-power integrated circuit designed to process received radar echoes efficiently. SAR systems require real-time signal correlation to reconstruct high-resolution images of targets from microwave signals. The digital correlator ASIC accelerates this process by implementing parallel cross-correlation computations, reducing computational load on general-purpose processors while improving speed and power efficiency. The research work involves various aspects of design and development:

- Design and development of high-speed, parallel-processing correlator architecture for efficient SAR signal processing.
- Implementation of low-latency data streaming and optimized memory management for continuous radar data processing.
- Development of optimize correlation algorithms for range/Doppler processing and pulse compression.
- Testing & Validation of design by post-silicon testing with real microwave SAR data to validate performance, perform radiation hardness testing for spaceborne applications of ASIC and thermal analysis for high-power environments and design optimize for reliability, ensuring minimal signal distortion and noise impact.

7.2.5. Design and Development of Digital Spectrometer ASIC

The Design and Development of a Digital Spectrometer ASIC focuses on creating a high-performance, low-power integrated circuit for real-time spectral analysis in applications such as radio astronomy, remote sensing, and communications. The research involves designing an optimized Fast Fourier Transform (FFT)-based architecture for spectral decomposition, incorporating a 6-bit high speed ADC (2 to 4 GHz Instantaneous bandwidth) along with wide analog input bandwidth support (8 to 10 GHz), a programmable Voltage Gain Amplifier (VGA), a Phase Locked Loop (PLL) based frequency synthesizer, a demultiplexer, a poly-phase filter bank, a programmable windowing function, a Fast Fourier Transform (FFT) core, a frequency-domain data analysis block, a programmable time accumulator of frequency-domain voltage or power, a data readout block, a Serial Peripheral Interface (SPI) for the ASIC's programming and low-speed data interchange, a low-voltage differential signal (LVDS) interface for high-speed data transfer, a digital control unit and ASIC testing features.

This research aims to develop a robust, scalable, and power-efficient spectrometer ASIC for deployment in radio telescopes, deep-space communication, and scientific instrumentation, contributing to advancements in spectral signal processing technologies.

7.2.6. Scrubbing techniques for SEU mitigation and On-board Reconfiguration

Scrubbing techniques play a critical role in mitigating Single Event Upsets (SEUs) in spaceborne and aerospace electronics, where radiation-induced bit flips can compromise system reliability. SEU mitigation is achieved through periodic configuration memory scrubbing, which detects and corrects errors in FPGAs and ASICs used in satellite payloads, avionics, and deep-space missions.

The development work involves implementing error detection and correction (EDAC) mechanisms, such as cyclic redundancy check (CRC), Hamming codes, and Triple Modular Redundancy (TMR), along with Partial and Dynamic Reconfiguration to ensure system resilience. Additionally, autonomous onboard reconfiguration is being developed to enable real-time recovery by reloading fault-free configurations stored in redundant memory banks. The scope of this research extends to radiation-hardened FPGA architectures, AI-driven fault prediction models, and low-power scrubbing techniques, ensuring robust operation.

7.2.7. IP Core development for fault tolerant Double Data Rate 4 (DDR4) memory controller

IP Core development for Single Event Functional Interrupt (SEFI) mitigation for DDR4 SDRAM memory chips. This IP Core will mitigate Single Event Upsets (SEUs) and SEFI in a radiation environment. This work involves,

- Development of a controller that handles address mapping, read/write operations from user and mitigates SEU and SEFI errors in background
- Design verification, synthesis and implementation targeting several FPGA platforms like Xilinx, RTG4, NanoXplore and ASIC.
- Test the IP core in a radiation environment to estimate the correctness of the IP core.

7.2.8. Design and Development of Generic RADAR Waveform Synthesis ASIC

A Generic RADAR Waveform Synthesis ASIC is a specialized integrated circuit required to generate and manipulate diverse radar waveforms in real time. It is crucial for modern radar systems, including synthetic aperture radar (SAR), phased array radar, Radar Altimeter and Ground penetrating radar (GPR) application. This capability is achieved by a high sampling data converter (DAC) and a processor or FPGA to generate the required waveform for different applications (linear frequency modulated signal (LFM) for SAR, Frequency Modulated Continuous Wav signal (FMCW) for altimeter and Step Frequency Continuous Wave (SFCW) for GPR). Given the widespread use of such devices in microwave payloads and the ongoing push for miniaturizing digital electronics, the design and development of an indigenous Generic RADAR Waveform Synthesis ASIC is proposed.

The proposed work includes,

- Design and development of a high-speed dual-channel DAC (12-bit, 500 MSps) and Direct Digital Synthesis (DDS), integrated onto a single chip using a 65nm CMOS process node.
- Radiation hardened design for use in space applications.
- Integration with controller ASICs to provide a truly single chip solution for a wide range of RADAR applications.

This will reduce the SWaP (Size, Weight, and Power) requirements and miniaturize the electronics and free up processing resources of the central controller of the digital subsystems.

7.2.9. Design and Development of Telemetry ASIC

Telemetry ASIC is a Mixed signal ASIC. It can receive analog (thermistor) and digital telemetry signals and can send them over serial link. It will have RS422/SPI interface along with ADC, modules. The objective of the proposal is to develop a miniaturized integrated single chip solution while presently this functionality is achieved with discrete components like FPGA, ADC, Mux etc.

The proposed work includes, Radiation hardened design for use in space applications, where digital modules will be designed using RHBD library and analog modules will be having RHBD layout techniques. It will be fabricated using 180nm CMOS process and the design should be modular, addressable and scalable design, based on no. of TM channel, multiple devices can be used.

7.2.10. Signal Processing algorithms for RADAR Velocity meter

This research focuses on developing and optimizing signal processing algorithms for Pulse Doppler RADAR-based velocity meter for Doppler shift estimation, range Doppler processing and clutter suppression to accurately measure object velocity. Key techniques such as FFT, kalman filtering, wavelet Transform and Machine learning based motion estimation will be explored for improved accuracy and noise reduction. The following research areas are identified,

- Designing algorithms and scheme for precise measurement technique
- Real time unambiguous velocity estimation from a Doppler radar

7.2.11. NVMe IP for FPGA

This IP will be useful for design and development of a digital design involving NVMe based memories for high-speed data recording and playback. NVMe protocol-based IP is need to be employed to maintain data integrity and reliable operation of data processing and storage. The main aim of the research would be to develop an efficient controller logic for NVMe protocol supported memories. Also, the research must focus on real time optimal implementation EDAC algorithm and efficient low overhead file system amenable for implementation on FPGA/ASIC.

7.2.12. Digital ASIC for Radar Altimeter Processor

MRSA/SAC has developed a RADAR altimeter based on FMCW technique. Presently design and development of Pulsed based Radar Altimeter is under progress in MRSA/SAC. These systems will be used in precise altitude and velocity measurements. The proposed work includes, Turnkey development of digital ASIC for Radar Altimeter Processor and MMCM development for Radar Altimeter System.

7.2.13. Signal Processing Platform for Terrain Relative Navigation and Hazard Detection and Avoidance (HDA) applications

Future generation of landing craft will autonomously map the surface, using vision, microwave, and/or laser-based sensors, during the terminal phase of powered descent and then, in real-time, choose and divert to a safe landing site in order to avoid hazards using Hazard Detection and Avoidance techniques. This will also require accurate position and velocity data during descent phase in order to ensure safe soft landing at the pre-designated sites. Following are the research areas

- Processing algorithms (for feature identification, feature matching, HDA, Position estimation, velocity estimation, image generation etc.) for real time microwave/optical based imaging sensors
- Algorithms for “pose estimation” for mission targeted to small bodies like asteroids
- Algorithms for “Natural Feature Tracking”
- Applications of AI and ML in Position Localization and Hazard Avoidance

7.2.14. On-board SAR Processor ASIC

The aim of On-board SAR Processor (OBSP) RH Digital ASIC is to acquire SAR raw data and generate well-focused images as a final output. It will have LVDS interface with the master FPGA. The objective of the proposal is to develop a low power, miniaturized solution which will comprise of major signal and image processing techniques to generate image from the raw data. Moreover, design of OBSP ASIC will be radiation hardened in nature which will enable it to be used in future planetary missions and other space applications.

7.2.15. Development and Realization of GNSS Remote Sensing Signal Simulator

In order to test GNSS RS signal reception with configurable scenarios, a GNSS (direct signal) and GNSS-RS (reflected signal) signal generator is required with the capability to simulate navigation messages to allow positioning, as well as simulating any user-defined, direct and reflected path with satellite handovers. This capability to simulate specular and scattered reflections is required to test the Delay-Doppler map (DDM) calculations in the GNSS RS Receiver.

The proposed work involves modelling of the direct navigation signal & and the corresponding reflected signal, received at LEO satellite in the operational scenario of a GNSS Remote Sensing spacecraft. The developed simulator should have the following capabilities:

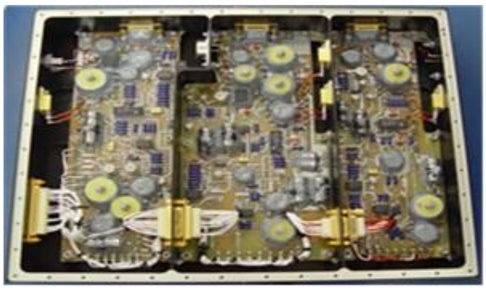
- GPS L1 C/A and IRNSS SPS signal generation with proper Ephemerides and Almanac information
- GNSS transmitting and receiving LEO satellites orbit simulation;
- Any user-defined path should be able to be uploaded, either on the Earth or in orbit, with as much temporal resolution as necessary
- Estimation of location of the specular reflection point and glistening zone (area where scattered power is collected);
- Reflected surface scattering coefficient generation based on geophysical parameters
- It shall be able to model and generate both direct and reflected signals, on rough or smooth surfaces incorporating tropospheric and ionospheric effects on both direct and reflected signal.
- Graphical input/output user interface (GUI).
- Generation of IF/RF direct and reflected navigation signals

7.3. Power Electronics

Electronic Power Conditioners EPCs (required for the various RF and Digital subsystems of Microwave remote sensing payloads are being designed and developed in-house at SAC .These EPCs have shown excellent performance on-board ISRO's microwave payloads flown so far .To mention a few, major successfully completed in-house developments are:

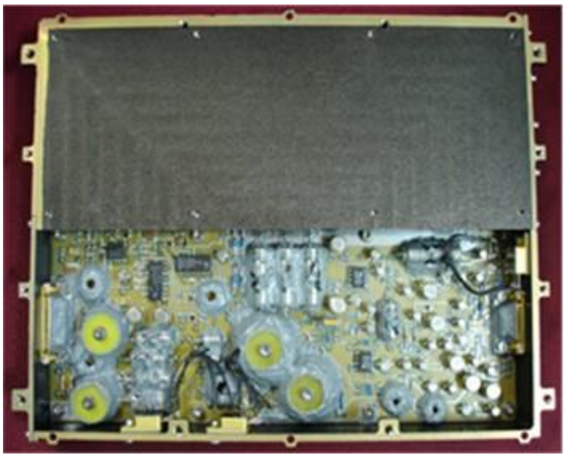
- Power Conditioning and Processing Unit for TR Modules of C-band SAR payload involving HMCs and planar magnetics.
- Multi-output pulsed EPC for TR integrated modules of X-band SAR.
- EPCs for GaN based Dual-Pol Pulsed Transmitters of Chandrayaan-3 SAR.
- High power EPC for X-Band 250W GaN Solid State Power Amplifiers.

PCPU for C-band TR Module



EPC for MADRAS RF Subsystem

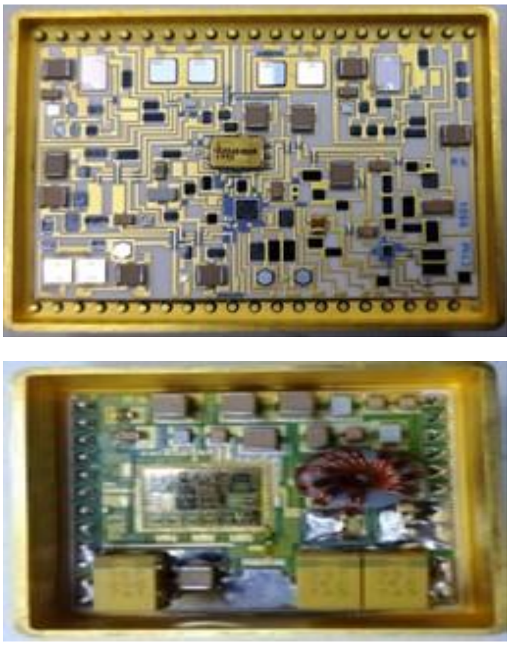
EPC for 250W GaN SSPA



EPC for Pulsed Transmitters of Chandrayan-II

- HMC based Point of Load (POL) converters (up to 13V).
- HMC based Controller for DC-DC converter and pulse Modulator
- 100W EPC for digital Subsystem of NISAR
- EPC for S-band TRiM (NISAR)
- EPC for RF subsystems of RISAT-2B
- Multi-output EPC for MHS payload

60W EPC for X-band TR modules for active antenna



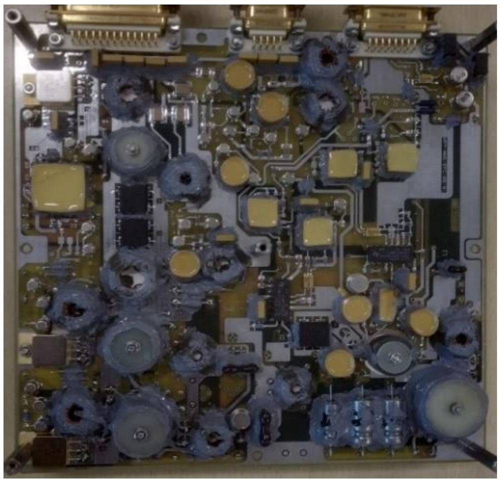
Hybridized Micro Circuits (HMCs) for EPC

4 channel Pulse modulator using HMCs for active antenna

EPC for S-band TRiM (NISAR)

100W EPC with HMC based POL (NISAR)

15W EPC for RISAT-2B



30W, 9 outputs EPC for MHS

Apart from above, High Voltage EPC for indigenous pulsed TWT have been demonstrated and its qualification for space version is under advanced stage. Power ASIC design and development activities have also been taken up and are at advanced stage. Higher efficiency, smaller mass and volume, efficient thermal design and EMI/EMC compliance are the major driving parameters for any space-borne EPC design.

7.3.1. Digitally controlled multi-output DC-DC Converter

This research focuses on development of Digitally controlled energy efficient multi-output DC-DC converter with fast transient response and MHz switching frequency. The work involves design, simulation, and proto-type development of highly efficient multi-output EPC for high-speed digital circuits with FPGAs. The EPC should have programmable output ON/OFF sequencing with fast transient response.

7.3.2. High frequency GaN FET based high voltage EPC for pulsed TWTA

This proposal is for design & development of topologies and packaging aspects of High frequency GaN FET based high voltage EPC for pulsed TWTA. The work involves study, simulation and comparison of various design topologies/ configurations for high voltage EPC for multi collector pulsed TWT with Beam focus electrode for pulsed operation. The work also involves analysis and implementation of space grade high voltage potting materials and high voltage packaging aspects for realization in space environments.

7.3.3. Thick Film hybrid + HMC based EPC system

This proposal is for design and development of the following systems,

- Thick Film hybrid + HMC based EPC with in-house developed ASIC LDOs & POLs for target of lower mass/volume and higher efficiency
- Thick Film hybrid + HMC based Pulsed EPC with in-house developed HMC PMC for target of lower mass/volume and higher efficiency.

7.3.4. Rad hard miniaturised POL and LDO

This proposal is for design and development of Rad hard, efficient and very compact high voltage (15V) POL as well LDO.

7.3.5. Development of software tool for design, modelling and analysis of planar power transformer and power inductor.

7.3.6. Miniaturized circuit protection module

This proposal is for Miniaturized circuit protection module DC-DC converters for Aerospace applications. The protection circuit comprises of Resettable eFuse, input plug-in inrush current limiter and Under Voltage Lock-out (UVLO). The work involves design, simulation, and optimization of Generic front-end protection circuit for DC-DC converters. The final circuit may be implemented on a power ASIC or HMC.

7.3.7. Integrated EPC for Multiple Subsystem Stacks

This proposal includes analysis, design and development of advanced EPCs, which can supply power to multiple subsystem stacks with individual control of commanding and Over Current Protection. This work involves several challenges viz.

- Electrical circuit modelling and simulation of circuit. Supplying power to multiple subsystems and meeting output voltage sequencing requirement of each individual.
- Dynamic switching load with fast transient response and converter stability.
- Selectable RF load at spacecraft through Tele-command.
- Protection of EPC in case of single/ multiple subsystem failures such that there is no impact on remaining subsystems if one or multiple subsystems fail to which EPC is supplying power.
- Thermal effects of subsystem failures on EPC.

8. HUMAN SPACEFLIGHT & ADVANCED TECHNOLOGIES

8.1. Optical and Quantum Related Technologies

Optical and Photonics technologies have widespread applications in the field of high data rate communication, optical inter-satellite links, microwave photonics. SAC has a well-defined road map for optical communication development. Starting from sub systems realization for lab demonstrations to complete program for full-fledged implementation for satellite terminals has been planned with short and long term goals. System engineering activities for optical communication payloads are being envisaged for Intersatellite and ground to satellite optical communication links. End-to-end system design for realization and operation of onboard optical communication payloads are being done.

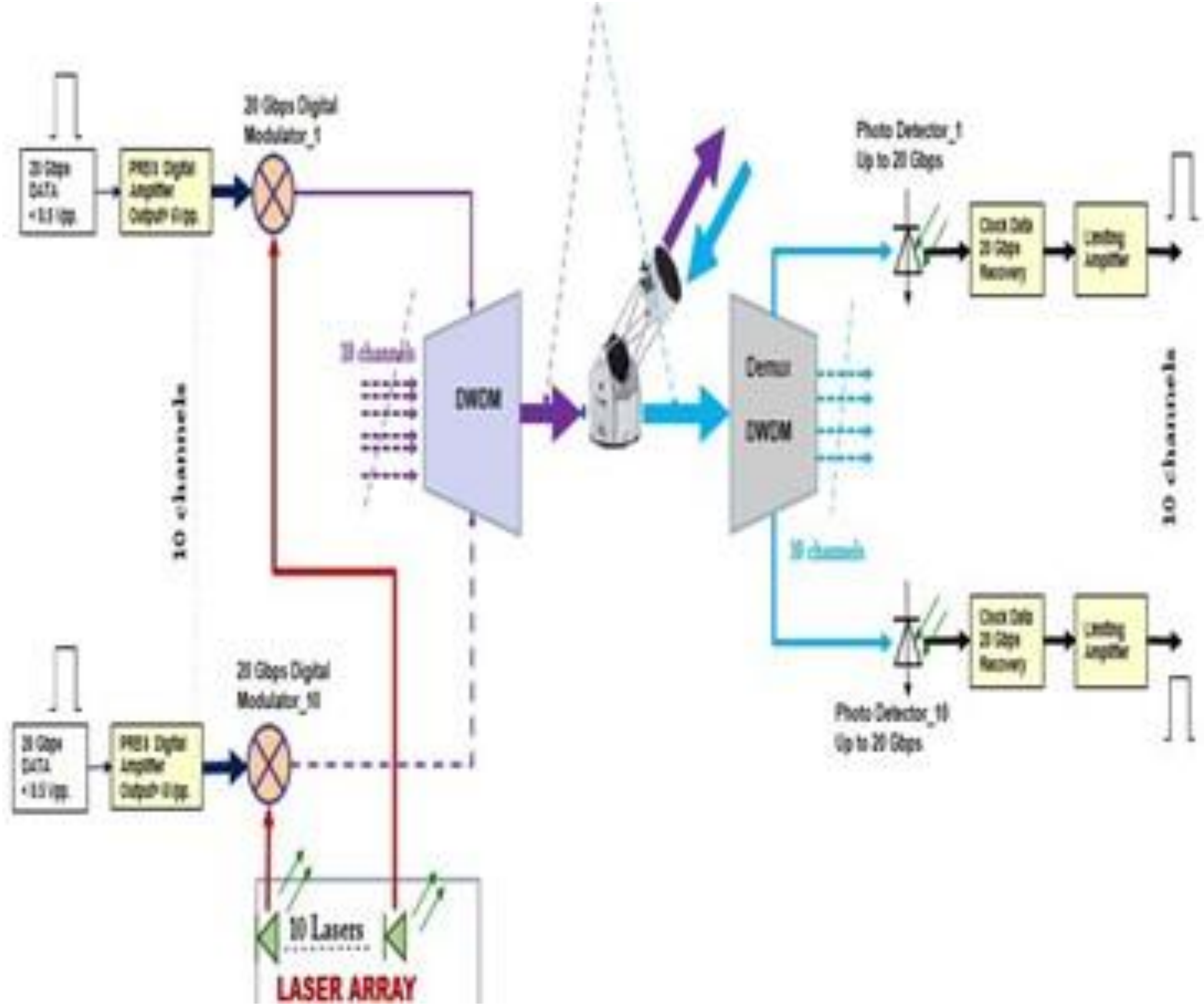
SAC is involved in design and development of advance optical communication subsystems like high data rate transmitters and receivers using different modulation/ demodulation techniques, EDFAs (high power and low noise), filters etc. Various microwave payload subsystems like filters/switches, beam formers, frequency generators etc. are being realized using optical technologies to incorporate multi functionality, flexibility and miniaturization of RF payloads. Photonics integrated circuits based designs are also being envisaged for miniaturized optical subsystems.

High data rate communication for satellite applications are utilizing the enormous potential of photonic components. With the advent of advanced and miniaturized components like laser diodes, modulators, modulator drivers, filters amplifiers and EDFAs, high data rate intersatellite links are possible using optical technologies. In today's data hungry environment, optical communication is providing 100s of Gbps of data rate using DWDM techniques. Microwave signals are being transported and processed using photonic techniques. This has paved the way for special areas of research called microwave photonics. Photonic technologies have the potential to replace conventional RF and microwave components use in the satellites to save space and power, which are very critical in satellite industry.

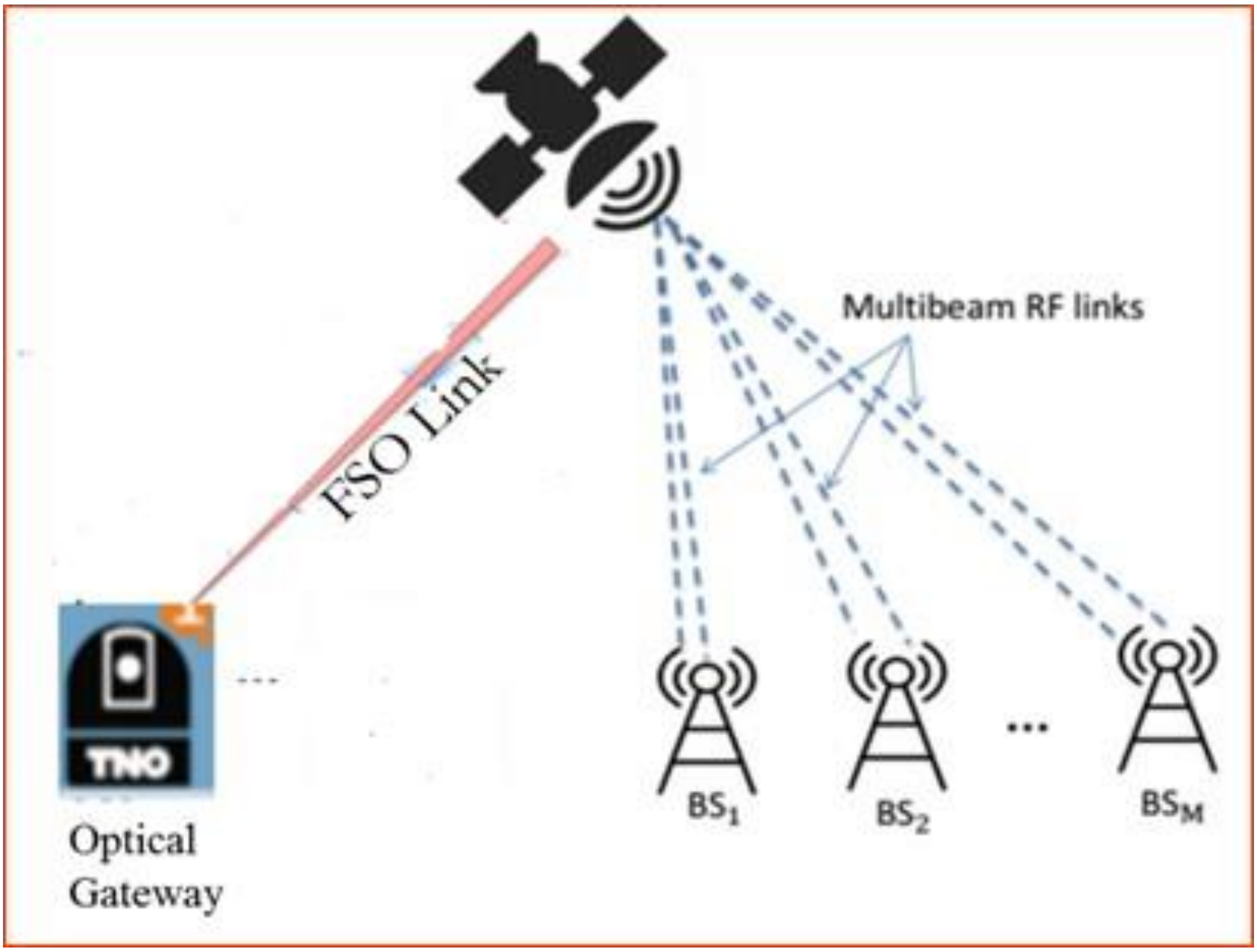
8.1.1. DWDM based 200 Gbps FSO link demonstration for future Terabit optical communication.

Terabits of data rate will be required for future high-speed links for LEO satellites and Intersatellite links for LEO constellations. Also high throughput satellites require 100s of Gbps data to be transmitted through multiple gateways. RF bands are facing saturation and limited to strict frequency regulation, leading to a requirement of large number ground stations for feeder links. Increasing frequency demand from terrestrial wireless communications also puts restriction RF frequencies and on feeder locations due to signal isolation requirement and practical operational issues. Multiple feeder stations call for multiple terrestrial links involving multiple operators and puts signal security at stake.

Technologies developed will be utilized for high data rate links for satellite-based links (LEO -ISL, LEO GEO, GEO-Ground) as well as for optical feeder links for high throughput satellites. A single optical feeder Station can cover vast geographical areas without number of RF feeder stations and their terrestrial links, which requires vast amount of ground infrastructure. These technologies can be extended to Terabits links for future Optical communication and HTS links.



Multichannel High data rate optical communication link @200Gbps



Feeder link for HTS

8.1.2. Multi wavelength Fiber Laser Generation Technique

Multi-wavelength laser generation from a single source of laser has attracted considerable attention among researchers over the last few decades. The Multiwavelength Fiber Laser Sources have potential Applications in dense wavelength-division-multiplexed (WDM) in High Throughput Satellite in optical communication, optical instrument testing and characterization.

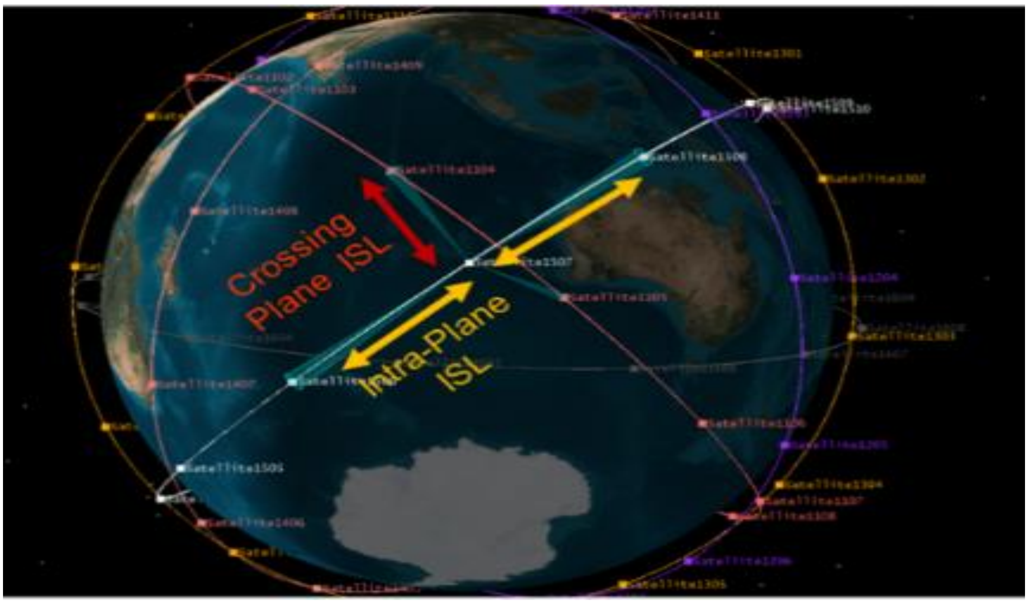
Such light sources are particularly in-demand because they provide an efficient and economical solution to increase the flexibility of WDM system. It has various advantage such as low cost and low insertion loss. The requirements for such optical sources are a high number of channels over large wavelength span, moderate output powers with good optical signal to noise ratio (OSNR) and spectral flatness, single longitudinal mode operation of each laser line, tunability and accurate positioning on the ITU frequency grid. Technologies developed in this research will be utilized for optical feeder link for high throughput satellite

The scope of the work shall include to explore the several techniques used for multi wavelength generation namely comb filter, cascaded modulation, Brillouin scattering technique, and arrayed waveguide grating.

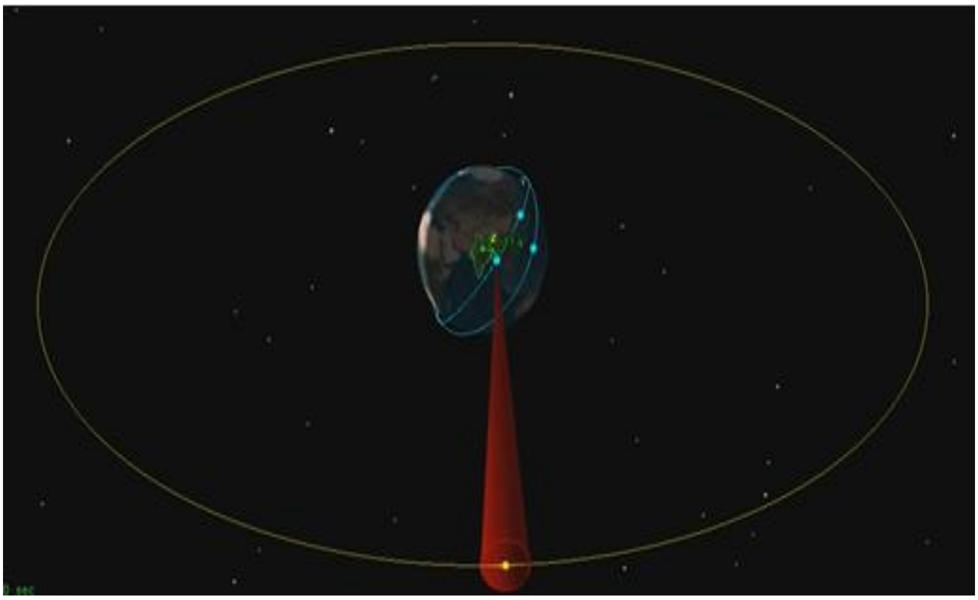
8.1.3. Compact Optical Terminal Development for Optical Inter-Satellite Link

The upcoming data rate requirement need a paradigm shift from conventional RF satellite link to free space optical link. RF link has some advantage over free space optical (FSO) link where atmosphere is involved. But for inter-satellite link, FSO link is the only viable solution in terms of size, weight and power. The added advantage of FSO link is high data rate, narrow beam width, low EMI/EMC etc.

ISRO has initiated the development for FSO inter-satellite link. The base band data will be modulated using optical carrier which has frequency in THz. Using a compact terminal consisting of optical telescope, optical communication subsystems and pointing acquisition and tracking (PAT) mechanism, ISL can be realized. This will also effective reduce the number of ground segment and will add space diversity.



Inter-plane and Intra-plane ISL representation



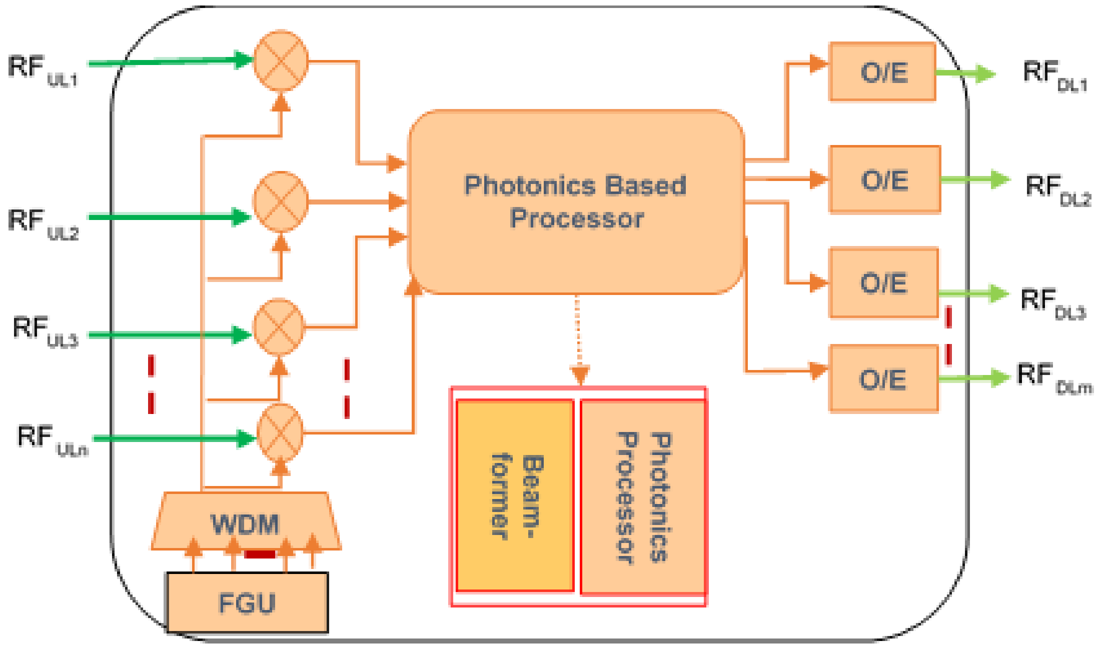
LEO-GEO ISL

8.1.4. Microwave Photonics for next generation broadband payload

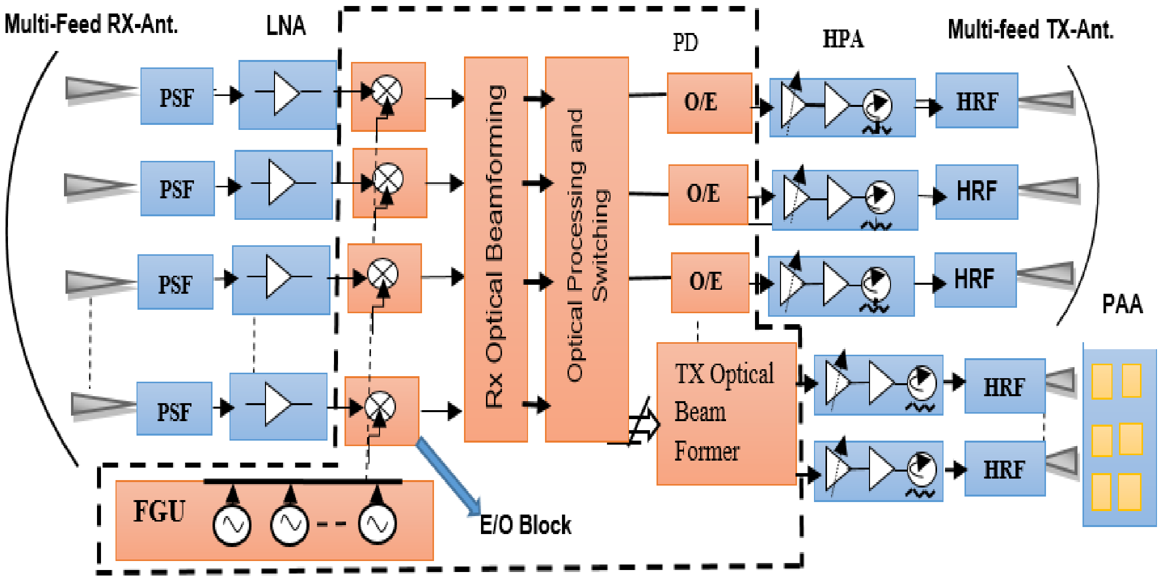
Broadband Satellite Communication in coming future shall have the capability of providing very high throughput (vHTS) 'Terabits/sec' with multi-beam coverage and with data rate >10Gsps on-board switching. It will be capable of providing flexible power, bandwidth and coverage depending on varying demand over the multi-beam coverage.

Microwave Photonic-based on-board processing will be a feasible solution to meet the high-speed processing demand of next-generation broadband satellite system with added advantage of lower mass, lower volume, less power consumption and better EMI performance.

The research areas in MWP are Microwave Photonic Filter, Photonic switching and Beam forming. PIC based approach for the above areas are also initiated.



General Architecture of Microwave Photonics based Processing



Photonics based Multi-beam Payload Architecture

8.1.5. High Power Er Doped Fiber Amplifier

High power optical amplifier (EDFA) is inevitable for the realization of free space optical communication link. This is the device, which amplify the 1550 nm optical signal directly without the need of any electrical conversion.

Er - doped fiber is popularly used as the gain medium for optical amplifier. The Pump laser will provide the required population inversion in Er fiber. Different pumping topologies e.g. forward pumping (co-propagation), Backward pumping (Counter propagation) and Bi-directional pumping (Co+ Counter propagation) is explored in the development to maximize the Gain, Saturated power and minimize the noise figure. Fiber fusion and thermal management of fiber plays the crucial role on the operation life EDFA.

For any type of optical communication payload, EDFA serves the purpose of power house to sustain the communication link. Though many commercial EDFAs are available, those are meant for ground applications. For space based EDFA, there are lots of design challenges in thermal design, optical fiber assembly, high power electronics aspects.

SAC have initiated the in-house development of EDFA in different phases with mid and high power output targets. This development is being carried out in phases. At present 5W output at ambient has been realized.

8.1.6. Higher order optical switch for low latency applications

The increasing user demands required high throughput microwave and optical payloads where onboard signal processing in photonics domain is the most viable option to meet the latency requirements of reconfigurable networks.

In photonic switching there are several techniques such as optical MEMS, Semiconductor optical amplifier, waveguide and thermal. In this technology, selection and hardware realization of the switch will be explored which has capability of high switching order (16*16 or higher), switching latency (few nano sec.) in optical C-band. The Cross talk (-40 dBc or better), polarization independent, transparent to data rate up to 10 Gbps with suitable tele command and telemetry provision are the key features of the hardware.

8.1.7. Digital Signal Processing for Optical Coherent Receiver in BPSK, QPSK or advanced modulation format

For advanced optical communication formats e.g. BPSK, QPSK, 8-PSK etc., the post processing of electrical signal is inevitable after detection through coherent receiver with single polarization (X channel) or dual polarization (X and Y channel) multiplexing. Several impairments cause the optical signal distortion and those effects need to counter through algorithm. Main algorithm stage conventionally consists of Bessel filtering, Resampling, Quadrature imbalance, non-linearity and Chromatic dispersion compensation etc.

The data rate is typically more than 10 Gbps. In such high data rate, the DSP using FPGA is very challenging. There is a scope of code development for FPGA to mitigate the effects.

8.1.8. High Sensitivity Optical Low Noise Amplifier

Low Noise optical amplifier (EDFA) is the front end of the optical receiver section and it is inevitable for the realization of free space optical communication link. This is the device which amplify the weak incoming optical signals for the detection by photodiode.

Single Mode Er - doped fiber is popularly used as the gain medium for optical amplifier. The Pump laser will provide the required population inversion in Er fiber. Different pumping topologies e.g. forward pumping (co- propagation), Backward pumping (Counter propagation) and Bi-directional pumping (Co+ Counter propagation) is explored in the development to maximize the Gain with minimal added noise figure and improved sensitivity.

To improve the link margin for the compact optical terminal the noise floor of the low noise amplifier should be as low as possible to provide the best amplification with minimal noise in incoming modulation signal.

SAC have initiated the in-house development of EDFA in different phases and development is being carried out in phases. At present -63 dBm with 50 dB gain at ambient has been realized as the state of the art worldwide.

8.1.9. Modeling of atmospheric turbulence parameters using radiosonde data and estimation of localized Fried parameter (r0) for new OGS location

Clear air turbulence phenomena affect the propagation of an optical beam because the refractive index randomly varies in space and time. Mainly, random variation of the refractive index of air depends on the air mixing due to temperature variation in the atmosphere. In fact, sunlight incident upon the earth's surface causes heating of the earth's surface and the air in its proximity. These effects happen at different points in the atmosphere, and hence it is worth discussing the structure of the earth's atmosphere briefly. There are many parameters to be considered for the atmosphere but the major points are Refractive index structure constant ($C_n{}^2$) & Coherence length (r_0). $C_n{}^2$ determines the strength of turbulence and depends on the geographical location, altitude, and time of day. Close to ground, there is the largest gradient of temperature associated with the largest values of atmospheric pressure (and air density), therefore one should expect larger values of $C_n{}^2$ at sea level. Typical value of $C_n{}^2$ for a weak turbulence at ground level can be as little as 10^{-17} $m^{-3/2}$, while for a strong turbulence it can be up to 10^{-12} $m^{-3/2}$ or larger. The refractive index structure constant is related to the temperature structure constant as $C_n{}^2$:

$$C_n^2 = \left(\frac{78p}{T^2} \times 10^{-6} \right)^2 C_T^2$$

C_T is the temperature structure constant:

$$C_T = \left(\left\langle (T_1 - T_2)^2 \right\rangle \right)^{1/2} r^{-1/3}$$

Theoretical models of measuring refractive index profile: Hufnagel-Valley Model (HV Model):

$$C_n^2(h) = 0.00594(v/27)^2(10^{-5}h)^{10} \exp(-h/1000) + 2.7 \times 10^{-16} \exp(-h/1500) + A_0 \exp(-h/100)$$

Where h is the altitude, v is the rms wind speed & A_0 is the turbulence level at ground level.

