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Autonomous Characterization of NISAR S-Band SAR Primary Antenna

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Abstract

NISAR, NASA, ISRO Synthetic Aperture Radar is an earth science project currently in its final development phase at JPL and at ISRO [1][5]. It will assess how our planet changes overtime by measuring differences in the Earth's solid surface due to factors like climate change, movement of glaciers, earthquakes, land-slides, deforestation, agriculture and others. The major instrument for this mission is dual band radar that feeds a 12m deployable mesh reflector.

In this paper, transmit and receive characterization of S-band Synthetic Aperture Radar (SAR) primary feed array antenna using an automated test setup consisting of 1-D portable scanner is presented. Using the automation set up along with Near field antenna testing facility (NFTF), we have established a methodology to balance the phase of 48 (24H and 24V) Transmit Receive Integrated Modules (TRiMs) in transmit to achieve the desired collimation of beams on secondary parabolic reflector antenna and balancing of receive phase & gain for (Digital Beamforming) DBF [2] in receive chain. The paper also focuses on estimation of phase coefficient for formation of circular pol (LHCP/RHCP) in transmission and validation of the same using axial ratio measurement and LHCP/RHCP conformity test. The salient feature of this automation is to reduce the testing turnaround time with very limited human intervention.

Keywords—SAR, NFTF, TRMs, Axial Ratio, Scanner, LHCP, RHCP

1. Introduction

NISAR is a collaboration between ISRO and NASA with ISRO developing the S-Band radar and JPL developing L-Band radar. The S-band primary feed antenna is an array of 24 dual-polarized (horizontal & vertical) elements, designed with an aim to attain the SweepSAR configuration in combination with secondary reflector antenna. During Transmit event, all the 48 TRiMs will radiate simultaneously, thereby resulting in aperture illumination on the reflector, which is narrow in the elevation direction but full 12m in the azimuth. The small aperture on the reflector antenna is achieved by the in-phase addition of all 24 TRiMs beams which then images a large footprint on ground to get a wide swath (~240km) [2]. During Receive event each TRiM is activated one at a time thereby maximizing the receive aperture to full 12m diameter which results in higher gain of ground return signal. Since the location of patches is linearly distributed in the elevation direction, the 24 TRMs (Dual Pol) will result in 24 individuals receive beams spanning the entire wide swath. Figure-1 shows the sketch of NISAR instrument with all its major components.

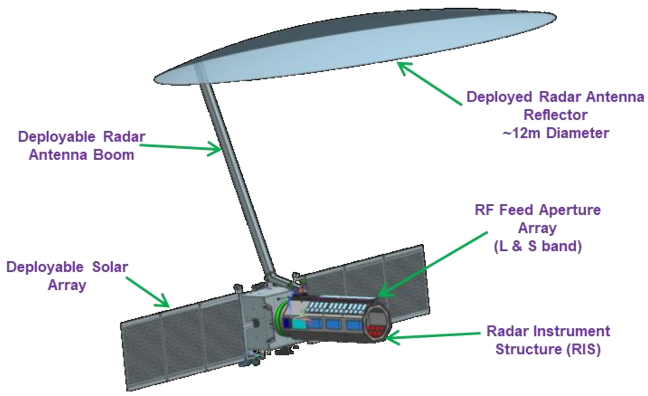

Figure 1 View of the deployed NISAR Instrument.

For S-FRAp transmit and receive beam characterization, following important aspects has been considered,

1. Transmit and receive patterns are not reciprocal.
2. The antenna pattern measurement of the complete active antenna is to be handled in the clean room environment as it contains space qualified RF microwave and control hardware also and in a near field test facility to fulfil the far-field conditions.
3. The antenna pattern in transmit and receive mode is to be measured with synchronized pulsed operation of SAR payload.

In this paper, the test setup and methodology for S-FRAp Tx & Rx characterization is presented. The paper is organized as follows: In Section 2 automated setup configuration is discussed in detail, which helped in eliminating errors due to human intervention while carrying out such sensitive tests. In Section 3 the details of S-FRAp characterization in both Transmit and Receive mode are provided. Further, post phase and gain balancing, the methodology to measure the axial ratio followed by the LHCP/RHCP conformity test is discussed. Section 4 summarizes the conclusion and the results.

