URSI - RCRS 2022, IIT (Indore), India, 1 - 4 December, 2022

Design and Characterization of a Multiband Polarimetric Active Radar Calibrator at L, S, C and X Band

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Abstract

With recent developments of SAR sensors in multiple frequency bands by different space agencies, their accurate calibration is becoming equally important before SAR data can be applied to generate final application product. Active and passive radar calibrators are often used in conjunction with airborne and spaceborne Polarimetric SAR acting as ground based calibration targets with specified RCS. ARC's provide a clear advantage against their Passive counterpart in the fact that their Scattering matrix can be accurately known by design and also for the same RCS it is much smaller than a Corner Reflector. This paper describes the design and Characterization of a Wideband Active Radar calibrator, which can operate in the L, S, C and X bands. Laboratory and field measurements are performed to characterize the performance of the developed ARC for establishing its RCS stability, settability and dynamic range, as well as to evaluate its integrated impulse response. Characterization methodology for lab testing of ARC in Full Polarization mode is also presented. This development has been tested in calibration campaigns for ISRO's EOS-04 SAR and later will be used for calibration of NISAR etc.

Keywords: ARC, SAR Calibration, Radar Cross Section (RCS), APMS.

1. Introduction

In current remote sensing scenario, as microwave imaging techniques have taken a quantum leap to provide sub meter resolution imaging for variety of applications, a large number of SAR sensor capable of operating from L – Band to X – Band are developed. Multi-polarization synthetic aperture radar data requires proper calibration of the images to extract accurate information contained in the polarimetric characteristics of the illuminated pixel. Improper calibration will lead to misinterpretation of the scattering mechanisms for the targets and the incorrect understanding of the targets. For quantitative application of this SAR data, external calibration is required [1-3].

There are many methods for polarimetric calibration. For passive calibration targets viz. dihedrals, triangular and square trihedral, etc., their radar cross section (RCS) is a function of their physical size. This necessitates development of a whole new target for every different RCS or polarizations or frequency requirement [3-5] which is a major snag in their versatile applicability and increases the calibration cost. In addition, due to sensitivity to misalignment accuracy, it is difficult to utilize passive calibrator viz. rotated dihedral corner reflectors for polarimetric calibration.

Active Radar Calibrators (ARC) play an important role in this task due to its tunable radar cross section (RCS) and polarimetric calibration capability that too in a single system with a small form factor. The Wideband Polarimetric ARC development presented in this paper is a further attempt to make it even frequency independent, which means a single solution can cater to all calibration requirements of SAR sensors at all frequencies (L, S, C & X band) with different polarization and resolution capabilities. The idea was first proposed in [6] and a design with slightly different frequencies given in [7]. This paper presents the design of a Wideband Polarimetric ARC system for RCS ranging from 10 dB-m^2 to 45 dB-m^2 with stability of ±0.2 dB for calibration of SAR sensors in linear, dual, cross and full polarization modes. A multiband RF design methodology has been adapted to make it frequency adaptive [6].

This paper is organized as follows: Section 2 provides design details of broadband ARC system, section 3 provides the RCS measurement methodology and results and section 4 concludes this paper.

2. System Design Methodology and Specifications for Broadband ARC

As per recent trends, host of SAR applications and sensors are being developed in L, S, C and X frequency bands. The proposed ARC system caters to all of the above-mentioned frequency bands. A summary of ARC specifications is given in Table – 1 and block diagram shown in figure 1. As shown in system block diagram, two-antenna topology consisting of multiband, dual Polarized patch antennas capable of operating at L, S, C and X band is chosen for system development. The received signal from Rx antenna is fed to a wideband receiver subsystem, which is then amplified and fed to the Tx antenna. Antennas are designed to provide wide beam width (> 30 deg.) so that the alignment errors between ARC and satellite will have minimum error contributions in RCS calibration.