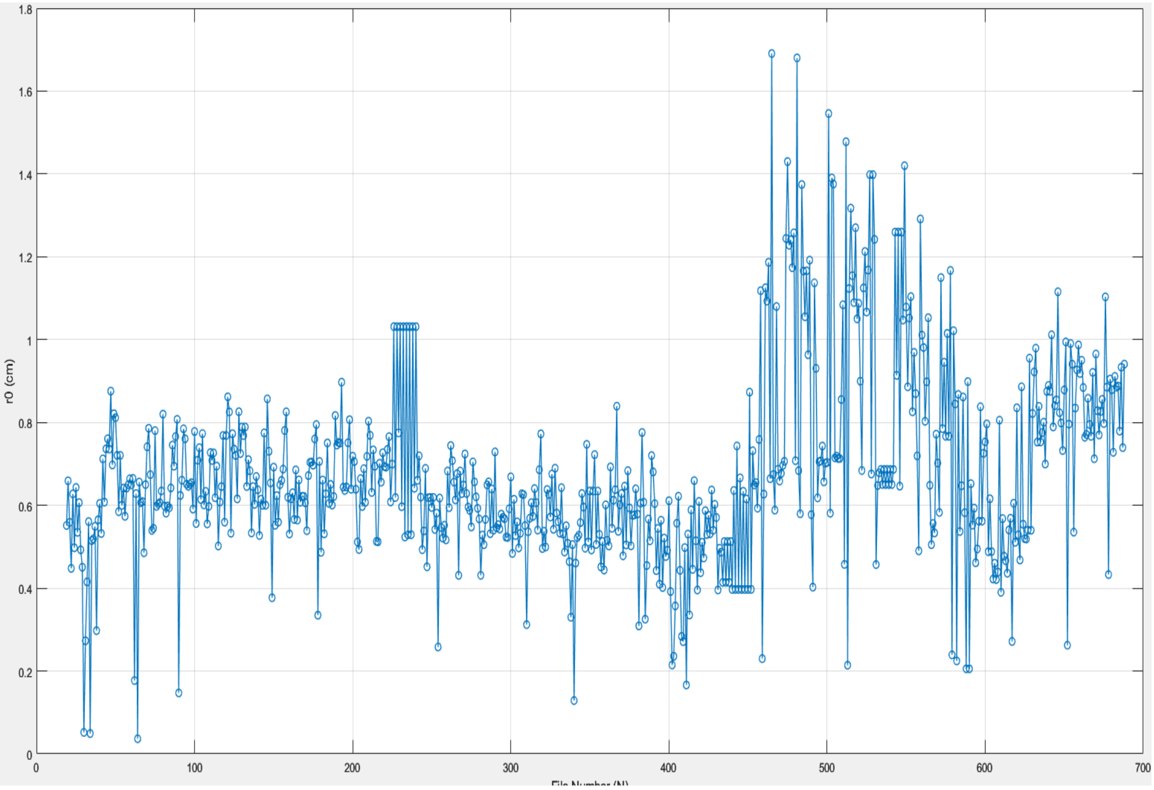
HV model is generally valid for mid-latitude regions where turbulence such as temperature gradients, humidity and wind speed differ from that of the Indian mainland.

Then defining r_0 which is the diameter of an equivalent aperture where the telescope resolution is approximately the same (diffraction limited) in absence of turbulence: the larger r_0 is the smaller the effects of turbulence on the propagating wave. Also, it depends on Zenith angle, wavelength, structure constant variation, Height, etc.:

$$r_o = 1.67 \left[\sec(\theta) k^2 \int_{h_o}^{H} C_n^2(h)\,dh \right]^{-\frac{3}{5}}$$

where θ is the angle from the zenith in the slant path

As per the above equation turbulence, in a space-to-Earth satellite link one should expect large atmospheric coherence length at the satellite (uplink), and smaller r_0 with more severe phase distortion at the ground station receiver (downlink). We measured the r_0 for Delhi throughout the year using Radiosonde data, which captures variations in temperature and pressure with altitude as shown below.



Variation of r_0 for 1 year of Delhi

8.2. Atomic Clock Related Technologies

Atomic frequency standards are the back-bone of the satellite navigation technology. SAC has developed indigenous atomic clocks for India's navigation programme – IRNSS (NavIC). The key concepts of atomic clocks involve atomic spectroscopy; RF & microwave electronics; microwave cavities; optics; low noise detection schemes and digital electronics. In view of supporting the in-house R&D activities, further detailed theoretical modelling can aid our practical work. Herewith, the following proposed research on theoretical and experimental studies can enhance our activities towards the optimization of atomic clocks.

8.2.1. Chip Scale atomic clocks

In the Coherent Population Trapping scheme, the use of microwave cavities can be avoided to build atomic clocks. This can, in principle, bring down the size to a considerable extent. The recent advances in chip-scale atomic clocks has been possible due to CPT methods. Research need to focus on development of physics package of chip-scale atomic clocks. Primary area of research include fabrication of Rb/Cs filled micro-fabricated cell, Modulation of VCSEL for CPT interrogation and assembly of VCSEL and Cell along with optics and heaters.

8.2.2. Studies on light-shift effects in atomic clocks and analyses of on-board clock jumps.

Rubidium atomic clocks are the widely used clocks in GNSS for space based navigation. These Rb clocks are prone to onboard frequency jumps, which results in the error on the navigation signals. It is of utmost importance to understand the source of the jumps in the Rb clocks. The prima facie understanding has brought to notice that light-shift effect is the main cause of these jumps. However, a detailed study is needed to quantitatively understand the physics behind these jumps. Moreover, in this study the other potential parameters such as the radiation effect, magnetic effects etc. need to be addressed which may result in giving rise to clock frequency jumps.

8.2.3. Trapped mercury-ion atomic clock

The trapped mercury-ion atomic clocks can reach stabilities and drifts, which are 1 and 2 orders (respectively) better than the rubidium lamp based RF clocks. These are strong potential candidates for the future deep space navigation missions alongside the current NavIC missions. The area of research include study, design and demonstrate the trapped mercury-ion-clock physics package meeting state of the art specifications.

8.2.4. Extraction of pure elements and their isotopes for atomic clock

Atomic clocks rely on the precise and stable oscillations of atoms to measure time. Elements are available in naturally occurring compounds. The extraction of pure elements and their isotopes is crucial for atomic clocks to ensure precision, stability and consistency in timekeeping. Pure natural mix of Rubidium, its isotopes (Rb87 and Rb85) and Mercury isotopes (Hg202 and Hg199) are primarily used in space atomic clock. Detailed research is required to develop efficient methods for extraction and storage of such pure elements.

8.2.5. Development of PLL based synthesizer IC for Atomic Clocks

Frequency Synthesizer is a crucial subsystem to generate precise RF signals in order to interrogate atomic transition levels. Development of PLL based synthesizer IC with low phase noise will greatly help in reducing electronic complexity and realization time of atomic clocks. PLL Synthesizer IC to be developed with 10MHz (sine) input reference should have minimum 2 outputs with following capabilities,

a) 6GHz to 8GHz or wider main RF output, with a provision to frequency modulate it with input signal of DC to 1KHz.
b) 30MHz to 100MHz or wider reference digital)CMOS/TTL/LVTTL/LVCMOS (output for digital electronic circuits.

8.3. Travelling Wave Tube Amplifier (TWTA)

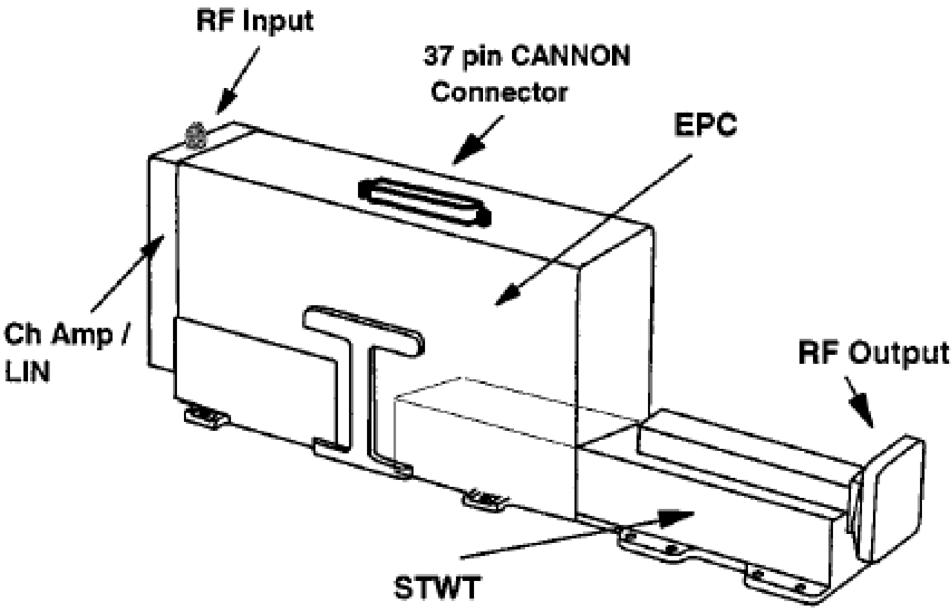
It is one of the critical technology elements used for efficient high power amplification in space borne payloads. Amongst all microwave amplifiers, TWTA offers unique combination of power, gain, efficiency and bandwidth.

Research opportunity in the field of TWTA is primarily oriented around

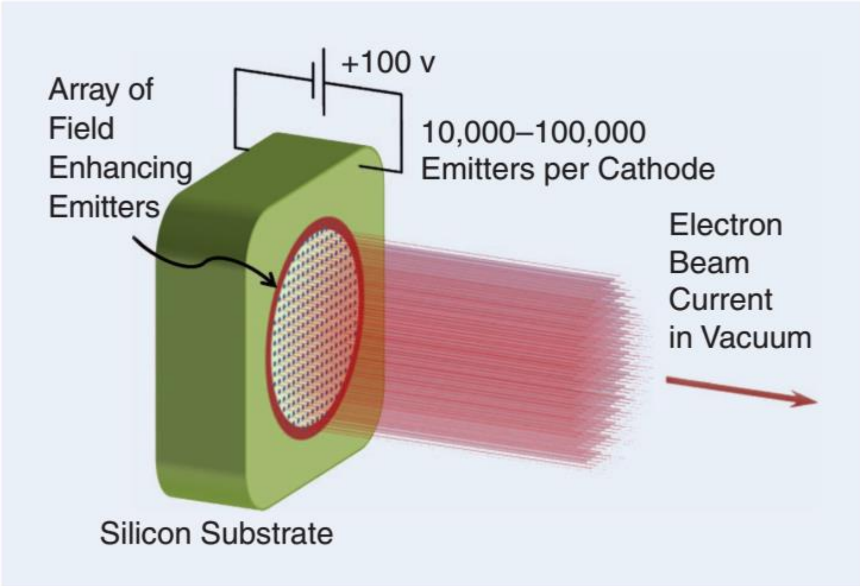
a) Development of large signal simulation tools,
b) Study & development of special UHV grade materials & special coating techniques on UHV material suitable for high temperature brazing,
c) Development of methods for texturing on copper surface for reducing SEE,
d) Techniques for measurement of high temperature stress & strain in complex shapes,
e) Design & development of long life high reliable space cathode.

Future research areas include development of

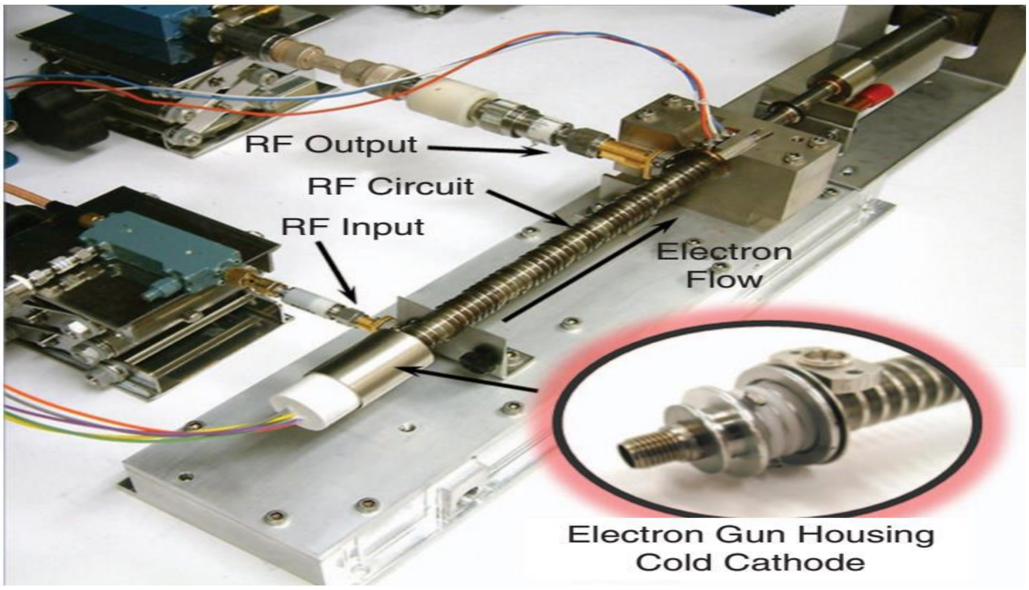
a) Very high peak power Pulse TWTAs for radar applications,
b) Folded waveguide TWTA and Coupled cavity TWTAs for higher frequency band power amplification,
c) Brazed Helix technology useful for higher CW power,
d) Microwave Power Modules – combination of Solid state amplifier and TWT with advantages of both the technologies,
e) Flexible TWTAs for dynamic allocation of frequency, BW & power,
f) Filtered Helix TWT with improved harmonic suppression,
g) Cold cathodes,
h) Mini TWT that can be placed right at the back of phased-array antenna,
i) High power source that can be beamed to Microwave rockets.



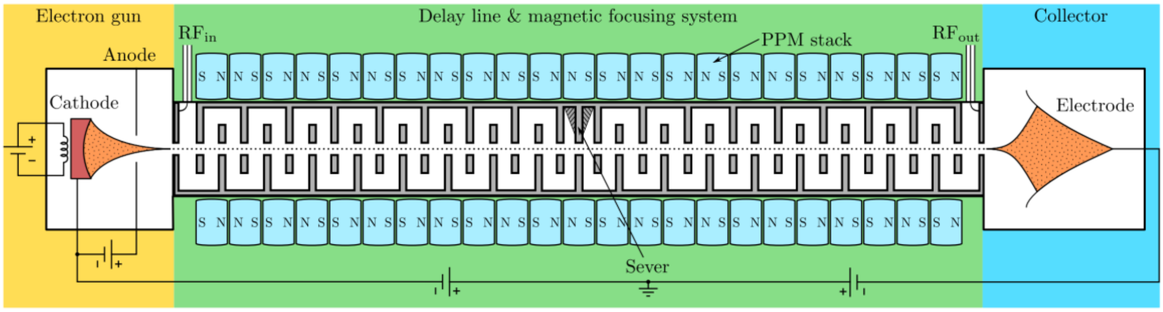
Microwave Power Module



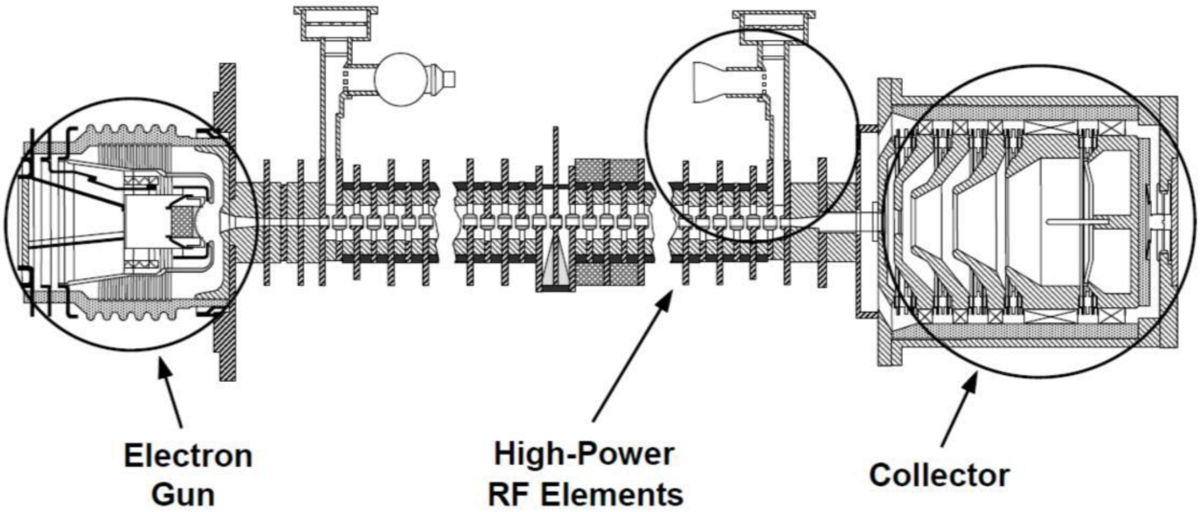
Embodiment of Cold Cathode Array



Cold Cathode TWT



Schematic of a generic folded-waveguide Travelling Wave Tube



Schematic of a generic Coupled Cavity Travelling Wave Tube

8.4. HUMAN SPACEFLIGHT RELATED TECHNOLOGIES

Human Spaceflight and Advanced Technology Area of ISRO has a well-defined roadmap for conducting space flights with humans and development of technologies to support the missions. Unlike other missions carried out by ISRO so far where mostly observation or service-oriented hardware was flown as payload, HSP will carry humans (as payloads). This creates bundle of opportunities for development of human centric technologies in a large spectrum of domains and disciplines. Some of the technologies fall under the category of 'must haves' while others can be innovative in nature, giving alternatives to existing technologies or enhancing certain aspects of mission.

SAC is developing various systems towards HSP where audio, video and text communication systems will enable end to end two-way communication between ground command and astronauts. The technologies involved in this service include following:

1. Compact, space qualified camera systems.
2. Baseband units to switch, encode, compress video and audio streams.
3. Noise cancellation based audio communication systems with versions, which can be wearable and can be panel mounted.
4. Modems for RF communications.
5. RF communication network elements like Solid state power amplifiers, switches, filters etc.
6. Antenna systems including phased array antenna.

ECLSS (Environmental Control and Life Support System) is system of systems which helps maintain earth like atmosphere inside habitat volume of crew module. This primarily includes maintaining optimal oxygen level, removing carbon dioxide and maintaining PTH (Pressure, Temperature, Humidity). SAC is engaged in developing EMS (Environmental Monitoring System) which measures the values of oxygen and carbon dioxide concentration in cabin environment along with PTH values. Methane and ammonia are by product of metabolism in human body. Carbon monoxide is emitted when something burns. EMS will also measure concentration of these trace gases to keep check on environmental quality and hazard prevention.

A portable version of EMS called, HEM (Handheld Environment Monitor) also is developed. Astronauts can use it to check presence of CO2 pockets, origin of trace gases, tracing source of fire, emergency backup of EMS etc.

Fire is one of the prominent hazard on board human spaceflight mission. Detection of fire is complex and many pronged approach is needed to evaluate a fire scenario. At the same time, one false alarm can cause unnecessary mission abort. An array of sensors and integration of data from all the sensors is necessary as part of fire detection architecture. UV flame sensors and optical smoke sensors are first line of detection supported by data from thermal cameras and temperature sensors. Change in gas concentration indices also are included in decision making before raising fire alarm. Dousing fire is manual and water mist based fire extinguishers will be used on board this mission.

First point of interaction for astronauts with their module is display system. As primary situational awareness instrumentation, display system receives data from mission computer in the form of parameter values like path, position, velocity and altitude of orbiter module and displays it as combination of graphs, bars and text. Another set of information is Environmental Control and Life-support Subsystem (ECLSS) parameters and medical parameters of astronauts that displays on separate pages. Mission status, date and time, list of tasks, warnings, alarms, text chat, video conferencing etc. are facilitated through display systems. Astronauts can navigate between pages using peripheral buttons on display. They can also command variety of actions using these peripheral buttons, which change its role based on current context or display page.

In addition to large LCD displays, a dot matrix display is developed which will show only critical parameters in alphanumerical formats.

Cabin lights are designed with white LEDs with intensity and color temperature control to automatically sync with time of the day. This feature would help maintain circadian rhythm of astronauts.

The most significant and critical phase of any human spaceflight mission is atmospheric re-entry and subsequent rescue of astronauts at rendezvous point of landing. Various systems are planned and being developed at SAC to support this phase of mission.

Radar Altimeter will be mounted beneath crew module to gauge exact altitude of crew module and pass it to mission computer so that parachutes can be deployed at right moment during descent phase. Location transmitter will read the precise location of landing after splash down through NavIC and GPS and relay the data to rescue team waiting at a safe distance in sea. An LED based high power VFB (Visible Flash Beacon) mounted on top of crew module will aid the rescue team in visibly locating the module in sea. Finally, a satellite phone in hands of astronauts with global coverage gives them ability to stay in touch with mission control even in last mile of mission.

Following areas are identified where academia can contribute directly. Driving factors of development shall be low mass, smaller volume, low power, environmental qualification for space and human rating aspects in design. Introduction of new technologies and improvement in existing technologies for HSP, both are seen as potential contribution from academia in this program. Indigenous development of these systems also adds value. The developed technique should also consider feasibility of implementation without affecting any of the existing functional requirements. Reliability aspects are of utmost importance in HSP. Hence, development should target reliability aspects right from concept formation stage and should be followed until building successful prototypes. Certification of every system for HSP is a significant aspect of development. Software used in such systems also undergo spell of certification. Certain design aspects in hardware and software must be built from beginning to aid certification process towards induction of hardware in an HSP mission.

8.4.1. Development of measurement systems and sensors for gas concentration

Human Spaceflight requires continuous measurement of concentration of major air constituents (O2, CO2, CH4, NH3 & CO) and more than 200 trace gases including trace volatile organic compounds (VOC) at ppm to ppb levels, which are relevant to astronaut's health. These are by-products of metabolism/combustion/chemical reactions in the cabin.

Measurement of these gases can be achieved by discrete sensors for each gas or by holistic techniques like spectrometry. Both approaches have their own advantages. Handheld measurement systems can use discrete sensors to build compact, light-weight and battery powered systems. Other techniques can be used to measure array of gases from the same sample. Indigenous development of compact and lightweight sensors and other systems using laser, chromatography, Fourier transform techniques etc. have good potential for present and future applications in HSP.

8.4.2. Development of mitigation techniques for Communication blackout during re-entry

A spacecraft entering the Earth's atmosphere is enveloped by a plasma sheath which results in complete loss or a severe decrease in the strength of RF signals between the re-entry vehicle and the ground. This is referred as Communication Blackout. It results in loss of voice communications and data telemetry during the re-entry of manned space vehicles. The black-out duration can be up to 10-15 minutes and it occurs during the most crucial part of the vehicle's flight. It coincides with the maneuver phase and eliminates ground support during this vital portion of the re-entry phase. In case of an accident during re-entry, this phase is important for post accidental analysis. Due to its criticality, it is important to develop techniques to mitigate this problem. The theoretical study and the analysis should be validated through the practical experiments. Practical experiments may be conducted in the suitable plasma environment to validate the following:

- Dependence of EM wave attenuation on plasma profile.
- Dependence of EM wave attenuation on operating frequency w.r.t. plasma frequency.

In principle, the most obvious way in which the reentry communication blackout problem can be alleviated is by designing the communications system with a system margin greater than the plasma signal attenuation encountered during reentry. Typical plasma attenuation may exceed 100 dB, thus the required system margin is unrealistically large and cannot be achieved in practice. Hence, other alleviation techniques should be investigated which can be used in conjunction with the system margin. Worldwide many experiments have been done using following techniques to overcome communication blackout:

- By avoiding attenuation region in plasma sheath: Higher Frequency method.
- By reducing concentration of electrons in plasma sheath: Aerodynamic shaping, Injection of coolants.
- By altering the properties of plasma to minimize its interaction with the electromagnetic waves: Magnetic Field Method

Development of techniques to enable communication during this phase or to mitigate complete communication black-out can help existing and future missions of HSP. Experiments and finding that can aid to the understanding of phenomenon also can be seen as value addition.

8.4.3. Development of wireless communication systems

Introduction of wireless networking enhances communication in the vicinity of a spacecraft and also facilitates many aspects of communication within a spacecraft including mobile crew monitoring and communication, environmental monitoring and control, structural monitoring, and situational awareness. Wireless system designs should also consider conditions of operational space environment.

It is required to develop wireless systems that demonstrate reliable data transfer across avionics components, subsystems, and interfaces to simplify system integration, reconfiguration, and testing. Solutions that enable new avionic architectures and provide capabilities that expand mission performance while decreasing the Size, Weight, and Power consumption and cost of the resulting spacecraft are highly desirable.

Applications include sensors communication within habitat volume, communication during Extra Vehicular Activities, video capturing of separation events etc.

8.4.4. Active Noise Cancellation for Crew Cabin System

Due to the presence of various payloads, instruments and other systems, the on-board environment is inherently very noisy. Such high noise exposure for longer mission durations can cause damage to crew hearing system, result in crew efficiency reduction and also hamper with on-going communication.

To reduce the effect of continuously present noise on crew communication system, an active noise cancellation system can be designed and developed. With the help of active noise cancellation, resultant noisy environment can be reduced and improved QoS communication can be provided.

- Development of algorithm for Active Noise Cancellation in audio band
- Development of ANC circuitry

8.4.5. Study of In-flight identification and quantification of species in water for long term space missions

Long Duration Human Spaceflight requires continuous monitoring of water quality to ensure crew health and safety. Water monitoring equipment like colorimetric water quality monitoring kit (CWQMK) are already a part of the ISS. For our future space station and interplanetary travel requirements, it is important to initiate the developments of these systems. These instruments would have immense applications in future space station, interplanetary travel and other long duration space missions.

Development of apparatus, test setups for experiments related to above subject, evaluation of data received from such experiments and development of mitigation techniques for observed ill effects can help in current and future missions of HSP.

8.4.6. Assessment of flame spread of large scale microgravity fire

Materials with high flammability must be assessed for the flame spread rate using HEAT AND SMOKE RELEASE RATE TEST (Reference: NASA-STD-6001)

Understanding nature of flame, process of combustion, rate of spread, mass consumption, quantity and rate of heat release etc. can be taken up as study. Additionally, apparatus, test setups and identification of methodology, both on ground as well as in micro gravity also is needed to further the understanding of the subject.

8.4.7. Microbial monitoring in microgravity environment i.e. Non- culture based in flight monitoring with species identification and quantification

Microgravity can affect the growth and survival of microbes. The research on this topic is essential to achievesafe and healthy long duration space habitation. Non-culture based in-flight monitoring with identification and quantification of microbial species is targeted for the development.

This research would help in understanding the relationship between humans and microbes, which may be affected hugely in microgravity. It will enable the understanding of how and where microbes proliferate in confined environment in space.

Test setups and instrumentation required for remote observations can be developed to achieve the above mentioned purpose followed by findings and conclusions that may become input or directive for future missions.

8.4.8. Disinfection technique and technologies for microbial control of water systems and environment in microgravity

Disinfection and de-contamination are highly essential to achieve safe and healthy long duration space habitation. ISS has a decontamination system which was designed with crew members' safety in mind by using high-power, ultraviolet, light-emitting diodes (UV LEDs) to sanitize surfaces. This cleaning process takes only a matter of minutes before and after the crew conducts the experiments. The sanitation process also removes airborne contaminants -- such as biological and chemical impurities -- and cleans up spills inside the glovebox, providing optimal accommodations for cell science and life science research. It also has an exchangeable glove system that was redesigned to be better suited for these types of studies.

These disinfection systems based various technologies like the Ultraviolet Germicidal Irradiation (UVGI) method etc. are essential for long duration space missions/Space Stations for disinfection/removal of microorganisms. Other alternate techniques also can be developed which are safer and more efficient.

8.4.9. Application of AI and ML in crewed missions

Currently, System controls are based on ground based command or crew inputs through button/switch controls which require specific user action. Warning systems are based on predefined criteria and thresholds. AI and ML are relatively in nascent phase as far as space systems are concerned. However, the potential of technique and its application in future cannot be ignored. Hence, exploring possibilities of AI and ML in HSP is encouraged with all potential applications. Some are listed below.

- Voice based system commanding mechanism without restricting/requiring use of any limb action.
- An early warning system which learns from previous data to warn on possible occurrence of a hazard.

8.4.10. Compact fire suppression systems for crewed missions for micro gravity applications

On board fire in HSP is one of the most serious on-board hazards. Every HSP mission carries fire suppression system. FSS should be safe for humans, should be quick and efficient in dousing fire, should be clean and its application should be safe for onboard electronics. Fine water mist based FSS is in use onboard ISS now. Indigenous development of compact, portable, easy to use and safe FSS is needed for current and future HSP missions.

1.10. Microgravity experiment platforms to simulate microgravity on earth

Research in microgravity is indispensable to disclose the impact of gravity on biological processes, organisms, materials, fire and functional systems. "True" weightlessness, for more than a few seconds at least, can only be achieved in space or zero-g flights in atmosphere. Drop towers, drone based agile platforms etc. have potential to bring out microgravity experiment platform.

Test setups, approaches, new ideas to carry-out such tests can be used in existing and future missions of HSP.

8.4.11. Next generation fire detection systems

Fire is one of the most critical on-board hazard for any HSP mission. Detection fire is of paramount importance. Sensors must have very high sensitivity to variety of fire, flame and electric spark. At the same time, it should offer high immunity to false detection.

Most mission experiences have reported early detection by humans through smell, rather than on-board sensors. Development of "Electronic Nose" which can detect very low concentrations of combustion products can help in early detection of fire.

Fire is detected by measurement of concentration of specific gases, heat, temperature, flame etc. Novel approaches n detection, new parameters that can aid to detection of fire also is needed to enhance the fire detection scenario.

8.4.12. Display and other situational awareness technologies

Visual information (for situational awareness) is made available to the crew either through print pages or displays. A more effective method should allow crew to quickly access context based information.

Development can be focused on fixed and portable display devices with higher efficiency (lower size, mass and power) and better human centric aspects, taking advantage of advancement in display panel technology like flexible films displays etc.

Augmented reality based devices can be used to provide context based information to the crew for information such as visual alert, holographic communication and object information. AI and ML can be included in such systems to make them more efficient and effective.

8.4.13. Instrumentation for docking

Docking of spacecraft with space station or other manned modules for human or cargo transfer is an autonomous activity in most contemporary HSP missions. ISRO envisages development of these technologies to support automated or assisted docking while in orbit. Laser based or other types of ranging systems, camera based video systems, RF based systems are required for beacons, altimetry or distometry, velocimetry, optical flow techniques, close range photogrammetry and other parameters of situational awareness either in assist mode or in close loop mode for automated docking. Development of sensors, integrated systems and demonstration models can help in future docking missions of HSP.

9. SIGNAL & IMAGE PROCESSING

9.1. Infrastructure mapping and monitoring using AI/ML techniques from Synthetic Aperture Radar (SAR) Data

Synthetic Aperture Radar (SAR) is an active microwave sensor that can take images of targets during day as well as night and can also penetrate cloud cover. The high resolution images acquired by SAR can be used to map and monitor various infrastructure such as highways, airports, railway, bridges, buildings, vegetation etc. With availability of large amount of images from past, current and future SAR missions, a software for classification and temporal monitoring of government and non-government assets can be very useful for administrative purposes. The prime focus of this research is design and development of AI/ML based technique for identification and classification of infrastructure in the readily available SAR image datasets. The infrastructures thus identified can be added to a library which can be referred by government/non-government agencies for various planning and temporal monitoring activities. It will also enable the monitoring of the areas for which optical images may not be available around the year due to cloud cover/day-night issues. SAR Images from RISAT-1 / RISAT-1A(EOS-04) / RISAT-1B (EOS-09) missions can be used for this activity.

9.2. Moving Targets identification and their parameter estimation from SAR Images

During Synthetic Aperture Radar (SAR) imaging, the sensor is flown in an Aircraft/spacecraft, pulses are sent and the return echoes are recorded. While processing, the range and the relative motion between sensor and target (earth) is utilized to generate images. In SAR, the background region, called clutter, is the region of interest and it is assumed to be stationary and SAR image focusing is done. Moving targets likes cars, trains, etc. in the images are defocused and/or displaced and may appear as artifact in the image. Primary focus of this research is algorithm and corresponding software development for

- Moving Target detection using state of art along track interferometry techniques
- Moving Target detection in Raw/Processed SAR datasets
- Estimation of target parameters like position and velocity
- Focusing of moving targets in SAR images
- Removal of artefacts from SAR images generated due to moving targets

Getting information of moving targets for SAR image will provide valuable information in utilization of SAR images in strategic applications. Artefact removal and refocusing of moving targets in SAR images will result in enhanced SAR image quality. Additionally, the work will help in designing the state of the art SAR systems for moving target indication.

9.3. Passive Bi-static SAR Image Formation using GNSS Signals

Synthetic Aperture Radar (SAR) are microwave sensors and have day night & all weather imaging capability. In SAR, pulses are transmitted from Airborne/Spaceborne platforms and return echoes are recorded. These return echoes are used to form the high resolution SAR images using signal processing methods. Image formation, in cases where receivers are at different platform than the transmitter, is termed as passive bistatic SAR image formation. Globally, around the earth, many microwave systems are working in microwave frequency range suitable for SAR image formation. Navigations systems like GPS & IRNSS, are such type of systems primarily operating in L & S Band. Reflected signal corresponding to the signals transmitted from these systems are being recorded in passive receiver (like GNSS-R onboard Microsat-2C, CyGNSS). These are signals of opportunity which are highly reliable & stable and can be used for SAR image formation as well.Design and development of techniques for SAR image formation from GNSS signals and corresponding software implementation is the primary focus of this research. This research has the potential to generate SAR images using low cost receiver only systems with enormous applications.

9.4. Hyperspectral and LiDAR Data Fusion for Enhanced Remote Sensing Analysis

Introduction:

Remote sensing technologies, such as Hyperspectral Imaging (HSI) and Light Detection and Ranging (LiDAR), provide valuable environmental and geographical data. While HSI offers detailed spectral information across a wide range of wavelengths, LiDAR captures precise three-dimensional (3D) spatial data, enabling high-resolution topographic measurements. Integrating these two datasets can significantly enhance our ability to analyze complex environments by combining spectral, spatial, and geometric features. The research should explore and implement recent trends in machine learning and deep learning models to achieve the hyperspectral and LiDAR fused output.

Research Objectives:

The goal of this research is to develop a robust framework for the fusion of Hyperspectral and LiDAR data to improve object detection, land cover classification, and environmental monitoring. The research objectives are as follows.

- To explore the potential benefits of fusing hyperspectral and LiDAR data for improved landscape classification, particularly in vegetation and urban areas.
- To develop and assess fusion algorithms that leverage both the spectral and spatial dimensions of these datasets.

- To evaluate the fusion's ability to detect and characterize environmental features such as vegetation health, urban structures, and terrain variation.

Expected Outcomes:

The fusion of hyperspectral and LiDAR data will enable more accurate and efficient classification of land cover types, particularly in challenging environments where either modality alone may be insufficient. It will also enhance our understanding of environmental changes over time, providing a powerful tool for monitoring ecosystems, urban development, and natural disasters.

9.5. Development of Foundation Model for Satellite Images

Introduction:

Satellite imagery plays a pivotal role in addressing global challenges such as climate monitoring, disaster management, urban planning, and defence. However, the vast volume and complexity of satellite data require advanced analytical tools. Foundation models, pre-trained on large-scale datasets, have revolutionized fields like natural language processing and computer vision. Developing a foundation model specifically for satellite images can unlock unprecedented capabilities in automating analysis, improving accuracy, and enabling cross-domain applications, thereby enhancing decision-making for space organizations and stakeholders.

Objectives:

- To design and train a foundation model tailored for satellite imagery, leveraging large-scale datasets from diverse sources.
- To enable multi-task learning for applications like land cover classification, object detection, and change detection.
- To improve generalization across geographic regions, sensors, and resolutions.
- To provide an open-source framework for fine-tuning and deployment in downstream tasks.

Scope:

The project will focus on developing a scalable, transformer-based architecture trained on datasets of Indian landscape from different Indian satellite (e.g., HRSAT, Cartosat, Resourcesat, NISAR, Microsat, RISAT etc.) catering data across different modality of optical and infrared data to SAR data, high-resolution data to coarse resolution imagery. The model will be evaluated on benchmark tasks and real-world use cases, ensuring adaptability to various space organization needs.

Methodologies:

1. **Data Collection and Preprocessing:** Curate a diverse dataset of satellite images with annotations for supervised and self-supervised learning.
2. **Model Design:** Implement a vision transformer (ViT) or hybrid CNN-transformer model optimized for multi-spectral and multi-temporal data.
3. **Training:** Utilize self-supervised learning techniques (e.g., masked autoencoding) to pre-train the model on unlabeled data, followed by fine-tuning on specific tasks.
4. **Evaluation:** Benchmark performance on tasks like segmentation, classification, and anomaly detection using standard metrics.

Possible Outcomes:

1. A robust foundation model capable of handling diverse satellite imagery tasks.
2. Reduced dependency on task-specific models, saving time and computational resources.
3. Enhanced interoperability across datasets and sensors, enabling seamless integration into existing workflows.

Benefits to our organizations:

The foundation model will empower our organization to automate routine analyses, improve disaster response, monitor environmental changes, and optimize resource allocation. It will also foster innovation by enabling researchers and developers to build specialized applications with minimal effort. By leveraging cutting-edge AI techniques, this project will provide a versatile tool for space organizations, driving advancements in global sustainability, security, and scientific discovery.

9.6. Utilizing Neural Radiance Fields for Multi-View Geometry Reconstruction in Satellite Imagery for DEM and DSM Generation

Introduction

Digital Elevation Models (DEM) and Digital Surface Models (DSM) are crucial for various geospatial applications, including topographic mapping, urban planning, and environmental monitoring. Traditional methods for DEM/DSM generation, such as photogrammetry and LiDAR, can be computationally expensive and sensitive to data quality. Additionally, photogrammetric approaches require high-quality stereo pairs with consistent lighting conditions, while LiDAR is costly and limited by accessibility constraints. The increasing availability of high-resolution satellite imagery presents an opportunity to explore alternative methodologies that can leverage deep learning techniques for enhanced 3D reconstruction.

Neural Radiance Fields (NeRF) have demonstrated impressive results in reconstructing 3D geometry from sparse 2D images by modeling volumetric scenes with high fidelity. However, existing NeRF implementations are optimized primarily for synthetic or ground-based images, with limited studies addressing large-scale aerial or satellite-based reconstructions. This research aims to bridge this gap by developing a NeRF-based framework tailored for multi-view satellite imagery, enabling accurate and scalable DEM and DSM generation. If successful, this approach could significantly improve terrain modeling efficiency and precision, benefiting industries such as agriculture, disaster response, and military reconnaissance. In addition, this method has direct applications in high resolution satellites such as HRSat and Cartosat.

Objectives

1. Investigate the feasibility of applying NeRF to reconstruct high-fidelity 3D structures from multi-view satellite images, considering factors such as atmospheric distortions, varying resolutions, and occlusions.
2. Develop an optimized pipeline for training NeRF on satellite datasets to generate DEM and DSM, incorporating domain-specific modifications such as multi-scale feature representations and geospatial constraints.
3. Compare the accuracy, resolution, and computational efficiency of NeRF-based reconstruction with traditional photogrammetry and LiDAR-based methods to assess its viability for large-scale applications.
4. Explore potential enhancements to NeRF, such as integrating hybrid neural representations, incorporating auxiliary sensor data (e.g., synthetic aperture radar), and leveraging super-resolution techniques for improved terrain detail extraction.

Expected Outcomes

1. A validated framework for leveraging NeRF in DEM and DSM generation from satellite imagery.
2. Improved elevation models with enhanced resolution and accuracy compared to traditional methods.
3. Insights into the applicability and limitations of NeRF in large-scale remote sensing tasks.

9.7. Automatic Road Extraction Using High-Resolution Satellite Imagery

Introduction:

This research focuses on developing an automatic road extraction model using high-resolution satellite imagery and deep learning techniques. Road networks are critical for transportation, urban planning, and disaster management. However, manual road extraction from high resolution satellite images is time-consuming and error-prone. This study proposes a deep learning-based framework leveraging Convolutional Neural Networks (CNNs) and Transformer-based architectures to enhance road detection accuracy, reduce occlusions, and improve computational efficiency. The research aims to develop a robust model that generalizes across different environments and datasets, contributing to remote sensing and geospatial analysis applications.

Research Objectives:

1. Develop an automatic road extraction model using high-resolution satellite imagery.
2. Improve segmentation accuracy using deep learning techniques.
3. Address challenges such as occlusions, varying road textures, and illumination differences.
4. Evaluate model performance on multiple datasets for better generalization.
5. Optimize computational efficiency for real-time or near real-time applications.

Expected Outcomes:

This research aims to develop a high-accuracy road extraction model applicable to urban planning, disaster response, and autonomous navigation, improving road segmentation in complex environments.

10. EARTH, OCEAN, ATMOSPHERE, PLANETARY, SPACE SCIENCES & APPLICATIONS

EPSA is responsible for activities related to understanding Earth System, its components, processes and interactions using earth observation data, and its applications towards societal benefits. It aims at identifying Earth Observational (EO) requirements, development of techniques to analyse data to address the science issues and applications related to land, ocean, atmospheric and planetary sciences. The research pertains to operational retrieval of biophysical and geophysical parameters from space borne sensors, sensitivity analysis, calibration and validation of the sensor and retrieved parameters, assimilation of remote sensing derived parameters, in-process modelling pertaining to interactions within the geosphere-biosphere system and atmosphere. EPSA as an excellent multi-disciplinary scientific team has the following major research themes:

- Sensor definition studies towards development of state-of-the art EO Sensors
- Development of operational retrieval techniques of bio-geophysical parameters from Indian Earth
- Observation as well as Planetary missions
- Advance R & D on retrieval of Geophysical and Biophysical parameters
- Synergetic use of space borne data to derive value added bio-geophysical parameters
- Development of procedures and advanced techniques for inventory and monitoring of natural resources using geo-informatics.
- Modeling of dynamic physical processes for improved weather and ocean state prediction
- Development of assimilation techniques for improved predictions
- Assessment of environmental impact and associated climate change over different ecosystems.
- Utilization of data from Indian Satellite Missions including INSAT-3D/3DR, Oceansat-2, Oceansat-3, Cartosat-1/2, Resourcesat-2/2A, SARAL AltiKa and Megha-Tropiques.
- Planetary Sciences
- Designing, generation and updating of resource database ranging from local to national scale.
- Capacity building of scientists at national and international level for EO application programs.
- Archival, Dissemination of the Meteorological & Oceanographic Satellite data, Experimental forecasts and value added products
- Archival, Dissemination of the Earth & Planetary Science Data
- Providing platform to students, academicians & researchers for the analysis of Satellite data

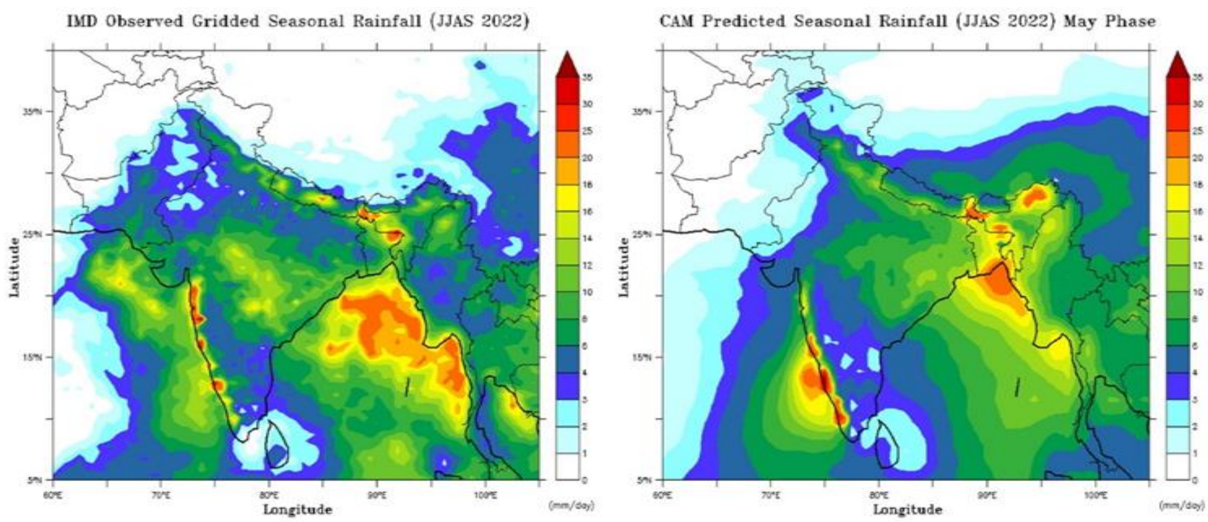
Major research areas are summarized below:

10.1. Research Areas in the field of Atmospheric Sciences

Atmospheric science is the study of the Earth's atmosphere and its various interacting physical processes. Atmospheric dynamics in particular is the study of motion systems of meteorological importance, integrating observations at various spatiotemporal scales. It includes diverse phenomena such as thunderstorms, monsoon, tropical cyclones, and global-scale circulations. The objectives of such studies incorporate improving weather forecasting, developing methods for predicting seasonal and inter-annual climate fluctuations, and understanding the implications of human-induced changes on the global climate. Important research areas and challenges involved in ongoing program is as follows.

