Validation of 126 Beams of RISAT-1 Active Array Antenna

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***Abstract*— Radar Imaging Satellite (RISAT-1) is a multi resolution/multi-swath/multi-polarization system and carries an Active Array Antenna of 6mx2m on-board. Multimode agility of the system demands complex system architecture. RISAT-1 system is configured with a dual polarized active antenna with 288 transmitting elements. 6mx2m antenna is configured in three identical panels. Each of the panel consists of 4 tiles of size 1mx1m each. TR modules, each with maximum pulse power capacity of 10 watts is mounted on the back side of the antenna. Total number of beams generated by RISAT-1 active array antenna amounts to 126V and 126H out of which 122V and 122H beams are used to cover cross track swath from 107km to 659km on both sides of azimuth track while rest 4V and 4H beams are used for fixed zero-degree pointing and internal radar calibration. Since phase and gain profile of antenna elements across aperture changes for left and right looking across azimuth track measurement of antenna pattern had to be carried out separately for both left and right side satellite pointing beams. RISAT-1 active array antenna demanded precise calibration of beam pointing angles while measurements are done in pulsed domain. A new method called "Pulsed Domain Antenna Measurement" was developed which takes advantage of signal time-gating to evaluate antenna response. On-ground measurement was done for limited number of beams (24V and 24H beams) while rest 102V and 102H beams were interpolated/synthesized to best fit actual antenna pattern measurement. This technique reduced total time of testing and validation to two-month instead of 24months. This paper concentrates on a new technique of Near-field measurement for pulsed mode testing by match filtering in time domain and beam synthesis technique applied to synthesize 102V and 102H beams to best fit actual measurement.**

***Index Terms*— Active Antenna, Active Arrays, Anechoic Chamber (Electromagnetic), Antenna Array Mutual Coupling, Antenna Measurements, Pulse Compression Radar, Synthetic Aperture Radar, Radar Testing.**

I. INTRODUCTION

Radar Imaging Satellite (RISAT-1) is a multi resolution/ multi-swath /multi-polarization synthetic Aperture Radar (SAR) which was launched on 26th April 2012 and has been performing with highest data quality since launch. This satellite is multimode SAR which operates from a sun synchronous orbit at a nominal altitude of 536km. Basic imaging modes are Coarse Resolution ScanSAR(CRS) with 50m (12 beam) resolution operation, Medium Resolution ScanSAR (MRS) with 25m (6 beam) resolution operation, Fine Resolution StripMap (FRS) with 3m and 6m resolution (single beam). All these modes can be operated in Linear as well as Circular Polarization. There is also a special operation mode called High Resolution Spotlight Mode (HRS) which has been kept as an experimental mode of operation and provides a sliding spotlight image of 10 km x 10 km with better than 2m resolution. RISAT-1 is configured on a dual receiver concept providing identical resolution and swath in co- and cross-polarization. The system is configured around a dual polarized active antenna with 288 radiating elements. 6mx2m antenna is configured in three identical panels of which the central one is fixed and rest two are deployable. Each of the panel consists of 4 tiles of size 1mx1m each. The earth viewing part of the antenna is a printed microstrip patch array. TR modules each with maximum pulse power capacity of 10 watts are mounted on the back side of the antenna.

