An Active Wideband Reference Target for the Calibration of Ground to Air Radar Systems

Monique Pienaar[1], Johann W. Odendaal[1], Jacques E. Cilliers[2], Kevin H. Kloke[2] and Johan Joubert[1]

[1] Centre for Electromagnetism, Department of EEC Engineering, University of Pretoria, South Africa; Corresponding author: u11175100@tuks.co.za

[2] Radar and Electronic Warfare Systems, Defence Peace Safety and Security, Council for Scientific and Industrial Research (CSIR), South Africa

ABSTRACT— The radar cross section (RCS) of passive calibration targets is relatively low, which leads to a commensurate increase in the uncertainty of the radar's calibration. To address this deficiency, an active radar calibration (ARC) target was developed, which was mounted on a small remote controlled tri-copter and used for radar calibration. Results are presented for this relatively small, light weight and cost effective airborne ARC, which is suitable for the calibration of a ground to air RCS measurement system. The static RCS characteristics of the airborne ARC target were measured in a compact range and compared to outdoor measurements with the ARC target mounted on the tri-copter. The airborne capability of the calibration target was used to reduce the effects of multi-path and clutter.

Key words*:* active calibration target; airborne calibration target; wideband calibration target; radar cross section

1. INTRODUCTION

Modern radar systems are becoming increasingly capable of measuring the scattering signatures (possibly fully polarimetric) of targets (airborne, land, sea, space and even underground) to enable better discrimination of targets from clutter as well as target recognition functionality. Accurate calibration of radar systems is thus required to increase measurement accuracy of the absolute Radar Cross Section (RCS). Calibration of radar systems is usually performed by measuring the backscatter of a calibration target with a known RCS value [1].

Radar systems are usually calibrated with passive calibration targets, mostly spheres, dihedral- and trihedral-corner reflectors or Luneburg Lenses [2]. The RCS of passive calibration targets is directly proportional to their electrical aperture, therefore large passive calibration targets are required to achieve accurate calibration. In order to achieve a backscatter signal which is significantly larger than the radar system's noise floor requires a physically large passive calibration target, which increases the complexity of manufacturing, transportation and deployment. Increasing the electrical aperture, therefore the physical size, of the passive calibration target to increase the RCS, also results in a decrease in scattering beamwidth in some cases, which leads to increased sensitivity to target alignment. The relatively low RCS values or narrow elevation or azimuth beamwidths of passive calibration targets and the resulting increase in the uncertainty of measurements are the main disadvantages of passive calibration targets. The use of ground based active radar calibration (ARC) targets for the calibration of airborne Synthetic Aperture Radar (SAR) systems was proposed in the 1980s [3] and was recently demonstrated for fully polarimetric SAR systems [4].

The limitations of passive calibration targets can be alleviated by using an airborne active calibration target, suitable for the calibration of a ground to air radar system. In this paper results are presented for a relatively small (33x18x11 cm) and light weight (500 g) airborne active calibration target. The target has wide bandwidth (3 GHz to 6 GHz) and wide beamwidth (approximately 20 degrees) properties. The target can easily be configured for the calibration of VV-, VH-, HV- and HHpolarized ground to air radar systems. The static RCS characteristics of the airborne active calibration target were measured in the compact range of the University of Pretoria (South Africa). Outdoor measurements of the active calibration target, with the target mounted on a small remote controlled tri-copter, were conducted at the Defence Peace Safety and Security (DPSS) unit of the Council for Scientific and Industrial Research (CSIR).

2. WIDE BAND ACTIVE CALIBRATION TARGET

This low cost, airborne active calibration target consists of two antennas (one for receive and one for transmit), an amplifier to increase the effective RCS values of the calibration target and an optional attenuator. A schematic diagram the active calibration target is shown in Fig. 1. The attenuator allows the RCS of the calibration target to be varied over a large dynamic range. Two light weight printed Vivaldi antennas were implemented which have wide bandwidth characteristics and low cross-polarization levels with relatively high gain. Their reasonably broad radiation patterns make it easier to align the calibration target and the radar [5]. The Vivaldi antennas were designed using Antenna Magus [6] and simulated in FEKO [7]. The isolator protects the amplifier from any potential feedback between the transmit and receive antennas.