10.1.1. Seasonal Prediction of Indian Summer Monsoon rainfall (ISMR) using Climate Model

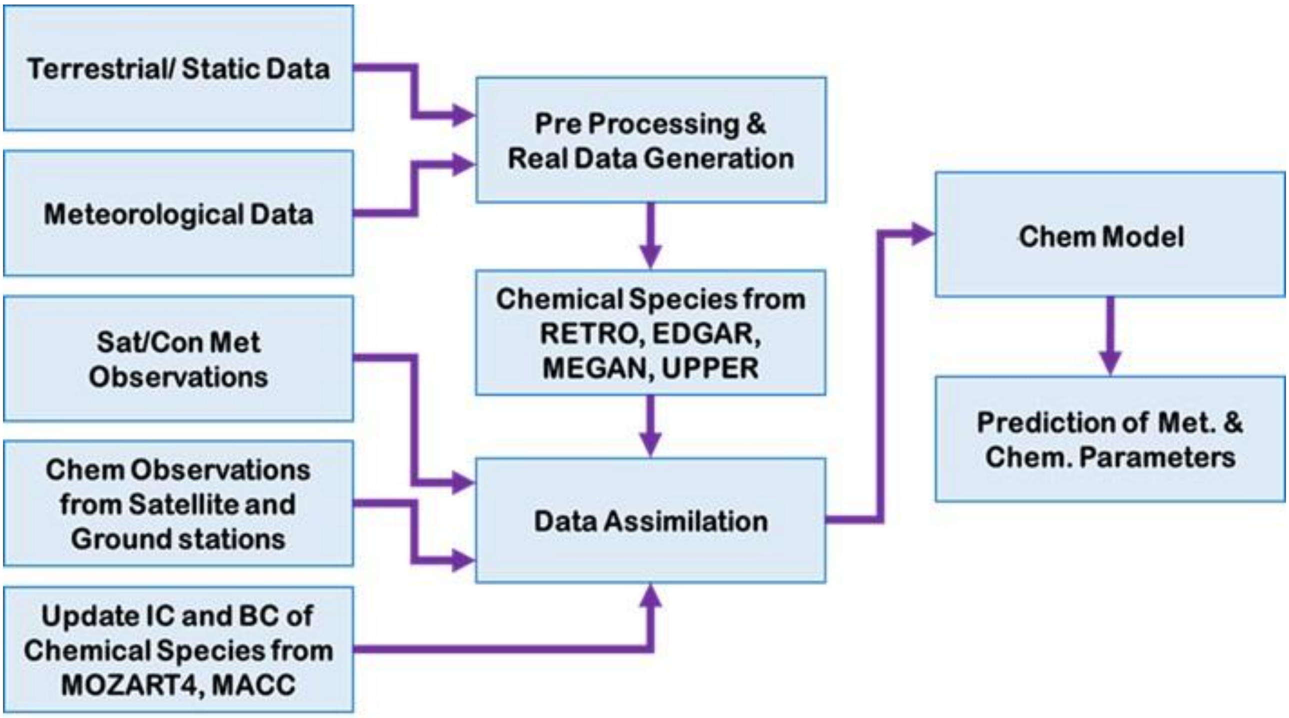
The Indian summer monsoon (ISM) occurring every year from June through September, is one of the most dominant features of the global hydrological cycle. It causes more than 75% of annual rainfall over the country during this period. Although, the onset of the monsoon over Kerala in India takes place at the start of June with the seasonal reversal of wind over the Arabian Sea with a consistent manner from year after year, the seasonal prediction of ISMR during the recent times become more and more challenging. It is mainly due to several external factors both natural and manmade viz. the fast changing climate, the manmade changes in land-use-land-cover, The fast growing infrastructure development activities in large scale over a landmass that significantly modify the respective land surface properties, heat and water budget, composition of atmospheric gases, aerosols etc. One of the biggest challenge is to model these changes and incorporate the impact of them in medium to long-term model prediction.



Therefore, there is a recognized need to demonstrate the state-of-art seasonal prediction of ISMR describing both the spatial and temporal variability of rainfall in conjunction with the satellite and in-situ observations. A seasonal prediction system has been setup at Space Applications Centre (SAC) Ahmedabad in research and operational mode. The experimental prediction of ISMR has been generated through 50-member ensemble CAM model simulation during April every year and updated monthly till September. Each ensemble member has been started with different initial conditions and sea-surface boundary conditions. End of season (EOS) validation has been conducted every year to measure the model prediction skill and to identify the shortcomings and lacuna of the prediction system. It is a continuous evolving process of the prediction system to improve its skill of prediction year after year.

10.1.2. Impact of Atmospheric Chemistry on Weather Prediction

Atmospheric aerosols have a large influence on air quality and, also in the well-being of human and ecosystem. Aerosols affect the earth-atmosphere radiation budget directly by scattering and absorbing the incoming solar radiation and indirectly by influencing the processes of formation of clouds and precipitation. Assimilation of satellite derived aerosols and other chemical constituents in NWP along with the chemical transport modelling have been planned (Figure). The impact of chemical data assimilation on mesoscale weather prediction will be also studied.



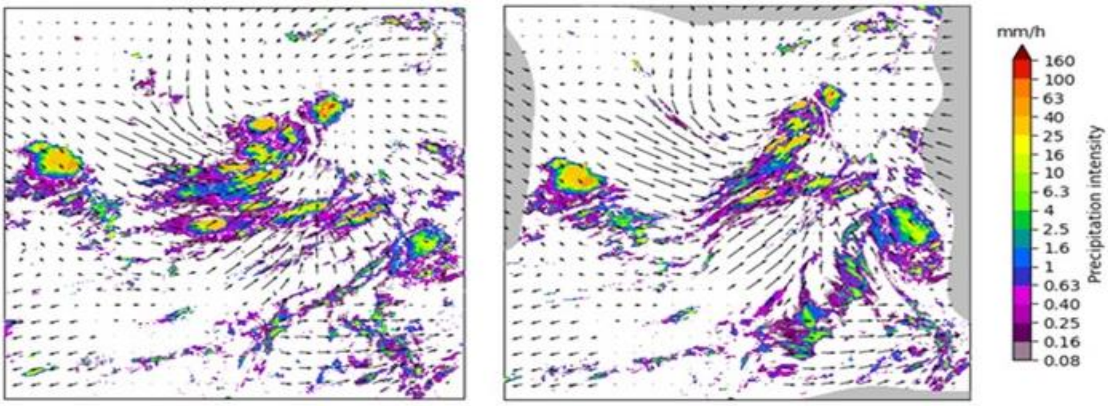
Design of Study

10.1.3. Assimilation of Satellite Data in Numerical Weather Prediction Models

Accurate prediction of high-impact weather events and the area of the greatest threat represent a major challenge for planners to minimize the loss of lives and damage to property. Advance research is being planned to carry out non-linear data assimilation of satellite measurements in the numerical weather prediction (NWP) models. ISRO is aiming at improving short-range weather forecasting using satellite observations. For this activity various satellite observations are ingested in the NWP model using advance data assimilation techniques. In addition, research is also focused to improve NWP prediction using combination of Data Assimilation and Machine Learning methods.

10.1.4. Satellite and radar based weather nowcasting

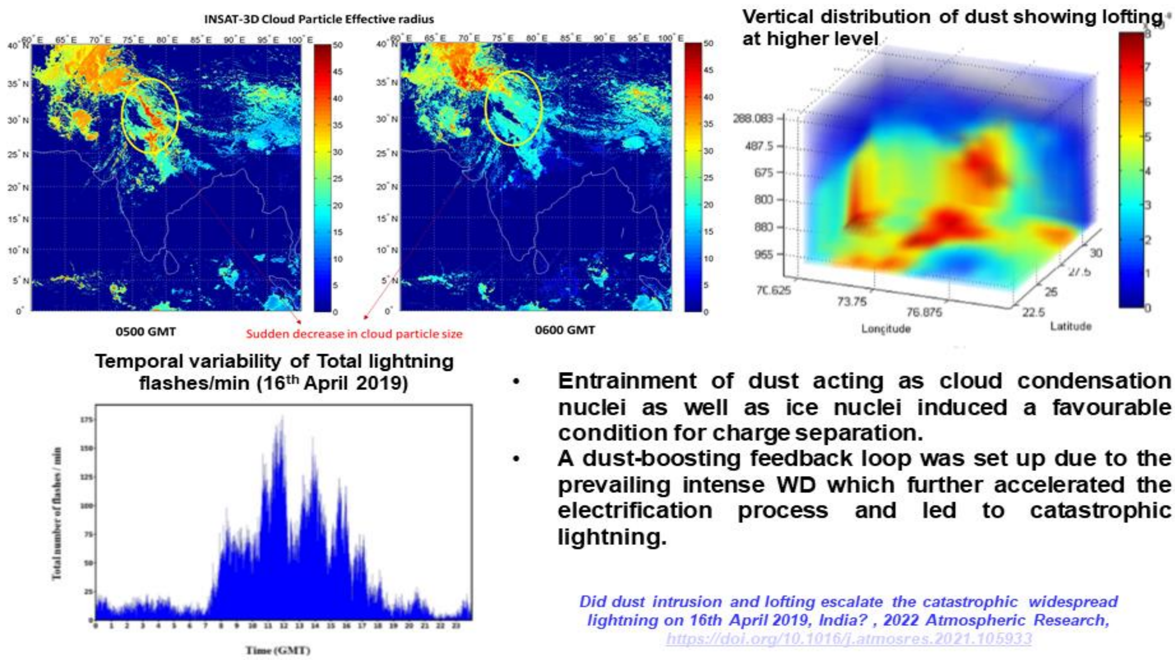
Satellite and radar data is being used for development of algorithms for nowcasting and tracking of cloud and precipitating systems. INSAT-3D/3DR data is extensively used for monitoring cloud growth and also for predicting the flow fields associated with precipitating systems. The research outputs feeds into the operational nowcasting application hosted on the MOSDAC webportal for societal benefit. In conjunction, Doppler weather radar (DWR) data is also used for developing algorithms to track and predict the movement of convective systems. Polarimeteric radar has also been used to develop Hydrometeor classification algorithm for more potential lightning prediction. Furthermore advanced AI/ML are been experimented on, for better accuracy and longer lead time. In near future blending of data / model outputs from different sources is future.



Optical Flow using LK *1 Hour Nowcast*

10.1.5. Satellite based Cloud Microphysical applications

Data from multitude of satellite sensors are used to derive information about cloud microphysical parameters. The study of cloud processes in microscale is also carried out to improve our understanding of many meteorological phenomena like monsoonal active and break phases, tropical cyclone development, intrusion of dust into thunderstorm and its impacts. In addition, we are also experimenting on different schemes to generate a merged cloud microphysical product from optical sensors onboard different satellites.



10.1.6. Cyclone Track and Intensity Prediction Using Satellite Data and Numerical Models

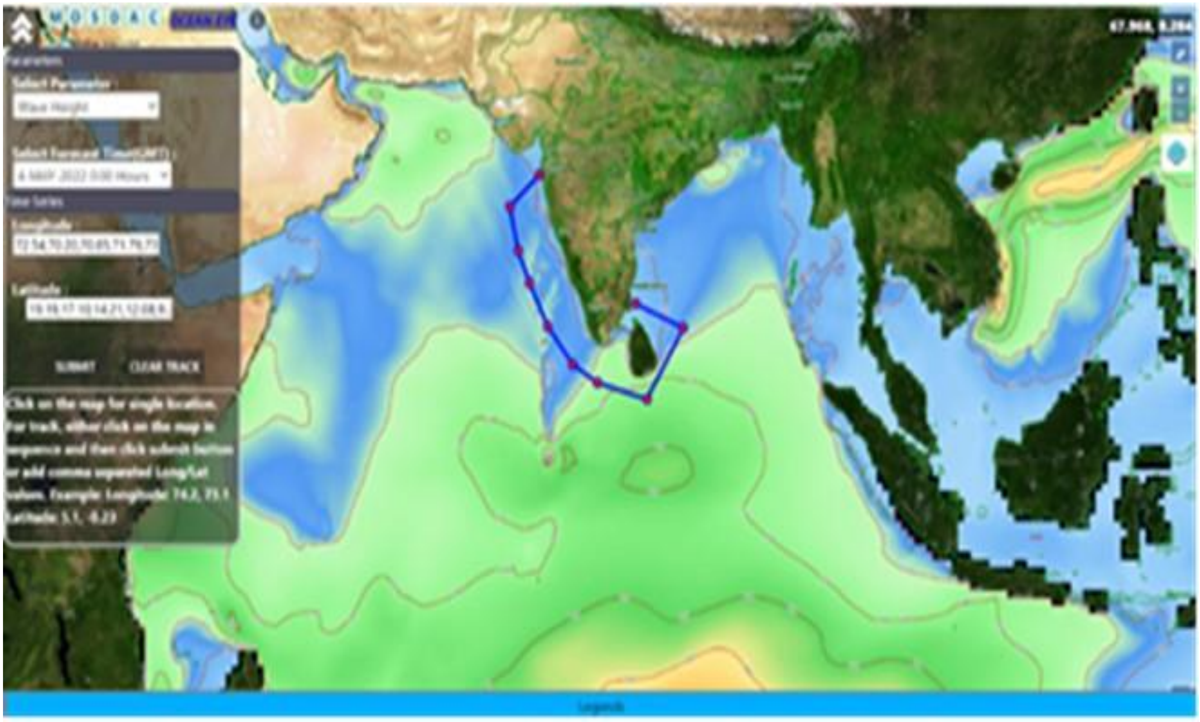
Advance and accurate prediction of tropical cyclones is highly important for issuing the warnings and saving the lives. Real-time winds obtained from scatterometer (SCATSAT-1) are used for tropical cyclogenesis predictions of all the low-pressure systems formed in the North Indian Ocean. The cyclone track and intensity prediction is being done using numerical models and satellite data that involves empirical and dynamic modelling and assimilation techniques. The cyclone centric satellite products are generated, which are very useful for cyclone positioning and its structure and intensity estimation.

10.2. Research Areas in the field of Physical Oceanography (Development of Blue Economy)

Physical oceanography research at the Space Applications Centre aims towards making use of current and future satellite observations in combination with in situ and numerical models to provide a holistic approach and to develop new techniques, novel modelling concepts, advanced data assimilation schemes, usage of very high-resolution satellite data for the wider areas of applications like monitoring and forecasting oceans for safe navigation, productivity and climate/long-term change impact in and around the Indian Ocean. These dedicated research activities would finally serve towards the sustainable development of the ocean based Blue Economy: an economy model that aim towards shifting society from scarcity to abundance with locally available resource

10.2.1. Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE)

Assimilation of Satellite/In Situ Data in Numerical Ocean Prediction Models: Observation System Studies Experiment (OSSE). Advance research is being carried out for assimilation of satellite derived parameters salinity, temperature, sea level, wave height, ocean color and wave spectrum) in ocean prediction models. This involves development of various assimilation techniques for improving the initial condition in the models. Apart from satellite data, lot of in situ measurements (glider, HF Radar, wave rider buoys etc.) are also being taken in the present. The outputs from these models are routinely available on the mosdac.gov.in through the “Ocean Eye and disseminated on request through an automatized email based system.

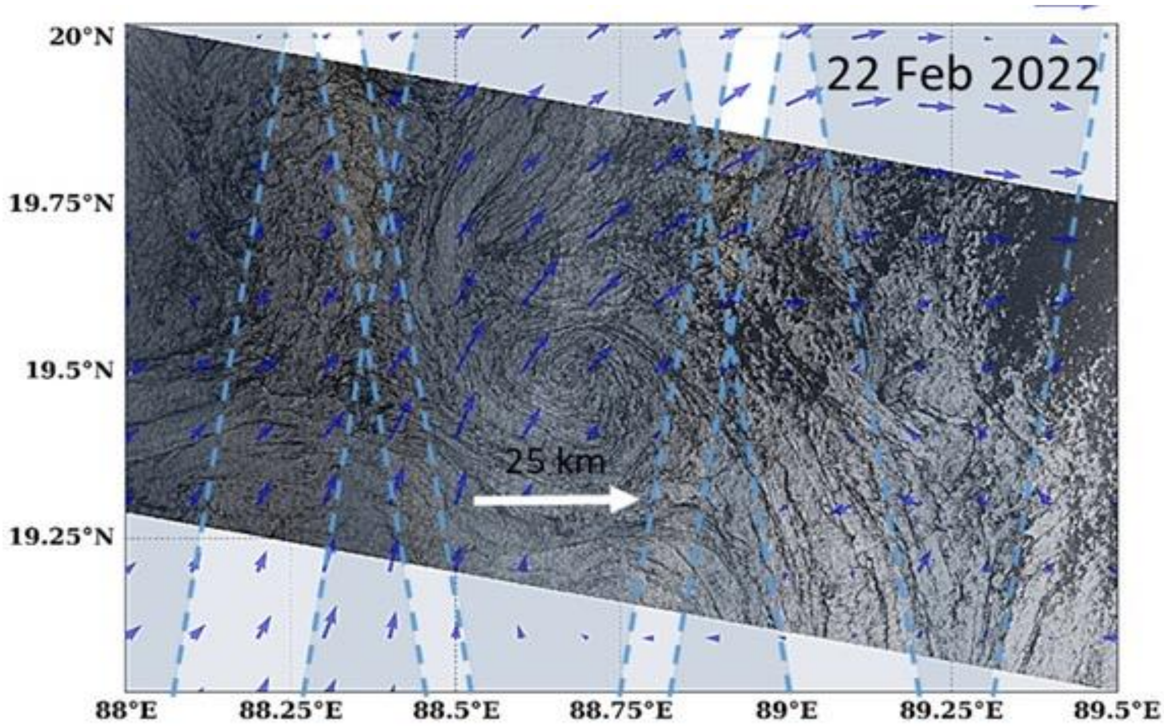


Snapshot of Ocean Eye web portal displaying the forecast map of significant wave height for a particular day. Blue lines indicate the track od ship, which can be overlaid using tools provided in the ocean eye web portal.

In order to identify gap areas in the current space based observing systems, observing system simulation experiments are performed for defining future sensor missions. This require intensive modelling and optimization techniques to ascertain the importance of satellite-based and in situ-based observations and to suggest optimum sensor characteristic. Model tuning by parameter estimation using data driven techniques (like AI/ML) can be an important step in improving the model simulations.

10.2.2. High Resolution Oceanography

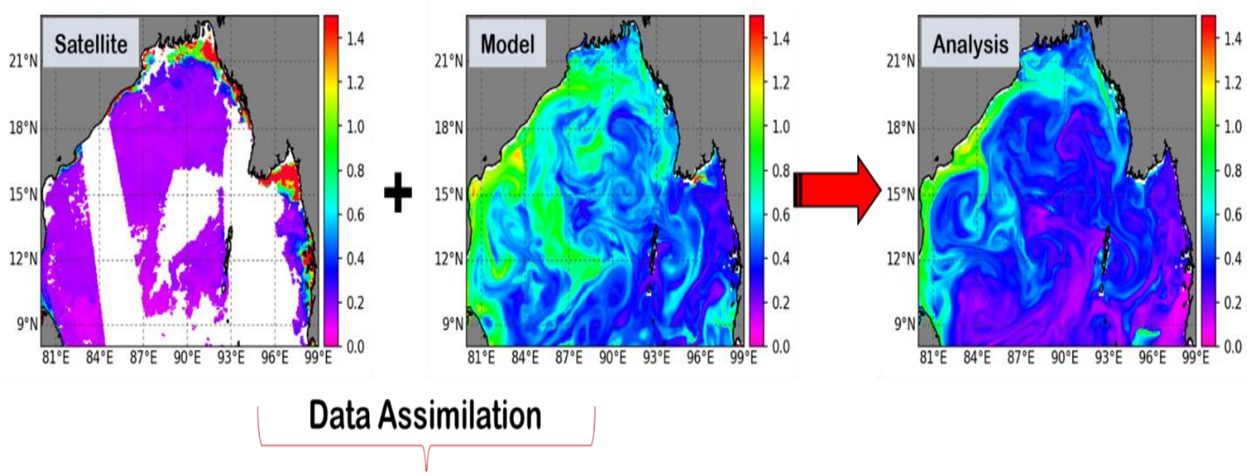
In the view of high resolution (temporal and spatial) satellite observations from synthetic aperture radar, forthcoming Oceansat-3, Surface Water and Ocean Topography mission (SWOT) mission, and optical imageries, high resolution oceanography is fast becoming a reality. Synergistic use of these information will be key to understanding many unresolved processes at sub-mesoscale level, which can help in better ocean estimation. Interaction of mesoscale scale dynamics (eddies) with sub-mesoscale is another interesting area of research for energy cascading. Region specific high resolution models with relocatable grids are being utilized for this purpose.



An example of high resolution eddy field from SAR which will be used to correct high resolution model generated currents (overlaid in blue vectors), in which the eddy is displaced by around 50km

10.2.3. Ocean Reanalysis and Air Sea Interaction Studies

One of the future goals is to develop a methodology to generate high quality three dimensional ocean reanalysis product for last 30 years based on satellite observations and numerical ocean model. This will be utilized not only for various oceanic process studies but also to initialize seasonal prediction coupled models. Some of the reanalysis fields that are currently being generated are of sea level, currents and chlorophyll.

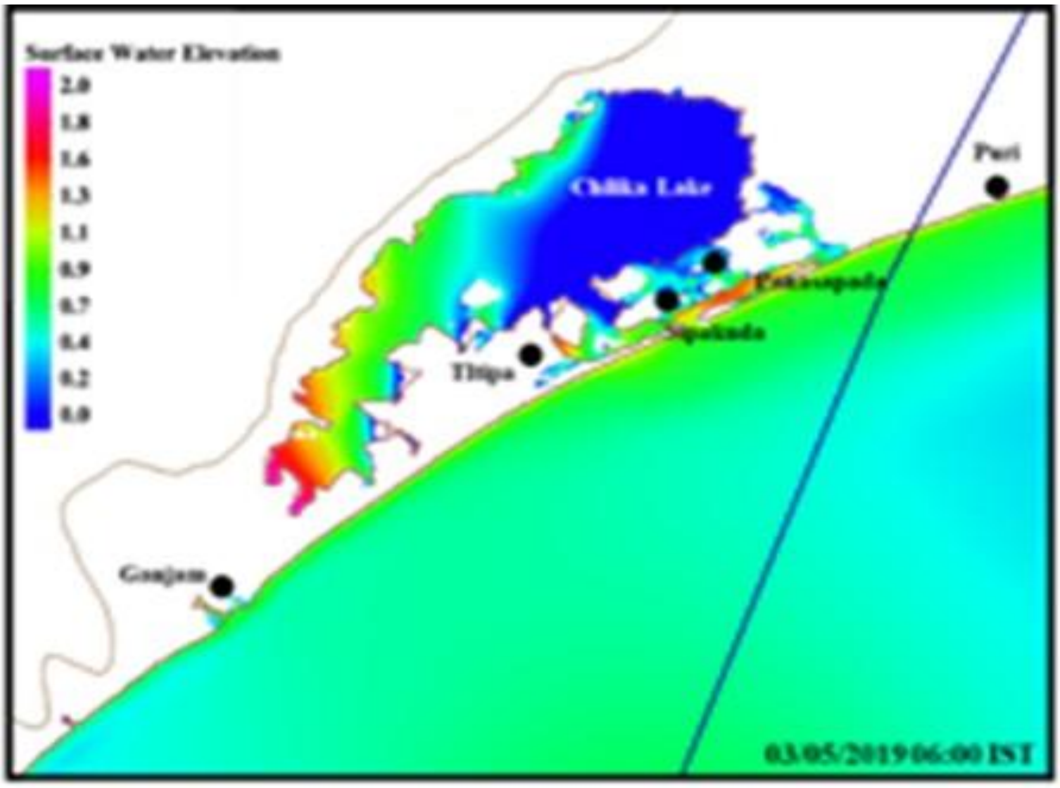


Generation of high resolution chlorophyll analysis using a combination of numerical model, satellite data assimilation technique

Research is also being carried out in generating merged products (like for e.g. SST) by combining observations from various Indian and International missions in order to provide continuous and gridded space-time observations for various applications and process studies. Efforts are also being carried out to generate high resolution salinity field from low resolution satellite observations using Lagrangian based techniques. These fields will be useful for fine scale process studies.

10.2.4. Study on Coastal dynamics Using Satellite and High Resolution Numerical Models

Coastal dynamics are extremely important to understand as it has significant implications on coastal population. Currently following research topics are being envisaged in SAC:

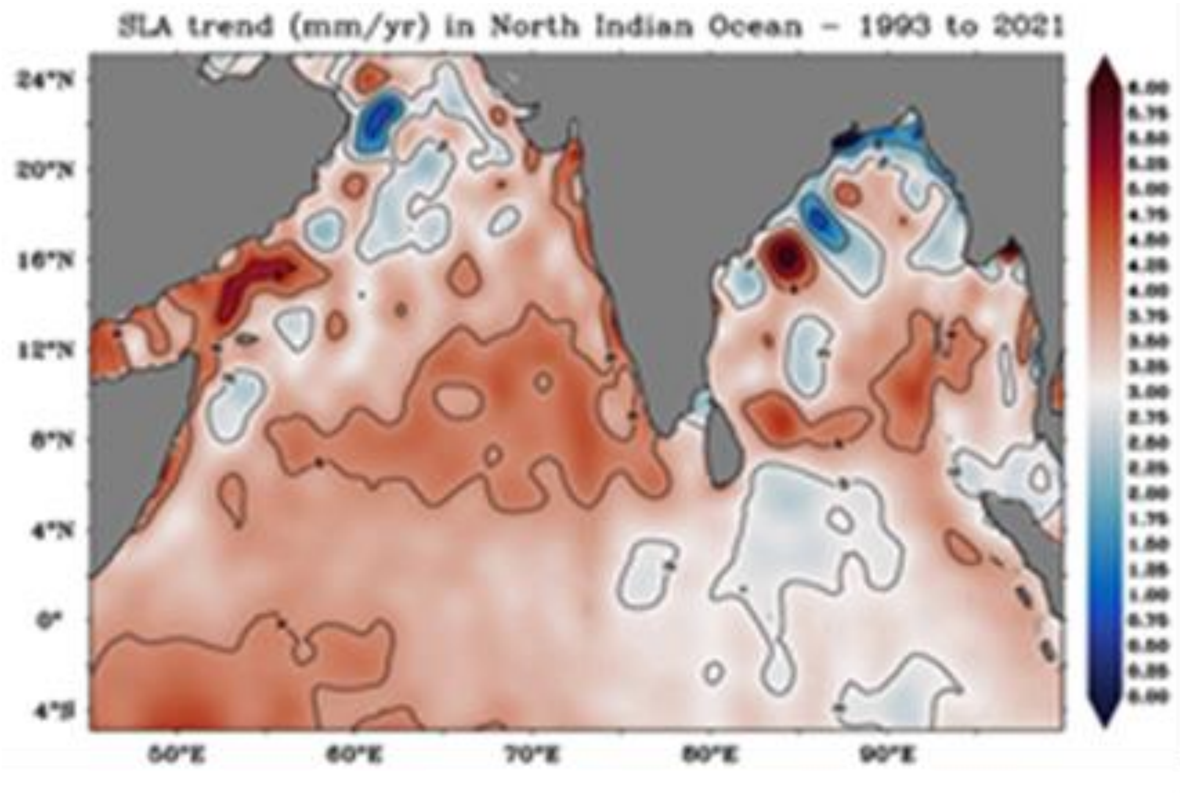


Coastal Inundation during TITLI Cyclone

- Storm surge and coastal inundation: In this component, numerical models and satellite data are used to simulate and forecast the storm surge and inundation along the Indian coasts during the event of cyclone. Impact of satellite derived winds is also studied. This activity will be further extended to generate vulnerability maps for Indian coasts due to storm surge inundation in the climate change scenario.
- Oil spill trajectory forecasting is extremely important for planning the mitigation steps in order to minimize the damage to the marine ecosystem due to an event of oil spill. Advection based models have been developed in house in order to identify the source of tar balls found on the beaches of various Indian coasts. Further research with high resolution satellite currents (from combination of SWOT and Oceansat-3) and introducing complexities in the trajectory models is being carried out. Finite time Lyapunov exponent (FTLE) fields derived from satellite currents are available on MOSDAC that help to forecast pathways of oil spill.

10.2.5. Seasonal Ocean Prediction with Coupled Atmosphere-Ocean Models

Forecast of anomalous oceanic conditions (Dipole/El Nino) at least one season in advance is of high importance as it has direct influence on the Indian Summer Monsoon. These seasonal to long term forecasts are required to be done by making synergistic use of satellite observations and couple Ocean Atmosphere models. Effect of satellite data assimilation on the skills of these forecasts are also required to be assessed.



Regional sea level trend using altimeter observations from 1993-2021

Regional Sea level rise is analyzed from the 36 years of altimeter observations and the mechanisms responsible for difference in Service-level Agreement (SLA) rise rates in different basins (Arabian Sea and Bay of Bengal) are being studied. One of the major challenges is the coastal sea level rise, for which the only source of observations are the tide gauge stations because of the non-availability of altimeter data near to the coast. Hence it is required to develop AI/ML based/dynamical techniques for interpolating/downscaling sea level observations from altimeter to the coastal regions by making use of numerical models and tide gauge stations. This is an important activity which will further help in identification of vulnerable zones in the climate change scenario.

10.2.6. Coastal Geosciences

Coastal zones are the interface between land and ocean and are dynamic fragile ecosystem, where interaction among complex natural coastal processes, coastal hazards, vital habitats and human activities occur and integrated studies for sustainable coastal zone management are required for protecting life, property and environment. Some of the major coastal geoscience research area includes coastal sediment transport modelling using satellite retrieved parameters, understanding coastal processes and causes of coastal erosion, dynamics of various coastal processes and its impact on evolution of coastal geomorphology, modeling coastal erosion and developing methods to predict shoreline changes, use of advanced automated methods to delineate shoreline (high Threshold Logic (HTL)/ Less than Truckload (LTL)) from satellite data, understanding impact of coastal processes on critical/vital habitats, understanding impact of predicted sea level rise on coastal zone, understanding coastal hazards and vulnerability/risk assessment, developing techniques for automated coastal landforms/wetlands/land use/land cover mapping, detecting and monitoring coastal pollution, understanding impact on coastal ecosystem and developing models for integrated coastal zone management.

10.3. Research Areas in the field of Geophysical Parameter Retrievals

Retrieval of geophysical parameters from satellite observations refers to assessment of surface and atmospheric parameters that have contributed to the observations. Innovation, accuracy, and timeliness are the key requirements for the parameter retrieval, particularly for their effective use in the operational services. Continuous efforts are needed to define new sensors for future missions, develop retrieval algorithms for new parameters from existing sensors and from advanced sensors proposed for the future.

10.3.1. Retrieval of Geophysical Parameters from Satellite Data

ISRO has planned for launching a number of meteorological and oceanographic satellites in near future. Presently it has INSAT-3D/3DR satellites in the orbit. In near future, it has plan to launch many satellites in Geostationary and polar orbits for the same such as Oceansat-3 and INSAT-3DS. This also includes many advanced sensors such as Microwave Temperature Sounding Unit (TSU) and Humidity Sounding Unit (HSU) in future missions. There is also possibility of inclusion of an advanced microwave radiometer similar to GPM Microwave Imager (GMI) in future missions. Future generation of INSAT satellite may also have advanced imager, lightning imager and hyperspectral sounder on-board. It is a challenging work to retrieve geophysical parameters from the sensor data of these satellites. This involves Radiative Transfer modelling, Geophysical Model Function development and the Inverse modeling techniques.

10.3.2. IRNSS/GNSS Applications

IRNSS/GNSS offers unique opportunity to retrieve atmospheric geophysical parameters such as TPW. ISRO may also develop satellite-borne receivers for IRNSS/GNSS reflectometry, which has potential to provide various surface parameters including sea surface height, intense sea surface wind speed and direction under severe weather conditions, soil moisture, ice and snow thickness, etc. Theoretical modelling and simulations of the reflectometry observations is desired for the retrieval of the parameters. Until IRNSS receivers are not available, International missions such as TDS-1 and Cyclone Global Navigation Satellite System (CYGNSS) can be used to validate the simulation studies and retrieval algorithms.

10.3.3. Merged Data Products

Develop data fusion methods to derive most optimized products using a synergy of observations. The examples are (a) Optimized temperature/humidity profiles using IR and microwave sounders (b) Optimized SST and rainfall products from IR and Microwave imagers.

10.3.4. Advanced System Studies for New Sensor Definition

For measurements of atmospheric and Oceanic parameters, new advance sensors have to be defined for future satellites. System studies are being done with the help of Radiative transfer models to define the appropriate frequency, NEDT/SNR and bandwidth of new sensors. Sensitivity analysis is also being carried out to understand the error budget and appropriate resolutions (both spatial and temporal) required for the retrieval of geophysical parameter.

10.3.5. Development of Procedures for Long Term Records of Essential Climate Variables

Long term records of essential climate variables such as SST, wind, radiation budget, water vapour, clouds, ozone, precipitation, sea surface salinity, sea level, sea state, etc., which are defined by Global Climate Observing System (GCOS), are necessary for characterising the trends in earth's climatic variations. Measurements from different satellite instruments suffer from different accuracies and biases due to evolution/performance of the instruments and/or retrieval algorithms. Thus there is need to intercalibrate the instruments/parameters to reduce the measurement biases among them.

10.3.6. Other Research Areas related to Parameter Retrieval

- Cloud/Rain type classification using INSAT/Kalpana observations.
- Study of cloud micro physics using 157 GHz of MADRAS and INSAT data
- Combination of INSAT-3D Imager and Sounder products to improve the quality of a few critical atmospheric products, such as atmospheric stability, total WV contents, SST etc.
- Improved tracer selection, tracking and height assignment methods for Atmospheric Motion Vectors (AMV) retrieval from VIS, MIR, WV, TIR1 channels.
- Retrieval of high-resolution winds is a challenging research area that may be attempted with Geo imagine Satellite (GISAT) satellite.

10.4. Research Areas in the field of Marine Biology and Ecosystem

The last two decades has seen an increased use of ocean remote sensing data since it provides a synoptic view of Earth's marine ecosystem on spatial and temporal scales unattainable via in situ methods. Ocean colour data is used for mapping and monitoring essential climate variables like green microscopic algal biomass, total particulate matter, coloured dissolved organic matter etc. ISRO has a dedicated Ocean Colour program and with successful launch of two Ocean colour sensors OCEANSAT1- Organizational Change Management (OCM)-1 (May,1999-2008) and OCEANSAT2- OCM-2 (September, 2009-present), is geared for the launch of Oceansat-3- OCM -3 in 2022. Apart from Indian ocean colour sensor OCM2, globally operational ocean colour sensors are MODIS -AQUA, National Power Portal (NPP)- Visible Infrared Imaging Radiometer Suite (VIIRS), Joint Polar Satellite System (JPSS1) & JPSS2, Sentinel 3 A&B - Ocean and Land Colour Instrument (OLCI). SAC is involved in the use of ocean colour data in science and climate related applications. It focusses on various parametric and non-parametric algorithms for retrieval of geophysical parameters, use of these geophysical parameters for various applications like algal bloom detection and monitoring, water quality phytoplankton community structure and biodiversity, carbon biogeochemistry, R & D projects for generating novel applications and defining new sensor requirements. Some of the challenging areas for research are

10.4.1. Bio-Optical characterization of estuaries, brackish water lagoons and coastal wetlands

Estuaries, lagoons and wetlands are important components of marine ecosystem, heavily influenced by anthropogenic activities and susceptible to climate change. These are categorized as optically complex waters (OCW). Challenging areas of research are

- Accurate estimation of optically active components such as chlorophyll concentration, coloured dissolved organic matter (CDOM) absorption, total particulate matter and total suspended sediments in optically complex waters.
- Development of atmospheric correction models for accurate estimation of remote sensing reflectances in OCW
- Hyperspectral characterization of optical constituents in VIS-NIR region
- AI -ML based techniques for retrieval of optical constituents in OCW.

10.4.2. Biogeochemical dynamics in coastal –estuarine ecosystems

Biogeochemical transformation and pathways of aquatic carbon in coastal, estuaries, lagoons and wetlands is an important area of research and use of ocean colour data along with in-situ observations in biogeochemical models are important for climate change studies. Some of the challenging areas are

- Quantifying various components of the aquatic carbon in diverse marine ecosystems using ocean colour (Total Organic Carbon (TOC), Dissolved Organic Carbon (DOC), Dissolved Inorganic Carbon (DIC), Particulate Organic Carbon (POC), Phytoplankton C, Detritus C)
- Quantifying nitrogen components of the aquatic system using remote sensing
- Evaluating nutrient dynamics in estuarine- coastal regions using remote sensing
- Modeling primary, new and export production from remote sensing

10.4.3. Marine Living Resource Management

Climate change is profoundly effecting habitat, breeding and population dynamics of marine living resources. Some of the challenging areas of research in this field are

- Habitat identification of endangered marine organism using geospatial information
- Site suitability for mariculture using remotely derived parameters and in-situ observations in GIS based models
- Ocean colour remote sensing in zooplankton, secondary production and tertiary production studies
- Ocean colour remote sensing for microbial ecosystems
- Habitats of large pelagics using remotely sensed parameters and fishery data

10.4.4. Biodiversity and ecosystem Studies

Climate change and global warming is rapidly effecting species biodiversity with native population replaced by few fast growing species and loss in biodiversity. Major areas of research are

- Ocean colour remote sensing in biodiversity studies of micro and macroalgae of Indian marine waters
- Optical and biological studies of harmful and beneficial algal blooms using remote sensing
- Optical and biological characteristics of benthic ecosystems (Sea grass, Seaweeds, benthic microalgae)
- Phytoplankton fluorescence and physiological studies
- Impact of ocean acidification on biodiversity

- Climate change studies on phytoplankton functional groups, size classes and ecosystem structure.

10.5. Research Areas in the field of Hydrology

Hydrology is the science that deals with the occurrence, distribution, movement and properties of the waters on earth and their relationship with the environment within each phase of the hydrologic cycle. Land hydrology aims to develop techniques to retrieve hydrological parameters for advanced water-centric Sensors and carry out hydrological and hydro-dynamic modeling, data assimilation to simulate and forecast various water fluxes to address a range of hydrological research and applications and sensor system studies. Advanced research dimensions in satellite hydrology such as wide-swath altimetry for river discharge, multi-frequency SAR for soil moisture, high resolution thermal sensing for lake temperature & submarine groundwater discharge, hyperfine spectral measurements for water isotopes are some of the important research areas. The challenges involved in ongoing work are as follows.

10.5.1. Advanced R&D for Wide swath altimetry

Monitoring Water level from space platform is important to augment existing ground network in remote and inaccessible regions including Trans-Boundary Rivers. There is need to develop advanced approach to estimate water level from Nadir Microwave as well as LIDAR based altimeters. Estimation of water velocity and discharge has been challenge from remote sensing observations, methods need to be developed to address river discharge and storage volume using nadir and high resolution interferometric wide swath altimetry.

10.5.2. Data Assimilation techniques for improved hydrological fluxes

Assimilation of hydrological variables in physics-based process driven hydrological models needs to be carried out for improved water flux simulations including Himalayan river catchment, due to challenging terrain and transboundary catchments.

10.5.3. High resolution Soil Moisture Retrieval

A majority of prior investigations into soil moisture estimation using SAR have predominantly relied on single-frequency data sourced mainly from C-band remote sensing systems. Development of multi-frequency and multi-polarization SAR models for retrieval of soil moisture taking into account forthcoming sensors such as NISAR, EOS-09 etc.

10.5.4. Wetland Health modeling

Comprehensive eco-hydrological assessment of wetlands is essential for conservation, planning and management of wetland eco-system. There is a need to develop a framework for wetland health monitoring using remote sensing observations with focus on water quality, spatial and temporal variability, eutrophication modelling, impact of climate change, biological indicator, pollution source etc.

10.5.5. Isotope Hydrology

Satellite-observed isotope ratio for estimation of catchment scale water balance has not been studied for Indian basins. With availability of long-term isotope datasets in the recent years, it is necessary to quantify surface water fluxes using water isotopes. Sensor system studies need to be carried out to define the next generation of sensors capable of detecting isotope ratios from ultrafine measurements.

10.5.6. Submarine Ground Water Discharge (SGD)

Quantification of water flow into ocean through sub marine ground water discharge is a challenge for Indian coast. High resolution thermal remote sensing observations from drone and space borne platforms provide initial signals of SGD in coastal region. There is need to identify the hot spot regions of SGD in Indian coast and develop model to estimate the discharge of fresh water going into the ocean.

10.5.7. Surface and ground water interactions and understanding the impact of anthropogenic activities

How surface and ground water availability is changing in space and time using SWOT, GRACE and LSM models along with science of changing water cycle which is accelerating/decelerating from local to regional to global scales

10.5.8. Hyperfine hydrological modelling to address the social hydrology involving local drivers of change

There is need to setup the hydrological models at much finer spatial resolutions (~ 50 meter) and simulate the water fluxes to provide the solutions at local scales and addressing the social hydrology.

10.5.9. Lake thermal Modelling under changing climate scenarios

Lack of thermal observations and modelling of Indian freshwater systems lead to poorly constrained weather predictions and climate processes? How does increasing anthropogenic stress and climate change affect thermal dynamics of fresh water ecosystems?

10.5.10. Long term changes in available hydrological ECVs and linkages with hydro-climatic extremes

Is there any positive or negative linkages/feedback between hydrological variability and extremes events for possibility of early detection mechanism through satellite observations?

10.6. Research Areas in the field of Cryosphere Sciences

Remote sensing science and applications of Cryosphere at SAC has mainly focused on two regions, i.e. Hindu-Kush-Himalayan (HKH) mountainous region of Northern part of Indian sub-continent and polar areas on Earth. Cryosphere of HKH region consists of snowpack (both seasonal and permanent), varieties of glaciers in terms of type and size and permafrost. Inventory, monitoring and applications of cryosphere elements of HKH region is must for the nation as water resources of northern India largely depend on freshwater melt discharge from snow and glaciers from large drainage basins of Indus, Ganga and Brahmaputra (IGB) rivers of earth surface. Occurrence of hazards such as Avalanches and Glacial Lake Outbursts Flood (GLOFs) are also associated with high altitude region. Polar cryosphere mainly consists of ice sheets and sea ice including snow over these two cryospheric elements. Mapping, monitoring, modelling and science of polar cryosphere elements in the Antarctic and Arctic regions is equally important for the nation as large areas of sea ice and ice sheets govern energy exchange processes between ice surface and atmosphere and melt from these elements contribute to global sea level. Although a large amount of applications using earth observation data acquired by Indian and other sensors has been carried out to study various dimensions of cryosphere in the last two and half decades but still a lot needs to be done at present and in future. Keeping in view the needs of nation and international research, following are the activities and challenging research areas in the mountain and polar cryospheric regions.

10.6.1. Himalayan snow

SAC has been generating sub-basin wise snow cover products database using Advanced Wide Field Sensor (AWiFS) data since 2004 in the Himalayan region. These products are the best available time series snow cover products having fine spatial and temporal resolution so far in the world. INSAT-3D/R/S provides daily snow cover products at India Meteorological Department (IMD) from geostationary platform. Snow products have been used in snow melt runoff estimations, in understanding of accumulation and ablation pattern of snow in different climatic zones of HKH region, and in assessing the snow cover trends to ever-changing climate. However, there are important challenging areas where research is needed to address cryosphere studies. These are estimation of annual seasonal snow mass using photogrammetric/interferometric and scattering mechanism using PolSAR data. Snow parameter retrieval (s.a. snow density, wetness, SWE) using SAR/Hyperspectral data, Radiative transfer modelling and role of snow parameters in climate model will be helpful to understand the impact of climate on Himalayan mountains. Disaster applications such as Avalanche, GLOF etc. are other crucial areas of research. Development of snow-melt runoff at high altitude area, suitable site selection for micro hydroelectric projects using geospatial modelling and real time assessment of discharge for Indian rivers using satellite data are important in the field of surface hydrology

10.6.2. Himalayan glaciers

Inventory and monitoring of Himalayan glaciers within periphery of IGB basins has been a foremost requirement of our nation to know the stock of glacier stored water, and variations in dimensions of glaciers as an impact of climatic variations. SAC has carried out extensive work in this direction using data from Indian sensors such as AWiFS, LISS III and LISS IV of Resourcesat series satellite. The glacier inventory in IGB basins is available at VEDAS portal of SAC for visualization. However, automatization of glacier feature extraction and change detection from space platform in Himalayan region are the research areas to be addressed. Glacier mass balance is important to assess the status of their current response to climate change, and requires improvement in estimates to minimize the uncertainty. Major research domain in mountain glacier region includes geodetic mass balance estimation with field validation at sub-basin scale using Cartosat-1 & future stereo mission, improvement in Accumulation Area Ratio (AAR) and Mass Balance relationship in HKH region, retrieval of ice velocity, snow/ice facies using SAR/PolSAR data, understanding the glacier dynamics, Regional Climate model for future projection, GLOF risk assessment, and impact assessment on cryospheric elements in different scenarios.