Use of active electronics and long signal distribution

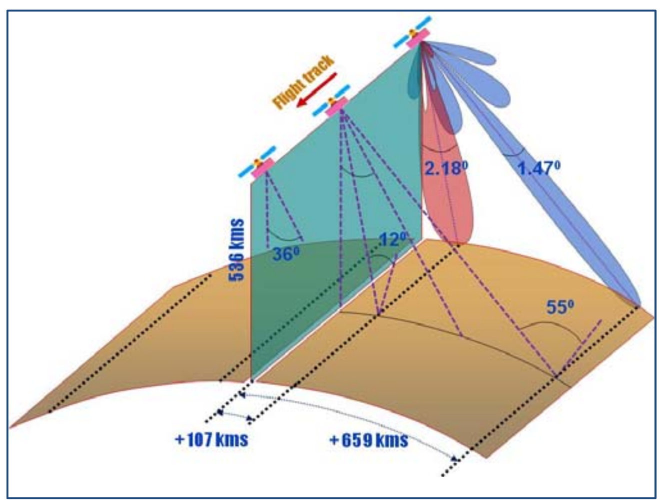

Fig.-1: RISAT-1 Antenna Beam Pointing showing Near and Far beams with variable beamwidth of 2.18 to 1.47 Range swath coverage from 107km to 659km is covered in 61 antenna beams with 10km step at spacecraft roll angle of 36^0 and nominal flight altitude of 536km.

networks creates gain/phase deviations across antenna elements leading to gain loss or distortion of pattern. RISAT-1 active antenna was subjected to unique method of 'collimation coefficient error measurement' with a single near-field trace. These estimated error coefficients were applied to antenna by Gain/Phase shifters resulting near theoretical pattern. RISAT-1 Antenna pattern measurement for 126 beams with near-field scanning was estimated to take two years. Instead measurement was done for sample beam pointing of 24 beams while rest all patterns were interpolated with a custom developed software algorithm. On-Board antenna pattern measurement and image analysis has confirmed the validity of interpolation algorithm.

Although RISAT-1 antenna of 6mx2m is a single entity, integration and testing was done in three phases namely (i) Tile 1mx1m size with 24 T/R elements (ii) Panel 2mx2m (4-tiles) with 96 T/R elements and (iii) Full antenna 6mx2m (3-Panles) with 288 T/R elements. Software algorithms and hardware setup was validated by comparing results of antenna tile with standard compact antenna testing facility (CATF). Table-1 captures major specification of RISAT-1 Antenna.

TABLE I
ANTENNA SPECIFICATIONS OF RISAT-1 SATELLITE

Parameter	Specification
Polarization	HH, HV, VV, VH, HH+HV+VV+VH
Frequency	5.35GHz ± 112.5MHz (BW)
Antenna Type & Size	Multi layer micro strip Patch Array, 6m X 2m
No. of TR modules	288, each with 10 W peak power
Pulse width	20 µsec
Average DC Input Power	3.1 kW
T/R Module	288 T/R Modules (H & V)

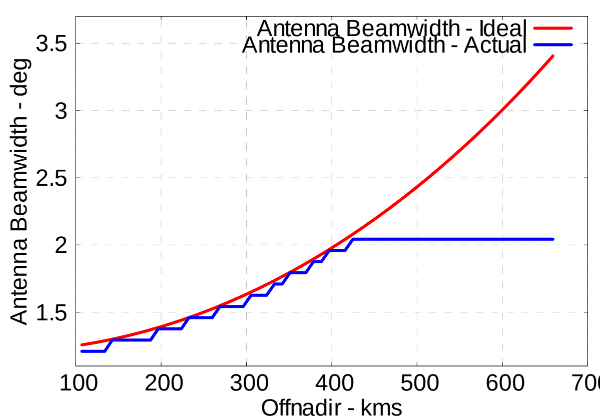

Fig.-2: In order to keep illumination swath constant across range swath, RISAT-1 Antenna beamwidth is being programically controlled w.r.t pointing by controlling antenna illumination along cross track. Figure shows variable beamwidth tracking required ideal beamwidth of antenna upto 420km swath, beyond that swath is controlled by return echo time.

RISAT-1 SAR Satellite being ISRO's first space borne radar with active array antenna demanded lot of new engineering techniques and technological development in Integration and Checkout, so that radar is characterized to its full performance in time effective manner. New techniques of testing which evolved during integration and testing are;

a) Pulsed Domain Antenna Testing.
b) Sleek and light weight PNF Antenna testing facility with customized in-house hardware and software development.
c) Equalized near-field holographic software algorithm development.
d) Customized Far-Field software development for customized PNF test facility.
e) Efficient technique for active array antenna collimation coefficient estimation, measurement and reverse correction.
f) In-House far-field antenna pattern estimation algorithm and software development.