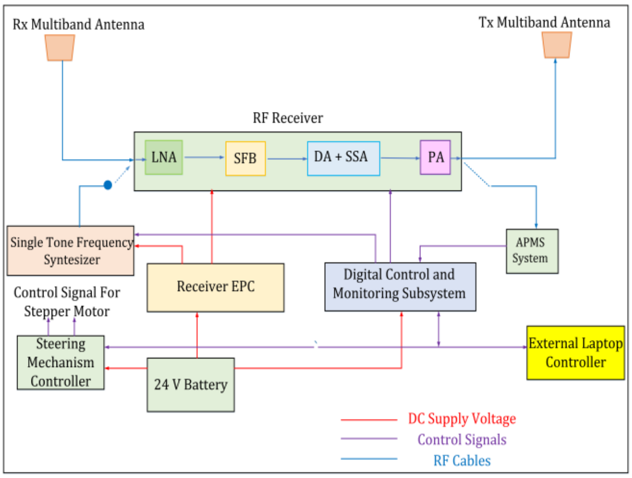

Figure 1: Block Diagram of Broadband ARC system.

The loop gain of receiver subsystem which in turn dictates the RCS, is set using digital attenuators (DA) which is commanded by Digital control and monitoring mechanism. Switchable Filter Bank (SFB) is used to select desired frequency band for ARC operation and provide isolation for other bands. The separation between antennas is chosen so as to have sufficient isolation between Tx/Rx antenna to avoid formation of a feedback loop. The component selection for receiver design ensures minimum gain drift with temperature and the residual drift is post facto compensated using knowledge of over temperature gain characterization of the system. This makes use of thermistor outputs for real-time measurement of receiver temperature.

The system has motorized control for precise and easier pointing of ARC antennas and thus can be aligned to any required azimuth and elevation angle as per calibration requirements. Antennas can be aligned to H or V polarization plane to produce HH/VV/X-Pol. component. The antenna can be rotated 45 deg. in the plane perpendicular to the direction of incidence so that the scattering matrix of the Polarimetric ARC(PARC) with respect to the SAR coordinates has equal entries that enable radiometric calibration of all four channels simultaneously[8].

Beacon and APMS Operation Modes

ARC system can be programmed to operate in beacon mode in which a single tone signal (of programmable frequency) is fed to Rx Amplifier input and amplified output is fed to Transmit antenna. This mode can be used to measured receive mode antenna pattern of SAR system.

The system also has an Azimuth Pattern Measurement System (APMS) mode to measure the Azimuth transmit antenna pattern of the SAR under calibration. This is implemented by connecting the coupled port of the receiver to an envelope detector system. The output of this envelope detector is then sampled by a digitizer and stored for further processing to derive SAR Azimuth antenna pattern.

Operations of all the subsystems of ARC are monitored and controlled by a digital control subsystem which is remotely controllable from Laptop using USB/LAN interface.

Figure 2: ARC deployed for field-testing.

Table 1: System Specifications of Broadband ARC.

Design Parameter	Specifications
Frequency Band	L Band: 1.25 GHz ± 50 MHz S Band: 3.20 GHz ± 50 MHz C Band: 5.40 GHz ± 125 MHz X Band: 9.60 GHz ± 375 MHz
RCS Range	10 – 45 db-m^2 in steps of 2 dB
Polarization	HH, VV, HV, VH, HH + HV, VV + VH, Full Pol., Circular Pol.
Mechanical Mount	Motorized steerable structure with steering steps of 0.5 deg.
Elevation Angle Range	0 – 90 deg.
Azimuth Angle Range	0 to ± 180 deg.
RCS Stability	± 0.2 dB
Operating Temperature Range	-20 deg. to 50 deg.

3. Lab Characterization Methodology and Results

Each ARC subsystem has gone through rigorous subsystem level testing before final system integration. Major subsystem level tests included antenna pattern and gain characterization, receiver dynamic range, gain stability testing and thermal cycling. Post subsystem level characterization, to assess the complex RCS of integrated ARC system; we have modified the RCS measurement setup as proposed in [2, 4, 5, 7] using

four port VNA and two standard dual polarized horn antennas. The block diagram of measurement setup is shown in figure 2.
Here a four port network analyzer is used as RF source and receiver. To emulate the full polarization mode functionality similar to SAR imaging the four ports of VNA are connected to two dual polarized horn antennas H and V ports. Mechanical H and V axis of standard gain horn antenna are aligned with ARC system H and V axis, also both ARC and test setup are aligned such that their antenna boresight axis are in line with each other. The ARC is kept at sufficient distance from horn antennas such that the both ARC and measurement setup are in far field w.r.t each other. Port connections of VNA and horn antennas are shown in measurement setup (figure 2). The complex RCS for ARC system for different polarization modes is derived equation 1 using insertion loss measurement from VNA [4].