10.6.3. Himalayan Permafrost

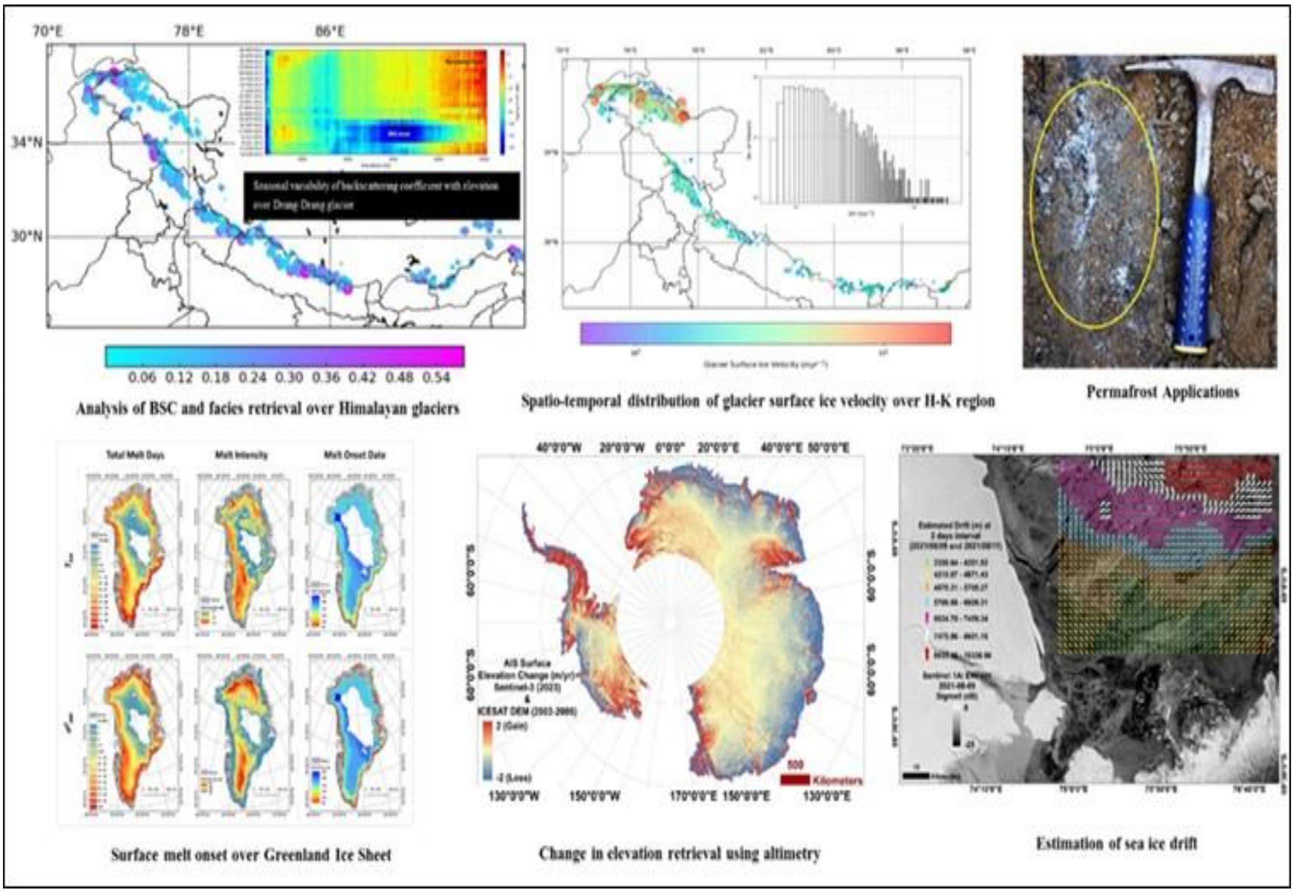
The permafrost is very important element of Cryosphere studies. The distribution and changes occurring at permafrost in the mountainous HKH region as a result of climatic variations needs to be known in view its importance to ecology and land cover changes. Exploration of Permafrost might give new insights to high altitude environmental changes through optical, thermal and active microwave data. Estimation of permafrost zonation, geomorphological signatures, degradation and interaction with SAR/PolSAR data are essential to understand the dynamics of permafrost in high altitudes of HKH region to assess the impact of climate change.

10.6.4. Polar ice sheets

One of the most challenging research area in polar ice sheets is estimation of ice sheet mass balance and resulting sea level rise. State of art techniques, development of algorithms utilizing SARAL/AltiKa data and analysis of results have been demonstrated at SAC through various studies. It needs to be expanded further by using globally available LASER/RADAR altimetry datasets. Another important research area is to investigate the dynamics of polar ice sheets using optical, SAR data along with incorporating numerical Ice sheet modelling, studying causes and linked processes for ice shelf instability. Development of techniques to automatize monitoring of ice shelves margin and calving events, to access the impact of various surface melt processes on the polar ice dynamics and exchange of surface energy fluxes are another important activities in polar ice sheet studies.

10.6.5. Polar sea ice

One of the major contribution of SAC in polar ice studies is extraction of sea ice area from ISRO's Scaterrometers data and understanding its spatial-temporal variability. Technique development has been demonstrated to measure sea ice thickness using data from SARAL/AltiKa. It needs to be a continuing activity by using other globally available LASER/RADAR altimetry datasets to enrich and analyse long-term trend in sea ice thickness. More research is required to address trend in sea ice extent, concentration, thickness, snow depth over sea ice, sea ice drift estimation, sea ice albedo & feedback mechanism, sea ice modelling and understanding the oceanic and atmospheric driving factors for global sea ice variability. Automatic techniques using multi-sensor approach along with iceberg detection and tracking are needed for improving sea ice advisories required for safer ship navigation during Indian Scientific Expedition to Antarctica.



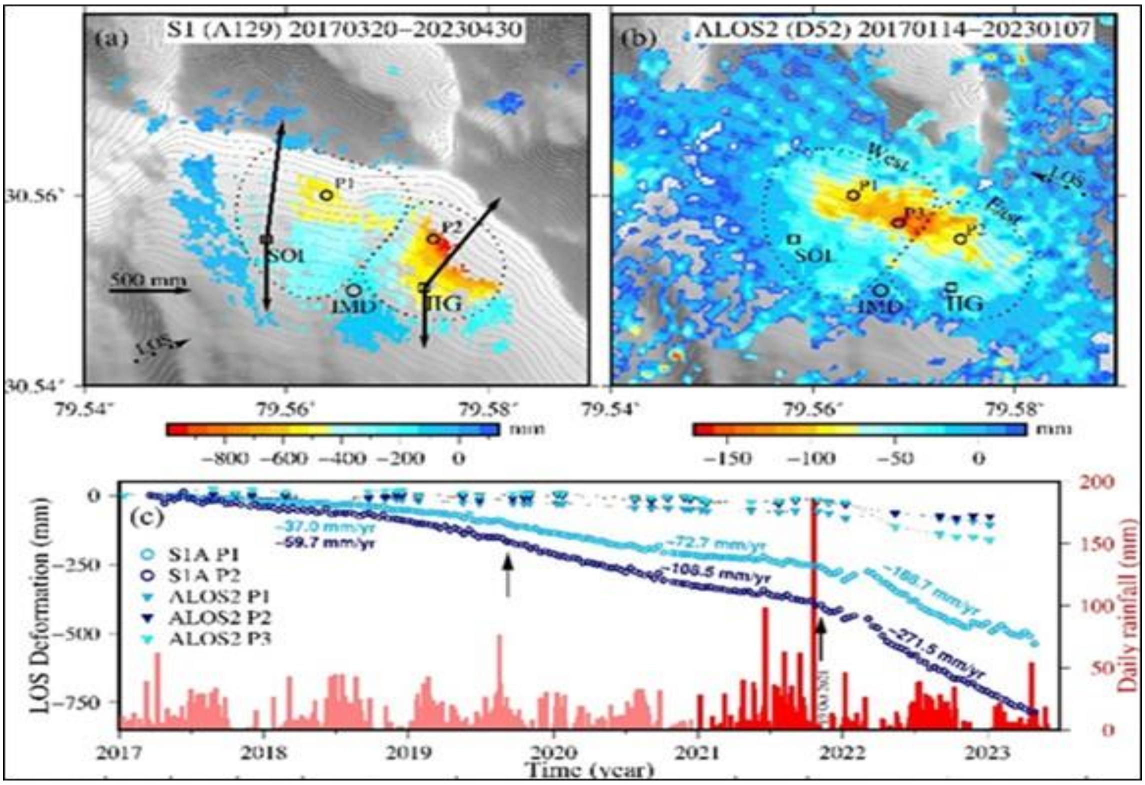
Few Illustrations of Cryosphere studies

10.7. Research Areas in the field of Geosciences

Geosciences deals with study of the earth and encompasses geology, geophysics, geodesy, geochemistry and environmental geosciences. SAC is currently involved in carrying out research related to study of earth surface and geodynamic processes for developing applications related to early warning of geohazards, sustainable coastal zone management, geo-resources and geo-archaeological exploration using space technology and geo-informatics. Following are the major research areas:

10.7.1. Geo hazards

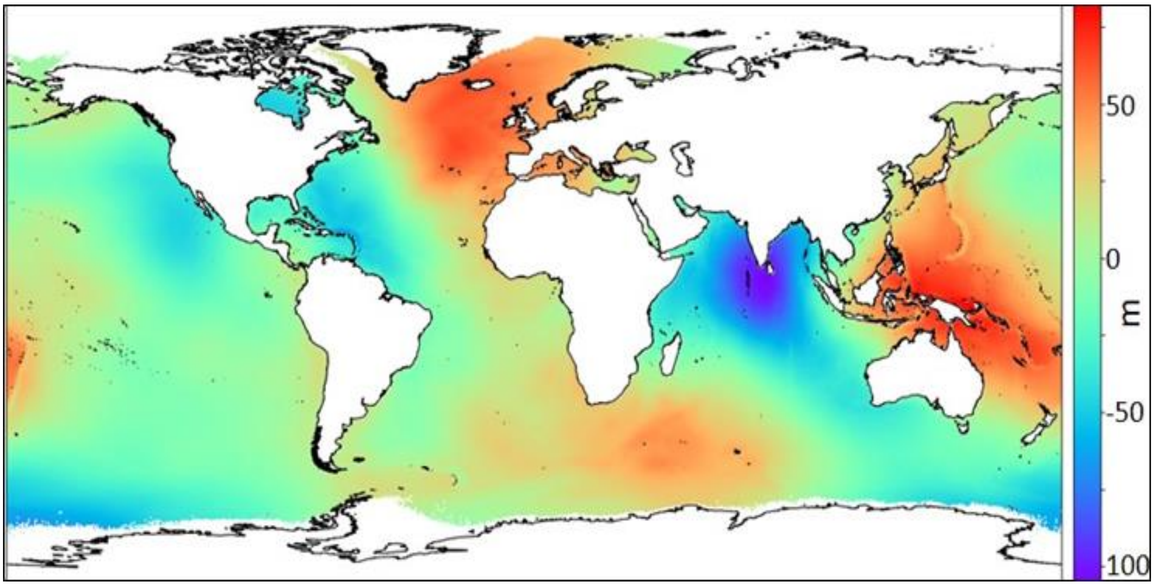
This theme focus on the study of geodynamical processes related to potentially hazardous geological events using advanced space based techniques. Space geodetic techniques such as GNSS and InSAR have been extensity used to understand the strain accumulation and release processes and there by the seismic hazard in regions like the Himalayas and active seismic zones in peninsular India. Other active areas of research include quantification of land subsidence due to over exploitation of ground water, coal, hydrocarbons and crustal deformation associated with volcanos and slow-moving landslides using geodetic measurements for hazard assessment.



Kinematics of Joshimath Landslide imaged by InSAR.

10.7.2. Marine Geosciences

Sea surface height measurements from satellite altimeters are extensively used to retrieve marine geoid and gravity data sets. High precision measurements from satellite altimeters such as the SARAL/ALtiKa and the recent SWOT have significantly improved the accuracy and resolution of the marine gravity field. Altimeter derived geoid undulation and free-air gravity anomalies over Indian Ocean needs to be utilised to understand plate tectonic processes relating to oceanic ridges, subduction zones, formation of marine sedimentary basins and the evolution of continental margins. Higher resolution marine gravity field is also essential for marine exploration.



Mean Sea Surface model derived using SARAL/ALtiKa data

10.7.3. Mineral Exploration

Although large part of the country has been conventionally surveyed and location of most of the economic mineral deposits have been investigated in detail, still new mineral deposits needs to be explored to meet ever-increasing demand of the industries. Mineral exploration using conventional techniques involve geological mapping followed by geophysical and geochemical investigations, pitting, trenching, exploratory drilling, estimating reserves etc. Remote sensing based methods have been so far limited to updating the existing geological/structural maps and in identifying hydrothermal alteration zones as a useful guide. Alteration halo is much more widespread of rocks surrounding a mineral deposit that are caused by solutions that formed the deposit. Research is required to explore integrated use of multispectral, hyperspectral, thermal and radar data along with high resolution DEM (space-borne as well aerial), geochemical and geophysical data sets in diverse geological and environmental settings to identify and map new mineral prognostic zones with special focus on Rare Earth Elements, base metals and precious metals.. Methods for automated mapping of minerals associated with alteration zones, development of spectral-geochemical relationship using spectral and geochemical datasets need to be developed. Research is also required for quantification of spectral changes in reflectance spectra due to hydrothermal alteration process associated with mineral prospects using advanced laboratory based spectral and geochemical studies.

10.7.4. Geo-Archaeology and Palaeochannel

Space based geo-archaeological exploration along with geo-spatial tools is one of the most fascinating geoscience application. It involves interpretation of multi-sensor satellite data to explore new archaeological sites, understand development, preservation and destruction of archaeological sites in context of regional scale environmental changes, evolution of physical landscape and impact of human groups by applying concepts and methods of geosciences (especially geology, geomorphology, hydrology, sedimentology, pedology and exploration geophysics). Research is required to develop methods/approach to explore archaeological sites using multi-sensor satellite data (Radar and high resolution multispectral data in particular) in conjunction with geospatial database of known archaeological sites. It is required to understand impact of neo-tectonic activities and palaeo-climatic changes on evolution of ancient civilisations. Another field is the detailed study of the palaeochannel. The lost River Sarawsati is one of the prominent study demonstrating the potential of Remote sensing data for palaeochannel study. Emphasis of on ground water potential site mapping also take advantage of palaeochannel.

10.7.5. Ground Water

Groundwater geohydrology research is at the heart of the food-water-energy nexus. Geological framework intrinsically controls sustainable development and management of groundwater resources in any area. Armed with multi-sensor observations and huge archive of time series data repository of various geospatial proxies, depth to water table is modelled using advanced geospatial and machine learning based algorithms at a high temporal resolution. Water policies and governance needs to be customized not only based on public demand but the inherent geohydrological properties of any region. Such remote sensing based modelling provides a holistic overview of the different controls on groundwater.

Groundwater potential mapping using remote sensing techniques presents a promising research area that should be efficiently explored. Integrating satellite imagery with GIS allows for the identification and delineation of groundwater potential zones (GWPZs), offering a spatially efficient approach to resource assessment. A particularly valuable aspect of this research lies in the use of the Analytic Hierarchy Process (AHP), which, when combined with remote sensing data, can weigh crucial factors such as slope, rainfall, geology, geomorphology, land use/land cover (LULC), and soil type, for enhancing the accuracy of groundwater potential mapping. Mapping geological formations, including lineaments and fractures, is essential for understanding groundwater flow and identifying recharge areas. Additionally, incorporating morphometric analysis with total rank method, which examines watershed aerial, linear, and relief characteristics (drainage density, basin shape, relief ratio, and stream frequency etc.), adds another layer in assessing groundwater potential. This comprehensive and multi-faceted approach offers great potential for refining groundwater management practices at larger scales and can significantly contribute to sustainable water resource planning.

Differential Interferometric measurements have demonstrated the potential application for monitoring the GW depletion/recharge and associated land subsidence / rebound. With the future launch of NISAR and existing Sentinel mission, these studies will provide a holistic picture. Research is needed in the analysis and interpretation of the remote sensing data especially interferometric data for ground water exploitation and recharge.

10.8. Research Areas in the field of Geospatial Data and Information Science

Development in space technology and associated launch of advanced satellites has started an operational era of theme specific satellites providing applications specific images with quick revisit and wide swath.
Global collaborations and data sharing are playing key role in optimal utilization of space data in effective and efficient ways. Both optical and microwave remote sensing are playing complimentary roles and providing operational solutions globally through remote sensing. Geospatial and Information science is key emerging area, which has potential to explore existing and long term satellite data to derive new information, data products and develop new advanced applications. Meteorology and Oceanography Data Archival Centre (MOSDAC) is a data centre of Space applications Centre (SAC) and has facility for satellite data reception, processing, analysis and dissemination.

MOSDAC is operationally supplying earth observation data from Indian meteorological and oceanography satellites, to cater to national research requirements. The vast amount of data available in

MOSDAC provides scope of carrying out research in the field of geo-spatial data and information processing. Themes under which Research is solicited under RESPOND

10.8.1. Advanced Data and Computing Architecture

- Optimized Data Cubes for multi-dimensional aggregation of satellite images and their spatiotemporal analysis.
- Techniques for forecasting and in-painting in Data Cubes
- High Performance Computing of satellite images on Cloud

10.8.2. Data Visualisation and Web Processing

- Advanced data rendering and fast visualization techniques of 2D and 3D satellite data.
- Fast Tiling and caching techniques for visualization of satellite Images
- Development of techniques for automatic on-demand web mashup generation.
- Cloud and Semantic enabling of Web Processing Services.

10.8.3. Data Security and Information Dissemination

- Data encryption and compression techniques for multicasting of satellite data
- Customization and optimization of multi-cast protocol using critical distance of client nodes to cater to requirements of real-time data dissemination.
- Content based data multicasting
- Information and Data security models for small devices
- Location aware satellite data dissemination for mobile devices

10.8.4. Data Mining and Web Analytics

- Real time analytics for Big Earth Data
- Pattern recognition based techniques for Event detection
- Geospatial feature extraction using deep learning techniques
- Automated event tracking (Cyclone, dust storm, etc.) using machine learning techniques
- Region growing algorithms for identification and tracking of meteorological and oceanographic events (Fog, bloom, convective initiation, etc.)

10.8.5. Data and Information Lifecycle Management

- Automated algorithms for value evaluation of data and information
- Techniques for automatic Quality checking of data
- Techniques for Persistent identifier management
- Techniques for generation of Linked data
- Faceted search and Browsing of satellite images
- Semantic annotation and labelling of satellite images

10.8.6. IoT and Sensor Network

- IoT enabled sensor network for acquisition of weather data
- Smart weather data acquisition systems
- RTOS based Data acquisition system
- Virtual Sensors for Weather data acquisition
- Optimal data capture and processing in Sensor Network

10.8.7. Virtualization and Cloud Computing

- High Performance Cloud for Satellite Image Processing
- Network Virtualization and Software Defined Network
- Software Defined Storage

10.9. Research Areas in the field of Visualization of Earth Data & Archival System (VEDAS)

To meet the user expectations of fast access to EO derived product for societal applications, there is a need to develop newer applications for better visualization and understanding of cause / effect of various covarying features. For that to happen, advanced tools and technologies have to be used in conjunction with improved algorithms and efficient analytics. Research and analysis of the following thrust areas by independent and expert researchers and academia will strengthen the impact of the work. It is expected that with such a handshake between data generators and potential analysts, newer and innovative ways will emerge which will meaningfully bring about transformation in decision making for benefit of population of our country.

10.9.1. Algorithms / Procedures for Time Series Visualization

VEDAS is responsible for archival and dissemination of thematic data and data products available within SAC. Large amount of spatial time series data is collected over time and visualization of available spatiotemporal data is essential for exploring and understanding structures and patterns, and to identify unusual observations or hidden patterns. However, the volume of data available and number of concurrent users that may be accessing the data challenges current time series map visualisation. The start and end time of episodic events or span of intensive observations may also be dynamic. So algorithms are required to be developed and modern techniques are required to be used for visualization of large spatio-temporal (ST) datasets ordered in time for animated mapping. This will be further used for exploring or monitoring unusual observations in large datasets like NDVI, snow, temperature, solar insolation etc.

10.9.2. Data Analytics and Knowledge Discovery

To understand and appreciate a natural phenomenon and attach cause and effects to an evolution, there is a growing demand of rendering "on the fly" multi-layer information. There may be concurrent users accessing same set of data. So there is motivation to parallelize computation to improve turn around time of a service. The research initiatives will be useful steps towards achieving this goal. Design & Development of parallelizable algorithms for interactive geospatial data analysis with high temporal resolution. Design & Development of parallel execution frameworks and/or distributed computing libraries for geospatial data processing operations. Design and Development of scalable general purpose systems/algorithms for removing noise from spatiotemporal datasets. Design and Development of scalable general purpose systems/algorithms for predictive analytics from spatiotemporal datasets. Design and Development of data-mining algorithms for spatial-temporal datasets. Design and Development of scalable techniques for semantic segmentation of orthoimagery.

10.9.3. Super Resolution Image Generation

Super Resolution is an Image Processing technique which is used to enhance the image resolution of scene from a number of lower resolution images of same area by reducing effects of noise in the reconstructed image. In case of satellite images, this can be seen as a powerful tool of getting high resolution multispectral images (spatial) from low resolution panchromatic images. This will facilitate improved (in spatial scale) Land cover for better natural resource management.

10.9.4. Web Enabled Sensor System for Efficient Resource Management

There is need to develop a prototype and demonstrate the applicability of wealth of information that can be gathered by set of remotely located instruments. Instruments can measure the meteorological conditions as well as ambient conditions and transmit the data to a central hub. Air quality monitoring of a region is a one such example where measurements of PM2.5 and PM10, concentrations of target gases (NOx and SOx - for example), their dispersal (based on wind direction and speed), temperature and humidity are all required by administrators and managers to issue advisory and / or take pro-active preventive measures.

10.10. Research Areas in the field of Urban Studies

10.10.1. Urban Feature Extraction (Road Network Delineation)

Transportation networks such as roads and railway lines are important for several urban applications including disaster management, urban planning, impervious surface extraction, urban growth modelling etc. The automatic methods such as template matching, object-based classifiers and machine learning methods such as neural networks, support vector machines, deep learning etc. can be used to efficiently extract road network from very high-resolution optical and SAR images acquired by Indian Remote Sensing satellites.

10.10.2. Urban Feature Extraction (Impervious Surface / Urban Area Mapping)

The mapping of urban land cover remains a challenging task owing to the high spectral and spatial heterogeneity of urban environment. The accuracy of urban area extraction can be improved by combining multi-temporal, multiresolution and multi-sensor optical and SAR earth observation data.

10.10.3. Urban Feature Extraction (3D Building Reconstruction)

The 2D and 3D information of buildings and other urban structures are needed not only for impressive visualisation of urban areas, but also as an input in several urban applications like population estimation, roof-top solar energy potential assessment, visibility studies etc. Building extraction from high-resolution satellite images in urban areas is an intricate problem. Techniques are to be developed for automatic extraction of buildings from Very High Resolution optical data. The availability of very high-resolution imagery from Cartosat series data necessitates development of techniques and algorithms for 3D building reconstruction.

10.10.4. Urban Heat Island

Spatial and Temporal Distribution of Urban Heat Islands on Land Surface and Near Surface Atmosphere Development of models for deriving day-time and night-time air temperature from satellite-derived land surface temperature and vegetation indices can assist in identification and analysis of spatial and temporal distribution of urban heat islands.

Impact of Land Cover Types on Urban Heat Islands The changes in land use-land cover pattern and declining vegetation cover in cities are predominant factors influencing the growth of urban heat islands in the cities. Satellite data derived land use land cover information can be compared with the temperature profiles to assess the impact of land cover on urban heat islands.

10.11. Research Areas in the field of Calibration and Validation

The success of any satellite mission is depending on usefulness of sensor measurement and its derived geophysical products. This goal is achieved through theoretical and experimental procedures, which generally called post launch vicarious calibration methods. The error inducted due to uncertainty of sensors performance, atmospheric correction and retrieval algorithm on geo-physical products is quantified through the validation procedure using in-situ data sets. These techniques vary by depending on sensor type and derived geo-physical products. To achieve these major task, calibration sites are being identified specific to sensor, sensor and target specific calibration methodologies development, and calibration site identification, establishment of sites and its qualification to standards. New research areas in the field of Met. & Ocean Calibration and validation are as follows:

10.11.1. Optical sensor calibration

- **Vicarious calibration**: Development of new Cal-Val sites can be established in synchronous with satellite over passes in collaborative mode for various Indian satellite missions (INSAT-3DS, GISAT series, TRISHNA missions etc)For . Presently, the vicarious (absolute) calibration is performed through simulation of top-of Atmosphere radiance for calibration gain and offset calculation. For this purpose we developed ocean site at Kavaratti and land site at Little Rann of Kutch (mostly in campaign mode).

- **Relative sensor calibration**: Development of advanced techniques for the relative sensor calibration exercises for the radiometric performance monitoring of Indian satellites can be performed through land, ocean, snow and deep convective cloud targets. Presently, the sensor performance is cross verified with contemporary sensors using synchronous nadir pass and its measurements. These exercises are performed by normalizing the central wavelength and out-off band contribution in case of optical sensors. Exploring of radiative modelling of satellite sensor measured radiance though ground truth measurements. Deep convective clouds, Ray-Tracing Techniques over desert and ocean sites can also be explored for optical sensors calibration both in high and coarser resolutions.
- **Moon calibration**: Development of algorithm for the Radiometric performance monitoring using moon data.

10.11.2. Microwave sensor calibration

- Development of advanced techniques for the data quality evaluation of ISRO's future scatterometer can be explored. At present novel approach for data quality evaluation of Scatterometer (OSCAT-2/3 and ScatSat-1) are being worked out where one can relate the parameters available at different levels of product to geophysical parameters.
- For scatterometer calibration, the essential points includes: i) the monitoring of on-board calibration data to keep a check on transmitted power and ii) regular monitoring of time series of backscattered or brightness temperature over invariant sites like Amazon rainforest, Sahara Desert, Antarctic snow are required.
- Development of techniques and new Altimeter calibration and validation site in India with FRM (Fiducial Reference Measurements) standards using data from a suitable sites.

10.11.3. Geo-physical products validation

- **Validation algorithms**: Development of automatic procedures for validating various satellite derived geo-physical parameters from Indian satellite missions (INSAT-3DR/3DS, Oceansat-3/3A, GISAT-1A and TRISHNA etc.) by following the Protocol development on measurements, instrument operation, quality control, and calibration standards. Presently, the most important exercise of validating sensor derived geo-physical products are done using community vetted matchup methodology and qualifying various data sets (in-situ, contemporary missions, climate data sets, data from various collaborative agencies, etc.).
- **Validation of Hyperspectral Satellite Data (PACE-OCI)**: Development of techniques for the assessment and refinement of hyperspectral remote sensing retrievals of chlorophyll-a and other phytoplankton pigments, Phytoplankton Functional Types (PFTs) and phytoplankton specific absorption.
- **Integration of CHEMTAX and HPLC for Algorithm Validation**: Development of new algorithms for the use of CHEMTAX-HPLC derived phytoplankton community composition to validate and refine ocean

colour algorithms for pigment-based estimates of phytoplankton diversity, algal bloom, primary production etc. in Indian Ocean region using satellite data and sea-truth measurements.

- **Enhancing validation in ultra-oligotrophic and coastal waters**: Improvement in validation efforts in very low-chlorophyll regions and optically complex coastal waters (using the sea-truth data collected during ship and boat cruises) by incorporating new bio-optical models, adaptive atmospheric correction, and regional algorithms tailored to case-2 waters.

10.12. Research Areas in the field of Application Techniques Development

10.12.1. Microwave Techniques Development

Microwave remote sensing instruments, like Synthetic Aperture Radar (SAR), Scatterometer, Radiometer, Altimeter and Ground Penetration Radar (GPR), provide valuable inputs for geophysical parameter retrievals, monitoring and investigative studies. Though, data from these sensors is regularly processed using various retrieval algorithms, to cater to corresponding user applications, there is still a huge scope to develop and employ advanced techniques to fully exploit the data for maximum utilization. There is also requirement to simulate and demonstrate newer techniques, which will enable definition of future microwave sensors. With the above requirements in perspective, following are the potential areas of research:

- Development of techniques to simulate new SAR configuration data eg., Geosynchronous SAR (GeoSAR), bistatic SAR, GEO-LEO SAR and their processing algorithms, to study geophysical parameters retrieval accuracies.
- Development of polarimetric SAR modelling for varied scenarios of target, terrain & canopy configurations.
- Development of subsurface models for polarimetric GPR simulations.
- Development of object/feature detection techniques using GPR and Wall-Penetration radars, and their performance evaluation.
- Development of processing methodologies for Rail-mounted Interferometric SAR system for land subsidence monitoring; system development, demonstration of processing methodology and its performance evaluation.
- Full-wave numerical Maxwell Model 3D simulations for microwave scattering from forests including detailed 3D modeling of forest canopy structure.
- Signal processing techniques for forest mapping using 3D-SAR Tomography and Higher dimensional SAR Tomography; applications of SAR tomography for forest mapping in plains and hill slopes.
- Development of techniques for root-zone soil moisture estimation
- Development of Polarimetric SAR models for Permafrost characterization in Himalayan regions
- PS- and DS-InSAR based algorithms for land-deformation estimation; Algorithms for Landslides

- damage assessment from SAR data; development of regular monitoring system with alert generation capability.

10.12.2. Hyperspectral Techniques Development

Hyperspectral remote sensing combines imaging and spectrometry. Most of Earth's surface materials contain characteristic absorption features which are very narrow in the spectral appearance, hence using high spectral resolution sensors called hyperspectral sensors, we can detect hundreds of very narrow, contiguous spectral bands throughout the visible, near-infrared, mid-infrared and thermal infrared portions of the electromagnetic spectrum. The very high spectral resolution facilitates fine discrimination between different targets and its inherent chemical compositional characteristics based on their spectral response in each of the narrow bands. Sophisticated and complex data analysis methods are required due to high dimensionality and size of the hyperspectral data, the spectral mixing and contamination in the measurement process such as noise and atmospheric effects. Therefore, we need to explore and develop advance hyperspectral data analysis techniques and tools, which may be organized in different themes: data fusion, spectral unmixing, classification, target detection, physical parameter retrieval etc.

- To explore Residual-3D-CNN, standard computer vision models such as LeNet-5, AlexNet, VGG, Darknet, Squeezenet to Hx classification with different learnable filters such as using 1D, 2D and 3D to see their effectiveness for remote sensing data classification.
- Another relevant challenge is to integrate spatial-contextual information in spectral- based classifiers for hyperspectral data to take advantage of the complementarities. For Example: 3D deep convolutional neural networks (CNN).
- The challenge in vegetation (multi-crop, forest species) classification now is learning temporal information from time series hyperspectral data. The addition of the time domain to the learning model apart from contextual and spectral information adds an additional dimension to the input data making the learning process much more challenging.
- Current research on simultaneous contextual information extraction and temporal information extraction can also be further explored by combining the concept of Convolutional and Recurrent neural Network (RNN) such as Convolutional Long Short-Term Memory (LSTM) or Convolutional Gated Recurrent Unit (GRU) to the temporal image data. This can be very effective for time series data classification.
- Physics inspired Deep-Learning based Inversion models for geophysical parameter retrieval.
- To explore hypersharpening based methods for denoising which are based on component substitution (CS) and multiresolution analysis (MRA).
- The unmixing based strategies such as Hyperspectral Image Superresolution via Subspace-Based Regularization (HySure) and CNMF (Coupled Non Negative Matrix Factorization) have great potential even when Spectral Response Function (SRF) has limited overlap.

- A possible future for further performance improvement lies in developing hybrid approaches that combine the advantages of different classes of methods such as MRA and Unmixing. Current Unmixing approaches rely mostly on the assumption of Linear Unmixing Model which can be further extended to Bi-linear or Non-Linear based models.
- VNIR-Hx and thermal-Hx data Fusion and Hyperspectral, LIDAR and SAR data fusion for precision agriculture, soil characteristics, forest biomass etc. studies.
- To develop physics-inspired and sparse based non-linear un-mixing models.
- Real-Time robust spectral unmixing algorithm and tools which can be used for airborne or drone based sensor data.
- Development of high performance / parallel computing model for spectral unmixing (Sparse unmixing models depend on spectral library which takes too much time).
- Dictionary Learning based Estimation and data recovery for sub-pixel classification of Hx data. For eg. soil property estimation from mixed pixels.

10.12.3. Aerosol Remote Sensing

Aerosol remote sensing and atmospheric corrections of optical data involve the following challenges, which are important areas of research:

- Simulation studies and specifications development of a hyperspectral sensor for retrieval of aerosol layer heights and aerosol characterization, and development of retrieval algorithms.
- Atmospheric corrections of VNIR sensors is a challenge in absence of SWIR channels. In this direction, there is need to develop methods for AOD and surface reflectance retrieval for VNIR sensors such as AWiFS, Linear Imaging Self Scanning (LISS-III), Cartosat-2 etc.
- Mapping and analysing the patterns of ground level particulate matter (an important factor to determine the ground level Air-Quality) using satellite data and modelling. Development of models to estimate particulate matter using satellite data specifically for Indian atmosphere. The quantification of factors leading to harmfully high levels of particulate matter.
- Development of on-board Parallel/FPGA algorithm for real-time application of hyperspectral data.
- Simulation of synthetic hyperspectral data using Radiative Transfer and Ray tracing models.

10.12.4. LIDAR Remote Sensing for Land Applications

- Development of processing algorithms for LIDAR data for land applications, which includes Tree height and structure mapping.
- Development of fusion techniques for LIDAR and fine resolution optical data for species diversity mapping.

10.13. Research Areas in the field of Agriculture, Forestry & Ecosystem

Estimation of agricultural crop yields and production at different spatial scale is of paramount importance for global food security. Crop production estimation at coarser scale such as at district and state levels is required for decision making and export-import policy formulation and trade-related activity while that at finer scale is necessary to understand the yield variability at farm level, which in turn is useful to improve the productivity of small and marginal farm holdings through proper management and to settle claims under crop insurance. Recent developments related to Automation, Geospatial pest forewarning, Crop insurance towards MoAFW, Digital agriculture initiative Individuals with Disabilities Education Act (IDEA) many research challenges. Research areas in the field of agriculture are as follows:

10.13.1. Crop production, yield and Price Forecasting

- Monthly forecast of major crops & long-lead forecast
- Automated crop yield estimation thorough process-based model
- Prediction of market arrival & price through statistical and AI/ML approaches
- Acreage of rabi pulse types, Kharif onion through Opti-SAR observations
- Fodder type-wise area, yield & production
- Site suitability of medicinal plants

10.13.2. Agro advisories and crop loss assessment

- New Drought product from Satellite and its use in crop loss
- Prototype demonstration of Digital agro-climatic atlas
- Horticulture-specific weather-based insurance product using satellite data
- Local-scale / high-resolution weather forecast using AI/ML
- Modelling macro/micro climate & animal disease prediction

10.13.3. Precision Agriculture

- Resource-use efficiency (Crop Water Productivity, Nutrient Use Efficiency), Soil carbon dynamics.
- Fodder nutrient, Active medical ingradient & pesticide residue investigation (UAV, satellite hyperspectral, thermal, Imaging microscopy - Experiments, analysis, data fusion).
- Investigations on Solar-Induced Fluorescence (SIF) & hyperspectral related to photosynthesis & early disease detection.

10.13.4. Forestry

10.13.4.1. Forest carbon mapping

Accurate estimation of vegetation biomass is crucial for accounting carbon sequestration and emissions from forest ecosystem. Advancement in remote sensing technology has enabled more precise quantification of forest above-ground biomass with lower levels of uncertainties in estimates. Following are the research areas that are proposed under this theme:

- Development of algorithm and tool for forest above-ground biomass using multi-sensor remote sensing data/ PolInSAR / SAR tomography
- Multi-sensor based remote sensing for biomass estimation of scrublands and grassland.
- Development of framework for quantification of carbon sequestration potential of forests/ ecosystems

10.13.4.2. Modelling and retrieval of 'blue carbon' and 'teal carbon' to assess the role of wetlands in climate change adaptations and resilience

Blue carbon is the carbon dioxide that is stored in coastal and ocean ecosystems, such as mangroves, seagrasses and salt marshes. Whereas, Teal carbon is the carbon stored in non-tidal freshwater wetlands, including vegetation, microbial biomass and organic matter. These carbons are major contributors to global carbon sequestration playing key roles in regulating greenhouse gases. Identifying and measuring the amount of these carbons is a part of the effort to understand how these wetlands can help with climate change adaptations and resilience. Following are the research areas that are proposed under this theme:

- Modelling and retrieval of 'blue carbon' and/or 'teal carbon' from coastal and inland ecosystems to assess their role in climate change adaptations and resilience
- Quantification of Essential Ecosystem Services for assessments and development of framework for monitoring climate change impacts on ecosystem services.

10.13.4.3. LiDAR remote sensing

Applications of LiDAR remote sensing in forestry and ecosystems studies is advancing fast in the recent times due to the proliferation of terrestrial, airborne and space-borne LiDAR scanning instruments. Also, LiDAR has been proven to complement other sensors viz. optical, radar and hyperspectral for studies related to vegetation and land. Development of various processing and analysis tools has aided to this and has made LiDAR a powerful tool for studying and monitoring vegetation and land ecosystems. Following are the research areas that can be addressed using LiDAR remote sensing:

- Retrieval of vegetation allometric parameters and above-ground biomass using LiDAR data.
- Applications of LiDAR remote sensing for habitat mapping, forest health monitoring and vegetation monitoring for understanding the climate change adaptations and resilience
- Development of automated tools using AI/ML for LiDAR based forest vegetation mapping

10.13.5. Desertification & Land Degradation

Desertification and land degradation constitutes one of the most alarming geo-environmental global problem affecting two third countries of the world on which one billion people live (one sixth of world's population). Land degradation is reduction or loss of productive land due to natural processes, climate change and human activities. Desertification is land degradation in arid, semi-arid and dry sub-humid areas (also known as Drylands). The processes of desertification and land degradation are observed to have accelerated during recent years globally. There is a need to stop and reverse the process of desertification and land degradation. It is required to develop advanced digital classification techniques using object based approaches, machine learning/artificial neural network for automated land degradation mapping using multi-temporal and multi-sensor satellite data, vulnerability and risk assessment and developing action plans to combat land degradation.

10.14. Research areas in the field of Air quality, Atmospheric Trace gases and Aerosols

Atmospheric trace gases, including greenhouse gases (CO_2, CH_4) and air pollutants (O_3, NO_2, CO, SO_2), play a pivotal role in climate change, atmospheric chemistry, and air quality. While satellite-based observations have advanced, retrieval of methane and carbon dioxide from space remains a critical gap within the Indian Remote Sensing Program. Addressing this challenge requires integrating state-of-the-art remote sensing technologies with advanced computational methods to enhance accuracy, resolution, and interpretation of atmospheric data. The upcoming Environmental Satellite on G20 mission is a major leap in this direction.

10.14.1. Advanced Trace Gas Retrieval

Utilizing Differential Optical Absorption Spectroscopy (DOAS), combined with ground-based FTIR and LIDAR, will enhance methane and carbon dioxide retrievals from space. The integration of polarimeter data enables improved characterization of aerosols, aiding in the correction of atmospheric interferences that impact gas retrieval accuracy.

10.14.2. LIDAR-Based Vertical Profiling of Aerosols

Developing models for vertical particulate extinction and backscatter profiles using satellite and ground-based LIDAR will provide critical insights into pollution transport and atmospheric layering. This will enable high-precision monitoring of aerosols from urban pollution, industrial emissions, and biomass burning.

10.14.3. Active Fire Detection

A multi-sensor approach using thermal infrared data will improve active fire detection, fire intensity assessment, and plume evolution tracking. Using geostationary satellite data, aapplications towards crop residue burning monitoring will help quantify aerosol and gas emissions, assessing their impact on ambient air quality and regional pollution events. AI-based forecasting models will further aid in early warning systems and mitigation strategies.

10.14.4. AI/ML-Driven Downscaling and Data Fusion

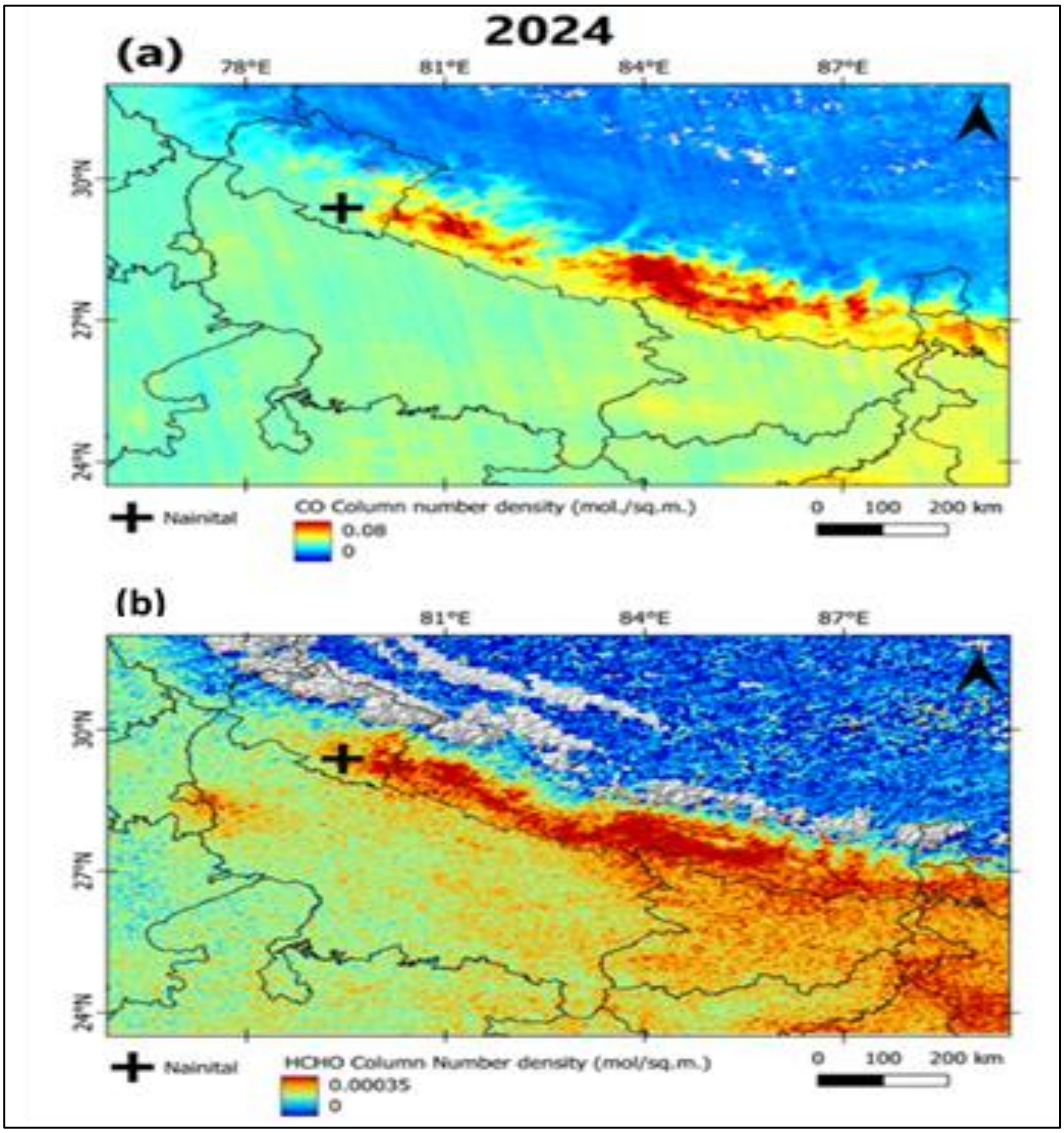
Incorporating AI/ML algorithms for data fusion and downscaling will enhance the spatial and temporal resolution of trace gas and aerosol datasets. Machine learning will optimize retrieval techniques, while data assimilation models will improve air quality forecasting and climate predictions.