As RISAT-1 antenna of 12m x 6m was developed in 12 parts of 1m x 1m each called antenna-tile (24 T/R Modules). Each tile was tested in sequence so that integration of next tile was time overlapped with the testing of previous one. This staggering of integration and testing operations was repeated for antenna Panels (3 No.'s) of 2m x 2m (96 T/R Modules). One antenna tile was also subjected to sun-simulation test to get confidence of thermal balance during operation.

II. PULSED DOMAIN ANTENNA MEASUREMENT CONCEPT

Majority of space borne Synthetic Aperture Radars existing in world are equipped with active array antenna operating in pulsed domain and so does RISAT-1 active phased array antenna. Requirement for the near field measurement is precise measurement and calibration of amplitude and phase front at a least distance of 10λ (λ is wavelength of operating frequency) and most distance of $2d^2/\lambda$ from the antenna aperture. Measurement of signal phase and amplitude is a critical process and classically Vector Network Analyzed (VNA) is used to perform these measurements. Antenna aperture data collected in 2D format is then synthesized to develop far-field pattern.

Fig.-3: RISAT-1 antenna test facility (Pulsed PNF) equipped with 3D scanning system. Left side image shows single antenna tile (24 TR elements) under test, whereas, right side image shows full antenna (288 TR elements) being scanned in Pulsed PNF

A new technique was developed which involves match-filtering and time-gating to eliminate unwanted reflections so that true antenna signal can be selected. Testing set-up requirement are two channel signal sampler of sufficient bandwidth, antenna input signal generator, Probe Antenna, 3D/2D Scanner and master timing Controller. Requirement of microwave absorbers is reduced by the use of FMCW pulsed signal as compression filter output response resolves the signal reflected from all the targets. Match filtering is a standard technique utilized in imaging radars for range compression.

III. Range compression and Time Gating

Match filter compression output for an FMCW (chirp) signal is a sinc pulse with a beam width of 1/Bw (Bw is the bandwidth of chirp). Match filter response of time delayed chirp is a shifted sinc function. Match filter response for multiple chirp signals with different time delays is compressed in time domain showing separate compression response as per individual time delay of original chirp although time domain signal seems to be random in nature

Near-Field Measurement { $A(\theta,\phi)$,eq(1)} can be simplified by the use of pulsed FMCW (Chirp) where match filter compression technique in time domain can be used to detect return signals from AUT. Match filtering of FMCW signal is a time domain correlation process which compresses the signal in time domain to a sinc function.

$x(t)$ - Input FMCW Signal to the AUT

$$x(t) = A_1 e^{-j(2\pi fct + \pi Kt^2)} \quad (1)$$

A_1 -Amplitude of signal

fc - Carrier Frequency (centre frequency)

K - Chirp Rate (Bandwidth/Time)

$y(t)$ - signal reaching to the probe after time delay (td_x) corresponding to path distance between antenna and probe.

$$y(t) = A_x.e^{-j\left(2\pi fc(t-tdx)+\pi K(t-tdx)^2\right)} \quad (2)$$

Cross-correlating of eq(1) and eq(2) in time domain for total pulse width equal of ‘T’ seconds,

$$z(t) \cong c.\int_{x=0}^{n-1} sinc(\pi K(t-td_x)T).dx \quad (3)$$

Time delayed reflections which are the returns from various unwanted targets in the close vicinity of AUT are compressed at different time bins corresponding to the real time delay between the signals. This is evident from eq(3), where time delayed chirp signals compress at different time bins after match filtering with reference function. Returns from different targets can be separated out in time domain if the physical distance of the targets are known. This concept can be utilized to pickup returns corresponding to AUT and rejecting the returns from background targets.