$$RCS_{ab} = S_{IL} - 10log10\left(\frac{\lambda^2}{(4\pi)^3 R^4}\right) - (G_a) - (G_b) \quad (1)$$

Where, RCS_{ab} denotes RCS for SAR sensor polarization ab (a = Transmit Pol., b = receive pol), S_{IL} is insertion loss measured by four port VNA as per table 2, λ is wavelength, R is distance between ARC and test horn antennas, G_a and G_b are gain for transmit and receive test antennas. Insertion Loss measurement is done in time domain to avoid contributions from reflection and other multipath components in measured RCS.

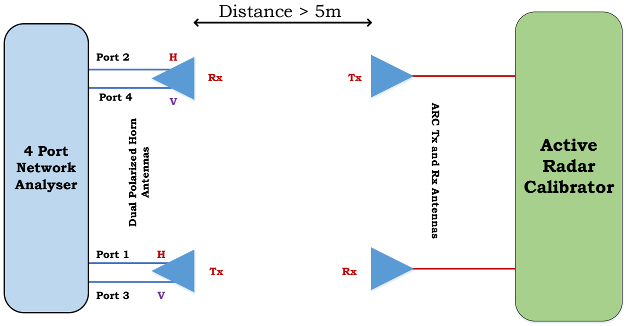

Figure 3: RCS measurement setup.

Table 2: Polarization and VNA insertion loss mapping for RCS calculation.

Polarization (ab)	Insertion Loss from VNA S_{IL}
HH	S21
HV	S41
VH	S23
VV	S43

Complex RCS measurement results for L, S and C bands is shown in figure 4 – 6. Magnitude of time domain impulse response is shown for two RCS settings of ARC. Advantages of time domain measurement can be clearly seen in the RCS impulse response for L Band. Due to larger bandwidth, this band is most susceptible to corruption from reflection of nearby structure in test setup. But as the delay of reflected signals is different from the signal from ARC, they are separated in time domain and will not affect the actual measurement of RCS. RCS phase is derived as the phase value of peak point of impulse response.
Figures 7 & 8 shows stability of RCS amplitude and phase across different measurement taken for same RCS setting but during different power on sessions and at different time. Developed broadband ARC system is also used during the calibration campaign of ISRO's EOS – 4 C – Band SAR satellite. Figure 9 and 10 shows the ARC response in EOS – 4 VV and VH polarized image taken over Ahmedabad region. Corner reflector placed along with ARC is also visible in image. Since ARC can be used both co and cross pol calibration, its response is visible in both co (VV) and cross (VH) pol image while corner reflector is only visible in co pol image. Point target impulse response of ARC from image is shown in figure 11.

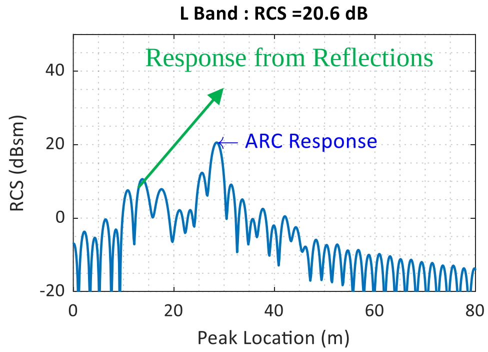

Figure 4: Measured RCS impulse response for L Band.

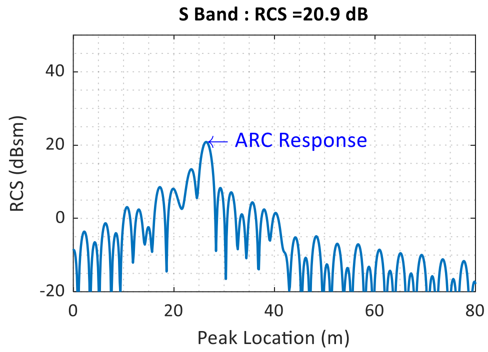

Figure 5: Measured RCS impulse response for S Band.