The theoretical RCS of an active calibration target is given by [8]:

$$\sigma_{eff} = G_{loop} \frac{G_r G_t \lambda^2}{4\pi} \tag{1}$$

with G_r the gain of the receive antenna, G_t the gain of the transmit antenna, λ the radar wavelength and

$$G_{loop} = G_a - G_{att} - G_{isolator} \tag{2}$$

where G_a is the amplifier gain, G_{att} is the attenuation of the attenuator and $G_{isolator}$ is the loss of the isolator in dB. The RCS values of the calibration target can be estimated from the measured values of the individual components in Fig. 1. The antenna gains of the two Vivaldi antennas were measured in the compact range and are shown in Fig. 2. The antenna gain increases form 8.7 dBi at 3 GHz to 12.6 dBi at 6 GHz. The mutual coupling between the two antennas was measured in the compact range for a VV-polarized configured calibration target and was below -20 dB as shown in Fig. 3.

The gain of the components and cables comprising G_{loop} was measured on a vector network analyser and is shown in Fig. 4. The measured gain of the loop varied from 3.9 dB to 5.7 dB and from (1), the theoretical RCS of the active target varied from 8.6 dBsm to 13.4 dBsm over the frequency band of operation.

3. MEASURED RCS RESULTS OF THE ACTIVE CALIBRATION TARGET

The RCS characteristics of the active calibration target were measured in the compact range, a photograph of the measurement setup is shown in Fig. 5. The target was measured for different polarization configurations, viz. VV-, HH- and VH-polarization allowing the calibration target to be used for the calibration of ground to air radar systems with different polarizations. The frequency response for the different configurations on boresight are presented in Fig. 6, and compared to the theoretical RCS of the target obtained from the gain and S-parameter measurements of the individual components in Section 2. The maximum variation in the VV-polarization configuration was 2.5 dB. The structural RCS of the calibration target (with the amplifier switched off) is also shown and is below -7.8 dBsm over the frequency range which is significantly lower than the RCS of the active target.

Fig. 7 shows the calibration target mounted on the tri-copter for deployment during the outdoor measurements of the calibration target using an S-band ground based Doppler radar. The normalized beam pattern of the active calibration target measured in the compact range for all the polarization configurations are shown in Fig. 8. The 3 dB beamwidth of the calibration target is larger than 43˚ for all the polarization configurations. This relatively broad beamwidth of the calibration target will significantly reduce the effects of alignment accuracy required between the radar antenna and the boresight of the calibration target. The beam pattern of the calibration target mounted on the tri-copter was also measured in the compact range (Fig. 8). The interaction between the active calibration target and the tri-copter's structure caused the 3 dB beamwidth of the calibration target, in the VV-polarization configuration, to decrease by 10° (from 54° to 44°).

Outdoor RCS measurements of the calibration target were conducted with a VV-polarized Doppler radar from 3.1 GHz to 3.3 GHz. The calibration target was mounted on a remote controlled tri-copter flying inbound and outbound profiles at a height of approximately 15 m and at a distance from the radar varying approximately between 150 m and 200 m. The gain of the radar antenna was 15 dBi with a beamwidth of 30°. The GPS position, roll, pitch and yaw of the tri-copter were measured by means of on-board sensors. This data, combined with the data received by the radar, was then used to calculate the effective RCS of the calibration target.

Fig. 9 compares the RCS of the calibration target and the calibration target mounted on the tri-copter, measured in the compact range, to the outdoor RCS, measured with the Doppler radar over the frequency range of 3.1 GHz to 3.3 GHz. The RCS was measured at an azimuth and elevation angle of approximately 0° towards the radar. The maximum difference between the compact range measurements, with the calibration target mounted on the tri-copter, and the outdoor measurements was 3.3 dB at 3.1 GHz. At 3.2 GHz and 3.3 GHz the differences were 0 dB and 1 dB respectively. Only data where the target was clear of clutter was used, thus removing the effect of clutter from the outdoor measurements. A first order multi-path analysis was conducted and it was determined that the effects of multipath was negligible for this setup. The slight differences between the outdoor data and compact range data can be attributed to alignment inaccuracies of the tri-copter towards the radar, especially in elevation. A stabilizing gimbal can be attached to the tri-copter as a mounting platform for the target or its antennas to reduce the fluctuations due to the roll, pitch and yaw of the tri-copter.