This concept is same as SAR processing where targets are resolved by pulse compression (match filtering) in azimuth and elevation. Eq(3) shows sum response of multiple chirp pulses delayed in time according to different target distances. RISAT-1 antenna testing procedure can be summarized as,

1) Antenna is excited by a chirped/FMCW signal. For radar systems the baseband system of Radar itself can be used to excite AUT.
2) Both the above mentioned received signal (AUT and Reference signals) are sampled/recorded simultaneously in the recording devices like High Bandwidth Digital Storage Oscilloscopes (DSO)
3) Cross-correlation of received signal with reference Chirp/FMCW signal is done with the help of a computer program. Returns from antenna and unwanted signals are separated in time.
4) For each of the raster scan position antenna response (amplitude and phase) is separated out and stored in a file as raw data of antenna near-field response.
5) Hologram of antenna is evaluated by back projecting raw data to antenna aperture plane.
6) Derived hologram is projected in far field for obtaining the final antenna pattern.

This method of antenna pattern evaluation basically pertains to modification in conventional near-field measurement systems with CW measurement techniques. Present method has an advantage of evaluating antenna response for full operational bandwidth of antenna.

IV. Absolute & relative calibration of PNF

RISAT-1 PNF antenna test facility carries custom built hardware for scanning and software for control, data capture, pre-processing and post processing. Although radar hardware was used as receiver data processing involves lot mathematical transformation and computation. Calibration of this facility was carried out in two phases namely,

A. *Relative Calibration*

Single passive antenna tile (without TR elements) was tested for far-field measurement in a standard CATF facility and custom PNF facility. Although concept of measurement is different for both the facilities results showed very good matching upto 5th sidelobe. This proved far-field transformation algorithm has been correctly implemented in custom PNF facility. Results captured in table-2 shows comparison of 1st sidelobe. There is a close match for peak sidelobe and beamwidth. ISLR and gain could not be compared as CATF facility has limited scan beyond second sidelobe and for PNF facility in general absolute gain measurement carries errors.

TABLE 2

1st Sidelobe level (decibel) for H-pol

Facility	Azimuth		Elevation	
	Left	Right	Left	Right
CATF	-13.60	-13.90	-11.30	-16.20
RISAT PNF	-13.70	-14.07	-11.91	-16.17

B. *Absolute Calibration*

RISAT-1 antenna tile was masked with an absorbing material (Embedded *RISAT*) made according to exact dimensions w..r.t operating wavelength. Evaluation of mask image in terms of deformation and orientation proved angular transformation and lateral resolution of the processing algorithm. Fig.-4 shows results of absolute calibration

V. Antenna testing & Validation in pulsed PNF

Near Field Antenna Measurement Setup based on Pulsed

Domain Measurement concept for RISAT-1 Active Array Antenna consists of a 3D-Scanner, Hardware Motion

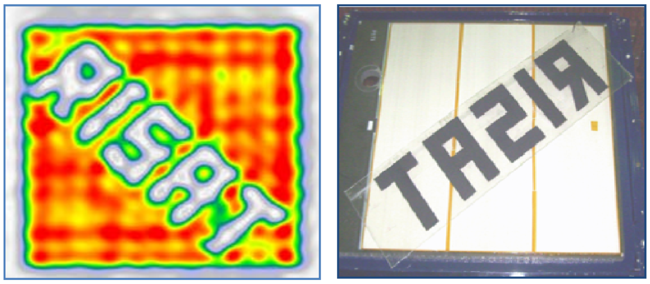

Fig.-4: RISAT-1 active array antenna single tile carrying 24 TR elements showing absorber mask on the left side image and resolved near-field hologram for the same on right side image.

Controller and antenna fixture/holding mechanism. As hardware setup of this newly built facility is similar to general PNF facility; difference remains in the measurement principle as mentioned earlier involving Pulse Compression and Time Gating of Signal.