2. Automation Test Set-Up

With the continuous update and development of radar technology, portability and real time requirements of radar testing equipment is becoming more and more intense. For S-FRAp characterization a new portable Near Field Antenna Test Facility (NFTF) has been installed which was able to perform single direction (1D) scan and can be easily dismantled and reinstalled to support the S-FRAp pattern integrity measurements at various stages of testing in SAC, ISRO and at JPL, NASA.Figure-2 shows the portable NFTF installed in cleanroom. The linear displacement of test probe mounted on the scanner can be commandable with a finest step size of 0.1mm and gives a total scan length of 4m along the S-FRAp direction which fulfilled our requirements.

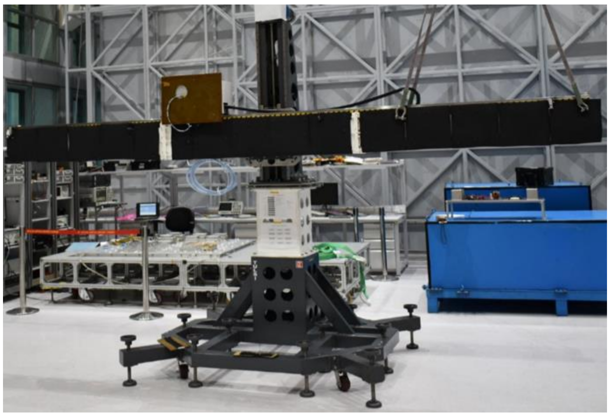

Figure 2 Near Field Antenna Test Facility Installed in Cleanroom.

The 1-D scanner controller comes with a feature of "Interrupt" based programming. For automation of testing, this feature has been extensively used to create an "interrupt-mechanism" based on LabVIEW. As shown in the Figure-3 the automated process begins by positioning the test probe mounted on scanner at starting position of 1-D scan. Once the position is acquired scanner will send signal to payload controller to config the system in Tx/Rx mode operation via LabVIEW software. The data will then be recorded and once it gets over, the LabVIEW software sends an interrupt to scanner controller via digital I/O interface. Controller software then directs the test probe to move to next desired position. The process continues until the last scanner position.

Figure 3 Automated Test Set-Up Events Flow Diagram

The automated characterization has been used for S-FRAp Transmit Phase balancing, Receive Phase & Gain Balancing, Axial Ratio computation and RHCP/LHCP conformity tests. Manual operation of this whole process would be more tedious, prone-to-error, cumbersome and time intensive.

3. S-FRAp Characterization

S-FRAp transmit and receive beam characterization has been carried out in Planar near field antenna test facility which can perform single direction(1D) scan. For planar near filed measurements [3],[4] a spatial sampling step of better than $\lambda/2$ is required. Considering this requirement, the total scan area of approx. 4m x 2m can be sampled with minimum step of 4.5cm with a margin of 1m at both ends . The test probe was kept away at a distance of >10 λ from the S-FRAp. The configuration setup of payload during transmit and receive mode characterization is shown in Figure-4.The same antenna will be used both in transmit and receive, a discrete feeding network made of coaxial phase-matched cables and power dividers was used to simulate the proper phasing of the array in Tx mode.

Figure 4 S-FRAp Characterization setup in cleanroom

3.1 Transmit Phase Balancing

For Transmit case the DA & MGC of all the TRiMs were already in preset condition to keep them in saturation state, thus the gain balancing was not needed. During transmit phase balancing, for each scanner position as shown in Figure-4, the radiated RF signal from S-FRAp gets captured

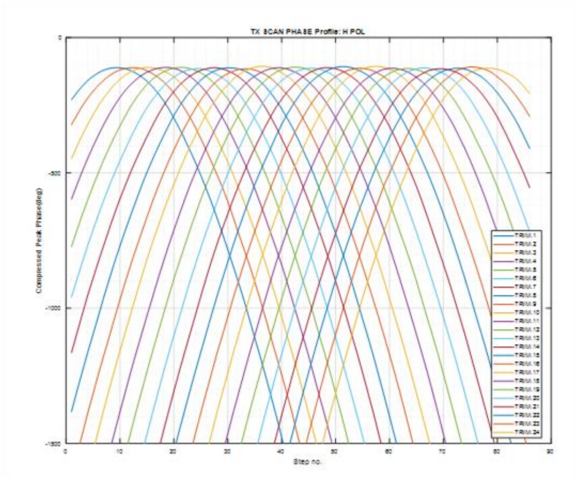

Figure 5 Transmit Balanced Phase profile for H-Pol TRiMs along the S-FRAp.

at test probe and fed back to payload via coupled port. The probe then advances to next step position automatically and gives feedback to the recorder for next data acquisition. The sequence will repeat for approx. 90 steps along the scanner length to cover the complete S-FRAp. During processing the recorded signal for each scanner position is time correlated with the Tx replica signal to obtain the compressed signal. Subsequently, the peak amplitude and phase were computed by using a linear interpolation technique. After getting the raw phase values at first iteration, the correction coefficients have been given to align the phase for all TRMs. The balanced phase profile for H-Pol TRiMs along the scanner length is shown in Figure-5. As shown in the Figure-6 for balanced phase, the finest resolution in the order of ±1 LSB of DPS have been achieved by carrying out multiple scans and computing the arithmetic mean of correction coefficient for all those scans.