10.14.5. Ultrafine Radiative Transfer Simulations

High-resolution radiative transfer simulations will improve understanding of gas-aerosol interactions, aiding in the refinement of retrieval techniques. These simulations will also help quantify radiative forcing effects, crucial for climate modeling and mitigation strategies.

10.14.6. Observing System Simulation Experiments (OSSEs)

Conducting OSSEs will help evaluate the performance of future satellite missions by simulating atmospheric observations under various scenarios.



Degradation of air quality and long rage transport of air pollutant for Uttarakhand wildfire, 2024

These experiments will guide sensor design, retrieval algorithm development, and mission planning, ensuring optimal coverage and accuracy for atmospheric monitoring

This integrated approach, leveraging futuristic retrieval techniques, advanced sensor fusion, and computational intelligence, will significantly enhance India's capabilities in atmospheric monitoring, climate research, and air quality management

10.15. Research Areas in the field of Planetary Sciences

Planetary Sciences activities deals with analysis & interpretation of science data from past planetary missions (Moon, Mars etc.), planning science experiments for future planetary missions (Venus, Mars etc.) and studying the Planetary Analogues on Earth for understanding the geological processes on other planets.

Planetary Sciences division is mainly involved in analyzing the data from the contemporary Indian and international planetary missions, formulating the objectives of future science missions and carrying out Planetary Analogue studies for developing customized spectral library.

Following are some of the present and future research interests of PSD:

10.15.1. Planetary Geology

10.15.1.1. Pre-investment Studies for Future Planetary Missions

- Characterization of potential landing sites for Chandrayaan-4 & 5 and follow-on missions.
- Modelling and simulation studies catering to sensor definitions of future payloads.
- Analysis of data from global missions to understand the surface and atmospheric processes , and to identify the science gaps and proposing instruments for addressing them.

10.15.1.2. Moon

- Characterizing the mineralogical diversity of the lunar crust and understanding the nature of lunar water cycle:
    a) Constraining lunar crustal composition through high-resolution hyperspectral data of the Moon obtained from recent, ongoing and upcoming lunar missions.
    b) Comparative compositional studies of lunar near and far side mare and their implications in thermal and chemical evolution of the Moon.
    c) Lunar hydration mapping of polar regions (molecular water /hydroxyl ions) and characterizing their nature using hyperspectral data.
- Investigation of lunar volatiles at polar regions: Development of new techniques and radar-based models for detection and quantitative estimation of water-ice deposits inside the permanently shadowed regions at lunar poles.

- Lunar morphological studies:
  a) Morphometric and rheological study of lunar domes.
  b) Analysis of spatial and statistical distribution of boulders from high-resolution optical datasets.
- Characterization of physical properties of lunar regolith:
  a) Inversion of global regolith thickness and physical properties of the lunar near-surface using multi-wavelength radar studies.
  b) Development of physical models for dielectric constant and surface roughness estimation over lunar surface.
  a) Development of empirical and semi-empirical radio-wave scattering models to address scattering from surface and subsurface heterogeneities.
- Understanding the lunar tectonics through modelling and analysis of lobate scarps of the Moon.
- VNIR and thermal remote sensing simulation Studies:
  a) Visible-Near Infrared (VNIR) reflectance studies using physics-based models and studying the effects of optical properties, viewing geometry, grain size, etc.
  b) Modelling and estimation of thermal conduction in lunar regolith.

10.15.1.3. Mars

- Martian geological studies: Mineralogical and morphological studies of volcanic provinces, and monitoring of Polar Ice caps on Mars using optical and hyperspectral remote sensing data.
- Modelling studies of Martian landforms and their implications.
- Modelling and simulation studies for Martian subsurface geology.

10.15.1.4. Venus

- Venus geological studies using microwave remote sensing data:
  a) Scattering properties of Venusian geologic features, i.e., volcanic landforms and highland regions using ground-based and orbital-based radar data and development of radar scattering models.
  b) Characterization of large-scale Venusian volcano-tectonic structures by integrating observations from Magellan SAR, Radiometer and Altimeter observations.
- Fast radiative transfer model development for retrieval and assimilation applications.
- Retrieval of Venus surface temperature and emissivity parameters.

10.15.1.5. Asteroids

- Investigation of Visible and Near Infrared spectra of Near-Earth Asteroids obtained from spacecraft-based observations.
- Polarimetric radar studies of Near-Earth Asteroids to characterize their near-surface physical properties.

10.15.2. Planetary Atmospheres

- Understanding the atmospheric circulation dynamics of the Venusian atmosphere: Retrieval of atmospheric winds from UV channels.
- Synergistic measurements from instruments aboard upcoming Venus mission of ISRO are targeted to probe unambiguous detection of Venus lightning in a more decisive manner.
- Measurements of Venus cloud top brightness temperature statistics at different locations, emission angles, and times, and generation of cloud top temperature maps.

10.15.3. Planetary Analogues

- Spectral characterization of Venus analogues under simulated Venusian surface temperature conditions with respect to the near-infrared filters proposed in the Venus Surface Emissivity and Atmospheric Mapping (VSEAM) instrument on-board Venus Orbiter Mission.
- Characterizing terrestrial Venusian analogues using polarimetric radar based and field based Ground Penetrating Radar (GPR) studies.
- Wide spectral range characterization of Moon and Mars analogues from different geological settings across India

10.16. Research Areas in the field of Space Sciences

Multi-wavelength astronomy is the major thrust area of research with special emphasis on terahertz (THz) or sub mm astronomy. THz astronomy has potential to answer some of the most profound questions related to the cold components of the Universe on scales of galaxies, molecular clouds, star and planets. Multi-wavelength observations along with theoretical models and simulations are used to understand various astronomical phenomenon. Apart from these studies research related to exoplanets and solar physics are also quite important themes being explored at SAC.

Important research areas and challenges involved in ongoing program is as follows.

- Understanding temporal evolution of elemental abundances in solar flares X-ray observations through theoretical modelling and satellite observations.

- Sub-mm astronomy can answer some of the most profound questions related to the cold components of the Universe on scales of galaxies, molecular clouds, star and planets. Precursor studies using multi-wavelength studies using observations from global sub-mm telescopes.
- Radiative transfer simulations and modelling for Terahertz site characterization studies.
- Research studies related to transit light curves and atmospheric characterization of exoplanets.
- Experiments and modelling of various physical, chemical and biological phenomena in microgravity conditions.
- Magnetohydrodynamic simulations and modelling studies for protoplanetary disc and filament formation in ISM.
- Ionospheric properties of Earth with modelling and satellite observations for understanding the space weather.

11. ELECTRONICS, MICROWAVE & MICRO ELECTRONICS DESIGN & FABRICATION

In order to be self-reliant in the realization of sophisticated Communication, Navigation, Remote Sensing and Planetary payloads, SAC has developed expertise in a host of design, modeling, fabrication, assembly, packaging and testing technologies and has established associated state-of-art infrastructure. SAC plans to augment this capability with a focus on payload miniaturization through development of micro/nano technologies and advanced assembly and packaging solutions. SAC also intends to augment its specialized space environment simulation capabilities to meet the needs of future missions.

In keeping with the above stated objectives, research proposals are invited on the topics that appear in the following sections:

11.1. Research areas in Quantum Device Design and Fabrication

11.1.1. Single & Entangled Photon Sources

For the implementation of Quantum Key Distribution (QKD) using single or entangled photon based protocols, hardware required is the single or entangled photon source. Currently the QKD demonstration is carried out using the photon sources made of Spontaneous Photon Down Conversion (SPDC). But, these sources are probabilistic sources and Quantum Key rate is limited by their generation rate. Faster key generation requires the Bright sources of Single or Entangled photons. QD based sources are capable of generating both single and entangled photons. They are also deterministic in nature and brightness is also high. But, the only drawback of low temperature operation. Two level systems (QDs, 2D materials, Defect centers in high bandgap materials) are capable of generating single or entangled photon sources, but the wavelength and operating temperature depends on the choice of materials. Design and fabrication of QD based quantum photon sources is very challenging and in campus we have the ongoing activity on design and fabrication of quantum sources working at 800 nm & 1550 nm. Proposals (both Design and Fabrication aspects) are invited to work on Bright Quantum Sources using any of the materials, but high temperature operated systems are preferred.

11.1.2. Single Photon Avalanche Diodes

Implementation of Quantum Key Distribution (QKD) also requires the Single Photon Detectors. Currently Superconducting Nanowire Single Photon Detectors (SNSPD) are the most efficient for detection at 800 & 1550 nm wavelengths. They are having good Photon Detection Efficiency and high speed detection, but their operating temperature is 4K or blow. Also, Semiconductor based Single Photon Detectors Namely Single Photon Avalanche Diodes (SPAD) are pursued for near room temperature operation. Silicon based SPADs are in operation near 800 nm and InGaAs based SPADs are operated for 1550nm. But, SPAD performance is not as that of SNSPD, but any improvement in performance is an advantage. Now a day, 2D materials based single photon Detectors are also paving the way due to their high detection efficiency and rate. Proposals are invited for development of highly efficient Single Photon Detectors using 2D materials, any other materials or ways to improve the efficiency of existing technologies.

11.2. Research areas in active and passive device and component technologies

11.2.1. Development of re-grown Ohmic-contact for RF GaN HEMT

AlGaN/GaN on SiC based HEMTs offer very high power densities at microwave and mm-wave frequencies. Ohmic contact resistance is one of the most important metrics for evaluating the HEMTs suitability for high power, high frequency applications. Ohmic contact formation via MOCVD "regrowth" of an n+ GaN layer to side contact to the 2DEG is a promising approach to reducing the contact resistance of GaN heterostructures. Low Ohmic contact resistances on the order of tenths of Ohms/mm can be reproducibly achieved using this technique.

Proposals are invited for the development of reproducible ohmic contact regrowth technique for SAC identified GaN heterostructures. The fabricated samples shall be jointly evaluated by the PI and SAC engineers and detailed process recipe for the developed process shall serve as the deliverable of the project.

11.2.2. Pospieszalski and Pucel type noise model development for GaN HEMT

Unlike GaAs LNAs, which require RF limiters or other protective circuitry to handle high-power signals degrading the overall noise figure, GaN HEMTs are sufficiently robust to endure high power surges without the need for such protective measures, resulting in a lower noise figure and improved signal integrity. The development of noise models for GaN HEMTs is essential for accurately predicting device performance by simulations.

We invite proposals for the development of Pospieszalski and Pucel-type noise models tailored to SAC GaN HEMT devices. The scope of the work includes:

1) Development of Pospieszalski and Pucel type noise model on SAC devices
2) Study of bias dependence of noise model parameters on these models
3) Integration of noise model with ADS software using Verilog-A code
4) Design of 2 stage LNA using developed model at X band
5) Subsequent validation and model refinement using characterization

11.2.3. Nonlinear HEMT model for AlGaN/GaN switch applications

GaN HEMTs are a promising technology for TR module development due to their ability to integrate various components—such as LNAs, switches, PAs, DAs, and DPS—on the same wafer. GaN-based switches can handle exceptionally high power levels, making them ideal for demanding applications. In switch design, a cold FET model (Vds = 0 V)is typically used. To ensure accuracy, the model must precisely capture voltage swings at both the gate and drain while maintaining continuity in current and its derivative. Additionally, it should accurately predict breakdown behavior, which is crucial for determining the input power level of the switch. Proposals are invited for Nonlinear HEMT model development for AlGaN/GaN switch application.

The scope of work should include

1) Development of nonlinear HEMT model for AlGaN/GaN switch application.
2) Integration of model with ADS software using verilog code.
3) Design of X band high power switch (1 dB compression point better than 40 dBm)
4) Measurement verification of switch and further improvement in models if required.

11.2.4. Simulators for SAW filter design

Surface Acoustic Wave (SAW) filters provide efficient RF filtering in a compact footprint, in the frequency range of 10 MHz to 3 GHz. In spite of the prevalence of these devices in modern communication equipment, general purpose design tools for the simulation of these filters are non-existent.

The scope of the proposed research work, hence, shall be to develop accurate simulation tools for the prediction of SAW filter performance. Target specifications and fabrication support shall be provided by SAC. The accuracy of the developed tools shall be checked against the measured performance of fabricated filters.

11.3. Research areas in microelectronic interconnects and packaging

11.3.1. Development of micro-via formation, micro-via filling and wafer planarization processes for Wafer Level Packaging

Wafer level packaging (WLP) of high frequency devices/circuits offers immense miniaturization and improved performance in terms of reduced parasitics. The process uses a bonded cover wafer to hermetically seal the devices/circuits, at the wafer level, followed by dicing of the sealed devices/circuits. This is in contrast to the conventional approach, where the device/circuit dies are first singulated from the wafer and then suitably packaged.

The access to the device pads, in WLP, is provided through vias in the cover wafer, which are completely filled using electroplating techniques. Post filling of the vias, the surface of the cover wafer is planarized, to make it suitable for subsequent lithographic processes.

Proposals are invited to develop production friendly processes for micro-via formation, micro-via filling and wafer planarization processes, in the (Si/SiC/Quartz) cover wafer, for their subsequent patterning and bonding to device wafer. The via-filled and planarized wafers shall be vetted for their suitability for bonding with the device wafer. Detailed process recipes shall serve as the deliverables of the project.

11.3.2. Development of Silicon micromachined THz interconnects

High transmission losses associated with planar transmission lines obviates their use at mm and sub-mm wavelengths. Metal waveguides realized through fine CNC milling techniques have hence become the preferred medium for signal transmission at THz frequencies. However, they need accurate hand alignment and are non-compatible to planar integration with THz active and passive devices. Since the last few years, Deep Reactive Ion Etching (DRIE) based Silicon micromachining has shown immense promise for the realization of THz interconnects and hence are being actively pursued in research.

Proposals are invited for development of DRIE based Silicon micromachining processes for realizing THz interconnects. The scope of the proposed work shall include (a) development of Si micromachining processes for THz interconnects suitable up to 500 GHz and (b) demonstration of performance through fabrication and testing of interconnects. The process recipes developed and the hardware realized shall serve as the deliverables of the project.

11.3.3. Development and integration of Ferrite material compatible with DuPont 951 LTCC tape system and realization of circulator

Low Temperature Cofired Ceramics (LTCC) is a 3D glass-ceramics multilayer packaging technology that enables the embedding of passive components such as resistors, inductors, capacitors, filters, and power dividers. As the demand for more compact and lightweight components increases, there is a need to integrate diverse materials like ferrite. The development and integration of ferrite materials compatible with the Dupont 951 LTCC tape system are crucial for the realization of circulators. This integration requires careful consideration of sintering compatibility, ensuring that the materials can withstand high temperatures while maintaining proper shrinkage matching during the firing process.

Proposals are invited for development of Ferrite materials compatible with Dupont 951 tape system The scope of work should include

1) Development of compatible ferrite materials
2) Integration with LTCC modules
3) Design of X band circulator in LTCC
4) Realization of circulator using developed process
5) Testing of circulator

11.3.4. Development and Integration of High-K Materials Compatible with the DuPont 951 LTCC Tape System

To enhance the integration density and reduce the size in electronic circuit, it is essential to incorporate as many components and elements as possible within the LTCC system. Middle or High-K materials (K > 300) are crucial for fabricating capacitors with values of 100 pF or higher. Usually a middle-k or high-k dielectric is integrated as screen-printed thick film or green tape in the multilayer modules during lamination. These materials must remain compatible with the LTCC process, particularly during the firing operation, to ensure reliability and performance.

Proposals are invited for development of High -K material compatible with Dupont 951 tape system The scope of work should include

1) Development of High K materials
2) Integration with LTCC modules
3) Realization of capacitor using developed process and subsequent testing.

11.3.5. Brazing/Attachment media for Ceramic /Quartz substrates for high reliable micro assembly

This work shall include selection of reliable micro assembly Candidate material based on thermomechanical modelling and experimentations for the following applications:

A) Void free low temperature (~ 300 degC) attachment media and process of large ceramic substrate (1"x1 "to 3"x5") attach over metallic carrier plates suitable to withstand -55 to +125 degC temperature cycle regime. Configuration study and recommendations on metallic carrier mechanical properties are also to be devised for reliable assembly for a given substrate configuration/design.

Simulation & experimental study of attachment void v/s over RF performance up to Ka Band Amplifier circuit made with discrete elements and alumina substrates.

B) Void free, thin bond line thickness (~ 200 nm) attachment media and process of quartz substrate (with 25:1 aspect ratio) attachment on metallic carrier plate, suitable to withstand 0 to - 4K temperature cycle regime.

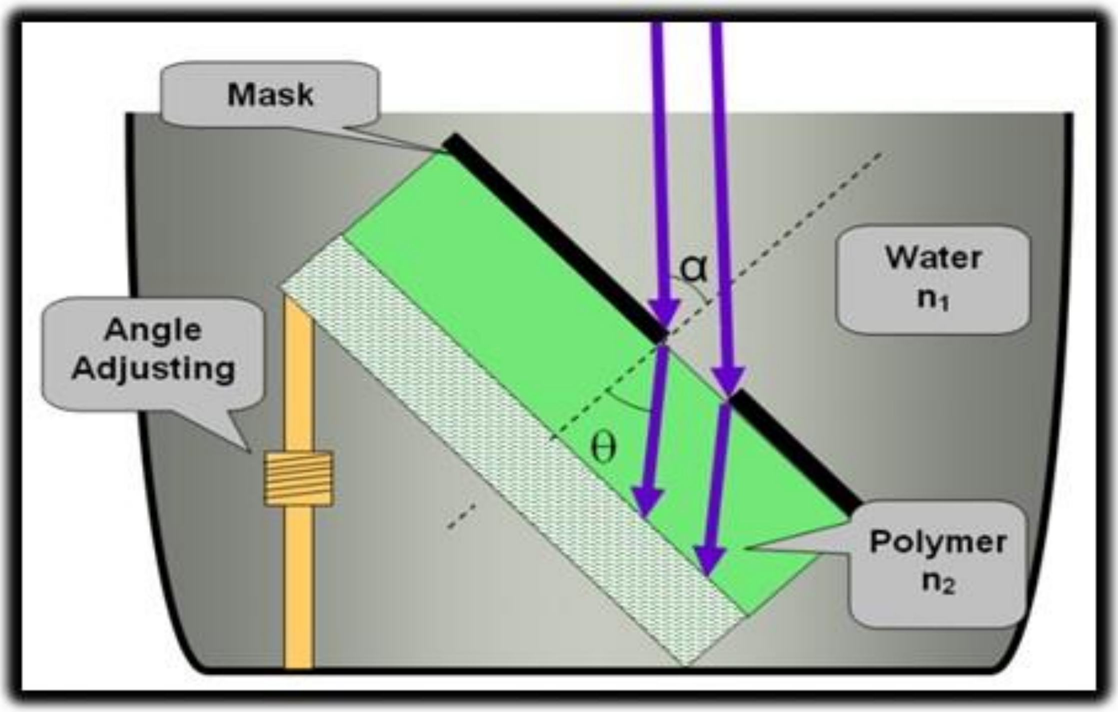
11.4. Research areas in micro and diffractive optical component technologies

11.4.1. Development of 45° Bending Mirror for out-of-plane coupling in Polymer Optical Waveguides for Optical Interconnects

Bending Mirror is one of the simple solutions for out-of-plane coupling of light between optical waveguides and optoelectronic devices fabrication. In this type of coupling, light is reflected due to either a metal coating or total internal reflection at the end of a polymer waveguide. A PCB compatible 45° bending micro mirror is to be fabricated on polymer optical waveguides using tilted beam photolithography. After successful fabrication, the mirror needs to be characterized for coupling efficiency.

The activity shall include the following:

a. Survey and selection of required materials and process as per detailed SAC requirements.
b. Development of fabrication process.
c. Component demonstration and measurement of coupling efficiency.



Schematic of improved UV photolithography on PCB substrate

11.4.2. Development of Precision Slits / Apertures / Bar Targets

Precision slits, apertures and bar targets are one of the essential components for realization / calibration of optical imaging cameras. These components when fabricated with high precision provide a well-defined desired image without problems like beam scattering etc.

The precision slits / apertures / bar targets may be fabricated in Si (with appropriate optical coatings) or in metal foils (of appropriate metal) so that it works with the visible and IR spectrums. The coated Si substrate / metal foil shall work as an opaque material with the gaps in them allowing the light to pass through as per the design of the pattern.

The activity shall include the following:

a. Survey and selection of required materials as per detailed SAC requirements.
b. Development of fabrication process, typically Si through etch / Lithographie, Galvanoformung, Abformung (LIGA) based processes.

c. Process, component demonstration and qualification.

11.4.3. Development of Deformable Mirror

Deformable mirror is an integral part of a variety of modern adaptive optics system, which are used to correct the optical aberration of the wave front. It is carried out by deforming the shape of a membrane (mirror) in response to an applied control signal.

A Polysilicon Multi-Users MEMS (PolyMUMPS) type or similar process is to be developed for Fabrication and Packaging of the deformable mirror array device. It is desirable that fabrication and packaging be followed by relevant characterization steps to validate the performance of the device.

The activity shall include the following:

a. Survey and selection of required materials and process as per detailed SAC requirements.

b. Development of the fabrication process.

c. Process, component demonstration and qualification.

11.4.4. Development of Reflective Optical Coating over PMMA Resist

Optical coating is an important process in several micro/diffractive optical devices in order to alter the way light interacts with them. To achieve required reflectance in the desired wavelength range appropriate reflective optical coatings are used. This application requires reflective optical coating on 2D/3D shapes fabricated over Poly Methyl Methacrylate (PMMA), a polymer.

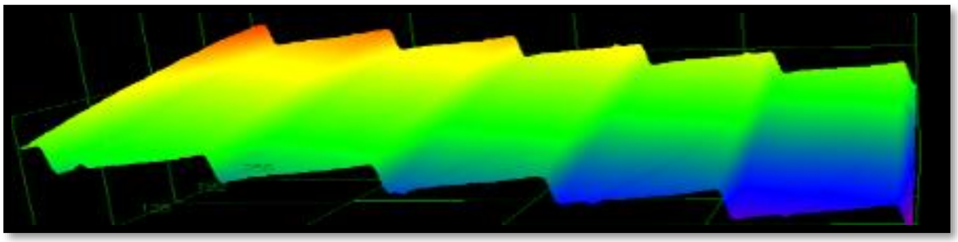
This work requires the development of optical coating over 950K PMMA Electron Beam Sensitive Resist. The structure shall have either binary or greyscale resist pattern over planar or non- planar substrates of irregular sizes. The coating shall have excellent adhesion with resist (PMMA) and shall preferably be abrasion free.

The activity shall include the following:

a. Survey and selection of required materials as per detailed SAC requirements.

b. Development of optical coating process over Patterned PMMA Resist Structures.

c. Process, coating performance demonstration and qualification.



Blazed grating on Silicon plano-convex lens

11.5. Research areas in microfabrication process technologies

11.5.1. Development of Electron Beam Sensitive and Dry Etch Compatible High Resolution Resist

Electron beam lithography has been an attractive technology to delineate nano-structures. These patterned structures can further be transferred on underlying metals (such as Aluminium in this case) using Dry Etching technique. This process requires the resist to be electron beam sensitive as well as dry etching compatible. Scope of Work includes a Dry etching compatible electron beam sensitive resist with its developer is to be prepared.

The activity shall include the following:

a. Survey, selection and development of required materials for synthesis of resist, developer etc. as per detailed SAC requirements.

b. Process, material demonstration and qualification - Process with Aluminium Deposition, Electron Beam Lithography, Aluminium Dry Etching over an area of 15mm x 15mm with 70nm half pitch (preferable 40nm) Binary Grating structures.

11.5.2. Development of Electron Beam Sensitive and Lift off Compatible Resist

In many standard micro-fabrication processes, Electron beam lithography and lift off process is inevitable. Electron beam lithography, a direct write technique, uses resists like PolyMethyl Methacrylate (PMMA) resist with its co-polymer for the lift off process. This process requires formation of an undercut resist profile, which helps in achieving smoother metal lift off.

Proposals are invited for the development of Electron beam resists with its co-polymer, suitable developer and removal agent (as per detailed SAC requirements)that should be able to support metal lift off process.

The activity shall include:

a. Survey, selection and development of required materials for synthesis of resist, developer, remover etc. as per detailed SAC requirements.

b. Process demonstration using the developed material

11.5.3. Development of Dry Film Resist for Thin Film Integration on LTCC

Low temperature co-fired ceramic is a useful technology for RF applications. Integration of multilayer structure in LTCC is based on thick film processing. Development of dry film resist (DFR) is required for thin film integration on LTCC. This is needed for the fabrication of certain circuit elements having smaller (<100μm) features.

Scope of Work:

A Dry Film Resist is to be developed and using it process needs to be demonstrated meeting SAC requirements. The LTCC contains slots (cavities) and may have process-induced warpage, bow etc.

The activity shall include the following:

a. Survey, selection and development of required materials, resists, developer, plating chemistries, suitable equipment etc.
b. Development of fabrication process, which includes seed-layer deposition, DFR lamination, lithography, electroplating, seed layer etching etc.
c. Process demonstration using developed resist

11.5.4. Electrically controlled tunable integrated devices using Magneto-electric (ME) composites (Thin film/Bulk & Thin film/thin film) for microwave integrated circuit applications

The emerging research area of Magneto-electric devices where the magnetic characteristics are controlled by an electric field and/or the electric characteristics are controlled by a magnetic field, the magnetoelectric (ME) effect, is a very attractive subject for novel microwave circuit applications. The composite systems usually include Ferrite-Ferroelectric/Piezoelectric combinations. In such bilayer system, the ferrite, when driven to Ferromagnetic Resonance (FMR) and an electrical signal is applied; the FMR frequency can be shift thereby facilitating tunable characteristic. It is proposed to develop suitable composite material system with at least one component in thin film form and demonstrate dual-tunable integrated microwave components like tunable inductor, phase-shifter, attenuators, filters etc. using the developed material system.

11.5.5. Studies on energy dependent Secondary Electron Yield of Carbon Nanotube (CNT) coatings on OFHC Copper for high frequency (Ka band) TWT

One of the prime objectives of very high frequency (e.g. Ka band) TWT especially for Space use, is to reduce the secondary electron emission (SEE) from Multistage Depressed Collectors (MDC) so as to improve the TWT efficiency. Variety of techniques have been investigated and being deployed for the intended objective. One of the recent research areas is developing CNT coating on conducting surface of collector which is expected to reduce secondary electron yield by a factor compare to other materials like Graphite. The activity aims to develop suitable method for CNT synthesis, deposition of CNT coating on OFHC cupper collector surface and characterizing the SEE.

11.5.6. Development of Nanostructured Magnetostrictive thin films for Surface Acoustic Wave Applications

Surface Acoustic Wave (SAW) devices are widely used in communications such as filters, delay line etc. Conventional SAW devices consist of metallic IDT on top of piezoelectric film or substrates. Research involves the development of high quality thin films of giant magnetostrictive materials (e.g. Fe-Si) which exhibit high magnetostriction coefficient suitable for low insertion loss SAW devices.

11.6. Research areas in Electronic fabrication

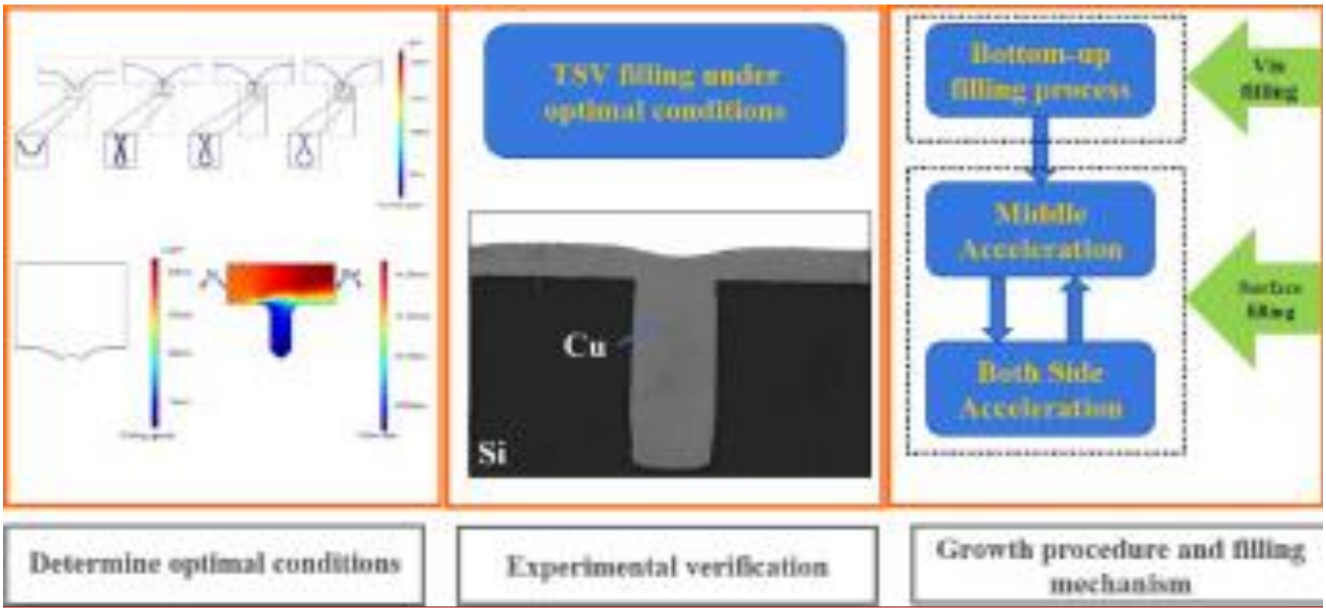
11.6.1. On-Line Process Monitoring of Organic Additives in Copper Electroplating Baths for PCBs

Copper Electroplating is one of the vital technologies in printed circuit fabrication processes. For Space industry, circuit board fabricated requires maximum efficiency and superior product quality in process. To achieve good via quality, plating solution requires constant monitoring of several key components in plating bath. There are few organic additives which cannot be determined through normal titration, but these additives play pivotal role in shaping final copper layer.

We need to develop the process analyzer which allows in process measurement and control of these additives and its concentration in plating solutions thereupon maintaining optimal plating conditions and improving overall efficiency and reliability of plated product in manufacturing.

This research may benefit in various aspects as follows:

- Cost saving through minimizing waste and maximizing efficiency of plating additives.
- Mitigating risk of defects by consistent monitoring of additives.
- Optimizing plating performance by maintaining narrow range and superior quality.



11.7. Research area in Electronic calibration

11.7.1. Calibration of Test & Measuring Equipment used in the field of Optical Communication

SAC is involved in development of optical communication devices like optical amplifier, photonics Analog to Digital convertor, optical switches, O-E & E-O convertors which are used in high speed optical links etc. For Testing of these devices Test & Measurement Equipments are used like Tuneable Laser Sources, Optical Power Meter, Optical Attenuator and Optical Spectrum Analyzers. So seeing increase in optical payload activity; SAC calibration facility is working for upgradation in the field of optical communication. For this Calibration lab is trying to establish the traceability for optical parameter especially in the band of 1550±20 nm and trying to find out the ways for calibration/validation of test & measuring equipment in optical communication field.

11.8. Research Areas in the field of Surface Treatment Process Technologies

11.8.1. Process Development to realize Electroforming Process for Aluminium Component

Electroforming is a technique used in fabrication of complex contoured components with high dimensional tolerances which are difficult to fabricate using conventional machining methodology. At present, electroforming process of copper components on Aluminium mandrels has been successfully realized at SAC. Copper has disadvantage of high density of 8.9 grams/cc.

Hence, efforts are invited to carry out in depth feasibility study to realize electroforming process of Aluminium components and develop detailed process & setup for the same. This process can be used for mm-wave components.

11.8.2. Development of Electroless Gold Plating Process

Gold plating on aluminium 6061T6 boxes and Kovar carrier plates is being carried out for EMI/EMC requirements, corrosion protection, solder ability etc.

Hence, efforts are invited in the area of Electro less gold plating process using either cyanide based or non-cyanide based chemistry for plating aluminium 6061T6 alloy components/Kovar substrates with plating thickness of >=2 microns of gold. Once developed, this process will be used for all ISRO projects as per requirements.

11.8.3. Indigenous Development of Black Thermal Control Paints for Space use

Thermal Paints are used to impart desired thermo-optical surface properties to space hardware. Black thermal paint with improved emissivity and solar absorptivity values and with very good adhesion to various base surfaces like Aluminium Alloy 6061, Silver plated Aluminium Alloy, Electroless Nickel plated Aluminium Alloy, Anodized Aluminium alloy, SS-316, CFRP etc., is proposed to indigenously develop and qualify for space use. Black Thermal paint shall meet outgassing properties as per ASTM E 595 / ECSC-Q-ST-70-02C) and pass various qualification tests like humidity test, Thermo-vacuum test, Thermal cycling test and adhesion test etc.

Hence efforts in research, development, testing and qualification and production of sprayable Black thermal paints, preferably environment friendly, are invited. The broad scope of work and specifications are: -

1. Development of primer system/s, preferably 1K, compatible for (1) Aluminium Alloy 6061, (2) Silver plated Aluminium Alloy, (3) Electroless Nickel plated Aluminium Alloy, (4) Anodized Aluminium alloy, (5) CFRP, (6) SS-306
2. Development of Black thermal paint (top coat) with outgassing properties., CVCM $\leq$ 0.1% and TML $\leq$ 1% and Thermo-optical properties., Emissivity $\geq$ 0.9 and solar absorptivity $\geq$ 0.9

11.8.4. Development of a Compact Water Electrolyzer Prototype for Gaganyaan Missions

A critical aspect of sustaining long-duration missions in space is the efficient generation of life-supporting gases, particularly oxygen and hydrogen from water. Proposal outlines the design and development of a compact water electrolyzer prototype, optimized for space conditions, which will facilitate the electrolysis of water to produce oxygen for breathing and hydrogen for fuel.

1. To design and fabricate a compact water electrolyzer that utilizes a suitable membrane for enhanced efficiency in electrolysis.
2. To develop an effective oxygen filtration and collection system to ensure the purity of generated oxygen.
3. To create a hydrogen filtration and collection cylinder capable of safely storing the produced hydrogen for possible fuel applications during the Gaganyaan missions.

11.8.5. Development of High Emissivity (>0.9) and Low Solar Absorptivity (<0.2) Oxide Coating using appropriate process on Al6061 Aluminium Alloy

The efficient thermal management of spacecraft and microwave devices such as Traveling Wave Tube Amplifiers (TWTAs) is crucial for enhancing performance and reliability in space environments. This project aims to develop a white oxide coating on aluminum alloy Al6061 that achieves a high emissivity of greater than 0.9 and a low solar absorptivity of less than 0.2. Such a coating will facilitate effective heat removal, ensuring optimal operational conditions for critical aerospace components.

1. Formulate an oxide coating process that includes specific bath compositions, process parameters, and conditions tailored for Al6061.
2. Achieve a coated surface with emissivity values exceeding 0.9 and solar absorptivity below 0.2.
3. Validate the coating's performance through rigorous testing against established space environment criteria, including heat resistance at 500°C, thermal cycling, outgassing, and thermo-vacuum conditions.

11.9. Research Areas in the field of Space Environment Simulation and testing technologies

Environmental Testing is an important activity in the process of Payload development. Facilities have several hot and cold chambers and Thermo-vacuum chambers up to 6.5m Dia. which meets the environmental test requirements of various payloads being developed at SAC, Ahmedabad.

Establishment of new facilities and augmentation of existing facilities to accommodate special test requirements is a continuous process. This demands innovative solution to emerge in close collaboration with the academic institutions and industrial research units.Collaborative efforts are invited from academic institutions in following upcoming requirements/research areas as outlined below.

11.9.1. Super Insulated Cryogenic Transfer Lines

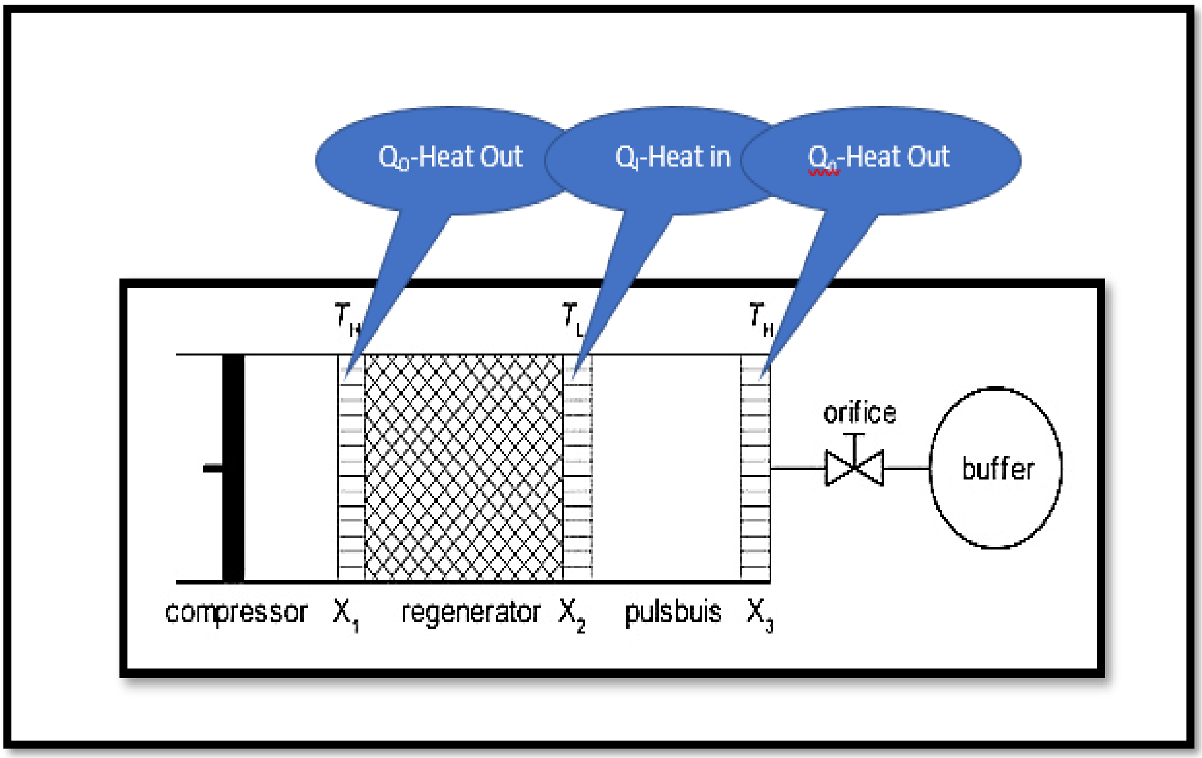
Vacuum jacketed Cryogenic transfer lines are an integral part of a thermal vacuum system, as they offer compact size footprint, extremely low heat inleak, aesthetic layouts, ease of installation and lower long-term maintenance costs.

The scope of this work will involve development for non-metallic, light weight; low loss cryogen transfers lines especially for efficient distribution of Liquid nitrogen. The functional temperature range to be considered for the SI lines should be -196degC to +50degC.

11.9.2. Pulse-Tube Cryo Cooler

Pulse tube cryo-coolers have been evolved in recent years and matured as a promising technology for meeting the challenging cooling requirements of space industry. They provide significant advantages in terms of overall size, extremely lower vibration levels, and higher reliability. These coolers have been used in ground segment testing of space hardware as well as for onboard applications.

The scope of this work shall entail development of compact, low cost single stage/ double stage Pulse Tube cryo-coolers to facilitate testing tiny devices at low temperature as well as for low cooling requirement for IR/CCD detectors. Expected cold tip temperature for this development activity is 80K with ~10-watt cooling capacity @80K, which can be verified in existing facilities at SAC with appropriate set-up.

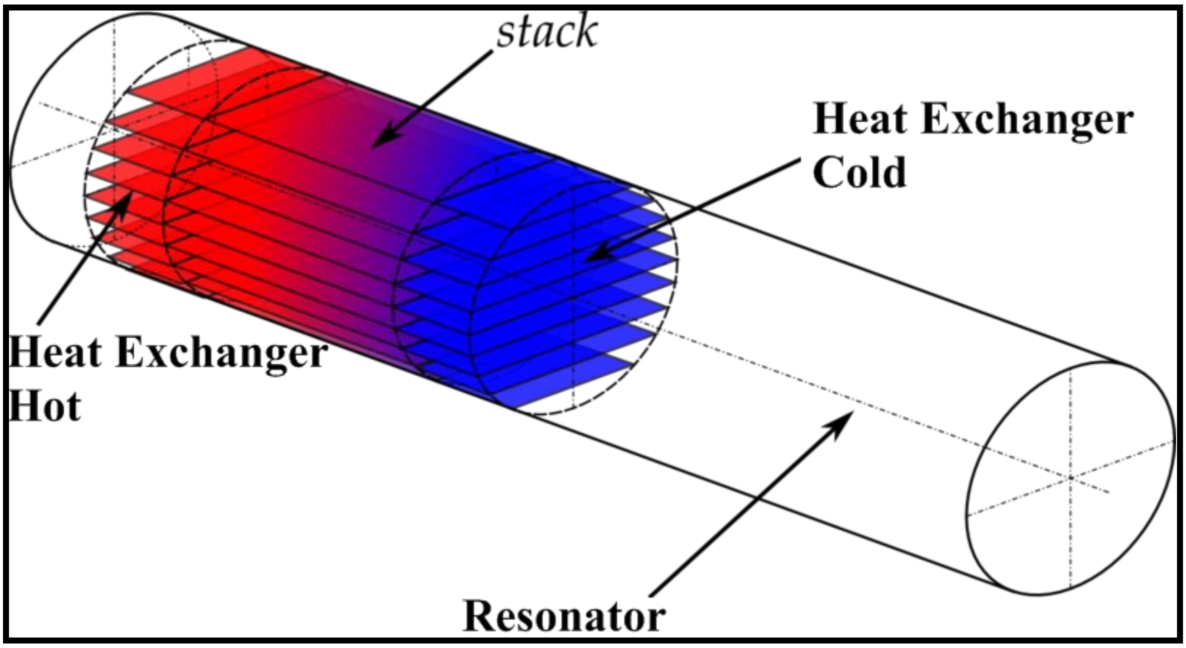


Representative schematic of a typical pulse tube cooler

11.9.3. ThermoAcoustic Cooler

Thermoacoustic coolers can provide a very compact, simple & reliable way for producing the desired refrigeration effect. This cooler also has an advantage of using inert gases and produces very low environmental impact.

The scope of this work will involve development of acoustic coolers for small detector cooling application and handling heat from the heat sinks etc.