Near-field antenna pattern measurement for RISAT-1 Antenna was done in three phases which involved development and testing of (a) Twelve 1mx1m antenna tiles (24 TR elements each) (b) Three 2mx2m antenna panels (96 TR elements each) and (c) Full antenna 6mx2m (288 TR elements). In-order to gain confidence of integration and measurement experiments were done on a 'discrete verification model (DVM)' of one antenna tile (1mx1m) and thermal balance test (inside sun simulation facility) was done on an engineering model of antenna tile.

Radar operating mode of CRS which generates 12-sequential antenna beams for wide swath operation was utilized to test antenna near-field for 12-pointings simultaneously. Although RISAT-1 radar is a monostatic radar active array elements for transmit and receive signal are separately operated which makes antenna non-reciprocal. Non-reciprocal nature of RISAT-1 antenna demanded separate measurement of transmit and receive beams.

VI. Antenna Pattern Synthesis/ Interpolation

Near-Field scan pattern measurement was done for 48 beams only (out of 126 beams) while rest of the patterns were generated synthetically with a software algorithm. Synthesized patterns were generated from zero-degree pointing and compared with practically measured patterns on sample basis.

TABLE 3
Typical results of RISAT-1 Antenna

Measured Scan Angle El x Az (deg)	Measured Beam Width El x Az (deg)	Worst Sidelobe Az (dB)	Worst Sidelobe EL (dB)
-13.05 X -0.04	1.44 X 0.48	-11.72	-12.59
-5.38 X -0.01	1.41 X 0.45	-11.87	-13.02
9.48 X -0.04	2.07 X 0.48	-11.74	-11.88
20.07 X -0.04	2.43 X 0.48	-11.59	-11.62
24.54 X -0.04	2.73 X 0.48	-11.35	-11.52

Table-3 shows typical results of Transmit-H pattern of 6mX2m antenna. Results show a close match of pointing with errors in 1/200th part. Elevation and Azimuth pointing error contains mechanical alignment error as major contributor and computational error as minor part. Scan loss contains antenna aperture illumination (electrical width change to keep ground swath same) as major contributor and antenna patch pattern convolution as minor contributor.

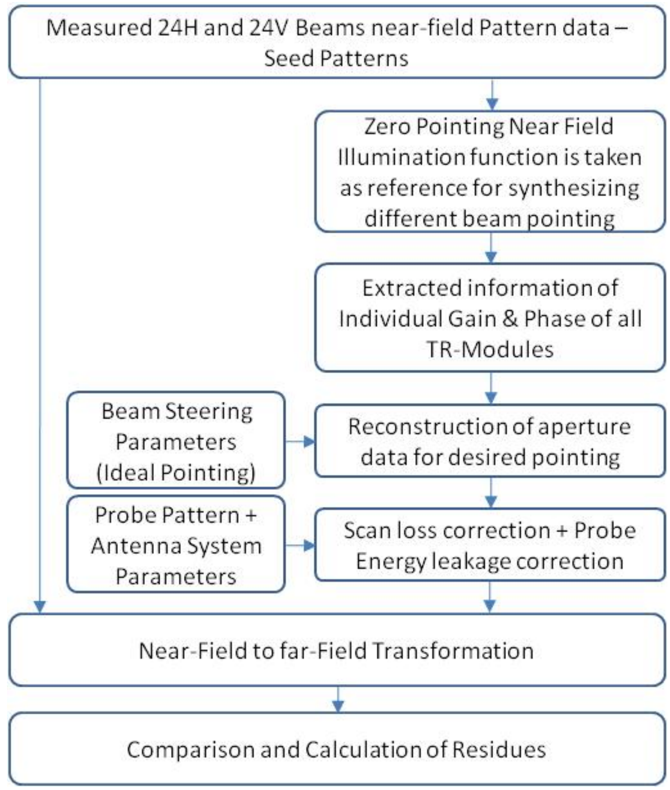

Fig.-5: Antenna pattern synthesis flow in which Zero-pointing illumination function is taken as reference/seed pattern to synthesize all patterns using Beam-Steering parameters and probe pattern to compensate for scan-loss.