4. CONCLUSION

Results were presented for a relatively small and light weight cost effective airborne active calibration target, suitable for the calibration of a ground to air RCS measurement system. It was demonstrated that the calibration target had wide bandwidth and wide beamwidth properties. The static RCS characteristics of the airborne active calibration target were measured in a compact range and compared to outdoor measurements of the active calibration target mounted on a small remote controlled tri-copter. The major advantages of the active calibration target are that it has a large beamwidth; is easy to deploy; is low cost as well as being wideband; and has a relatively large absolute RCS making it a suitable alternative over passive calibration targets for ground based radar systems. Another advantage of being airborne and in motion is that calibration measurements are out of ground clutter. This calibration system is also useful for independent verification of radar specifications by defence evaluation and research institutes. The airborne capability could also give the opportunity to verify the minimum detectable velocity of a target of a specified RCS. The RCS of the calibration target can be varied which could also be used to test deployed/installed radar systems.

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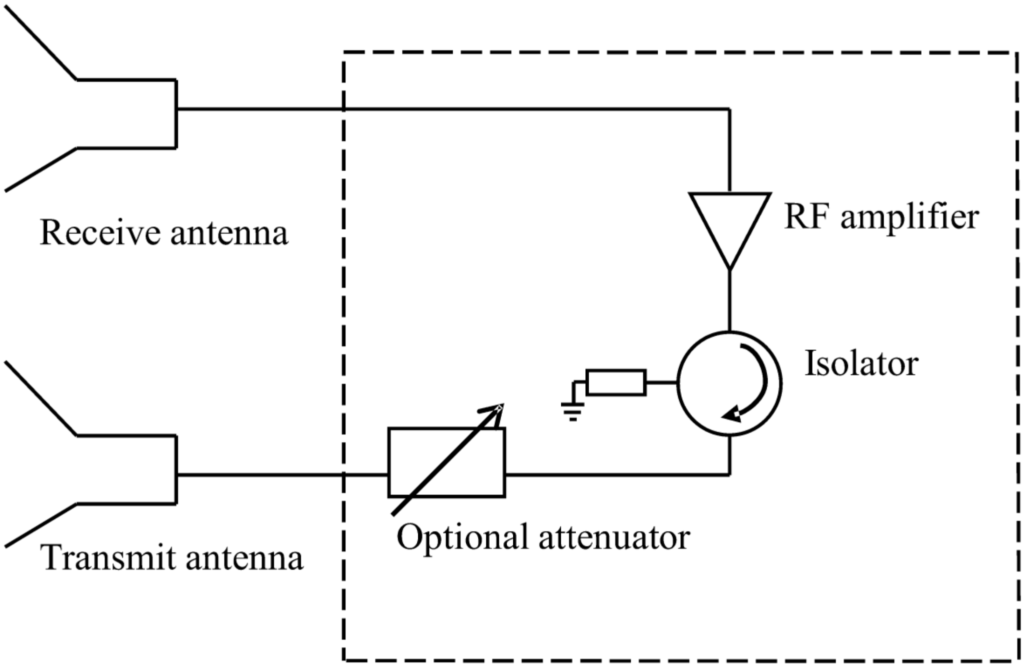

Figure 1. Active calibration target schematic.