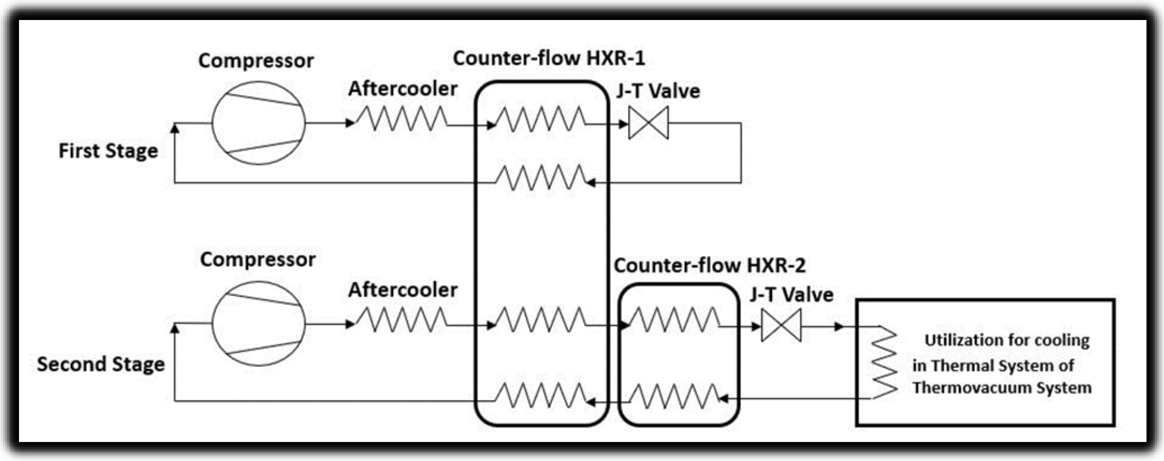
Representative schematic of a typical acoustic cooler

11.9.4. Mixed Gas Refrigeration System

The recent advancements in the development of mixed gas refrigeration systems has generated considerable interests in potential application of such systems, which were earlier out of reach for mechanical refrigeration systems particularly for cryogenic temperatures.

The scope of this work shall involve development of mixed gas refrigeration based thermal system for compact climate test chambers and thermal vacuum chambers. The researchers shall be responsible for design, simulation, analysis, optimization & realization and testing of thermoelectric coolers.

The expected lowest temperature for mixed gas refrigeration system is -150degC in cascade mode. The performance of the realized system will be tested and verified against the target specifications.



Representative schematic of a typical mixed gas refrigeration system

11.9.5. Contamination Control study

Contamination control plays an extremely important role particularly in realization of electro-optical payloads, where any unintended activity/process can lead to severely impact the mission life.

The present proposal entails a study, simulation and analysis of various forms of contaminations like surface and airborne particulates, surface and airborne molecular contaminants in and around thermo-vacuum chambers. Carryout in-depth measurement of such contaminants using APC, PFO, RGA, TQCM available and carry out detailed process study as well as make recommendations in this regard for implementation.

11.9.6. Liquid nitrogen consumption and optimization study

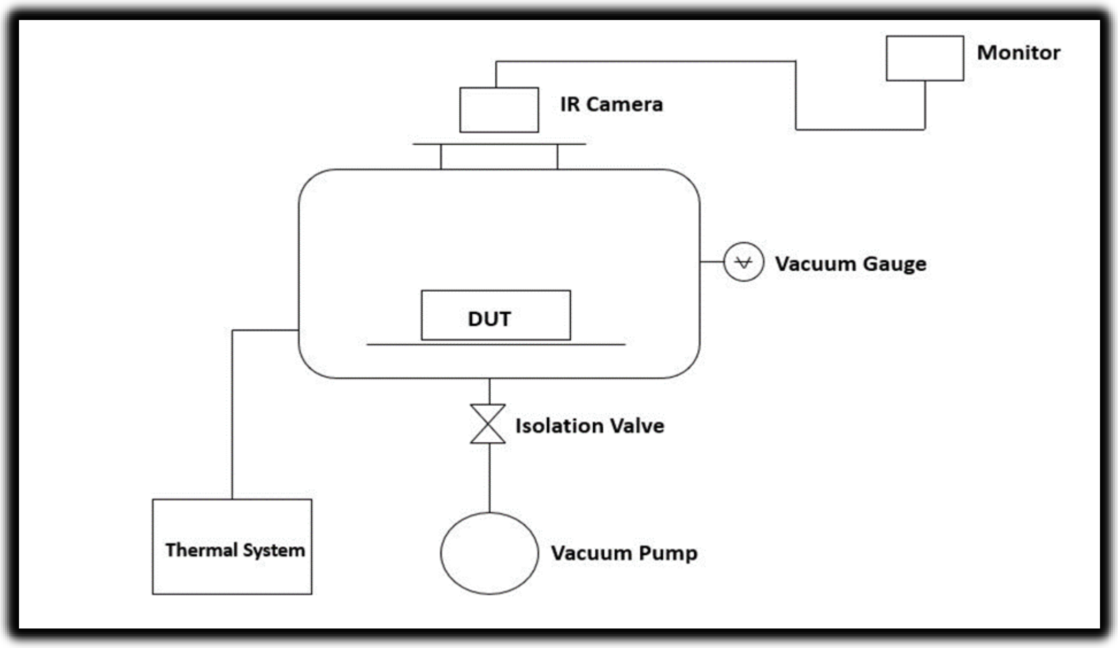
Liquid nitrogen is a fluid of choice for majority of thermal vacuum chambers due to its characteristics like low temperature of liquefaction, very wide temperature range in single phase, large latent heat of evaporation and lower cost. As LN2 is utilized across the facilities in majority of thermal vacuum chambers, its overall usage and optimization is equally important.

The present proposal will involve Study and analysis of Liquid Nitrogen consumption in Thermo-vacuum test facility with respect to different type of tests being carried out in different LN2 based thermo-vacuum chambers. Study and analyze transfer, static and flash losses taking place in various system elements during thermo-vacuum tests and carry out detailed process study as well as make recommendations in this regard for implementation.

11.9.7. InfraRed imaging system for temperature monitoring

Real time temperature monitoring of different critical components and surfaces during a thermal vacuum testing necessitates availability and utilization of an accurate & fast response-based temperature measurement system. Temperature sensor mounting at the required locations on a subsystem is an essential but laborious and time intensive activity, and an IR based imaging system can provide a non-contact type real time temperature monitoring inside a thermal vacuum chamber.

The present scope of work involves a development of IR mapper-based temperature measurement system for monitoring the package temperature inside a thermal vacuum chamber, thereby eliminating the need of physically temperature sensor mounting. The required temperature range for the measurements is, from -40degC to +85degC.

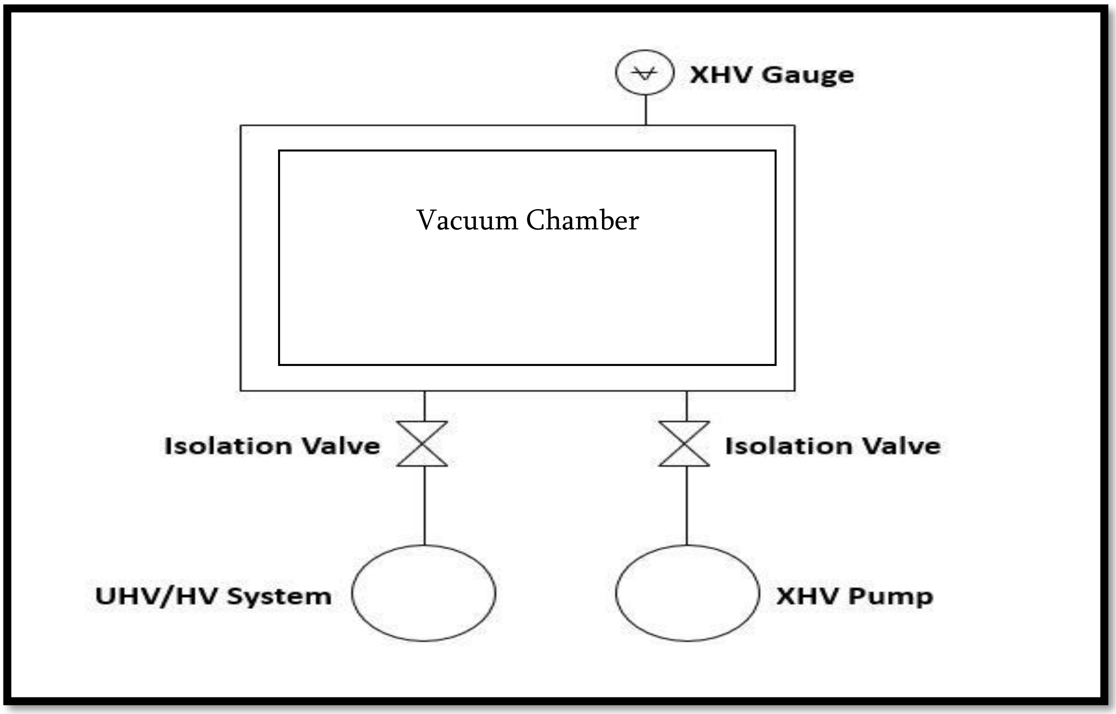


Representative schematic of a typical IR camera-based imaging system

11.9.8. Design and realization of XHV system

Achieving Extreme High vacuum has been a holy grail of vacuum science. Simulation of interstellar space, processing of some advanced semiconductor devices, surface science experiments and measurements are few important applications for XHV level.

The present scope of work will involve development of a small experimental cavity/volume XHV system for achieving better than 1e-12 mbar vacuum.

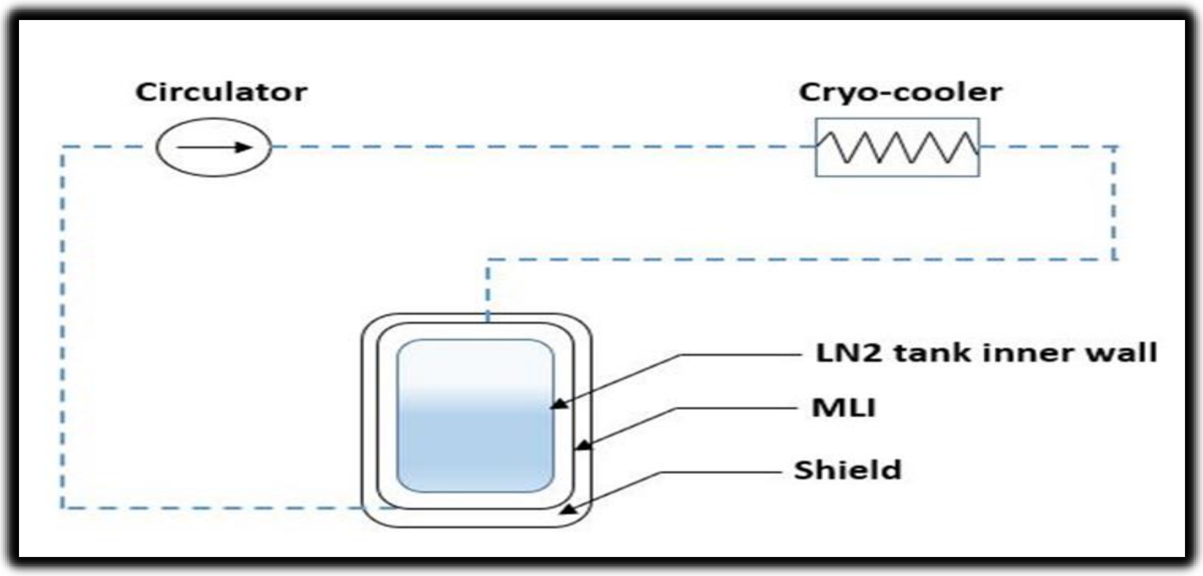


Representative schematic of a typical XHV system

11.9.9. Zero-Boil-Off System

Zero-Boil-Off (ZBO) systems can provide considerable savings for mission critical cryogens particularly for interplanetary missions. These systems become more critical for human space missions needing long duration in space. ZBO-Zero Boil Off Cryogenic system will demonstrate long term storage & saving of cryogen (Experimental system) with minimal cryogen losses from the storage tanks due to natural boil-off. The proposed prototype may also be utilized as a platform for future interplanetary type missions which will certainly have this requirement.

The proposed study will involve study of different options, simulation and analysis of ZBO system, realization of an experimental system to validate the theoretical models and to make proposal for an operation system.



Representative schematic of a typical ZBO-Zero Boil Off scheme

11.9.10. Cryogenic Radial fan Blower for Thermal Conditioning Unit

The devices under test (DUTs) in a Thermal Vacuum chamber need to be heated or cooled by radiation and conduction heat transfer in a maximum temperature range typically ranging from +100°C to -100°C under high vacuum conditions. A Thermal Conditioning Unit (TCU) is a dense gas circulation based closed loop system, which is used to achieve this stringent temperature excursion requirement with required temperature uniformity. A Cryogenic radial fan/blower (which is a centrifugal blower) is the heart of this TCU, which is used to circulate this dense gas, generally Nitrogen. A Thermal Conditioning Unit is developed in house in SAC under TDP, but the cryogenic blower in this TCU is still to be indigenize

The present study will involve the design, development, testing, and delivery of VFD driven high RPM cryogenic centrifugal blower, with a wide temperature range operation (-100°C to +100°C) for the performance parameters defined as follows

Sr. No.	Specification	Value	Remarks
1	Fluid-Medium	Nitrogen gas	
2	Mass flow rate	80 - 350 kg/hr	Or wider
3	Inlet/outlet size	50 NB	With CF 65 Flange end connections
4	Inlet pressure	6 bar	Or higher
5	Inlet Temperature range	-100°C to +100°C	Or wider
6	Material Of construction	SS-304L/316L	Or suitable material catering to this temperature range
7	Differential pressure	300mbar to 1000mbar	Minimum
8	Rotational speed	Controllable as per requirement	With variable frequency drive-VFD to control the mass flow rate specified in spec. 2
9	Power	3 Phase 415V 50 Hz	

Note: The above details are indicated to provide a broad understanding of overall requirements; a detailed performance requirements and its delivery/demonstration need to be worked out at the designing stage

11.9.11. Bayonet couplings

Bayonet couplings are vacuum jacketed cryogenic couplings and are regularly used in the field distributions lines for cryogenic applications as well as directly on the cryogenic equipment for ease of connection and disconnection. These specialised mechanical couplings provide a leak tight connection with minimal heat transfer and allow safe and efficient transfer of cryogenic liquid (like liquid nitrogen).

The present study will involve the design, analysis, development, testing, and delivery of two sets (1/2 inch NB size) of bayonet joints (both male and female components with their seals and clamping system) for the transfer of liquid nitrogen.

11.9.12. Micro-Pirani gauge for vacuum measurements

Pirani gauges are the mainstay of sub-atmospheric pressure measurement systems in the process industry as well as in the R&D labs for myriad applications. The Pirani gauges have a limited sensitivity towards the lower pressures (or the improving vacuum levels), and this limitation can be overcome with the introduction of Pirani element at miniaturised level. Such sensors are already available from the import sources, and hence the proposal is invited to develop these sensors indegeously.

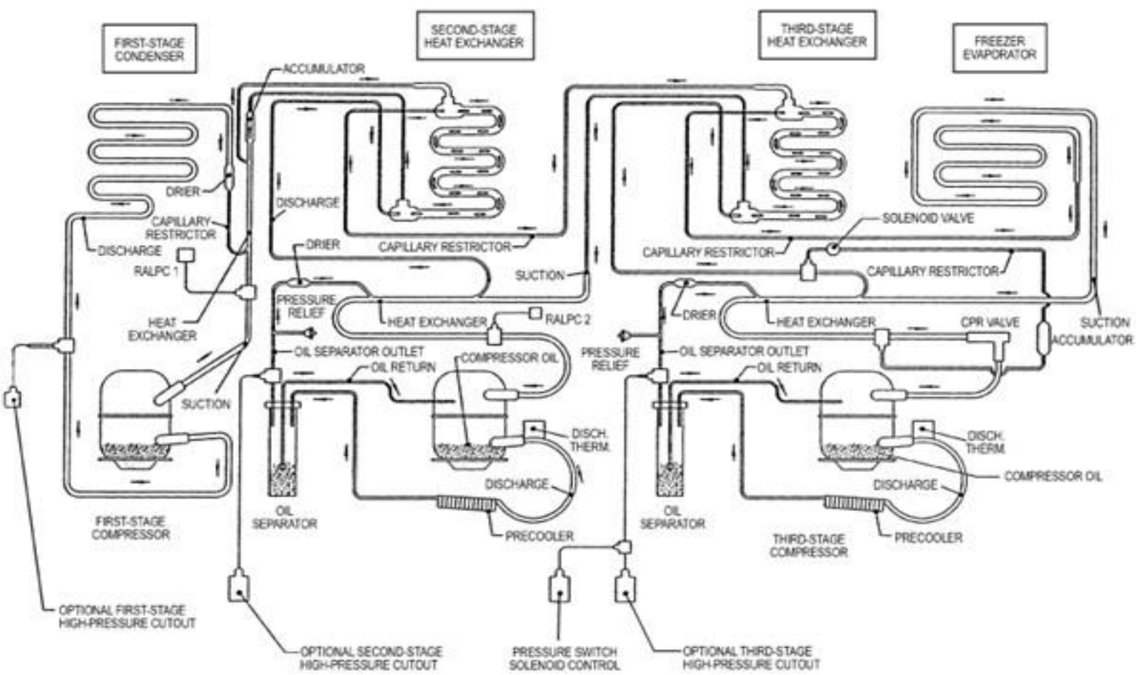
The present study will involve the configuration, design, simulation, and prototyping the sensor for measuring the vacuum levels in the sensor cavity in the range of 1000mbar to 1e-4mbar.

11.9.13. Three stage Cascade Refrigeration System

The recent advancements in the development of three stage cascade refrigeration systems has generated considerable interests in potential application of such systems, which were earlier out of reach for mechanical refrigeration systems particularly for cryogenic temperatures.

The expected lowest temperature from three stage cascade refrigeration system is -120 °C. The principle of cascade system is very simple. But realizing the mechanical system with such a low temperature with non-CFC refrigerant is another aspect.

The scope of this work shall achieve for fast transition rate with cryogenic range temperature cycle tests in climate test chambers. The researchers shall be responsible for design, simulation, analysis, optimization, realization and testing of refrigeration systems with use of non-CFC and non-HCFC refrigerants.



Representative schematic of a typical three stage cascade refrigeration system

11.10. Research Areas in Thermal Engineering

11.10.1. Cryo Coolers and related Drive Electronics

Cryo-coolers and its associated technologies need to be developed for cooling of various kinds of detectors/systems in cryogenic temperature ranges up to 4.2K. Sterling Type Pulsed Tube Cryo-cooler (STPC) is promising candidate for such requirement for Space use due to less mass and power requirement. Following are the envisaged development requirement for

Cold-Head Assembly

Pressure Wave Generator (PWG)

Cooler Drive Electronics (CDE)

11.10.2. Variable Emissivity Coated (VEC) Micro-electromechanical System (MEMS) radiators

Technologies/process related to development of VEC/MEMS based radiators for optimizing radiator size for deep space missions need to be developed. Collaboration is envisaged in any experimental/numerical aspect of the same.

11.10.3. Cooling technologies for ultra-low temperature range cooling

(a) Adiabatic demagnetization refrigerator (ADR)

It is a cooling technology based on the magneto caloric effect. This technique can be used to attain extremely low temperatures (below 0.5K). The basic operating principle of an ADR is the use of a strong magnetic field to control the entropy of a sample of material, often called the "refrigerant". The operation of a standard ADR proceeds roughly as follows. First, a strong magnetic field is applied to the refrigerant, forcing its various magnetic dipoles to align and putting these degrees of freedom of the refrigerant into a state of lowered entropy. The heat sink then absorbs the heat released by the refrigerant due to its loss of entropy. Thermal contact with the heat sink is then broken so that the system is insulated, and the magnetic field is switched off, increasing the heat capacity of the refrigerant, thus decreasing its temperature below the temperature of the heat sink. In practice, the magnetic field is decreased slowly in order to provide continuous cooling and keep the sample at an approximately constant low temperature. Once the field falls to zero or to some low limiting value determined by the properties of the refrigerant, the cooling power of the ADR vanishes, and heat leaks will cause the refrigerant to warm up.

Collaboration is envisaged in development of various subsystems and critical technologies related to ADR like salt pill, Magneto Resistive Heat Switches, Superconducting Magnets, etc. Development of numerical code for modelling of magneto calorific effect (MCE) and system level modelling of ADR also need to be taken up in joint academic collaboration.

(b) Optical Cooling:

Optical refers to a number of techniques in which atomic and molecular samples are cooled down to near absolute zero. Laser cooling techniques rely on the fact that when an object (usually an atom) absorbs and re-emits a photon (a particle of light) its momentum changes. For an ensemble of particles, their temperature is proportional to the variance in their velocity. That is, more homogeneous velocities among particles corresponds to a lower temperature. Laser cooling techniques combine atomic spectroscopy with the aforementioned mechanical effect of light to compress the velocity distribution of an ensemble of particles, thereby cooling the particles.

11.10.4. Heat Diffusion/Transportation devices for heat transfer through conduction of miniature high heat flux electronics device/system

In space conduction is the prime mode of heat transfer from heat source to space exposed sink. Thermal management of High dissipating miniature electronics devices is quite challenging. Through this topic, expects researcher to explore various passive means of heat diffuser and high heat conductive devices, easy to interface with the heat source and offers efficient heat transportation.

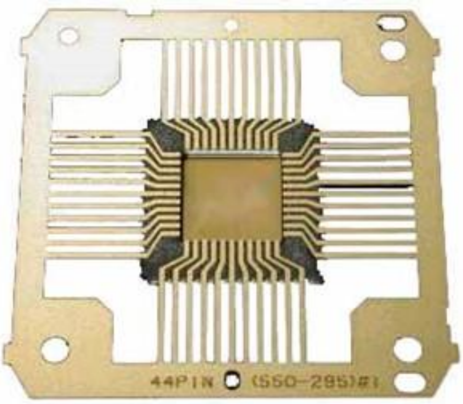
12. MECHANICAL ENGINEERING SYSTEMS

12.1. Research areas in Mechanical Design and Development of Microwave Remote Sensing Payloads

12.1.1. Evaluation of material mechanical properties after plastic deformation

Behaviour of metal components beyond linear elastic range has remained a gray area in the field of space payload component development. Understanding variation of mechanical properties post plastic deformation will enable accurate life estimation and mass optimization in payload components. For comparison one can take example of an L-angle realized using matching and the other realized by bending a sheet of same material and cross section. The structural behaviour of both the components will be in a way that machined component will be more rigid than the formed component.

The study will enable us to mathematically understand the behaviour, which can be further included in analysis programs to predict accurate life of metals components and joints, where metal forming is inevitable. Such applications are forming of connector and CQFP pins, formed structural components.

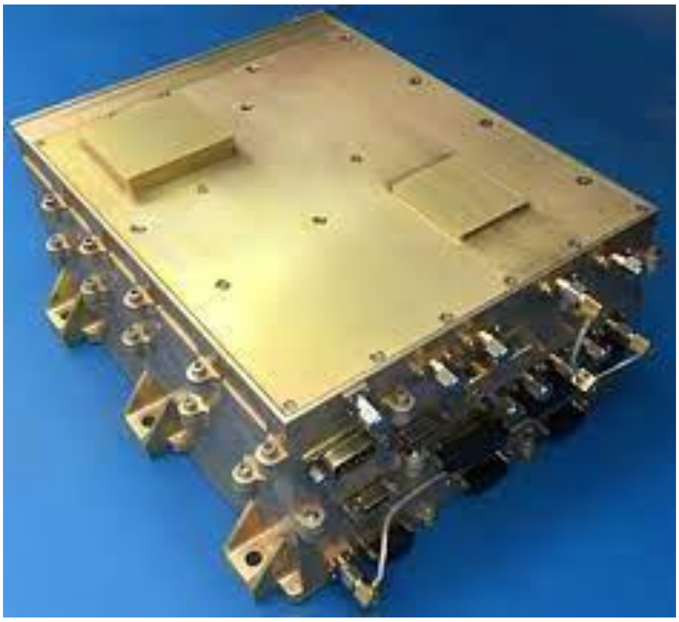


QFP before and after pin bending

It's expected to evaluate mechanical properties, evolve mathematical formulation, FE code for behaviour of metals post plastic deformation & Experiment set-up for validation of the mathematical code.

12.1.2. Suppression of structural dynamic response in Multi-level Stacked electronics package assemblies.

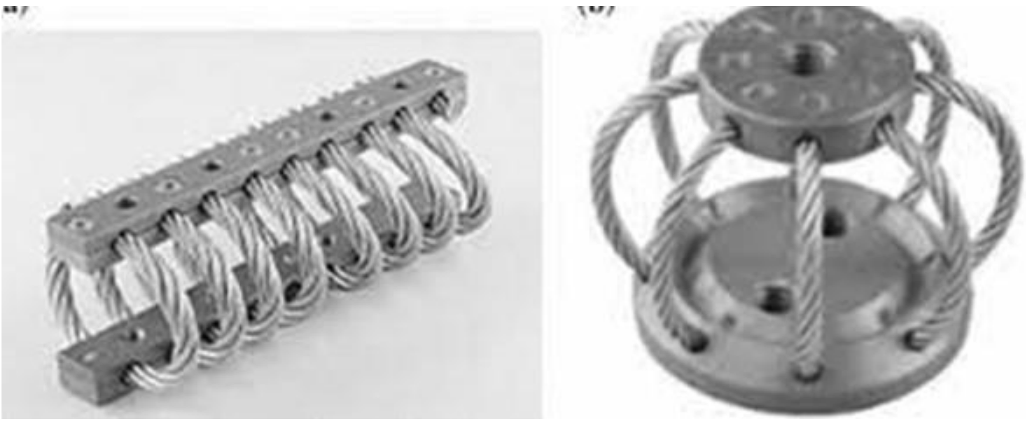
Payload subsystems are stacked one over the other in order to reduce footprint of electronics subsystems on spacecraft deck. With each level increase in package stacking, the structural dynamic response of the stack on the top increases, which forms limiting factor for the packages/ devices planned to be stacked on the top. A methodology to reduce structural dynamics responses on the stack-up top, without compromising thermal coupling between packages, will enable further reduction in footprint by accommodating more packages on stack-up top.



Multi-level stacked package example

12.1.3. Numerical simulation of Wire rope isolators under vibration environment

Wire rope isolators have been widely used in transportation industry ranging from Rail, road, sea, air to Space transportation. The isolation products made of wire ropes cater to both vibration isolation as well as shock suppression and provide a robust solution to the transportation industry. The products are robust, durable & reliable.



However, the behaviour of such product is less understood in FE environment. Through, the characterization details of each type of isolator are widely available, if a capability of 'simulating wire rope isolator behaviour' in FE environment is developed, it will enable us to explore many more geometries/ topologies/ arrangements and various loading conditions along with the behaviour of suspended system.

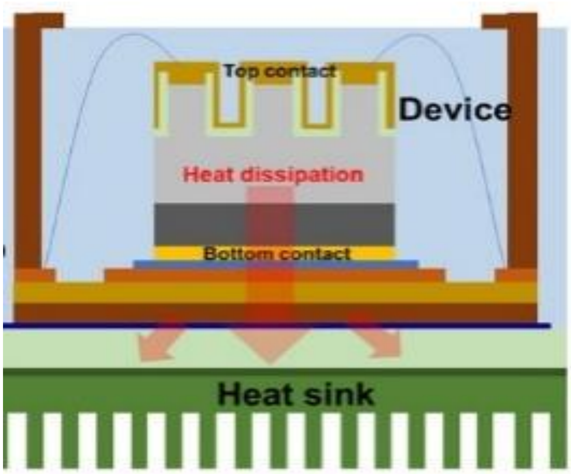
12.1.4. Measurement of structural & thermal material properties of adhesives for a temperature range of 4K to 500K

Objective of this research is to carry out measurement of structural material properties of adhesives such as Elastic modulus, Poisson's Ratio, yield strength, ultimate strength, shear strength, surface hardness, thermal expansion co-efficient and thermal properties such as thermal conductivity, specific heat capacity. Epoxy based structural, thermal and Room Temperature Vulcanizing (RTV) adhesives, which are used for Aerospace applications, can be considered for the purpose of evaluation of the above mentioned properties for a temperature range of 4K to 500K.

This results obtained from this research should be compiled in a report for use of structural and thermal designers.

12.1.5. Active cooling methods for Microwave packages of space payloads.

With increase in heat dissipation densities due to increase in power of RF devices and miniaturization of subsystems, current passive cooling techniques have a limitation, which can be overcome by design of compact Active cooling for such devices, which enables utilizing the device capabilities to the fullest. The proposed cooling methods may include Phase change materials, Thermo-electric coolers, micro heat pipes etc.



12.1.6. Deployable Radiators

Spacecraft and space payloads largely depend upon Passive cooling using radiator plates for thermal control and heat management, without using spacecraft power. Though beneficial, the technology is constrained with the limited radiation area that comes within the assigned payload volume. A deployable radiator is stowed while being accommodated inside payload fairing on launch vehicle and can be deployed in space, when payload is operational and thermal management is needed. Many such examples including deployable thermal shield for JWST are already working in orbit and have proved their effectiveness. Though, smaller deployable radiators associated to payload subsystems are commonly not observed. Technologies associated with deployable radiators to obtain improved thermal control of payload are required to be explored.

12.1.7. Effect of Annealing (Heat Treatment) on Thermal Contact Resistance of Copper and Aluminium at Cryogenic Temperature

Objective of this study is to examine effect of annealing on Thermal Contact Resistance of metal-to-metal joints. This study is to be done for annealed samples as well as for non-annealed samples to quantify the variations. All experiments are to be done in cryogenic temperature range of 4-10K or 20-40K or 80-100 K or in all ranges.

Experiments are to be done using OFHC Copper and various metal joint combinations such as 1) Oxygen free High Conductivity (OFHC) Copper to OFHC Copper. 2) Aluminum to OFHC Copper 4) OFHC Copper to Tellurium Copper (TeCu) 4) Aluminum to Tellurium Copper (TeCu) etc.
Effect of bulk material conductivity and thermal contact resistance is to be studied after machining annealed samples to achieve better surface roughness. All the results are to be consolidated and guideline based on the experiments is to be made.

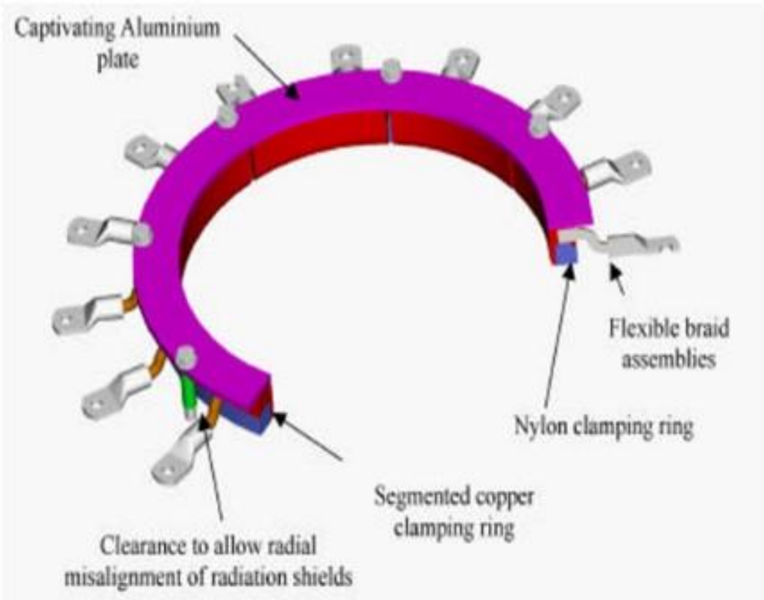
12.1.8. Design and Development of Thermal Link to achieve Thermal Contact at Cryogenic Temperature based on Differential Contraction

Cryostat used for ground based astronomical telescopes consists of Cryogenically cooled front-end electronics to improve the system sensitivity. Cryostat for these applications consists of a vacuum enclosure and to achieve cryogenic temperature, GM Cryocoolers are used. GM Cryocooler cold head is inserted inside Cryostat and is anchored with components to be cooled using Flexible metal straps.

Cryogenically cooled electronics is mounted on a separate structure having multiple stages to maintain different temperature inside Cryostat. These stages are separated using low thermal conductivity rods. This structure is assembled inside Cryostat and required thermal contact is made to achieve temperatures at various stages of structure during operation.

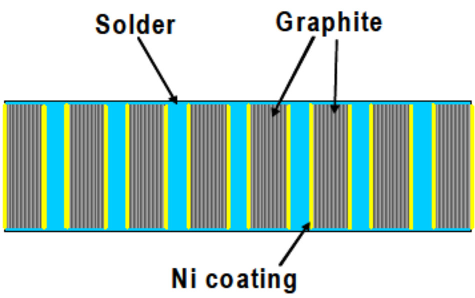
Proposed thermal link will be used to achieve required thermal contact between Cryocooler Cold Head and Front-end electronics structure. Thermal link will be made of two parts, first part (external Housing) will be assembled inside Cryostat and second part (Internal Housing) will be assembled on the structure over which electronics is mounted. External housing assembled inside Cryostat will be anchored with Cryocooler Cold head using Flexible straps/braids. Internal Housing assembled on the electronics structure will be inserted inside Cryostat. External housing will receive the structure during assembly and structure will be connected with Cryostat vessel. During Cool down both parts of thermal link will contract to establish heat conduction path. Thermal path shall be established by achieving differential contraction by specific geometry of both parts of link or by selection of different combination of materials. An image of a similar arrangement made for ALMA telescope is given for reference.

This proposal is Design and Development of Thermal link along with realization and testing of a prototype, which can be used for above-mentioned application. Developed thermal link shall be compatible for operating temperature as low as ~ 3 K and thermal contact resistance of the link shall be in order of ~ 0.4 K/W @ 4 K and ~ 0.6 K/W @ 80K~100K.



12.1.9. Design and Development of Vertically stacked Graphite structure as Thermal Interface Material with thin metallic fillers to achieve very high out of plane thermal conductivity

Graphite or similar material sheets can be used to design and realize TIM to achieve very high out of plane conductivity. These sheets shall be formed in a laminated structure along with thin metallic layers adjoining these graphite layers to achieve required thermal conductivity as well as stiffness. Contact pressure to join these laminates shall also be optimized to achieve minimum possible thermal resistance.



Thermal management of electronic subsystems having very high dissipating electronic devices is a challenge. With the advancement in Technology, heat flux of devices are also increasing giving rise to a local hotspot. For thermal management of such high dissipating application, specifically designed thermal interface materials are required.

This proposal is for design and development of thermal interface material (TIM), which will be used to effectively transmit heat in out of plane, to reduce thermal gradient from device to the heat sink. These vertically stacked fillers would be required in form of blocks of different sizes with maximum footprint of 50 mm x 50 mm and thermal resistance of ~ 0.3 cm2.K/W

12.1.10. Design and Development of Material Based Solutions for Efficient Heat Conduction Technologies

In order to effectively transport of heat from source to sink, advanced materials with excellent thermal conduction performance are usually implemented. Heat spreaders and thermal interface materials facilitate efficient heat transfer. In past, large varieties of novel materials have been developed by different agencies worldwide to achieve effective heat conduction path.

Evolution of materials designed for spacecraft thermal management reflects a shift from isotropic metals to carbon-reinforced polymers, and moving forward to advanced materials including carbon-carbon composites and annealed pyrolytic graphite (APG). Typically, composites are composed of at least two disparate substances. A primary substance acts as a host matrix, whereas another serves as the reinforcement, commonly in the form of fibers embedded in the matrix. With thermosetting compounds such as epoxy, bismaleimide, and polyimide often employed as standard matrix materials, both ceramic and metal matrix composites have garnered considerable interest for use in the aerospace sector in recent years due to their weight saving feature as well as the high-temperature capability/oxidation resistance characteristics.

This proposal is for design and development of such high thermal conductivity composite materials, which can be used as thermal interface material (TIM) for thermal management of space-borne systems. Typical range of in-plane Thermal Conductivity shall be greater than 800 W/m.K and shall be developed in form of square sheets of 100 mm in thickness of 0.1 mm & 0.2 mm.

12.2. Research areas in Composites and Advanced Materials Applications

12.2.1. Modelling and analysing the curing parameters and predicting the thermo-elastic distortions in the fibre-reinforced polymer composites.

During curing process of the composites, process-induced residual stresses occur because of mainly mismatch in thermal expansion coefficients of the constituents, chemical shrinkage of the resin and non-uniform curing of the composite laminates. Severe residual stresses can result in transverse matrix cracks and delamination after processing. Composite parts are prone to bending or warpage due to thermal gradients and residual stresses build up.

To predict the actual distortion, accurate mathematical modelling is required which addresses chemical reactions, heat generation, heat conduction, selection of the mould material and other relevant parameters. Critical mechanical component of this model are evolution of stress and progressive damage analysis. The outcome of the study and analysis will be helpful in determining optimum process parameters. The scope is to develop a mathematical/analytical model of the temperature and curing pattern in polymer composites using a thermo-chemical model, and coupling it with a thermo-mechanical model to predict the residual stresses and viscoelastic response of the material, predict distortion and damage in the polymer composite using a continuum damage model. Deciding optimum process parameters of the curing.

12.2.2. Development of acoustic holography-based testing and fault diagnosis techniques for payload structures.

Conventional vibration-based fault diagnosis methods are contact-based and require the mounting of vibration sensors such as accelerometers close to locations of interest on the engineering equipment. This limits their application in actual situations specifically for simultaneous testing of various payload components with different shapes and sizes, monitoring of large surfaces and parts difficult to access. Further, in contact-based measurements, it is always difficult to decide proper measurement positions and identify the exact location of fault.

Research is required to explore advanced methods to overcome these challenges. The near-field acoustic holography (NAH) is a promising technique where an array of microphones can be installed near the structure to record the acoustic-field in a non-contact way and use the acoustic information to detect as well as locate the faults. NAH is an effective technique for visualizing sound field data from multi-channel measurements and has been frequently used for sound source recognition at any observed. Development of this technique will be helpful in testing of all the sensitive payload structure which have borderline margin of safety.

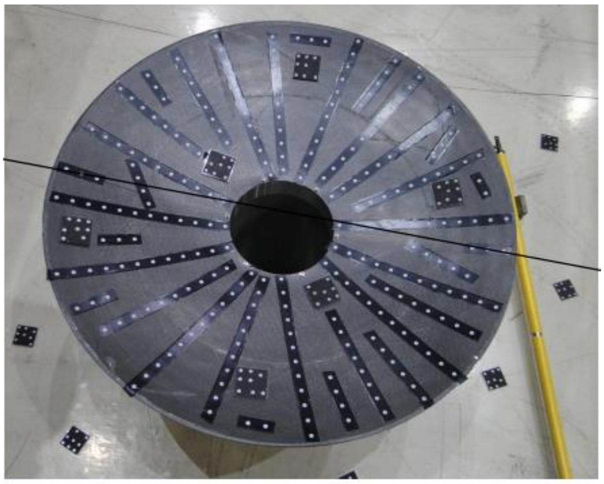
12.2.3. Development of High Strain Tolerant Infusion Grade Resin System for the Space Applications.

Resin systems are the essential elements for the Development of the Composites materials and components. The resin systems are primarily responsible for the load transferring between the reinforcement materials and protecting it for the environmental effects.

The composites material exhibits linear behaviour against the applied load near to its fracture. Large strain tolerant resin system will lead this for the foldable structure to minimize the space requirements by folding it in the launch vehicle envelope. The development of the large strain tolerant (>20 %) resin system will pave the way for minimizing the space about 50% in the stowed conditions.

12.2.4. Design, FE Simulation and Development of Elastic Foldable Reflector for Large Aperture Antenna.

Antenna Reflector are the main element for the satellite communication. Due to requirement of the large shape antenna for the future space missions and limitations for the space in the launch vehicle for the accommodation, elastic foldable antenna reflectors are the prime candidate for the future satellite based communications and navigations.



Reflector surfaces in deployed and stowed conditions (indicative)

Development of the large aperture antenna reflectors (at least 2.5m diameter) for the foldable volume <50% to be targeted for stowing. Non-linear FE simulation to be carried out for folding, deployment and stability conditions. A prototype reflector is to be developed and characterized.

12.2.5. Development of shape configurable/deformable parabolic reflector using shape memory alloy (SMA) or equivalent actuation.

Development of large flexible antennas is becoming critical today; such antennas can be realized with shape memory alloy actuated mechanism. It can be reconfigured in space for variable antenna footprint, and hence can be utilized for signal transmission to different geographical locations. Requirement of changing the shape is quasi-static and hence SMA based actuators and very much suitable for this application.

12.2.6. Metallization of composites for enhancing electrical and thermal conductivity for development of RF components.

Light weight & high modulus composite structures are the need of the current Space scenario. These composite structures provides excellent load carrying member as well as maintaining dimensional stability in harsh space environment. The use of composites are limited to only structural parts. To utilize in realizing RF parts, there is need of improvement of electrical and thermal conductivity of the composites. Metallization on a composite part itself calls for the various qualification and always leaves uncertainty in terms of quality. The biggest challenge is survival of the metallization in extreme space environment in the orbit. There are various methods, which may be tried for metallization:

- Conductive surface coating or metallization of CFRP. Surface activation & Electro plating or Electro-less plating.
- Development of Electrically Conductive Prepregs /Resin system (lamination) for Space grade composite systems.
- Development of carbon-carbon composites with excellent electrical and thermal conductivity for realization of RF components.
- Metallization of CFRP may also be done by inclusion of graphene/CNT at layup stage.

Existing properties of CFRP:

Electrical Conductivity: 10^4 S/m

Electrical Resistivity: 10^{-3} Ω.m

Thermal Conductivity: < 1 W/m/K

Desired properties of CFRP:

Electrical Conductivity: 10^7 S/m

Electrical Resistivity: 10^{-8} Ω.m

Thermal Conductivity: > 50 W/m/K

12.3. Research areas in Antenna Alignment and Integration

12.3.1. Development of retroreflective targets to for generating points cloud using optical metrological tools.

In development of spaceborne antennae & payloads; measurement and alignment play a very critical role. All components of the payload are required to be placed at its designed position within a very tight tolerances for its efficient performance. The metrology tools used for the purpose is optical photogrammetry tools. This photogrammetry camera flashes light over the component under measurement, which is represented by a number of reference points by using retroreflective target. This target reflects back the light which is captured by camera and processed to represent as a dot point. These point clouds are monitored for any change and correction of component position.

These targets are essential consumable accessory which is required to be manufactured indigenously to be available easily and economically to widen the measurement of components. Therefore, study in this area is required to understand the optical behaviour of metrology system to synchronize with photogrammetry system within high accuracy. The target may be developed and can be tested to make it operational.

12.3.2. Development of mathematical model for optimization of surface profile RMS in segmented reflector antenna.

The segmented antenna with stringent surface RMS for Ground based is a challenging from Antenna assembly, integration and alignment aspects. Since wavelength at higher frequency comes to sub-mm level, it calls for very stringent alignment of each panel of the segmented antenna systems. In line with this, each panel shall be aligned with respect to global antenna in six degrees of freedom. So overall surface RMS requirement of segmented antenna is very stringent. To achieve overall antenna RMS, the individual panel rigid body correction need be corrected by using provided 5 control points on each reflector panels from given measured point cloud data. This requires mathematical model for calculation of control points of all panels for optimization / correction of overall surface profile RMS of antenna.

12.4. Research areas in Mechanical Design and Development of Communication Payloads

12.4.1. TPG Encapsulated High Conductivity Plates/chassis for High Power Subsystems

Technologies/process related to development of Thermal Pyrolytic Graphite (TPG) encapsulated high conductivity plates. These plates can be of Stainless Steel, Copper and Aluminum with TPG encapsulated within. Collaboration is envisaged for the development of different encapsulation techniques based on Electroforming, bonding, soldering or any integration methods such that it effectively produce a high conductivity plate.