In the beam synthesis approach near-filed data for bore sight pointing (uniform phase aperture antenna pointing or zero-pointing) has been taken as reference illumination function to synthesize all antenna pointing patterns. Fig-5 shows pointing synthesis flow diagram which was applied to RISAT-1 antenna pattern synthesis. Zero-pointing near-filed data is used as seed pattern to extract (best estimate) phase and gain of each 288 T/R modules.

Baseband signal passes through radar digital chain which does data encoding and recording. Digital encoded data needs pre-processing to decode original data and Pulse compression (match filter) to perform time gating to evaluate Gain/Phase characteristics from the pulsed LFM (Chirp) signal. Post processing of data involved holographic back-projection, filtering and weighting. Reciprocity of active array antenna having power amplifier in transmit path and low noise amplifier in the receive path is not always guaranteed because of hardware mismatch between the two paths. Reciprocity of the patterns can be achieved by calibrating the antenna array elements for transmit and receive paths with the same electrical/mechanical reference. Power comparison of Transmit and Receive patterns across different beam pointing angles yields the true characteristics of a power balanced antenna. Maximum power of non-normalized Far-Field (computed far-field) for zero pointing angle in Transmit has been taken here as reference for normalizing power for each swath angle. Maximum angular mismatch measured for RISAT-1 antenna tile is 8% of total beam width.

Measurement of Co-Polarization and Cross Polarization components is an indication of polarization purity of the signal generated by the antenna. Polarization isolation measured is of the order of -18dB which is meeting the specifications of RISAT-1 antenna.

VII. ON-BOARD ANTENNA PATTERN VALIDATION

Using standard calibrated receiver on-ground antenna azimuth transmit pattern can be measured by orienting fixed horn antenna orthogonal to the flight-track. Ground receiver is oriented towards the boresight direction of onboard antenna and along track cut of 2D antenna radiation pattern is captured. Ground receiver is placed at the beam centre of the transmitting beam and Azimuth and Elevation direction of the receiving

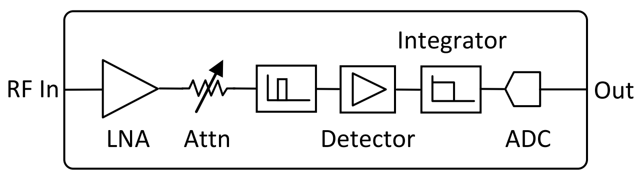

Fig.-6: Block diagram of RISAT-1 antenna pattern measurement setup. Variable attenuator is used to bring down hardware dynamic range requirements due to orbital range variation in different satellite passes and beam pointing.

horn is oriented such that it is in line of sight with the RISAT-1 onboard antenna. Ground receivers dynamic range is decided such that atleast ±2 sidelobe of the azimuth pattern can be detected. This system is designed for C-band operation with a frequency of 5.35 GHz and a bandwidth of 225MHz. It consists

TABLE 4
ANTENNA PATTERN MEASUREMENT SETUP

Parameter	Specification
Peak Input RF Power	-29 dBm
Sensitivity	- 78 dBm
Dynamic Range	49 dB
Digitizer	16 bit
Sampling Rate	4 KHz
Accuracy	±0.5 dB
Raw Bus Supply	+12V to +15V
Power Consumption	24 Watt

of two cascaded amplifier followed by a band pass filter (5.35 GHz ± 300 MHz). A 16dB directional coupler is used at the output of filter. Detector is fed by the main path of the coupler. Received signal power is detected by the detector and is averaged out by the integrator. Received RF signal can be captured by scope through a coupler. One thermistor is placed on each of the amplifier to get the real time temperature of the amplifier for temperature correction. System parameters of antenna pattern measurement setup are summarized in table-4.