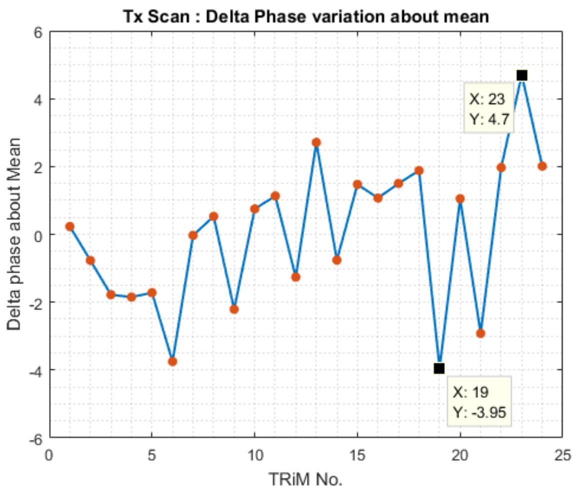

Figure 6 Transmit Phase Variation about mean across H-Pol TRiMs post phase balancing.

3.2 Receive Gain and Phase Balancing

In Receive mode both gain and phase were balanced for all 48 TRiMs to maintain the uniformity for a particular ground target. The same automated setup as the Tx-balance was used, except for payload operation mode & the signal flow. Also, to have a coherent phase addition of Rx channels for-N-point DBF, their phase and gains must be aligned. In this test a time synced LFM signal from payload was transmitted through the test probe and received eventually by S-FRAp. The time delayed signal gets recorded in the payload for each TRiM along the S-FRAp at various position of test probe. The recorded signal was processed and the delta variations of compressed peak phase post balancing is shown in Figure-7. Similarly, the Rx-MGC were adjusted post scanning and the delta variation about mean is plotted in Figure-8. The results obtained were in compliance with the specifications.

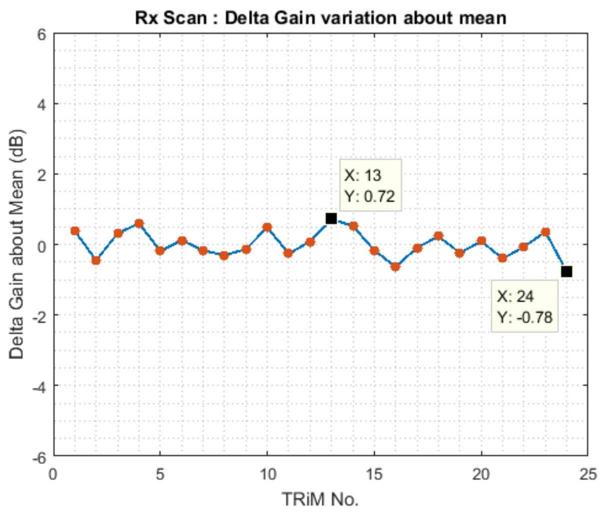

Figure 7 Receive Gain variation about mean for H-pol TRiMs post gain balancing.

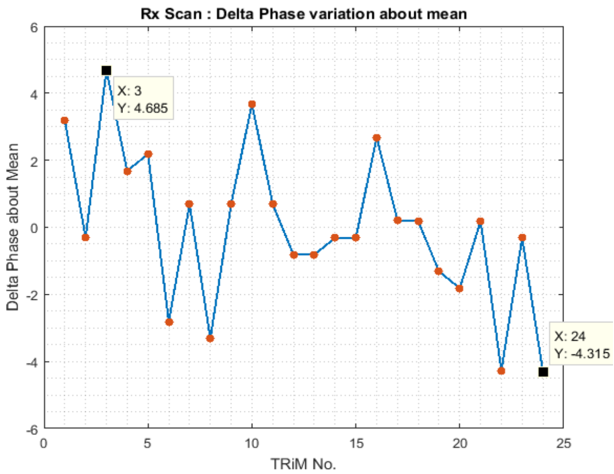

Figure 8 Receive phase variation about mean for H-pol TRiMs post phase balancing.