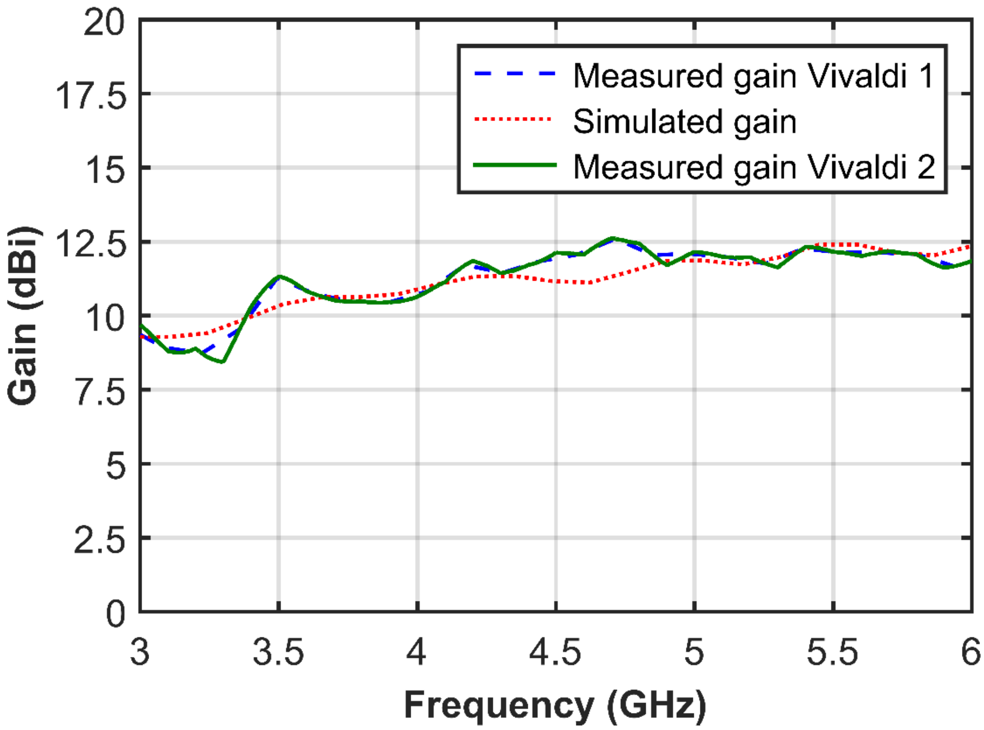

Figure 2. Measured and simulated gain of the two Vivaldi antennas.

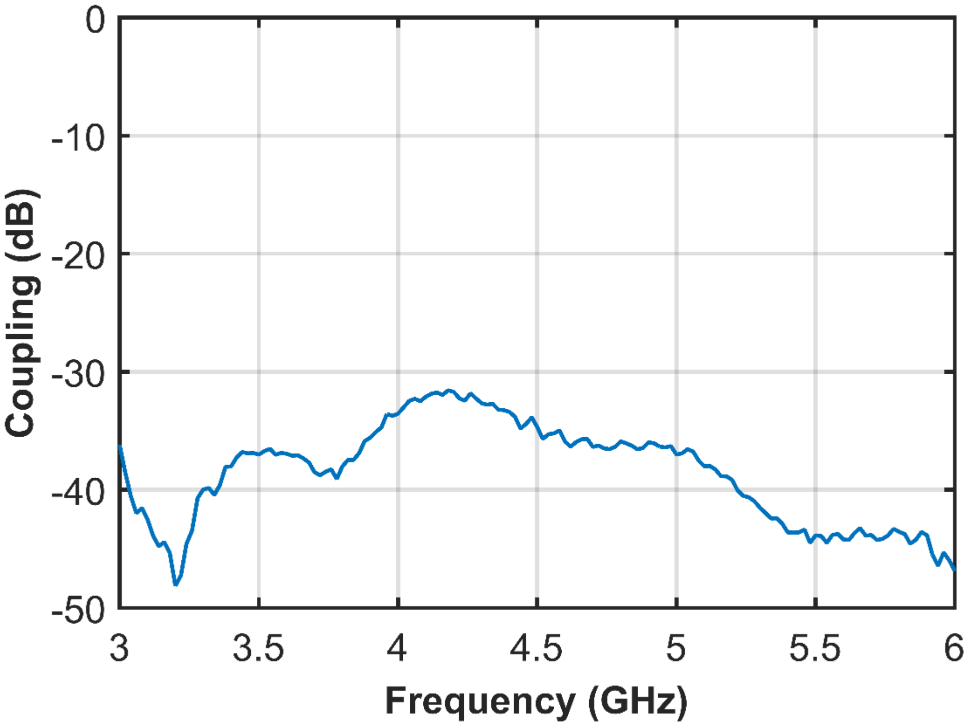

Figure 3. Mutual coupling between the two Vivaldi antennas in a typical configuration for a VV-polarized calibration target.