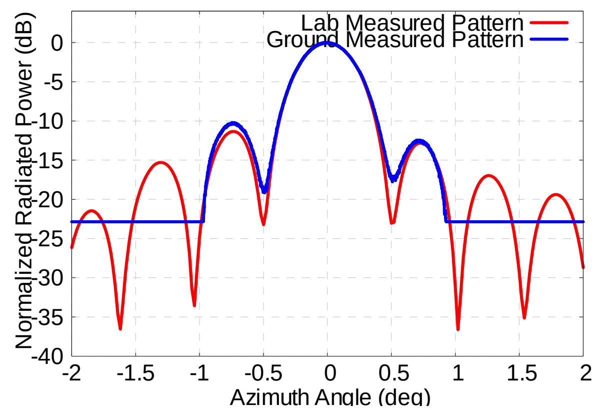

Fig.-7: Comparison of measured Azimuth Antenna Pattern during testing in Lab and after launch ground measurement with a customized measurement setup. Results show a reasonable match upto first sidelobe.

VIII. CONCLUSION

This paper has presented an insight view of RISAT-1 active array antenna development, testing and calibration with a customized planer near-field facility operating in pulsed domain. Realization of RISAT-1 antenna is a first ever attempt of ISRO to develop an active array antenna based radar for space use. Pulsed domain antenna testing ensures measurement of antenna pattern over full bandwidth of operation while using radar hardware as transmitter and receiver for near-field measurement. This type of antenna testing results in cheaper antenna testing and eliminates need of anechoic chamber by using time gating technique to eliminate unwanted reflections. Pattern synthesis of 102H and 102V beams was done to an accuracy of 10% of actual beam pointing which was validated by ground measurement and comparison with reference pattern data. Techniques mentioned in the paper ensured cost effective and time optimized measurement and validation of RISAT-1 active array antenna.

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Dilip B Dave received his diploma in electronics and sound engineering in 1976. He joined Indian Space Research Organisation(ISRO) Ahmadabad in 1976. He has been associated with the development and testing of Airborne SAR systems, X-band real aperture side looking radar (SLAR), microwave components for first Indian communication transponder for APPLE programme and spaceborne multi-frequency radiometer for oceansat-I programme. He was lead engineer for ISRO-CNES joint development of MADRAS instrument for Megha-tropiques, RISAT-1 and C-band Airborne SAR. He is currently working for the development of Chandrayaan-II L/S band SAR and millimeter wave passive temperature sounder. His research interests include microwave remote sensing, radar calibration and System T&E.

Partha Sarathi Nandy was born in Kolkata, West Bengal, India in 1984. He received his Bachelor's and Master's degree in Electronics and Communication Engineering from Burdwan University, Burdwan, West Bengal in 2005 and 2007 respectively. He joined Space Applications Centre (ISRO)-Ahmedabad in 2008. Since 2008, he has been associated with System Configuration, Integration, Validation and Characterization of Active Array Antenna of RISAT-1 SAR Payload, System design and configuration of X-band MiniSAR and X-Band SAR. His specific contribution includes (i) RISAT-1 SAR Antenna Pattern Synthesization (ii) RISAT-1 SAR Antenna Analysis for different Error condition like deployment error, Tile Bow Error etc. (iii) RISAT-1 SAR Failure Mode Analysis (iv) RISAT-1 SAR On-board Mission Operation Sequence Generation (vi) RISAT-1 SAR Calibration Activities (v) Concept validation and generating requirement of True Time Delay for RISAT-3 SAR development (vi) X-band MiniSAR and Active SAR System Design and analysis. He is an member of Astronautical Society of India (ASI). His research interests include Signal Analysis, Antenna design and analysis.