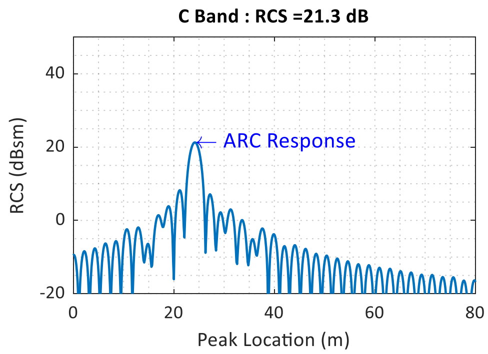

Figure 6: Measured RCS impulse response for C Band.

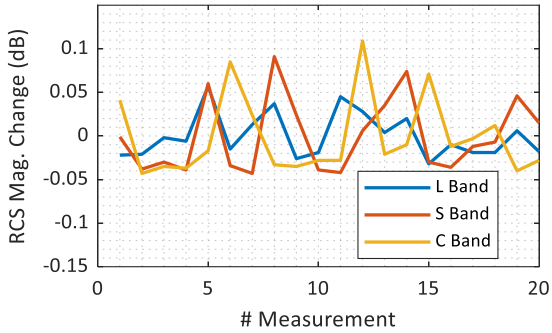

Figure 7: RCS magnitude stability.

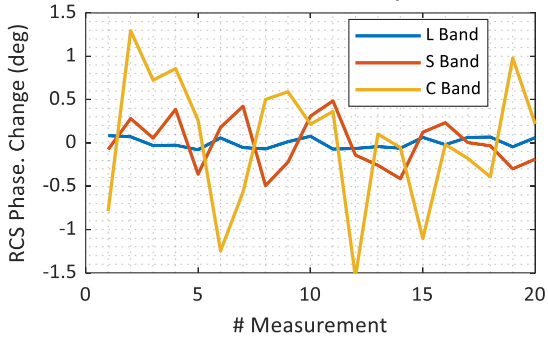

Figure 8: RCS phase stability.

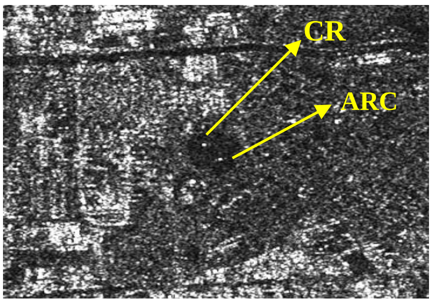

Figure 9: ARC and CR response in EOS-4 VV Pol. image.

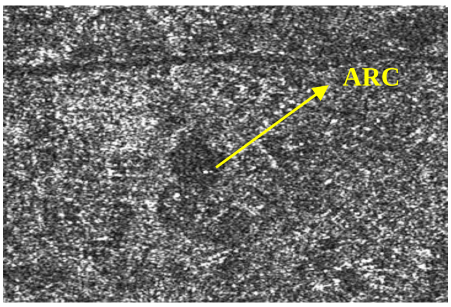

Figure 10: ARC and CR response in EOS - 4 VH Pol. (cross pol.) image.

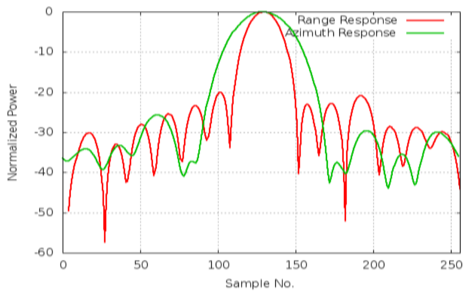

Figure 11: Impulse Response for ARC in VV pol.

4. Conclusions

This paper introduces an indigenously developed multi band ARC system. System design and characterization methodology of developed ARC system is presented. RCS amplitude and phase stability of developed ARC is within ±0.2dB and $\pm 2^0$ respectively for all bands. This developed ARC will be used as prime calibration target during different calibration campaign of SAR satellite operating in L, S, C and X bands. Also, Commercial Off the Shelf (COTS) based approach used for system development make it economically viable for technology transfer to local industry for volume production.

5. References

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