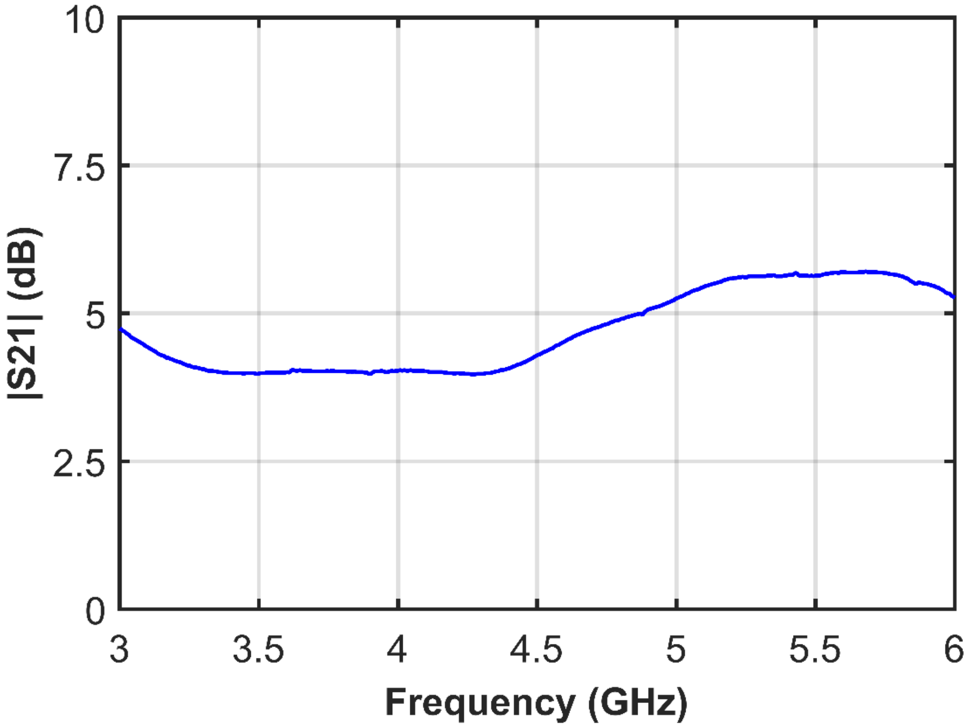

Figure 4. S_{21} parameter of the loop elements (G_{loop}) of the active calibration target.

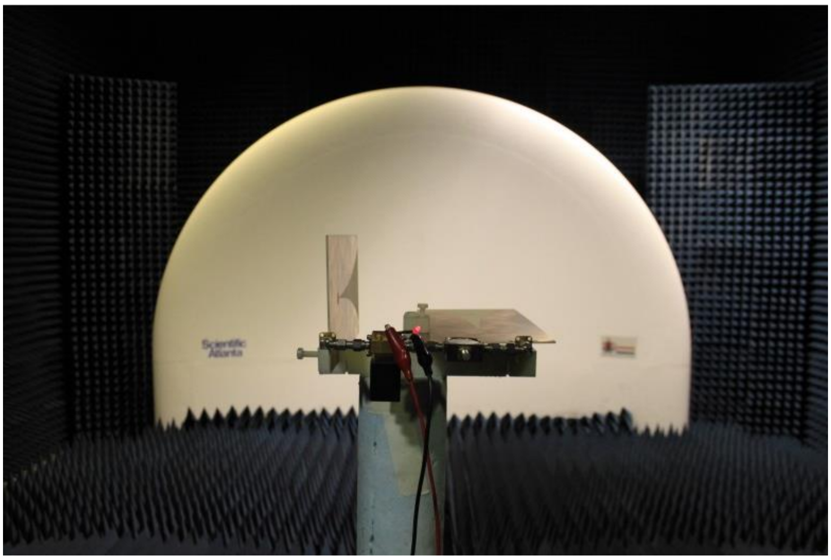

Figure 5. The active calibration target in the compact range, setup for VH-polarization measurements.