3.3 Axial Ratio Measurement

Axial Ratio (AR) represents the orthogonality of an E-Field. It provides a confirmation of the formation of circular pol in transmit chain. Subsequent to individual phase balancing of H and V pol feed array, digital phase shifter of TRMs were programmed to attain a phase shift of 90 deg between H and V Pol. In order to validate the phase balancing and phase shifter input calculations, axial ratio measurement of individual pair of H and V was carried out using the test setup shown in Figure-9 below.

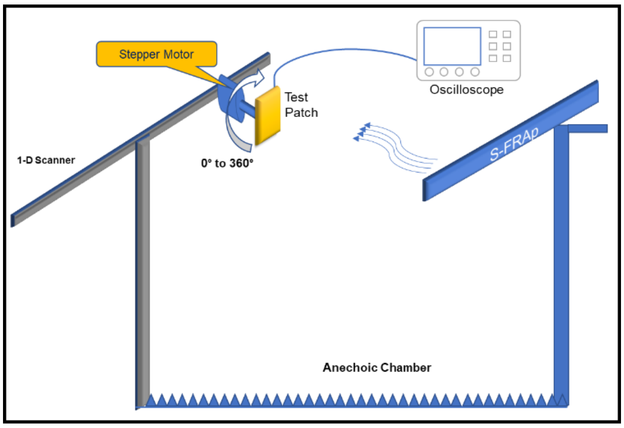

Figure 9 Axial ratio test setup block diagram.

The test setup includes a stepper motor for angular rotation of test probe, 1-D scanner and a scope to capture the received RF signal output from S-FRAp. The stepper motor's angular rotation & test probe's linear displacement along the scanner is an automated embedded system which is controlled via LabVIEW environment. The software control aided in avoiding measurement errors while probe rotation or its movement.

During the test, a single pair of H and V patch from S-FRAp are excited to form a compact polarized field and receive power from test probe at an angular resolution of 5 degree gets captured on scope. Signal processing to compute the axial ratio involved demodulation, pulse compression and subsequent detection of maximum amplitude with respect to probe angular position data. The compressed peak power v/s test probe angular rotation for various TRiMs is shown in Figure-10.

The computation of axial ratio from data is done using following formula:

$$Axial\ Ratio \ = \ P_{max} / \ P_{min}.$$

The ideal value of AR for circularly polarized fields is 1 or 0 dB and this tends to degrade away from the main beam of an antenna, limiting the practical acceptance values to less than 3 dB.

The axial ratio of 24 TRMs pairs varies from 0.3 dB to 1.7 dB which is in compliance with specification of 3dB.

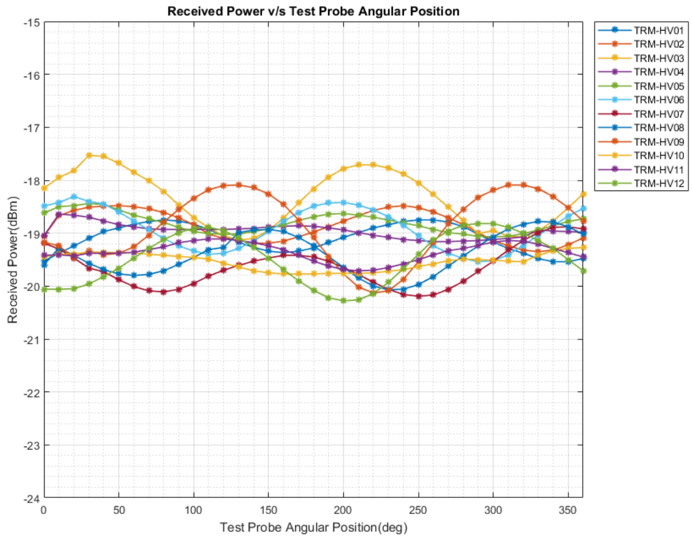

Figure 10 Received Power captured at scope for various TRiMs at different angular positions.

- Integrated Axial Ratio Calculation

Derivation of integrated axial ratio at S-FRAp level shown in Figure-11 and can be done using following equations. It basically utilizes the principle of superposition while calculation of power contributed by each pair of patch feed at a particular angular position.

$$P_{total}(\theta) = \sum_{TR=1}^{TR=24} P_{comp\_power}(\theta) \qquad (1)$$

Where θ : $Probe\ rotation\ angle$

$P_{comp\_power}(\theta)$: *Pulse compressed power at angle* θ

$P_{total}(\theta)$: *Sum of individual TRiMs pulse compressed peak power at angle* θ .