12.5. Research Areas in Production Technologies

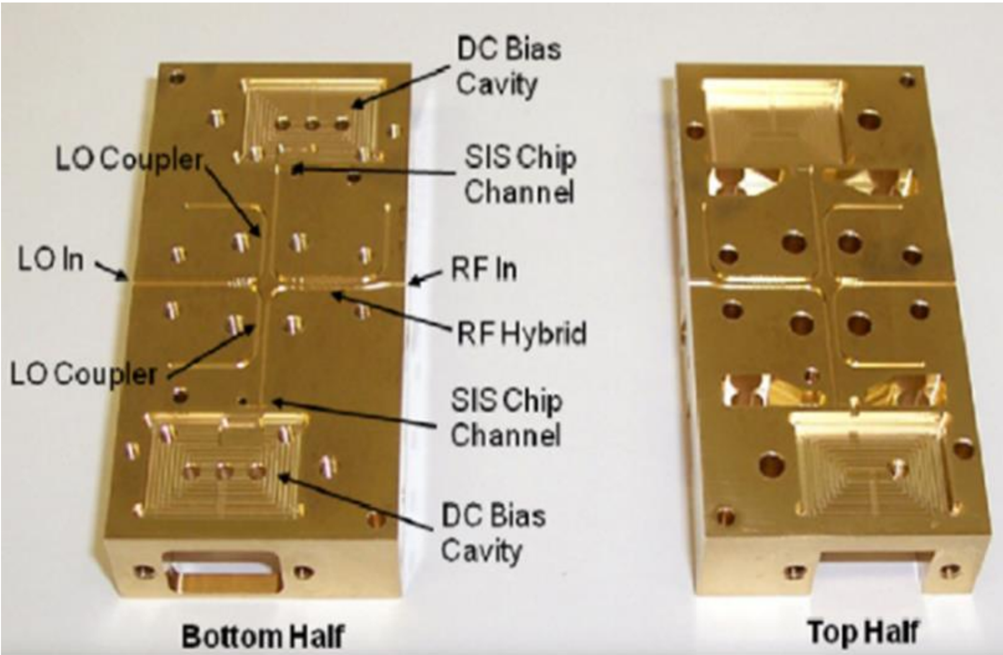
12.5.1. Micromachining of metal components

Mechanical housing for mm and sub-mm wave length front end RF components are having micron scale features interconnected with one-another. Fabrication of mechanical housing for these components are very challenging. Post fabrication, dimensional inspection is also critical and require special instruments.

Materials, which is used for making mechanical housing, will be primarily OFHC Copper, Tellurium Copper, Al 6061-T6 etc. Typical feature size and Geometrical tolerances for these mechanical housings for mm wavelength components are as follows and are made using precision milling machines or pulse laser machining. These dimensions would reduce further for sub-mm wavelength components. An image showing a similar component is given here for better visualization of job. This proposal seeks to utilize existing capabilities and infrastructure with academia for fabrication of such components.

Sr. No.	Feature size (Length x Width x Depth)	Tolerance (mm)
1	3.30 x 0.30 x 0.05 mm	+0.015 -0
2	1.484 x 0.52 x 1.016 mm	+0 -0.05
3	0.285 x 0.909 x 0.546	+0 -0.01

Sr. No.	Geometrical Tolerance	Value
1	Flatness	0.01 mm
2	Perpendicularity	0.01 mm
3	Parallelism	0.01 mm
4	Position	0.025 mm
5	Surface Roughness	0.025-1.6 microns



12.5.2. Development of Flexible Mandrel for bending of Rectangular Waveguide (WR) sections

Rectangular waveguides are used in communication satellites for transmission of RF signals because of low signal loss characteristics. Application of the same on satellite panels, require bending in both cross section dimensions i.e. width as well as height direction, as per below images. At present, fusible alloy is used for bending applications.

It is required to design and develop a flexible mandrel to support inside cavities during bending applications. So that we get finished product without distortion in cross-section and damaging the inner surface finish. Both surface finish and uniformity of cross section along the length of the waveguide, are crucial features to transfer RF signals with minimum losses.

Following are the parameters which should be considered while designing and development of the Flexible Mandrel:

- Material: Aluminium alloy 6061 (Annealed condition)
- Wall thickness: 0.635 mm
- Inner dimensions of rectangular waveguide section and required bending radii :

Width (mm)	Height (mm)	Mean Bending Radii in plane of broad side, E-Plane (mm)	Mean Bending Radii in plane of narrow side, H-Plane (mm)
19.05	9.52	35	30
15.74	7.87	35	30
12.95	6.47	25	20
8.63	4.31	20	20
7.11	3.55	20	20

- Image of the waveguide with bend in both direction for ref.

Bending in plane of broad side (E-Plane)

Bending in plane of narrow side (H-Plane)

Targeted Specifications:

- Flexible Mandrel which can support inner walls of the Waveguide section while bending operation.
- Mandrel shall be drawn out of the sections without damaging the inner walls.
- Single section may also have both types of bends, mandrel flexibility shall be such that it can be drawn out from both bends.

12.5.3. Realization of "Flexible" Waveguide and establishing Fabrication Process for repeat Production

Microwave Sensors and Payloads require Waveguides as Transmission Line Elements to route High Power RF Signals across multiple Functional building blocks of the Integrated System. In certain cases Such Units are located across places having relative motions (rotations or translations). To route RF Power across such interfaces having relative motion, there is an option of using suitable "Flexible" Waveguide. Such waveguide is expected to mainly offer H plane and E Plane Bending upto the extent of 90 degrees. The Sizes to be explored for development are WR62, WR75, WR90 and WR28(Ka band, Ku band, X band). In international market, there exists sources and technology to realize such Flexible waveguides. Make-In-India sources are to be established for which, through this opportunity, proposals are being sought from resourceful academic teams/collaborators to Realize Products at First Stage and thereby Establish Fabrication Process for further Repeat Production. For better understanding of Flexible waveguides, it is recommended that a simple internet search may be done with the key word "Flexible waveguide". They can be visualized as Metallic Corrugated Bellows, the profile being rectangular instead of circular for tube as well as for Mating Flanges at either ends. It should be possible to Implement Surface Treatments like Silver Plating onto the Product. The surface Finish of internal cavity to be of best achievable order to minimize RF Losses. The Product should be compatible for use-application in Vacuum environment with operating temperatures, typically, upto +/-100 degree Celsius.

12.6. Research Areas in Mechanical Design and Development for Optical Payloads

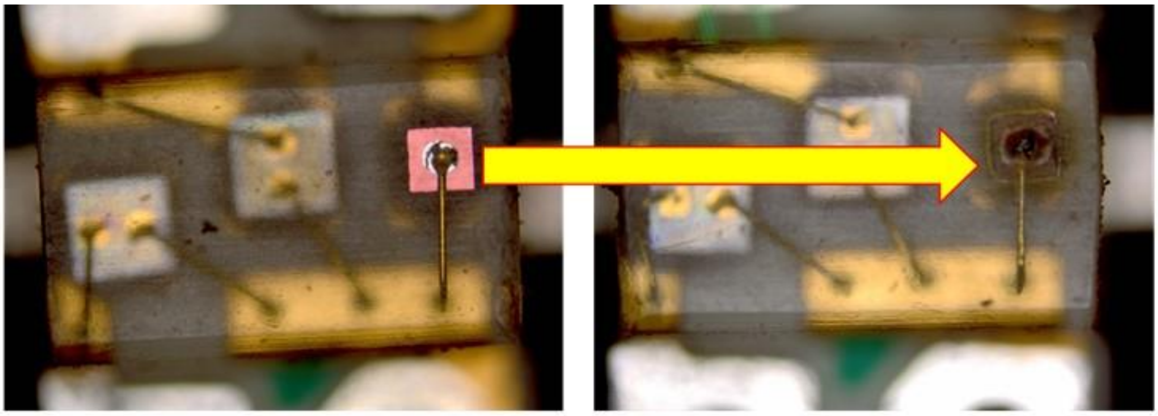
12.6.1. Design and Development of vibration isolation system with hybrid D-struts for space payloads

This research work focuses on the design and development of actively controlled D-struts (three parameter vibration isolators) for space payload of mass up to 100 Kgs. The three parameter vibration isolators, which are also called D-struts (dual struts), are low frequency vibration isolators which are better absorbers as well as better isolators as compared to conventional spring-mass-damper (two parameter) vibration isolators. In the D-strut isolator the damper is elastically connected, due to which it offers 40 dB/decade roll-off in the isolation region as compared to 20 dB/decade roll-off of two parameter isolator; while maintain the absorbing capacity in the transmissibility region. Hybrid D-struts consist of an active actuation element to control and suppress the vibration loads. The design of a single D-strut is independent of the payload mass as opposed to the conventional isolator which are designed for a particular payload mass

13. SYSTEMS RELIABILITY SAFETY & HUMAN RATING

The Systems Reliability and Safety is responsible for ensuring quality and reliability for different type of space borne payloads including Communications Payloads, Remote Sensing (optical and microwave), Navigation, Planetary Mission Payloads and Advanced Sensor Systems essential to the Human Space Program (Gaganyaan). SRSA is also responsible for Ground systems and software reliability aspects as well as Centre safety aspects. In order to meet the performance and reliability criteria, SRSA has implemented stringent quality assurance framework covering every stage of the payload development cycle encompassing design validation for hardware & software, material & component selection, process validation, quality inspection and audit, subsystem realization, test & evaluation, stage clearances and final approval.

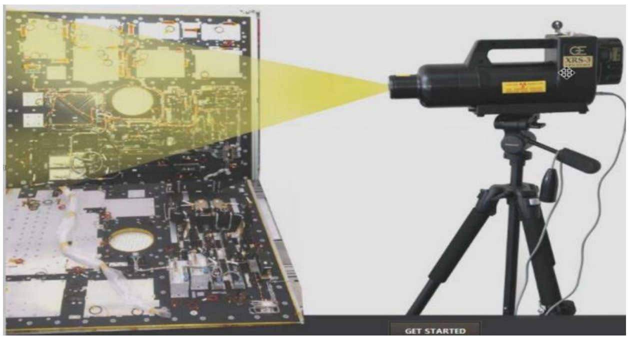
A cornerstone of SRSA's expertise lies in failure analysis, addressing both catastrophic failures and gradual degradation phenomena encountered during development, testing and even in-orbit operations. By identifying and implementing corrective and preventive measures, SRSA mitigates the recurrence of failures, thereby enhancing mission safety and operational success. Beyond component and subsystem validation, SRSA plays a critical role in spacecraft-level testing and in-orbit assessments, ensuring that every system performs optimally under real mission conditions.



Metallization Discoloration during Reliability Testing

As space technology evolves, SRSA remains committed to its mission of ensuring the quality and reliability of onboard and ground systems developed at SAC. With the increasing complexity and miniaturization of payloads and the need for shorter development timelines, SRSA continuously refines its tools, methodologies, and procedures to meet these emerging challenges. Recognizing the necessity for continuous research and innovation, SRSA has identified key research areas and compiled them into this document, providing a structured guide for universities and academic institutions. This initiative aims to encourage focused research proposals in the field of Reliability Engineering, Quality Assurance (QA) and Quality Control (QC) as well as indigenization of materials and components for development of space borne payloads.

PCB Defect Detection



X-Ray Radiography

This was followed by participation in the spacecraft level tests and In-Orbit testing. SRSA played a pivotal role in all phases of development including, parts selection, screening, extensive design reviews of circuits and mechanical assemblies at subsystem and payload level, quality audits, process verification and subjecting them to rigorous cycles of T&E including life testing. Software QA was also carried out for on-board, checkout and all ground applications software.

Systems Reliability and Safety Area (SRSA) continued to be guided by its mandate to insure R&QA requirements of all on-board and ground systems developed in the SAC. SRSA recognizes the need for continuous update of tools, techniques and procedures to be employed for assuring quality and reliability of increasingly complex and miniaturized payloads with very aggressive development schedule. Other than that in order to meet the challenges of new payload development, SRSA has continued to build & augment infrastructure and facilities to cater for future payloads. Over the years, SRSA has also played a vital role in the indigenization efforts of the Centre.

SRSA recognises the importance of continuous research and implementation of innovative techniques; to meet the challenges posed by induction of state of the art technologies & reduced delivery schedules. The present document provides a brief summary of research areas identified by SRSA. This is intended to encourage universities and academia to come forward with focused proposals on Reliability and Quality Engineering/ Qualification aspects of systems reliability of payload realisation for funding under RESPOND program of Indian Space Research Organisation (ISRO) through SAC. The document is inspired by a need for pro-active request for research proposals from academic sector in addition to usual mode of receiving and processing funding proposals. The backdrop for this initiative comes from realization of deepening and broadening research fronts at the Centre and the greater professionalism and sophistication of domestic academic sector in the field of system reliability.

13.1. Research Areas in Material and Process Development

13.1.1. Development of Nanoparticle-Enhanced MWCNT reinforcement in PEEK Matrix Hybrid Nano Composites for Space Antenna Applications

Space missions have strict weight limits for payloads. Antennae used in space mission must be designed to be as lightweight as possible to minimize the overall weight of the antenna system. Structural elements including Ribs are generally made up of metals which makes them heavy in weight. Development of light weight structure is one of the major challenges involved in the realisation of the antenna. Polymer nanocomposites are materials that incorporate nanoparticles into a polymer matrix material to enhance the properties of the resulting composite. These nanocomposites often show enhanced strength and stiffness compared to their micro or macro counterparts. The inclusion of nanoparticles can significantly improve the mechanical, thermal, electrical, or optical properties of the nanocomposite. A thorough investigation on characterization of these nanocomposites could position them as viable candidates for structural elements and Antenna ribs, potentially leading to reductions in both weight and cost.

Scope:

The scope of the proposed research includes thorough analysis and characterization of the developed nanocomposite with the desired properties that could make them suitable candidates for radial rib antennae fabrication for space missions. The properties that are to be taken into consideration may also include-

- Resistance to Corrosion and Flammability
- Mechanical Strength and Thermal Stability
- Microstructural Analysis

Anticipated Benefits:

Use of nanoparticles into a polymer matrix material shall ensure better mechanical, electrical and thermal properties, at lesser weight than metal which shall benefit it in incorporating more transponders and subsequently effectiveness of payload.

13.1.2. Weldability of Additively Manufactured (AM) 3D Printed AlSi10Mg Alloy

The Additive Manufacturing (AM) process in which feedstock material which is in the form of powder, wire and sheet; is converted into a dense metallic object by melting and solidification with the use of various heat sources types like Arc, Plasma, Beam-Laser and Electron Beam and Ultrasonic Vibration in case of sheets. By now use of the welding process for additive manufacturing is common, use of arc welding heat sources like GMAW, GTAW, Plasma, and SAW are reported for additive manufacturing. The most widely used heat source for additive manufacturing is a LASER. The Laser Powder Bed Fusion (LPBF) process is widely reported with additive manufacturing of complex parts in small batches. One of the limitations from a commercial perspective is the size of the build chamber. Different elements of one component can be manufactured separately and welded subsequently. Thus, the size of the build chamber can be solved if additively manufactured parts are welded. Overall work done in the domain of welding of additively manufactured components is limited. Based on the above research gap, the current proposal objective is the Welding of AM-AM, AM-Wrought, and AM to Cast using solid-state and fusion welding processes (Friction Stir Welding, GTAW & LBW) for AlSi10Mg will be investigated.

Scope:

The scope of the project is to deliver the data set on behaviour of AM welded joints using fusion and solid state under different space environments. Thermal shock, Thermo Vacuum, Humidity tests will be investigated and its mechanical & metallurgical comparison with normal joints.

Anticipated Benefits:

Large complex designs can be developed using additive manufacturing process and subsequent welding process developed, this will help in mass optimization higher strength, manufacturing time reduction and meeting intricate design requirement of space payloads. This will be helpful in development of up to C Band Feed Cluster.

13.1.3. Development of CNT based blackest-black material for blackbody.

SAC is involved in the development of optical remote sensing payloads. These payloads involves space borne cameras working in infra-red (IR) and visible band. These on-board IR cameras do need in-orbit high-precision calibration regularly after a certain time period. The calibration is basically done with respect to a blackbody surface having ultra-high emissivity (>99.5%). The blackbody typically need to possess excellent temperature stability and uniformity along with ultra-high emissivity. Of late, Carbon Nano Tubes (CNTs) based coatings have provided remarkable light trapping properties in comparison with conventional ultra-black coatings. An array of 'vertically aligned nano tubes' creates a forest-like structure of aligned, equally-spaced, high-aspect-ratio carbon nanotubes. The spacing of the tubes is such that virtually all of the light arriving at the surface enters the spaces between the tubes and is absorbed after multiple reflections between neighbouring tubes.

Scope:

The scope of the proposed research includes development of vertically aligned CNT on the Aluminium substrate. This includes: -

- Development of the technology for growing the vertically aligned CNTs on electrically conductive substrate preferably Aluminium alloy.
- Surface emissivity performance evaluation and validation in MWIR and LWIR spectral regions (3-14 micro-meter wavelength)

Space qualification, including shock, vibration, thermal cycling, outgassing, no particle fallout (PFO) and no significant mass loss.

Anticipated Benefits:

- Indigenous development of ultra-emissive black body surfaces.
- A customizable high quality blackbody source for in-orbit calibration for all IR based space missions.

13.2. Research Areas in Quality Control of Electronic Systems

13.2.1. Defect Dataset Augmentation using Generative Adversarial Networks (GAN)

Scope:

Deep learning algorithms have vast application in the field of automated inspection of electronics assembly. However, there capability are limited by the scarcity of training data. Defects datasets of electronics assembly exhibit Long Tail effect, i.e. the number of defect classes are more but the number of images in each class is less. To overcome these challenges traditional Image augmentation techniques such as image rotation, brightness/contrast variation, random cropping of images are incorporated but with limited success. Generative Adversarial Network have gained interest in the recent past due to their robust application in image augmentation techniques.

- The purpose of this project is to explore the application of different GAN architectures such as Conditional GANs, CycleGAN and Wasserstien GAN to generate high quality synthetic data of defects observed in electronics assemblies.
- To study the modifications that can be implemented in the GAN models to best suit the generation of data pertaining to electronic assemblies.
- Generate synthetic data that closely resemble the real data and augment the defect dataset to train deep learning model to automate the inspection process.

Anticipated Benefits:

Image augmentation using GAN will help in developing a more robust defect dataset that could be used to train deep learning models that can detect defects in electronics assemblies with high accuracy.

13.2.2. Automated High-Precision Measurement System for Substrates with DXF Comparison and Tolerance Analysis

In space industry, precision and reliability are paramount. The substrates used in subsystems require precise dimensional verification to ensure optimal performance. This research aims to develop an advanced automated measurement system tailored for the substrates used in satellite electronic subsystems.

Scope:

- **Input Handling:**

- Upload high-resolution images of substrates in standard formats (e.g., JPEG, PNG).
- Import DXF files to define reference dimensions and design patterns.

➢ **Image Pre-processing:**

- Apply advanced noise reduction and contrast enhancement for clean inputs.
- Correct lens distortion, perspective skew, and align images for consistent measurement.

➢ **Object Detection and Measurement:**

- Automatically detect multiple features on substrates, including length, width and other geometric details.
- Accurately segment and measure features on complex or overlapping patterns.
- Maintain measurement precision within **±3 micrometres** using robust calibration techniques.

➢ **Tolerance Management:**

- Provide an interface for users to define allowable tolerances for each measurement parameter.
- Highlight measurements that fall outside the defined tolerance range.
- Enable batch application of tolerances for similar patterns or dimensions.

➢ **Comparison with DXF Design:**

- Extract reference dimensions from the DXF file.
- Compare measured dimensions with the DXF specifications.
- Report deviations, highlighting values exceeding tolerance limits.

➢ **User Interface:**

- Design a user-friendly platform to upload images, import DXF files, and define tolerances.
- Display annotated images with measurements and color-coded indicators for dimensions within or outside tolerance limits.

➢ **Reporting:**

- Generate detailed Word or PDF reports, including: Annotated images of patterns with measured dimensions, Tabular comparisons of measured versus reference dimensions with deviation and tolerance analysis, Summary of compliance with defined tolerances.

➢ **Calibration and Accuracy:**

- Incorporate a calibration process using known scale markers.
- Ensure system maintains **±3 micrometre** accuracy under defined operational conditions.

Anticipated Benefits:

➢ **Efficiency:** Automates measurement, reducing inspection time, Fatigue and costs; with micrometre-level accuracy, meeting stringent quality demands and delivering reliability.

13.2.3. Quality Inspection of RF/Electronics Hardware using Artificial Intelligence/Machine Learning Techniques

Scope:

Defects in electronics hardware such as PCBs are characterized by smaller size, more diverse types and more complex features. As such many of the existing Deep learning algorithms cannot be readily applied to the task of detecting defects in electronics hardware. The aim of this project is thus to develop deep learning algorithms for detection of defects in relatively complex electronic/RF hardware trained on a defect dataset comprising of defect images taken at various magnification levels with diverse background and varying illumination level.

- Develop a deep neural network based algorithm to identify defects in electronics/RF hardware in real time as well as in offline scenario.
- Developed algorithm must be agnostic to the magnification level of the image, background of the electronic board, illumination intensity and size & location of defects and must be robust enough to identify micro defects with complex features.
- Explore the application of Transformer model and attention mechanism in the development of algorithm.

Anticipated Benefits:

Automating the quality inspection of RF/electronic hardware will reduce manual intervention and subjectivity. Improve the turnaround time by reducing the time required for inspection.

13.3. Design & Development of Automation for Deep Space Extravehicular activities

Long duration human space missions involve several maintenance tasks which need to be performed at regular intervals. These include solar panel inspection, structural integrity checks and other anomaly monitoring tasks. Extra-vehicular activities (EVA) require astronauts to exit the crew cabin in order to access the maintenance sites, which may be tens of meters away from the habitation zone. Owing to harsh sub-zero thermal and vacuum conditions in deep space, any sub-system failure while carrying out the above mentioned tasks, is extremely dangerous and may result in loss of human life. The present research proposes to explore the feasibility of novel remote controlled automation techniques which could substitute the astronauts in EVA by a customized robot mounted on a maneuverable platform which would travel to the maintenance site. This would ensure human safety in addition to system reliability, during extra-vehicular activities.

Scope:

The scope of the proposed research includes design and thorough analysis of customized robot for automation of deep space extravehicular activities. This includes -

- Establishing optimal control laws for various manoeuvre scenarios.

- Simulating/ prototyping ground based pose stability and robotic arm maneuverability.
- Simulating/ prototyping air based pose stability and robotic arm maneuverability.
- Explore and document safe propulsion technologies for robotic automation.

Targeted outcome:

The following are the expected deliverables for the proposed research.

- Demonstration and delivery of fully functional robot working on ground without human intervention.
- Demonstration and delivery of fully functional robot working in air without human intervention.
- Design, thorough analysis and simulation of fully functional robot mounted on a maneuverable platform for deep space usage.

Anticipated Benefits:

- Such Respond Proposals shall be useful in realisation of BAS (Bharat Antriksha Station), which ISRO has proposed.
- This will reduce and may eliminate astronauts working directly in harsh sub-zero thermal and vacuum conditions in deep space, which is extremely dangerous and may result in loss of human life.

This will also increase system reliability during extra-vehicular activities by substituting direct human intervention by machines.

14. CYBER SECURITY & INFORMATION TECHNOLOGY

Cyber Security and Information Technology Area (CITA) is responsible for catering to the Cyber Services and IT needs of the centre. CITA is responsible for managing Cyber Security, Network Infrastructure, Centralised Data Centre, Information Management Systems, Data visualisation services and related infrastructure.

In keeping with the above stated responsibilities, research proposals are invited on the topics that appear in the following sections:

14.1. Research Areas in Cyber Services and Information Security

14.1.1. Development of AI-based IT-Services

Scope:

- To develop a solution to automate IT-Service management activities using AI/ML techniques to support predictive maintenance.
- To develop an AI-powered virtual assistants to provide IT-support and maintenance services to end-users.
- To develop an end-to-end ticketing system for all IT-services support and maintenance.

Anticipated benefits:

- Effective and efficient dissemination of IT-services and provide insights & recommendations to improve the overall end-user satisfaction.
- Aid in enhanced troubleshooting, auditing and real time monitoring.

14.1.2. Development of Botnet Detection & DNS Security Solution

Scope:

- To develop techniques for identify and detect botnet activity on a network using AI/ML techniques.
- Implementation of various AL/ML detection techniques namely, host-based, behavioural-based and signature-based.
- Implementation of GUI Dashboard for botnet activity alerts.

Anticipated benefits:

- Aid in monitoring and maintenance of the overall cyber services.

14.1.3. Development of Generic Log Analysers

Scope:

- To develop a distributed & scalable Generic Log Analyser for collecting, storing, analysing and reporting the network devices, servers, desktops and software application events recorded as part of respective logs of different formats using AI/ML techniques.
- The large data sets for different log types will be analysed using data mining techniques without changing the core algorithms.
- Implementation of GUI Dashboard for reporting the network events recorded as part of various server logs.

Anticipated benefits:

- GUI Dashboard for alert on specific events.
- The developed software will be utilised for the purpose of system auditing and performance improvement activities.
- Aid in monitoring and maintenance of the overall cyber services.

14.1.4. Establishing a Software Defined Network (SDN)

Scope:

- To establish a Secure & Scalable SDN Infrastructure.
- To integrate SDN with the existing network infrastructure and protocols.
- To develop standard programmability options for configuring and managing the network infrastructure.

Anticipated benefits:

- Enabling centralised management and orchestration of network resources.
- Aid in faster troubleshooting, increased scalability and real time monitoring.

14.1.5. Development of AI-powered Email Security

Scope:

- To analyse emails from a human perspective, understanding context and intent behind every message.
- To use Natural language processing (NLP) techniques that can detect sophisticated phishing attacks, spear phishing, and other types of email-borne malware that traditional security measures often miss
- To perform sentiment analysis on emails to identify emotional cues that may indicate a potential threat or malicious intent.
- To implement enhanced authentication which uses machine learning algorithms to analyse sender behavior, IP addresses, and other factors to verify the authenticity of incoming emails.

Anticipated benefits:

- Handling the cases where traditional security measures often miss
- Enhancing security posture of Email which is the most accessible and critical IT service

14.1.6. Active Directory (AD) Security and Threat Detection

Scope:

- Passwordless authentication
- Real-time monitoring and detection of suspicious activity within AD using AI/ML, such as tracking admin actions, policy modifications, group membership changes, abnormal logon patterns, privilege escalations, identity based attacks, etc.
- Infrastructure as Code for AD: Managing AD configurations and policies.

Anticipated benefits:

- Aid in the security of Active Directory.

14.1.7. Development of Blockchain Identity Management

Scope:

- Development of a decentralised identity management based on blockchain based solutions.

Anticipated benefits:

- Aid for managing user identities in distributed environment.

14.1.8. Development of Data Analytics in Data Transfer and File Share Services

Scope:

- Data Analytics in Data Transfer Service such as average download size, total data transfer within a day, types of transferred files, etc and File Share Services such as logged in users, file share analysis, user quota usage, public/private shares, etc.

Anticipated benefits:

- Aid for monitoring and usage analysis in the data transfer and file share services.
- GUI dashboard for the monitoring and management of services.

14.1.9. Design Vehicle Monitoring Surveillance System

Scope:

- To design a Vehicle Monitoring System (VMS) which shall track vehicle in-and-out movements using existing CCTV Surveillance System within SAC campuses.

- System should record license plate numbers and store data in a database.

Anticipated Benefits:

- Help real-time reporting on vehicle.
- Help in supporting emergency response and incident investigation efforts.

14.1.10. Design Head Count Surveillance System

Scope:

- To design a Headcount System using existing CCTV Surveillance System
- It shall be integrated with existing Biometric Access Control System.
- It should count number of staff entering & exiting the BACS peripheral gates.

Anticipated Benefits:

- Help real-time number of staff inside SAC Campuses.
- Store head count data in a database for further processing.

14.1.11. Other cyber services and information security related topics includes

- Breach detection and response solutions
- Cryptography and cryptoanalysis
- Indigenous hardware-based VPN
- Kiosk for Virus/malware sanitisation
- Malware Sandbox
- Network Admission Control
- Security of air-gap networks
- Secured data flow between different trust networks
- Secure cloud techniques
- System Forensics
- Perimeter and endpoint security
- Progressive Web App (PWA) Service
- Zero day vulnerability detection
- Zero Trust Network Access

14.2. Research Areas in Multimedia Technology and IT Services

14.2.1. Development of AI-powered DocBot Solution

Scope:

- Create a chatbot that reads rule books like Service Rules, purchase manual, office orders, etc and answer the user's queries.
- The system should extract and organise content from rule books using document parsing and NLP techniques.
- Use natural language understanding and contextual search to retrieve relevant information, providing concise answers based on the user's queries.

Anticipated Benefits:

- Help users in getting clarifications about Promotion / Review / Leave / Pay-Scales, etc.
- Help users to resolve their query related to indent, tender, procurement policy etc.

14.2.2. Development of AL/ML based automated Database Query System (Talk2DB)

Scope:

- Software to generate SQL from natural language, evaluate results, and produce reports/charts based on user requirement on-the-fly.
- NLP module to parse user queries and normalize text.
- SQL generation module to translate queries into equivalent SQL statements.
- Query evaluation module to execute SQL queries and provide performance feedback.
- Reporting module to extract data and generate reports in various formats.

Anticipated Benefits:

- Users can interact with databases using an intuitive GUI.
- Users can quickly generate complex SQL queries without needing to code.
- Insightful reports and charts enable data-driven decision-making.
- Automated query evaluation reduces the risk of errors and improves query performance.
- To simplify the database management tasks.

14.2.3. Development of Augmented & Virtual Reality System

Scope:

- To develop immersive interfaces that simulate real-world environments.
- To develop overlapping digital information onto the real world for enhanced user experience with AI integration to support object recognition and tracking.

Anticipated benefits:

- To provide simulated and interactive experiences that reduces timeline and improves overall user experience.

14.2.4. Other IT services and multimedia related topics includes

- Immersive visualisation
- e-Learning platform
- Animation technology
- Multimedia content generation

15. MANAGEMENT & INFORMATION SYSTEMS

Management and Information Systems Area (MISA) at SAC is responsible for coordination and management of In-house Technology Development/Advanced R&D, Sponsored Research with Academia, Outreach, Knowledge management, Training, Programme planning & Project Evaluation, Technology transfer and Industry coordination, multimedia programme production and several other managerial activities, providing all necessary support to Centre's activities.

Academia is invited to contribute in various aspects of R&D in Management and Information Systems.

15.1. Research Proposal Evaluations for Sponsored Research with SAC

A number of sponsored research avenues are currently undertaken under SAC such as RESPOND, Space Technology Cell (STC), Space Technology-Incubation Cell (STI-C), RAC-S (Regional academic Centres of Space), to name a few. Several project proposals in various subjects related to Space applications are received from academia across India under these avenues. In order to screen-in proposals , especially with regard to expertise and publications of the proposer (PI: Principle investigator), it is proposed to design an automatic screen-in procedure, combining AI/ML techniques to identify and match the PI/CO-PIs expertise and bibliometric information (publication, grant funding received, patents etc) with that of the expertise required in project proposals by SAC. Suitable analytics such as cluster analysis techniques may be employed to identify subject experts and match it with expertise required for SAC's sponsored research activities. Offline/Intranet use of this facility may also be employed to gather details about previous projects, support in the monitoring and will help to identify duplication, gaps and additional opportunities in future research activities.

15.2. Experimental Social Research studies including Randomised Control trials to execute Impact assessment studies of ISRO's educational outreach activities

As a leading space agency in the country, SAC/ISRO has actively promoted STEAM (Science, Technology, Engineering, Arts and Mathematics) education, facilitated research collaborations, and contributed to the dissemination of advanced space technologies. SAC's initiatives, including student outreach programs, satellite-based educational services, and academic partnerships, have directly influenced students, researchers, and educational institutions. With India's growing emphasis on space science, innovation, and technological advancements, it is essential to evaluate ISRO's role in shaping the country's scientific progress and the broader implications of its educational and research-driven initiatives. It is proposed to conduct social experimental studies such as Randomised Control Trials (RCTs), Cohort studies or Case Control studies or other types of pre and post taest studies to understand the ways in which SAC/ISRO's educational outreach programmes such as GujSAC BHAvi VaIgnank KAryakram (GujSAC BHAVIKA), YUVIKA, UNNATI, has supported to pursue students to select careers in STEM subjects. Such studies can support in providing data-driven insights in understanding long-term engagement and knowledge retention of the participants, identify best practices and areas for improvement in program structure and delivery, quantify the return on investment (ROI) from educational outreach programs and support in identifying high-impact strategies to improving the reach and effectiveness of future initiatives.

15.3. Analysing Public Sentiment on ISRO's Major Space Missions through Social Media Analysis

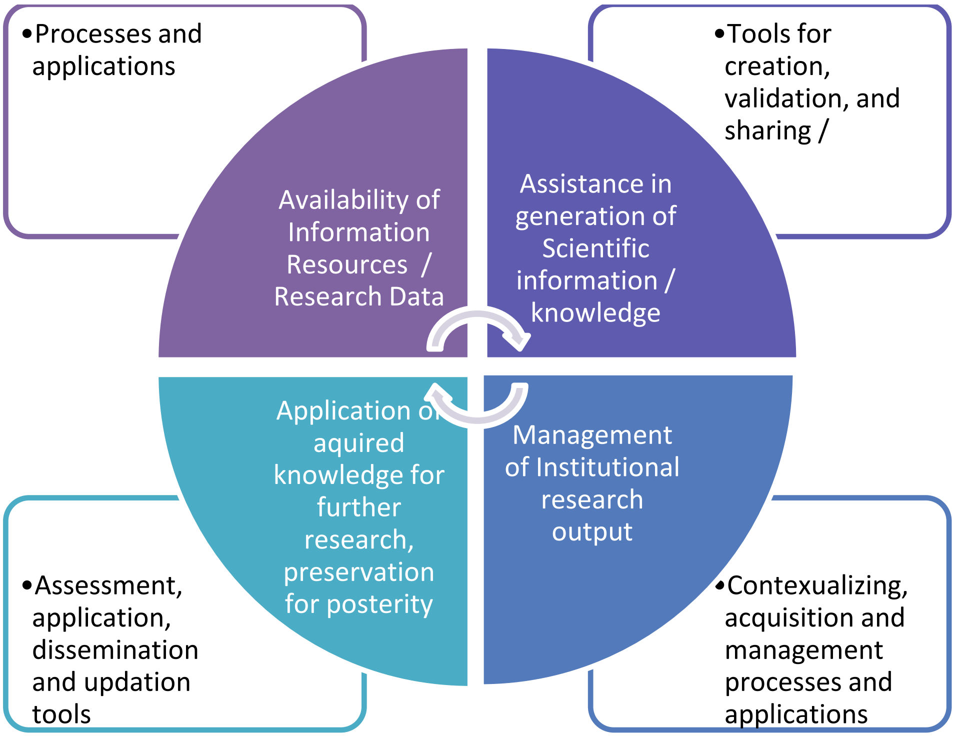
The Indian Space Research Organisation (ISRO) has garnered significant global attention through its ambitious space missions, including Chandrayaan, Mangalyaan, Aditya-L1, and the forthcoming Gaganyaan project. Public perception of these missions is instrumental in shaping both national and international support, influencing funding allocations, and informing policy decisions. In the contemporary digital era, social media platforms serve as critical spaces for public discourse, facilitating real-time expression of sentiment, engagement, and opinion formation.

This proposed research area include sentiment analysis of social media data to systematically examine public emotions, concerns, and enthusiasm surrounding ISRO's major space missions. By analyzing sentiment fluctuations before, during, and after key mission events, this research seeks to provide a comprehensive assessment of the impact of ISRO's achievements on its global reputation. The findings will contribute to a deeper understanding of how public discourse evolves in response to space exploration milestones and will offer insights into the broader implications for public engagement, policy formulation, and scientific communication strategies.

15.4. Space education for differently abled students

A study conducted in SAC highlighted the importance of designing engaging learning modules related to Space Science & Technology for differently abled students which may be in Braille, audio content or in sign language. Studies indicates that such learning modules, especially in local languages, are limited in scope. Options may be explored to design 3D tactile models of space systems, tactile books, audio books, immersive models based on ISRO's space journey, developing space Science based lexicon for Indian Sign Language for supporting SAC's Space exhibition centre at Ahmedabad.

15.5. Knowledge Management Practices in Research and Development



Libraries represent an indispensable link in the scientific research and knowledge generation system chain. Knowledge management (KM) has rapidly moved beyond the stage of a trend and has established itself as a key part of many libraries knowledge strategy. Consumed and produced knowledge and information are key resources and is prime indicator for assessment of growth of any organization.Due to increasingly dynamic environment, organizations are realizing that there is a vast and largely untapped knowledge asset floating around the organization, which may be tapped and utilized by an effective KM strategy and implementation plan. Major areas of Knowledge Management includes development of processes and applications for transforming research data into scientific information; tools for creation, validation, standardization and dissemination or sharing of knowledge; the acquisition, contextualizing, and management processes; and assessment and applications tools using information and knowledge. The core of the process is how to make implicit or tacit knowledge, explicit.

It involves a multi-disciplinary approach to achieve organisational objectives by making the best use of the explicit and tacit knowledge of researchers. The suggested research topics are:

- Exploring various Knowledge Management Systems (KMS) programs in different R&D organisations. Investigating missing interactions in present knowledge management system. Designing suitable framework for effective Knowledge Management System.
- Development and designing of processes and applications for access management; resource management, validation, contextualizing, and standardization.

- Development and designing of processes and applications for effective information retrieval and dissemination tools, integrated search and other applications for meaningful utilization of knowledge pool.
- Delivery of organized knowledge resources through innovative information services.
- Preservation of Institutional Intellectual output.

15.6. Artificial Intelligence (AI) and Libraries

Application of AI in libraries, digital preservation, information literacy, and knowledge management gaining momentum day-by -day. Feasibility studies and subsequent application developments may be undertaken in some key areas, like in Library Operations-enhancing search and discovery, and improve user experience; Information Literacy for librarians and researchers; AI-powered Information Retrieval and Management like metadata extraction, content analysis, and personalized information delivery, etc.

Libraries can use AI powered recommendation systems to suggest books, articles, or other resources to users based on their reading history and preferences. Machine learning algorithms can analyse borrowing patterns and predict future trends, helping library professionals make informed decisions about which material to acquire, retain or discard.

15.7. Research Information Network System

In the present age of networking and immensely potent tools for communication, scientific communication is no longer limited to scholarly and traditional modes of research communication. Many research network for collaboration are already in place and being utilized for advancement of scientific research. Indian research Information Network System (IRINS) is one such web-based Research Information Management (RIM) service developed by the Information and Library Network (INFLIBNET) Centre. The portal facilitates the academic, R&D organisations and faculty members, scientists to collect, curate and showcase the scholarly communication activities and provide an opportunity to create the scholarly network. The IRINS is available as free software-as-service to the academic and R&D organisations in India.

The IRINS supports to integrate the existing research management system such as HR system, course management, grant management system, institutional repository, open and commercial citation databases, scholarly publishers, etc. It has integrated with academic identity such as ORCID ID, ScopusID, Research ID, Microsoft Academic ID, Google Scholar ID for ingesting the scholarly publication from various sources.Studies may be taken up regarding pros and cons of designing and deployment of a dedicated or joining an existing such networks for better synergy between academia and research institution.

15.8. Data Analytics and Predictive Modelling in Library Services

Library can use cutting edge technologies like data analytics and predictive modelling to enhance their services and meet the evolving needs of patrons. By leveraging the power of data, libraries can gain valuable insights into patron behaviour, usage patterns and collection trends, ultimately leading to more efficient and personalized services.

15.9. Other topics

- Impact assessment of deployed space-based services such as Vessel Monitoring System and developing associated science and technology narratives.
- SWOT analysis of the Indian space ecosystem in line with projected Indian space economy.
- Assessing and Benchmarking Project Management practices at ISRO besides developing a case study.
- Understanding the influence of psychological variables on the scientific productivity or performance of scientific and technical personnel.
- Study and development of assessment centre for Training Need Identification of various cadres.
- Assessing the technology/economic dividends of technology transfer in promoting private players and enumerating actionable items for improving Indian space economy
- Content generation for a specific eLearning modules embedding learning analytics.