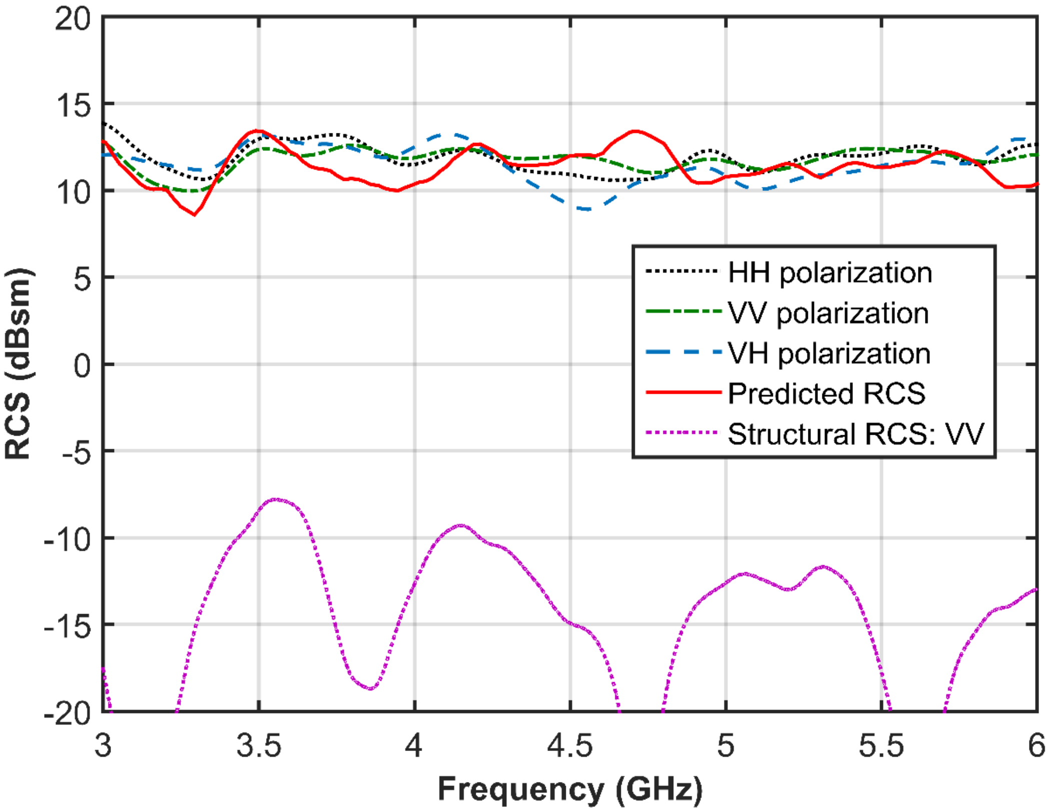

Figure 6. Predicted and compact range measured (VV, VH and HH) RCS results of the active calibration target versus frequency.

Figure 7. Active calibration target mounted on the tri-copter for outdoor measurements with the antennas oriented for VV-polarization.