$$AR = \frac{\max\left(P_{total}(\theta)_{\theta=0°,10°,20°...360°}\right)}{\min\left(P_{total}(\theta)_{\theta=0°,10°,20°...360°}\right)} \qquad (2)$$

$$AR_{dB} = 10 * log10(AR) \qquad (3)$$

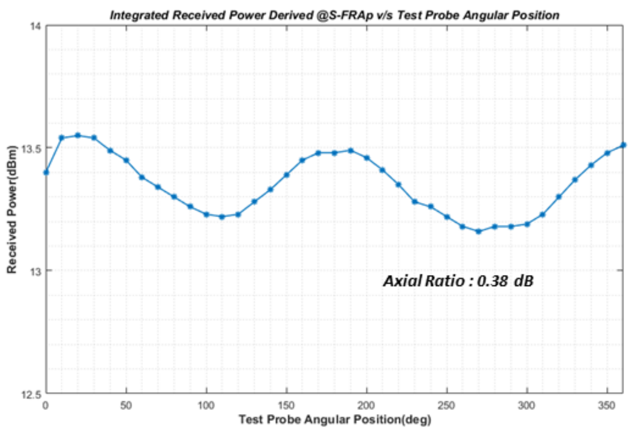

Figure 11 Integrated derived received power at S-FRAp v/s test probe angular positions.

3.4 LHCP/RHCP Conformity Test

Further to the computation of axial ratio with the desired phase settings for circular polarization, conformity test for Right-Hand Circular polarization (RHCP) or Left-Hand Circular Polarization (LHCP) is carried out. For this, LHCP and RHCP test patches are placed in front of S-FRAp. One pair of TRiMs are commanded in circular polarization radiative mode and the received signal is captured in scope for both LHCP and RHCP test probe, one at a time. The received RF signal at scope is captured at a high sampling rate as shown in Figure-12.

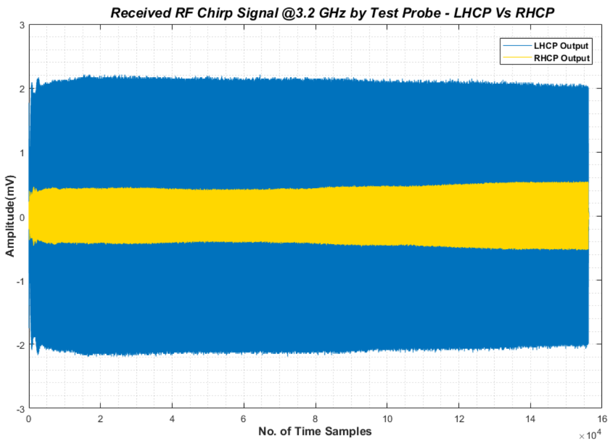

Figure 12 Received RF signal at Scope for LHCP & RHCP test probes.

From the received signal amplitude data one can easily interpret that the configured coefficients orient the output beam of S-FRAp as LHCP and it is as per the estimation. The same test is repeated by adjusting the phase coefficients for RHCP and the data has been validated.

4. Conclusion & Result

S-band primary feed antenna characterization was completed successfully with the help of automated test set-up, with reduced testing time. Also, it ensured lower probability of error as minimum human intervention was involved. S-SAR primary antenna lab characterization results and their compliance with specifications are summarized in the below table. The results provide a good confidence of the payload performance and the lab characterization results will be correlated with the in-orbit performance after launch.

S. No	Parameter	Specification	Measured
1	Transmit Phase	≤ ± 5.625°	≤ ± 4.7°
2	Receive Phase	≤ ± 5.625°	≤ ± 4.6°
3	Receive Gain	< ± 1 dB	± 0.5 dB
4	Axial Ratio	< 3 dB	0.3-1.7 dB

5. References

1. P.A. Rosen S. Hensley S. Shaffer L. Veilleux M. Chakraborty T. Misra et al. "The NASA-ISRO SAR mission - An international space partnership for science and societal benefit" Radar Conference (RadarCon) 2015 IEEE pp. 1610-1613 10–15 May 2015
2. A. Freeman G. Krieger P. Rosen M. Younis W. Johnson S. Huber et al. "SweepSAR: Beam-forming on receive using a reflector-phased array feed combination for spaceborne SAR" Proc. Radar Conference 2009.
3. Slater, D., 1991. Near-Field antenna measurements. Artech House
4. Slater, D., 1985. Near-field test facility design. In Antenna Measurement Techniques Association Conference (Vol. 6, pp. 769-773).
5. Paul A. Rosen, & Raj Kumar “NASA-ISRO SAR (NISAR) Mission Status” 2021 IEEE Radar Conference (RadarConf21).