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Acronyms

3GPP: 3rd Generation Partnership Project

AAR: Accumulation Area Ratio

ACeS: Adaptive Communication Environment

ACM: Adaptive Coding and Modulation

ACRs: Active cavity radiometers

ADCs: Analog to Digital Converters

ADR: Adiabatic demagnetization refrigerator

ADS-B: Automatic Dependent Surveillance-Broadcast

AGC: Automatic Gain Control

AI: Integer Ambiguity

AIS: Automatic Identification System

AIT: Assembly, Integration, Testing

AL/ML: Artificial Intelligence and Machine Learning

AMBA: Advanced Microcontroller Bus Architecture

AMR: Automatic Modulation Recognition

AMS: Additional Member System

AMV: Atmospheric Motion Vectors

ANN: Artificial Neural Network

AOD: Aerosol Optical Depth

APB: Aadhaar Payment Bridge

APS: Active Pixel Service

AR: Ambiguity Resolution

ARD: Analysis-Ready-Data

ARM: Advanced RISC Machine

AS: Autonomous System

ASA: Antenna Systems Area

ASIC: Application-Specific Integrated Circuit

ASICs: Application Specific Integrated Circuits

ATS: Automated Test System

AVIRIS: Airborne Visible/Infrared Imaging Spectrometer

AVPU: Audio Video Processing Unit

AWGN: Additive white Gaussian noise

AWiSF: Advanced Wide Field Sensor

AWLR: Acoustic-Wave Lumped, Element Resonator

BaF2: Barium Fluoride

BAQ: Block Adaptive Quantization

BCH: Bose-Chaudhuri-Hocquenghem

BDU: Battery Disconnect Unit

BER: Bit Error Rate

BiCMOS: Bipolar Complementary Metal-Oxide Semiconductor

BLDC: Brushless Direct Current

BOC: Binary offset carrier

BPF: Broncho Pleural Fistula

BPSK: Binary Phase Shift Keying

BUC: Block Up Converter

BW: Bandwidth

BWG: Beam Waveguide

CAD: Computer Aided Design

CAM: Computer Aided Manufacturing

CAN: Controller Area Network

CATR: Compact Antenna Test Range

CBOC: The Composite BOC

CBPO: Capacity Building Programme Office

CCD: Charge Coupled Device

CCSDS: Consultative Committee for Space Data Systems

CDMA: Code Division Multiple Access

CDOM: Coloured Dissolved Organic Matter

CFDC: Clock Fault Detection and Correction

CFRP: Carbon Fiber Reinforced Polymer

CGH: Computer Generated Holograms

CIC: Carrier-In-Carrier

CLEO: Conference on Laser and Electro-Optics

CMM: Comparison Measurement

CMOS: Complementary Metal-Oxide Semiconductor

CNC: Computer Numerical Control

CNMF: Coupled Non Negative Matrix Factorization

CNN: Convolutional Neural Networks

CNT: Carbon Nanotube

COTM/SOTM: Communication on the Move / Satcom on the Move

COTM: Communication On The Move

COTS: Commercial-off-the-shelf

CS: Component Substitution

CSI: Channel State Information

CSSTEAP: Centre for Space Science and Technology Education in Asia Pacific

CTAG: Communication Technology and Applications Group

CuTe: Copper Tellurium

CW: Continuous Waves

CYGNSS: Cyclone Global Navigation Satellite System

DABF: Data Acquisition and Beam forming

DACs: Data Assimilation Converters

DAOs: Distributed Autonomous Organizations

DAU & MAU: Daily & Monthly Active Users

DC: Data Cube

DDM: Delay Doppler Map

DDR3: Double Data Rate 3

DEM: Digital Elevation Model

DIC: Dissolved Inorganic Carbon

DL: Deep Learning

DMA: Direct Memory Access

DMS: Dilute Magnetic Semiconductor

DN: Digital Number

DOAS: Differential Optical Absorption Spectroscopy

DOC: Dissolved Organic Carbon

DPA: Dual Polarization Antenna

DPRAM: Dual Port RAM

DRIE: Deep Reactive Ion Etching

DRT: Data Relay Transponders

DSP: Digital Signal Processors

DTH: Direct To Home

DVB-RCS: Digital Video Broadcasting - Return Channel via Satellite

DVB-S2/T2: digital video broadcast satellite/terrestrial

DVB-S2: Digital Video Broadcasting - Second Generation

DWDM: Dense Wavelength Division Multiplexing

DWL: Direct Write Laser

DWR: Doppler weather radar

ECLSS: Environmental Control and Life-support Subsystem

ECMWF: European Centre for Medium Range Weather Forecasting

ECTC: Electronic Components and Technology Conference

EDFA: Erbium Doped Fiber Amplifier

EKF: Extended Kalman Filter

EMC: Electro Magnetic Compatibility

EMI: Electromagnetic Interference

EO: Earth Observation

EO: Electro Optical

EOS: End of Season

EPC: Electronic Power Conditioner

EPSA: Earth, Ocean, Atmosphere, Planetary Sciences and Applications

ESA: European Space Agency

ESCES: Experimental Satellite Communication Earth Station

ESIM: Earth stations in motion

E-SSA: Enhanced Spread Spectrum Aloha

EVM: Error Vector magnitude

FD SOI: Fully Depleted Silicon On Insulator

FDTD: Finite-difference Time Domain

FE: Finite Element

FEC: Forward Error Correction

FEM: Finite Element Method

FFT: Fast Fourier Transform

FMCW: Frequency Modulated Continuous Wave

FMR: Ferromagnetic Resonance

FOV: Field-Of-View

FPGA: Field Programmable Gate Array

FTLE: Finite time Lyapunov exponent

G/T: Antenna Gain-To-Noise-Temperature

GaAs: Gallium Arsenide

GAGAN: GPS Aided Geo Augmented Navigation

GaN HEMT: Gallium Nitride High Electron Mobility Transistor

GaN: Gallium Nitride

GCOS: Global Climate Observing System

GEO: Geostationary Orbit

GeoSAR: Geosynchronous Synthetic Aperture Radar

GIS: Geographical Information System

GISAT: Geo imagine Satellite

GLOFs: Glacial Lake Outbursts Flood

GMI: GPM Microwave Imager

GMR: Grandhi Mallikarjuna Rao

GMSK: Gaussian Minimum Shift Keying

GNSS: Global Navigation Satellite System

GNSS-R: GNSS Reflectometry

GOPS: Giga Operations per Second

GPR: Ground penetrating RADAR

GRIN: Graded refractive index

GRU: Gated Recurrent Unit

GSAT: Geosynchronous Satellite

GSM: Global System for Mobile Communication

GSO: Geosynchronous Orbit

GTS: Ground-To-Satellite

GTU: Gujarat Technological University

HabEx: Habitable Exoplanet

HAD: Hazard Detection and Avoidance

HDLC: High-level Data Link Control

HDR: High Data Rate

HEM: Handheld Environment Monitor

HEMT: High-Electron-Mobility Transistor

HKH: Hindu-Kush-Himalayan

HMC: Hybrid Microcircuits

HRWS: High Resolutions Wide Swath

HSU: Humidity Sounder

HSU: Humidity Sounding Unit

HTL: High Threshold Logic

HTS: High Throughput Satellite

HySure: Hyperspectral Image Superresolution via Subspace-Based Regularization

IBIS: I/O Buffer information Specification

IC: Integrated Circuit

ICCSAE: International Conference on Computer Sciences and Automation Engineering

ICO: Initial Coin Offering

ICT: Information and Communication Technology

IDDCA: IR detector cooler assembly

IDEA: Individuals with Disabilities Education Act

IEMs: Interest Exploration Meetings

IF: Instruction Fetch

IFFT: Inverse Fast Fourier Transform

IGB: Indus, Ganga and Brahmaputra

IISc: Indian Institute of Science

IITs: Indian Institute of Technology

IMD: India Meteorological Department

IMPRINT: IMPacting Research INnovation and Technology

IMS: Indian Micro Satellite Bus

INS: Indian Nano Satellite Bus

INS: Inertial Navigation System

INSAT: Indian National Satellite

IoT: Internet of Things

IPC: Indian Panel Code

IR: Infrared Radiation

IRNSS: Indian Regional Navigation Satellite System

ISL: Inter satellite link

ISM: Indian summer monsoon

ISM: Industrial, Scientific and Medical

ISMR: Indian Summer Monsoon rainfall

ISO: International Organization for Standardization

ISRO: Indian Space Research Organisation

ITU: International Telecommunication Union

ITWG: International Technical Working Group

IWV: Integrated Water Vapour

JPSS1: Joint Polar Satellite System

KaRa: Ka band RADAR

KMP: Knowledge Management Practices

KMS: Knowledge Management Systems

KPIs: Key Performance Indicators

LASER: Light Amplification by Stimulated Emission of Radiation

LDPC: Low density Parity check code

LEO: Low Earth Orbit

LIDAR: Light Detection and ranging

LIGA: Lithographie, Galvanoformung, Abformung

LISS: Linear Imaging Self Scanning

LMS: Least Mean Square

LN2: Liquid nitrogen

LNAs: Low-Noise Amplifier

LO: Local Oscillator

LOS: Line of Sight

Low-Swap: Low-Size, Weight and Power

LSPRs: Localized Surface Plasmon Resonances

LSTM: Long Short-Term Memory

LTCC: Low Temperate Co-fired Ceramics

LTF: Logistics Task Force

LTL: Less than Truckload

LUT: Letter of Undertaking

LVCMOS: Low Voltage Complementary Metal Oxide Semiconductor

LVDS: Low-Voltage Differ-ential Signaling

LWIR: Low-Wave IR

M2M: Machine to Machine

MATLAB: Matrix Laboratory

MBOC: Multiplexed binary offset carrier

MBSA: Mechanical Beam-Steering Array Antenna

MCC: Master Control Centre

MCE: Magneto Calorific Effect

MDA: Model-Driven Architecture

mDBF-AC: Multi-Channel Digital Beam Forming & Autonomous Controller

MDC: Multistage Depressed Collectors

ME: Magneto-electric

MEMS: Micro-electromechanical System

MEO: Medium Earth Orbit

MF: Measurement Filtering

MHRD: Ministry of Human Resource Development

MHS: Millimeter Wave Humidity Sounder

MIC: Microphone Circuit

MIMO: Multiple-Input Multiple-Output

MLM: Mars Landing Mission

MMICs: Monolithic Microwave Integrated Circuits

MNIT: Malaviya National Institute of Technology

MOSDAC: Meteorological & Oceanographic Satellite Data Archival Centre

MOSFET: Metal-Oxide Semiconductor Field Effect Transistor

MRA: Multiresolution Analysis

MRAM: Magnetoresistive Random Access Memory

MRS: Magnetic Resonance Spectroscopy

MRSA: Microwave Remote Sensors Area

MSK: Minimum Shift Keying

MSS: Mobile Satellite Service

MWIR: Medium-Wave IR

MWP: Microwave Photonic

MX: Multi-Spectral

NAND: Not AND

NASA: National Aeronautics and Space Administration

NavIC: Navigation with Indian Constellation

NCMRWF: National Centre for Medium Range Weather Forecasting

NCP: Network Control Program

NISAR: NASA ISRO Synthetic Aperture Radar

NIST: National Institute of Standards and Technology

NIT: National Institute of Technology

NLP: Natural Language Processing

NMOS: N-channel Metal-Oxide Semiconductor

NMS: No Man's Sky

NOMA: Non Orthogonal Multiple Access

NPP: National Power Portal

NTA: Nanoparticle Tracking Analysis

NTAG: Navigation Technology and Applications Group

NTN: Non-Terrestrial Network

NWP: Numerical Weather Prediction

OBC: On-Board Computer

OBDH: On-Board Data Handling

OBSP: Onboard SAR processor

OCB: Organization Citizenship Behavior

OCM: Organizational Change Management

OCT: Optical Communication Terminal

OCW: Optically Complex Waters

OFDM: Orthogonal Frequency-Division Multiplexing

OFHC: Oxygen free High Conductivity

OGS: Optical ground stations

OLCI: Ocean and Land Colour Instrument

OMA: Orthogonal Multiple Access

ONCLE: Onboard Clock Ensemble

ONFI: Open NAND Flash Interface

OSNR: Optical Signal to Noise Ratio

OSSE: Observation System Studies Experiment

PAA: Phase Array Antenna

PAT: Pointing Acquisition and Tracking

PCB: Printed Circuit Board

PCCC: Parallel-Concatenated Convolutional Codes

PCMA: Professional Convention Management Association

PHP: Pulsating Heat Pipe

PIC: Photonics Integrated circuits

PID: Proportional-Integral-Derivative

PIM: Passive Intermodulation

PLL: Phase Locked Loop

PMAs: Plasmonic Metamaterial Absorbers

PMMA: Poly (methyl methacrylate)

PNT: Positioning, Navigation and Timing

POC: Particulate Organic Carbon

POL: Point of Load

PolyMUMPS: Polysilicon Multi-Users MEMS

PPP: Precise Point Positioning

PRN: Permanent Registration Number

PRT: Platinum Resistance Thermometer

PSU: Power Supply Unit

PTH: Pressure, Temperature, Humidity

PWM: Pulse-width modulation

PZT: Lead Zirconate Titanate

QA: Quality audits

QAM: Quadrature Amplitude Modulation

QKD: Quantum Key Distribution

QMBOC: Quadrature Multiplexed binary offset carrier

QoS: Quality of Service

QPSK: Quadrature Phase Shift Keying

QUTG: Quantum Technology Group

R&D: Research and Development

RAC-S: Regional Academic Centres for Space

RADAR: Radio Detection and Ranging

RAFS: Rubidium Atom Frequency Standards

RAIM: Receiver Autonomous Integrity Monitor

RC: Ritchey-Chritien

RDM: Research Data Management

RF: Radio Frequency

RFIC: Radio Frequency Integrated Circuit

RHBD: Radiation Hardening by Design

RNN: Recurrent neural Network

ROIC: Readout Integrated Circuits

RS: Reed-Solomon

RTIS: Real-time Train-tracking Information System

RTK: Real Time Kinematic

RTL: Resistor Transistor Logics

RTOS: Real Time Operating System

RT-PCR: Real Time Polymerase Chain Reaction

RTT: Radiative Transfer Theory

RTT: Round Trip Time

RTV: Room Temperature Vulcanizing

SAC: Space Applications Centre

SLA: Service-level Agreement

SAMIR: Satellite Microwave Radiometers

SAR: Search And Rescue

SARS-CoV-2: Severe Acute Respiratory Syndrome Coronavirus 2

SATCOM: Satellite Communication

SATNAV: Satellite-Based Navigation

SAW: Surface Acoustic Wave

SBAS: Space-Based Augmentation Systems

SBD: Schottky Barrier Diode

SCATSAT: Scatterometer Satellite

SDM: Software Defined Modem

SDR: Software defined radio

SEDA: Sensors Development Area

SEE: Secondary Electron Emission

SERDES: serializer/deserializer

SEU: Single Event Upset

SGD: Submarine Ground Water Discharge

SIC: Successive Interference Cancellation

SIF: Solar-Induced Fluorescence

SINR: Signal to Interference plus Noise Ratio

SIPG: Signal & Image Processing and Data Product Group

SIS: Secret Intelligence Service

SIW: Substrate-Integrated Waveguide

SLM: Spatial Light Modulator

SM: Single Mode

SMA: Shape Memory Alloy

SMART: Satellite Meteorology and Oceanography Research and Training

S-NAP: Space National Academic Partner

SNPA: SATCOM & Navigation Payload Area

SNR: Signal-to-Noise Ratio

SNS: Satellite Network Simulator

SNSPD: Super Conducting Nanowires

SOC: System on Chip

SoPC: System-On-A-Programmable-Chip

SOS: Sum of Squares

SOTM: Satellite Communication On The Move

SPAD: Single photon avalanche diodes

SPDT: Single Pole, Double Throw

SPI: Serial Peripheral Interface

SPICE: Simulation Program with Integrated Circuit Emphasis

SPPU: Savitribai Phule Pune University

SPRAM: Single Port RAM

SPS: Standard Positioning Service

SRA: Systems Reliability Area

SRF: Spectral Response Function

SSLV: Small Satellite Launch Vehicle

SSPA: Solid State Power Amplifier

SSPA: Supplier Security and Privacy Assurance

SSR: Solid State Recorder

ST: Spatio-Temporal

STCs: Space Technology Cells

STG: Satellite-To-Ground

S-TICs: Space Technology Incubation Centres

SWIR: Short-Wave IR

SWOT: Surface Water and Ocean Topography mission

TCAD: Technology Computer-Aided Design

TCC: Turbo convolutional codes

TCP: Transmission Control Protocol

TCU: Tile Control Units

TCXO: Temperature Compensated Crystal Oscillator

TDD: Test Driven Development

TEC: Total Electron Content

TeCu: Tellurium Copper

TM: Telemetry

TMA: Three Mirror Anastigmat

TMBOC: The Time-Multiplexed BOC

TOAR: top of the atmosphere reflectance

TOC: Total Organic Carbon

ToT: Transfer Of Technology

TPC: Turbo product code

TRC: Transmit/Receive Controller

TREES: Training and Research in Earth Eco-System

TRIB: Transmit Receive Integration Block

TRM: Transmit Receive Modules

TRNG: True Random Number Generators

TSU: Temperature Sounding Unit

TTFF: Time to First Fix

TWI: Tilted Wave Interferometer

TWTA: Travelling Wave Tube Amplifier

UART: Universal Asynchronous Receiver-Transmitter

UAV: Unmanned Aerial Vehicle

UAY: Uutachar Avishakar Yojna

UDL: Up-and-Downlink

UHDR: Ultra High Data Rate

UHF: Ultrahigh Frequency

UKF: Unscented Kalman Filter

ULPC: Uplink Power Control

UML: Unified Modeling Language

UMTS: Universal Mobile Telecommunications System

UV LEDs: Ultraviolet, Light-Emitting Diodes

UVGI: Ultraviolet Germicidal Irradiation

UVLO: Under Voltage Lock-out

UWB: Ultra wideband

VCM: Variable Coding and Modulation

VCO: Voltage Controlled Oscillator

VEC: Variable Emissivity Coated

VEDAS: Visualization of Earth Data & Archival System

VEDAS: Visualization of Earth observation Data and Archival System

VFB: Visible Flash Beacon

VGA: Video Graphics Array

VHDL: Hardware Description Language

VHG: Volume Holographic Grating

VHTS: Very High Throughput

VIIRS: Visible Infrared Imaging Radiometer Suite

VIS/NIR: Visible/Near-Infrared

VLBI: Very-Long-Baseline Interferometry

VOC: Volatile Organic Compounds

VSAT: Very Small Aperture Terminal

VVA: Variable Valve Actuation

WAAS: Wide Area Augmentation System

W-CDMA: Wideband Code Division Multiple Access

WDM: wavelength-division-multiplexed

WLAN: Wireless Local Area Network

WRF HYDRO: weather forecasting coupled hydrological system

WSS: Wideband Spectrum Sensing

XHV: Extreme High vacuum

ZBO: Zero-Boil-Off

Annexure: RESPOND Proposal Submission Guidelines and Formats

(For further details and latest information particularly on salaries etc. refer to Respond page on www.sac.gov.in/respond/ or https://www.isro.gov.in)

Proposal Submission Guidelines

An individual or group(s) of scientists / faculty members affiliated to any academic institution/autonomous R&D institutions may submit proposals. Faculty of STCs and RAC-S established at various IITs/NITs; IISc and SPPU can select and generate proposals from 'Research Areas of SAC' document. Faculty of the academic institutions/R&D labs other than STCs and RAC-S can select and generate proposals from Respond Basket. The Principal Investigator(s) should be full-time employee(s) of the concerned institution. The age limit for the Principal Investigator should be below 65 years (sixty five) including the project period. The Head of the academic institution must forward proposals with application for research grants. Proposals from individuals not affiliated to any recognized institution will not be considered.

Each proposal must name a Principal Investigator who is a domain expert in the area to which the proposal belongs and who is a full time employee/faculty of the institution forwarding the application. There may also be co-investigator(s) from the same/different institutions working on the project. But satisfactory completion of a project will be the responsibility of the Principal Investigator and her/his institution. The following information will be required for the submission of the proposal online.

- Detailed bio-data of all the investigators (Age also to be indicated) including publications/awards & recognition received.
- Contact details: address, email id, telephone/fax numbers of investigators as well as the institution.
- In case the institution belongs to Non Government Category, NGO Darpan ID and PAN number of the institution.
- Brief description of the research proposal including the objectives and the scientific/application merits of the work.
- Description of the research methodology or technique to be used for the proposed project.
- The extent of financial support needed from ISRO for executing the work within the shortest possible time.
- A list of research projects related to the proposal undertaken or carried out through funding by other Agencies.
- Scanned copy of the declaration form (Annexure-1 in "RESPOND Basket") signed by head of the institution.

Proposals will be evaluated by domain experts (internal and/or external) for its novelty, usefulness to Indian Space Programme and other Scientific/ technical merits. The proposal may call for changes based on review and the PI will have to re-submit the proposal incorporating the recommended changes. Proposers are informed about the outcome of the evaluation of their research proposals.

Research Grants

The institutions proposing a project for support are expected to commit the use of the existing infrastructure available with them. ISRO provides financial grants to support fellowship, materials, consumables, internal travel, testing charges, data etc. The fund for purchase of only essential minor equipment's which are not available in the institution and would be useful for future projects will also be provided. There is no provision for any kind of payment to the Principal Investigator (or other staff) belonging to the Institution. The allocated funds cannot be used for travel abroad for any reasons.

Guidelines governing the allocation of funds by ISRO are set out below. These may change from time to time.

- Grants for the purchase of equipment may be provided for the investigation. The equipment must be of a specialized nature, required exclusively for the project and is either not available at, or cannot be spared from, parent Institution for the project. Such equipment should be useful for new projects to be taken up in future. In this category, PC/Computer means desktop computer only.

- The overhead cost of the project shall not exceed 20% of the total project cost or Rs. 3.00 Lakhs whichever is less and shall be scattered over the years.

- Appointment of approved Research Fellows to support PI in the project activities can be made by the Academic/Research Institution for the approved project. The services of supporting staff like administrative personnel, support technical staff, technicians & technical Assistants, Surveyor, data entry operators etc., will have to be exclusively sourced by the academic or research institution undertaking the project and funds sanctioned under the project should not be diverted for any purpose. However, at the closure of the project, ISRO cannot assume any responsibility of providing continuity in employment either in the same or new project for the project staff. Such project staff who will have no claim whatsoever for recruitment in ISRO on any.

- The selection and appointment of the above project staff is the responsibility of the Principal Investigator as per the rules in vogue in respective / academic research institutions. These should be made according to the normal selection procedures of the university or institution submitting the research proposal. The qualification/ experience required and the fellowship offered shall be as per ISRO norms and the selection should have the approval of the head of the institution according to the rules followed in the respective Institution.
- The research personnel who are associated with the project may be awarded ISRO's research Fellowships according to guidelines laid down by ISRO for this purpose. Details on the award of Research personnel are given in following sections.
- Approved grant may be utilized for the following heads only:
    - Purchase of books and scientific literature, which are essential for the investigation, and are not available in the concerned academic/research Institution. Subscription for Journals are normally not permitted and expenditure towards Journals cannot be charged to project. In the event of a particular Journal which is not available in the academic/research institution and which is very important and relevant to the investigation may be procured on single copy basis or Photostat copies only on prior approval of ISRO. Subscription to journals on a regular basis cannot be covered by these funds.
    - Special consumable materials essential to the project.
    - Computer time, observatory time and other services.
    - Travel within India, in connection with the project or for attending seminars and symposia of relevance to the subject of the investigation.

- Miscellaneous expenses (contingency) such as typing charges, stationery, postage, etc.
- Contingency grants shall not exceed 3% of the Total Project Cost and shall be distributed equally over the years.

- All requirements of foreign exchange for the purchase of equipment and/or consumables should be clearly identified and mentioned in the budget. The Academic Institution /Research Institution shall arrange to provide the required foreign exchange to the project and ISRO will provide equivalent money in Indian Rupees.
- No funds are available for international travel either partly or fully, for personnel connected with the project.
- ISRO does not provide funds in the project for printing any material in connection with the project.
- ISRO does not grant any funds for buildings and civil works for housing any equipment or personnel. However, charges for equipment installation can be provided only on specific approvals.
- All travel in connection with the project should be approved by the Principal Investigator according to the TA/DA rules of the concerned Institution. The mode of Journey including air-travel may also be approved by him so that the implementation of the project takes place in time subject to the condition that the institution has no objection to such an arrangement and that the travel expenses are contained within the budgetary provisions for the project approved by ISRO.
- The funds will be sanctioned under different specific heads and will normally be released by ISRO once in every year. Re-appropriation of funds, if necessary among different approved heads is not permissible without prior approval.
- If the total grant released to an Institution is not fully spent, the unspent balance will be deducted out of the approved budget earmarked for next immediate release.
- Any unspent grant at the end of the project will have to be returned to Pay and Accounts Officer, Department of Space, Antariksh Bhavan, New BEL road, Bangalore-560 094.

Terms and Conditions of ISRO Research grants

1. ISRO reserves the right to revoke in whole or in part the funds approved for a project at any time without assigning any reason.
2. Approved funds must be utilized solely for the purpose for which they have been granted unless ISRO agrees other-wise. A certificate that the funds have been so used must be produced by the grantee Institution at the end of each year of support.
3. Acknowledgement of ISRO support must be made in all reports and publications arising out of an approved project/investigation. The Institution will take prior permission of ISRO before publishing any work based on an ISRO supported project. Such permission will not be unreasonably withheld.
4. Two copies of all publications resulting from the research conducted with the aid of the grants should be submitted to ISRO.
5. Intellectual Property Rights
    - Any intellectual property rights or such information/knowledge being able to sustain or create or any such right arising out of the projects sponsored by ISRO will be held jointly by the Academic Institution/R & D institution and ISRO as per RESPOND norms.
    - Academic Institute/R & D institution and ISRO shall inform each other before filing for any protection of any Intellectual Property Rights resulting from any of the project sponsored by ISRO.
    - Academic institute/R & D institution and ISRO will ensure appropriate protection of Intellectual Property Rights generated from cooperation, consistent with laws, rules and regulations of India.
    - The expenses for filling the Patent protection in India and abroad shall be borne equally between Institute and ISRO.

- Any/all financial accruals due to any commercial exploitation, of this patent shall be shared equally between them, on 50:50 basis. However any of the parties is free to utilize the IPR for their own use on non-commercial basis.

6. The Principal Investigator is required to submit two copies of yearly reports indicating the progress of the work accomplished. He is also required to submit two copies of a detailed scientific/technical report on the results of the research and development work after the completion of the project. One copy of these reports should be sent to the address to which the proposal was sent and other to the Director, CBPO, ISRO Headquarters. Annual reports should be sent to enable release of funds for the subsequent year. The reports will become the property of ISRO.
7. ISRO may designate scientists/specialists to visit the Institution periodically, for reviewing the progress of work on an ISRO-funded project.
8. An inventory of items purchased from ISRO funds should be sent to ISRO giving the description of the equipment, brief specifications, cost in rupees, date of purchase and name of supplier along with a purchase certificate from the Head of the Institution. All items of equipment and non -consumable items costing more than Rs. 5,000/- remain the property of ISRO and ISRO reserves and right to recall, transfer or dispose them off either during the tenure or on the termination of the project.
9. The accounts of the expenses incurred out of ISRO funds should be properly maintained and should be audited by an approved auditor. The final financial documents comprising of audited accounts statement and fund utilization certificate in duplicate, should be sent to ISRO at the end of each financial year of support. The final financial documents pertaining to the project should be sent to ISRO for every operational year of the project sufficiently in advance to enable the release of funds for the subsequent year. It is the responsibility of the institution to submit the Fund Utilization Certificate (FUC) and Audited Accounts Statement (AAS) to Pay and Accounts Officer (PAO), Department of Space at the end of 12 months from the date of drawl of grant(s) from ISRO for Research Projects and at the end of 6 months for Conferences/ Seminars/ Workshops/ Symposium etc. It is mandatory for all institutions drawing grants from Department of Space to submit all financial documents within the stipulated period and any delay in the submission of the financial documents for all grants drawn from Department to Pay and Accounts Officer (PAO), Department of Space will result in delay in release of funds. In such situations, the PI cannot seek extension of project or modification of objectives of the project.
10. The funds for the projects are released on annual basis. Further release of funds for ensuing year will be based on the technical performance of the project and utilization of the funds released for the project during the previous year. Any unspent balance shown in the reporting year, will be adjusted with the funds due for release during the next year.
11. If the total amount sanctioned is not spent during the whole period of support, the remainder amount must be surrendered to the Pay and Accounts Officer, Department of Space, within one month after completion of the project.
12. The Institution cannot divert the grants for a project to another institution if it is not in a position to execute or complete the assignment. In such a case the entire amount of the grant must be immediately refunded to ISRO.
13. A register of assets, permanent and semi-permanent, should be maintained by the Institution and this should be available for scrutiny by ISRO staff.
14. The assets acquired wholly or substantially out of an ISRO grant should not, without prior sanction, be disposed off or transferred to other agencies or utilized for purposes other than that for which the grant is sanctioned.
15. The terms and conditions of ISRO research grants are subject to change from time to time, but the funding of any project till its completion will be governed by the terms and conditions existed on the date of starting of the project, unless mutually agreed to otherwise. The academic institution/PI cannot claim revision of fellowships or any of its elements from a retrospective date.

16. ISRO reserves the right to transfer any approved project(s) from one institution to other institutions in the event of institution's inability to continue the project , PI leaving the institution etc.

General Rules:

- ISRO Research Fellowships, Research Associateships and Research Scientists hereinafter referred to as Fellowships/ Associateships/ Scientists are awarded for specific projects or Education/Research Schemes approved by ISRO. Change of level of Research Fellow, subsequent to the approval of the project will not be permitted.
- The recipients of these Fellowships/ Associateships /Scientists are expected to conduct research work whole time under the Principal Investigator of the ISRO sponsored project. In special cases of individual Research Fellows/Associates, the candidates could be governed by the conditions of Research work as specified by the projects/ programmes/ schemes for which the Fellowships have been offered by ISRO.
- ISRO may nominate a member in the committee(s) appointed by the institution in connection with the approved project.
- The Fellows/ Associates/ Scientists, appointed for ISRO project, shall not be transferred from one institution to another.
- The award of ISRO Fellowships/Associateships/ Scientists does not imply any assurance or guarantee by or from ISRO or any kind of employment to the beneficiaries.
- Generally the upper limit for the period of Fellowships/ Associateships/ Scientists will be the same as that of the project. However, in exceptional cases, mainly to enable the Fellow to complete all formalities required for submission of doctoral thesis, ISRO may consider extension of the fellowship purely based on the merit on case by case basis. However, such extensions cannot be claimed as right by either fellow or PI.
- Monthly emoluments of the Fellowships/ Associateships/ Scientists will be paid by the concerned institution by utilizing the project grant.

Note: The scales of pay, service benefits, terms and conditions, etc. for appointment are subject to revision from time to time by the Department of Space/Government of India.

Research Fellowships:

There is a provision for engaging research personnel in RESPOND projects. The norms governing as per DOS orders, the qualification required for each category and service conditions of the research personnel are given below:

Junior Research Fellow (JRF) Senior Research Fellow (SRF)

Designation and Qualification	Ist & 2nd Yr (monthly emoluments)(w.e.f 01/01/2023)
<u>A: Junior Research Fellow (JRF)</u> Post Graduate Degree in Basic Science OR Graduate/Post Graduate Degree in Professional Course selected through a process described through any one of the following : **a.** Scholars who are selected through National Eligibility Tests - CSIR-UGC NET including lectureship (Assistant professorship) and GATE. **b.** The selection process through National level examinations conducted by Central Government Departments and their Agencies and	**Rs. 37, 000/- + HRA**

institutions such as DST, DBT,DAE,DOS,DRDO,MHRD, ICAR, ICMR, IIT, IISc, IISER etc.	
B: Senior Research Fellow (SRF) Qualification prescribed for JRF with two years of research experience	**Rs. 42, 000/- + HRA**

Note: *The performance of the Junior Research Fellows (JRF) shall be reviewed on completion of the two years, by an appropriate Review Committee duly constituted by the Head of the Institute. Based on the recommendations of the review committee, and approval of Director of the Centre /Unit, Junior Research Fellow may be awarded the position of Senior Research Fellow (SRF).*

NET Examinations and Its Equivalent for Coverage under the OM.

Any National Level Examination conducted by the Central Government departments/agencies for admission to PhD programme are considered equivalent to NET. The following are the list of examination which can be equated to NET:

I. CSIR-UGC National Eligibility Test Including NET –Lecturership.
II. Graduate Aptitude Test in Engineering (GATE) conducted by MHRD.
III. Joint Admission Test (JAM) conducted by MHRD.
IV. Graduate Pharmacy Aptitude Test (GPAT) conducted by MHRD.
V. Biotechnology Eligibility Test & Test conducted in Bio-Informatics by Bio-Informatics National Consortium.
VI. Joint Entrance Screening Test (JEST), Joint Graduate Entrance Examination for Biology & Interdisciplinary Life Sciences (JGEEBILS) conducted by Department of Atomic Energy.
VII. JRF Entrance Examination conducted by Indian Council of Medical Research.
VIII. All India Competitive Examination (AICE) conducted by Indian Council of Agricultural Research.

Research Associates (RA) / Research Scientists (RS):

Research Associates (RA):

The fellowship for Research Associates may be fixed as a consolidated amount at any of three pay levels given below depending upon the qualification and experience.

Educational Qualification: Ph.D/MD/MS/MDS or equivalent degree or having 3 years years of research, teaching and design and development experience after MVSc/M.Pharm/ME / MTech with atleast one research paper in Science Citation Indexed (SCI) journal.

SI. No.	Category	Fellowship per month(in Rs) (w.e.f 01/01/2023)
1.	Research Associate I (RA-I)	Rs. 58, 000
2.	Research Associate II (RA-II)	Rs. 61, 000
3.	Research Associate III (RA-III)	Rs. 67, 000

Research Scientists (RS):

The fellowship for Research Scientists remains unaltered:

SI. No.	Levels in the Pay matrix (as per VII CPC)
1.	Level 10
2.	Level 11
3.	Level 12

4.	Other Scales below in the Level 10 of pay matrix, as recommended by VII CPC and approved by Govt. of India.

Service Conditions :

Dearness Allowance (D.A.):

JRFs, SRFs and Research Associates will not be entitled to this allowance. The Research Scientists will be eligible to draw DA as per rates of Central Government as per rules of the local institutions where they are working.

House Rent Allowance:

House Rent Allowance will be allowed to all research fellows viz. Junior Research Fellows (JRF), Senior Research Fellows (SRF), Research Associates (RA) and Research Scientists (RS), if they are not provided with hostel accommodation, as per rules of the institutions where they are working. For this purpose, the fellowship amount for JRF/SRF / Research Associates and Research Scientists will be taken as Basic Pay.

Medical Benefits:

The JRF, SRF, Research Associates and Research Scientists will be allowed medical benefits, as per rule of the institution where they are working.

Leave and other services benefits:

JRFs/SRFs are eligible only for casual leave while Research Associates/Scientists are eligible for leave as per rules of the Institutions. Maternity leave as per Govt. of India instructions would be available to all female JRFs/SRFs/ RAs/RSs.

Participation of JRF/SRF/ RA/RS in any scientific event in India or abroad will be treated as “on duty”. The travel entitlement for JRF/SRF/RA/RS for participation in scientific events/ workshops In India will continue to be the same as earlier i.e., IInd AC by rail.

Bonus & Leave Travel Concession:

Not admissible to any category.

Retirement Benefits:

JRFs / SRFs / Research Associates and Research Scientists will not be entitled to these benefits.However, Research Scientists who are appointed for the duration of the project may be allowed to be members of the New Pension Scheme (NPS) of the Institution.

Encouragement for pursuing higher studies:

JRFs/SRFs may be encouraged to register for higher studies and the tuition fees to undertake these studies may be reimbursed from the contingency grant sanctioned under the project grant, if required.

Benefits to Host Institutes:

Overhead expenses of 20% of the total project cost not exceeding Rs 3.00 lakhs may be permitted to the host institutions for meeting their costs including infrastructural facilities.

Obligations of JRF/SRF/RA:

a) JRF/SRF/RA/RS shall be governed by the disciplinary regulations of the host institute.

b) The JRF/ SRF/RA/RS must send a detailed consolidated report of the research work done during the entire period of Fellowship on completion of the tenure/ resignation at the earliest.

The periodic enhancement of Research fellowship: The Research Fellows, Research Associates and Research Scientists are not entitled for annual increment.

The revised emoluments will take effect from January 01, 2023 for all categories of JRS/SRF/ Research Associates.

Other Categories :

Sl. No.	Manpower Position	Essential Qualification	Upper Age limit (years)	Monthly Emoluments (Rs.)
1.	Project Associate-I	Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent	35	31,000/- + HRA
2.	Project Associate-II	(i) Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent; and (ii) 2 years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services	35	35,000/- +HRA
3.	Senior Project Associate	(i) Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent; and (ii) Four years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services OR Doctoral Degree in Science/Engineering/Technology /Pharma / MD/ MS from a recognized University or equivalent	40	42,000/- + HRA
4.	Principal Project Associate	(i) Master's Degree in Natural or Agricultural Sciences/MVSc or bachelor's degree in Engineering or Technology or Medicine from a recognized University or equivalent; and (ii) Eight years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services OR	40	49,000/- + HRA

		(i) Doctoral Degree in Science/Engineering/Technology /Pharma / MD/ MS from a recognized University or equivalent; and (ii) Four years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services		
5.	Project Scientist I	Doctoral Degree in Science or Master's Degree in Engineering or Technology from a recognized University or equivalent	35	56,000/- + HRA
6.	Project Scientist II	(i) Doctoral Degree in Science or Master's Degree in Engineering or Technology from a recognized University or equivalent; and (ii) Three years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services	40	67,000/- + HRA
7.	Project Scientist III	(i) Doctoral Degree in Science or Master's Degree in Engineering or Technology from a recognized University or equivalent; and (ii) Six years' experience in Research and Development in Industrial and Academic Institutions or Science and Technology Organizations and Scientific activities and services	42	78,000/-+ HRA

Service conditions of other categories:

(i) **DA & CCA:** Scientific/Technical Manpower in projects are not entitled to DA & CCA.

(ii) **House Rent Allowance (HRA):** HRA is allowed to all categories, except for Project Investigator (PI)/Project Coordinators in Non-Governmental/Voluntary Organizations (NGO/VO)/Project Manager as per Central Government norms applicable in the city/location where they are working. The percentage required for calculating HRA will be based on the remuneration.

(iii) **Medical Benefits:** The Scientific/Technical manpower will be entitled for medical benefits as applicable in the implementing institution.

(iv) The Scientific/Technical manpower are entitled to leave as per rules of the host institution. Maternity leave as per the Govt. Of India instructions issued from time to time would b available to all categories. The travel entitlement is as per Institute norms.

(v) **Bonus, Gratuity & Leave Travel Concession :**The Scientific/Technical manpower will not be entitled to these allowances.

Formats for submitting research proposals under Space Technology Cell (STC) and Regional Academic Centres for Space (RAC-S)

www.sac.gov.in/respond/forms.jsp

Form A

Bio-data of the Investigator(s)

(Bio-data for **all the investigators** should be given, each on a separate sheet)

1.	Name	
2.	Date of Birth (dd/mm/yyyy)	
3.	Designation	
4.	Degrees conferred (begin with Bachelor's degree)	

Degree	Institution conferring the degree	Field(s)	Year

5.	Research/training experience (in chronological order)

Duration	Institution	Name of work done

6.	Major scientific fields of Interest	
7.	List of publications	
8.	Email id, Mobile number and Telephone number of PI with STD Code	
9.	Email id, Mobile number and Telephone number of the Head of the academic institution	

Form B
Proposal Format

1.	**Title of the research proposal**	
2.	**Summary of the proposed research** A Simple concise statement about the investigation, its conduct and the anticipated results in no more than 200 words	
3.	**Objectives** A brief definition of the objectives and their scientific, technical and techno-economic importance.	
4.	**Major Scientific fields of Interest** A brief history and basis for the proposal and a demonstration of the need for such an investigation preferably with reference to the possible application of the results to ISRO's activities. A reference should also be made to the latest work being carried out in the field and the present state-of-art of the subject.	
5.	**Linkages to Space Programme /** **Deliverables to ISRO on successful completion of the project**	
6.	**Approach** 6.1 Back ground / Introduction 6.2 State of the art 6.3 Detailed algorithm/ Methodology along with concepts 6.4 Expected outcome A clear description of the concepts to be used in the investigation should be given.	

	Details of the method and procedures for carrying out the investigation with necessary instrumentation and expected time schedules should be included. All supporting studies necessary for the investigation should be identified. The necessary information of any collaborative arrangement, if existing with other investigators for such studies, should be furnished. The principal Investigator is expected to have worked out his collaborative arrangement himself. For the development of balloon, rocket and satellite-borne payloads it will be necessary to provide relevant details of their design. ISRO should also be informed whether the Institution has adequate facilities for such payload development or will be dependent on ISRO or some other Institution for this purpose.	
7.	**Data base and analysis** A brief description of the data base and analysis plan should be included. If any assistance is required from ISRO for data analysis purposes, it should be indicated clearly.	
8.	**Available Institutional facilities** Facilities such as equipments, etc, available at the parent Institution for the proposed investigation should be listed.	

9.	**Fund Requirement** Detailed year wise break-up for the Project budget should be given as follows:

Head	Ist Yr	2nd Yr	3rd Yr	Justification of each of the budgeted heads
Research Fellows/ Research Associate/ Research Scientist				
*Note: please specify the designation, qualification and rate of salary per month for each category				
Equipment**				
Please specify the various individual items of equipment and indicate foreign exchange requirement, if any				
Satellite data/data				
Consumables & Supplies				
Internal Travel				
Contingencies				
Others				
Overheads (Note: Overhead Expenses of 20% of Total Project Cost not exceeding 3.00 lakhs)				
Total				

**Justify each equipment. If computer is proposed, only desktop has to be purchased not laptop

10.	Whether the same or similar proposal has been submitted to other funding agencies of Government of India. If Yes please provide details of the institution & status of the proposal.	Yes/No

Form –C

Terms and Conditions of ISRO Research Grants

I. The approved funds should be utilized solely for the purpose for which they have been granted unless ISRO agrees otherwise. A Certification that the funds have been so used should be produced by the grantee Institution after the end of each year of the support.

2. Due acknowledgement to ISRO should be made in all reports and publications arising out of the part of the work supported by ISRO. The grantee will take prior permission of ISRO before publishing any work based on the ISRO supported project.

3. Two copies of all the publications resulting from the research conducted with the aid of the grant should be submitted to ISRO.

4. Any intellectual property rights or such information/knowledge being able to sustain or create or any such right arising out of the projects sponsored by ISRO will be held jointly by the Academic Institution/R & D institution and ISRO as per RESPOND norms. Academic Institute/R & D institution and ISRO shall inform each other before filing for any protection of any Intellectual Property Rights resulting from any of the project sponsored by ISRO. Academic institute/R & D institution and ISRO will ensure appropriate protection of Intellectual Property Rights generated from cooperation, consistent with laws, rules and regulations of India. The expenses for filling the Patent protection in India and abroad shall be borne equally between Institute and ISRO. Any/all financial accruals due to any commercial exploitation, of this patent shall be shared equally between them, on 50:50 basis. However any of the parties is free to utilize the IPR for their own use on non commercial basis.

5. The principal Investigator is required to submit two copies of yearly reports indicating the progress of the work accomplished. He is also required to submit two copies of a detailed technical report on the results of the research/development after the completion of the project. The reports will become the property of ISRO.

6. In addition, ISRO may designate Scientists/specialists to visit the Institution periodically for reviewing the progress of the work.

7. An inventory of items purchased from ISRO funds should be sent to ISRO, giving the description of equipment, cost in rupees, date of purchase and name of the supplier along with a purchase certificate from the Administration of the Institution. All items of equipments and unconsumable items costing more than Rs. 5,000/- shall remain the property of ISRO and ISRO reserves the right to transfer them or dispose of them on the termination of the project as ISRO may deem fit.

8. The accounts of the expenses incurred out of ISRO funds should be properly maintained and should be authenticated by an approved auditor. The final accounts statement in duplicate duly audit should be sent to the pay & Accounts Officer, DOS/Senior Accounts Officer, ISRO Headquarters, as the case may be, at the end of each financial year of support.

9. If the total amount sanctioned is not spent during the period of support, the remainder amount should be surrendered to the Pay & Accounts Officer, ISRO Headquarters, as the case may be, within one month after the completion of the project.

10. The assets acquired wholly or substantially out of the ISRO grant should not, without its prior sanction, be disposed off, encumbered or utilized for purposes other than that for which the grant is sanctioned.

11. A register of assets permanent and semi-permanent should be maintained by the grantee Institution, which should be available for scrutiny by Audit.

12. The grantee institution should not divert the grants-in-aid for utilization of the same for similar objects of another institution if it is not in a position to execute or complete the assignment. The entire amount of the grant should then be immediately refunded to ISRO by the institution.

13. The terms and condition of ISRO research grants are subject to change from time to time, but the funding of any project will be governed by the terms and conditions existing on the date of starting of the project with ISRO funds.

Declaration

I / We have clearly read the above terms and conditions and hereby agree to abide by the rules and regulations of ISRO research grants and accept to be governed by all the terms and conditions laid down for this purpose.

I / We certify that I / We have not received any grant-in-aid for the same purpose from any other Department of the Central Government / State Government / Public Sector Enterprise during the period to which the grant relates.

	Signature & Name	**Designation**
Principal Investigator		
Head of the Department / Area		
Head of the Institution		

Formats for submitting research proposals under Space Technology Incubation Centres (S-TIC)

The project proposal under S-TIC should have the Content as detailed below.

1. Title of the Proposal:
2. **Project Team**

2.1. **S-TIC Principal Investigator,** (Name, Designation, Email ID, Mobile number)

2.2. **S-TIC Co-Principal Investigator/s**, (Name, Designation, Email ID/s, Mobile number/s)

2.3. **Student/s** (Name/s, Course/PhD, Email ID/s , Mobile number/s)

3. **ISRO Mentor:** Name, Designation, Email ID, Mobile number
4. Objective
5. Scope
6. Scientific / Technical Need Aspect
7. Stake holders
8. Product / Service Marketability
9. Brief description
10. Experimentation / Studies / Field Work
11. **Expected Results** (please highlight Envisaged outcome that can be indigenised / realised at the end of the projects that would lead to start-ups in collaboration with S-TIC)
12. Deliverables (Software / Hardware)
13. Project duration(in years)
14. Milestones including **end to end schedule**
15. Budget
16. **Necessary equipment/tool/software** required to carry out the S-TIC. Please also mention whether the same is available at or not.
17. Describe the Societal application part of the outcome of this project.
18. **Describe, how it is going to generate business.**
19. **Describe how it will help start-ups.**
20. Describe how it will help students to become future entrepreneurs.
21. Other Details (if any)

Note:

1. *The ideas conceived for Serial numbers 17, 18, 19 and 20 need to be elaborated for better clarity.*

वार्षिक रिसपांड समीक्षा
Annual RESPOND Review

अंतरिक्ष प्रौद्योगिकी कक्ष (अं. प्रौ. क.) परियोजनाओं की वार्षिक समीक्षा
Annual Review of Space Technology Cell (STC) Projects

2017

2018

2019

सैक वार्षिक प्रायोजित अनुसंधान समीक्षा
SAC Annual Sponsored reseArch Review
(सैक-असर / SAC-ASAR)

2020

2022

2021

2023

रिसपांड एवं अनुसंधान प्रबंधन प्रभाग RESPOND and Research Management Division

अनुसंधान, बह्यासंपर्क एवं प्रशिक्षण समनव्य समूह Research, Outreach and Training Coordination Group

प्रबंधन एवं सूचना प्रणाली क्षेत्र Management and Information System Area

अंतरिक्ष उपयोग केंद्र, इसरो, अहमदाबाद - 380015 Space Applications Centre, ISRO, Ahmedabad - 380015

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