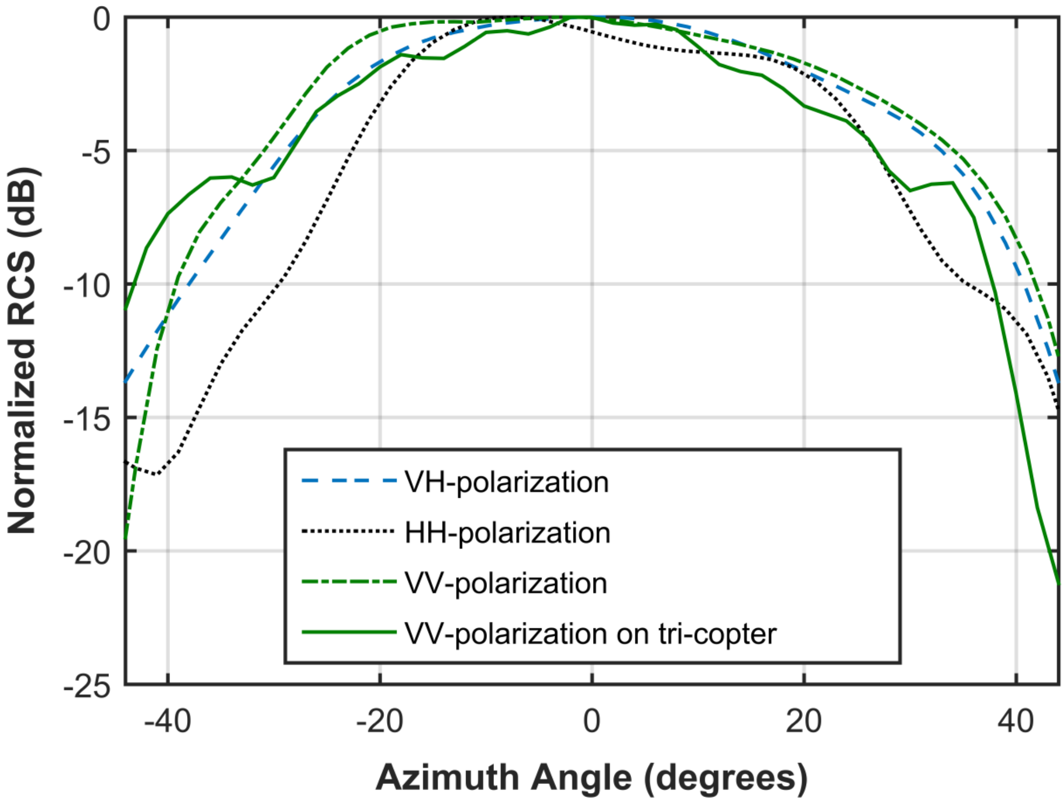

Figure 8. Normalized RCS beamwidth of the active calibration target measured in the compact range for VV-, VH- and HH-polarization configuration without the tri-copter and for VV-polarization configuration with the tri-copter at 3.1 GHz.

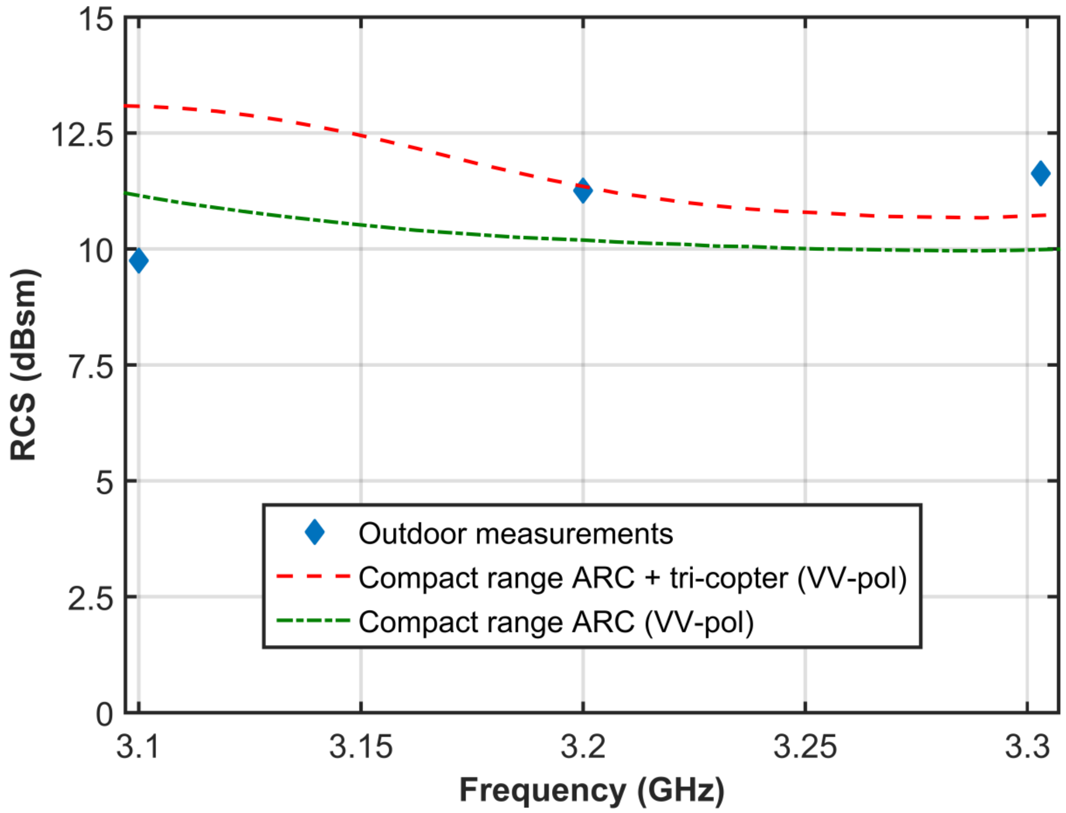

Figure 9. Outdoor and compact range measured RCS versus frequency, (VV-polarization configuration).