EXPERIMENTAL PLAN FOR POLARIMETRIC CALIBRATION OF AIR AND SPACE SAR's

Masaharu Fujita
Communications Research Laboratory
Koganei, Tokyo 184-8795, Japan
e-mail: mfujita@crl.go.jp

1. Introduction

Polarimetric radar can measure a scattering matrix for a target. Vertical and horizontal polarizations (V-pol and H-pol) are usual basis for the scattering matrix. The elements of the 2 by 2 matrix are complex numbers that specify the amplitude variation and phase rotation that arises from scattering in four combinations of polarization states of waves to and from the target. The scattering matrix gives complete information on the scattering. The scattering matrix makes it easy to, for example, distinguish volume scattering from surface scattering, identify the orientation of bar- or needle-like scatterers, or enhance specific target images by polarization synthesis. Since the scattering matrix is measured via radar hardware, the measured data are usually distorted by the imperfect polarization transfer. This influence must, therefore be removed to obtain an accurate scattering matrix.

This paper presents an experimental plan for polarimetric calibration of L-band synthetic aperture radars (SAR) using novel depolarization targets of Van Atta array design. The design of such targets is also described briefly.

2. Calibration procedure and novel depolarizing target

The polarization transfer characteristics of a radar receiving and transmitting system, R and T, will always include an error so that the measured scattering matrix M differs from the actual scattering matrix of a target S. In a polarimetric radar, M is related to S by:

$$M = cRST + N \qquad (1)$$

where c is a constant and R and T are the polarization transfer matrices of the radar receiving and transmitting systems. N is the noise matrix. To compensate for the polarimetric errors that are inherent in the hardware, several techniques for polarimetric calibration have been proposed. They can all be divided into two major categories, i.e. one in which three reference targets are used, each with a different scattering matrix and another in which a single reference target is used, and assumptions are made regarding the characteristics of the scene and/or radar. Since the former approach, which will be called three target approach (TTA) hereafter, needs no assumptions, it is more suitable for calibration purposes. Only the TTA is thus assumed to use in the present investigation.

In one approach for polarimetric calibration by TTA [1], three polarimetric active radar calibrators (PARC's) are used as targets. Two of the targets depolarize incoming waves from H-pol to V-pol, and from V-pol to H-pol, respectively. The other target returns both V- and H-pol waves when either a V- or H-pol wave is received. In [1], appropriate depolarization characteristics were provided by properly aligning a field direction across the aperture of each of a pair of square horn antennas. Since the assumed SAR operates in the L-band (wavelength: 24 cm), the horn antennas are somewhat large and heavy even for a low gain, so the handling is difficult in the field. The author has already proposed a novel depolarizing target of Van Atta array design [2]. Essentially, it consists of two dual-polarized sub-arrays arranged side by side. The H-pol port of the left-hand sub-array is connected to the V-pol port of the right-hand sub-array, and the V-pol port of the left-hand sub-array is connected to the H-pol port of the right-hand sub-array, and the electrical path length is the same on both routes. This connection provides the target with a Van Atta array function of retrodirective beamforming with a polarization angle rotation by 90 degrees. If the connections are not directional, the target acts as either an H-to-V or V-to-H depolarizing target depending on the polarization of the incoming wave. Polarization characteristics as required for the third target in [1] can be obtained by rotating each of the dual-polarization elements in a sub-array by 45 degrees. The configuration of the target is shown in very simplified form as Figure 1.

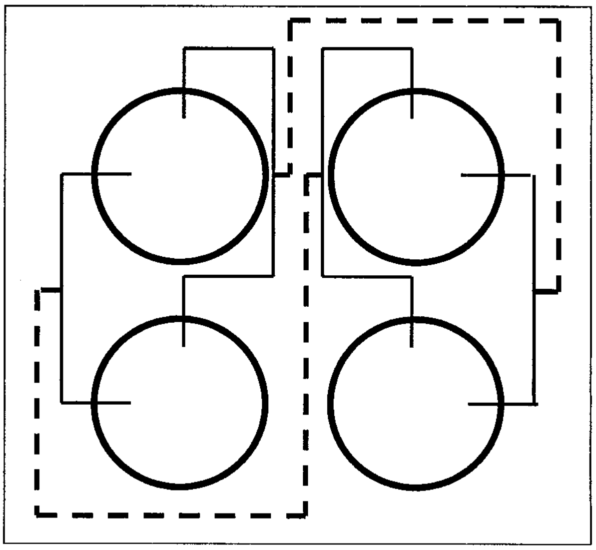

Figure 1. Basic configuration of the novel depolarizing target.

In the figure, the circles are antenna elements. The vertical and horizontal lines that enter the circles are feed lines for two orthogonal polarization components. The thick broken lines mean are the routes which connect the cross-polarization ports of the right-hand and left-hand sub-arrays.

3. Calibration experiment plan for air and space SAR's

The radar cross section σ of an active radar calibrator is given as follows:

$$\sigma = \frac{G_e G_a{}^2 \lambda^2}{4\pi} \qquad (2)$$

where G_a and G_e are respectively the antenna and amplifier gains, and λ is the radar wavelength. If there are no amplifiers along the connection routes as depicted in Figure 1, G_e is unity, assuming no loss. When the array is assumed to be 1 m^2, its 100% gain is calculated as 23.4 dB in the L-band. Since the whole aperture is used to receive and transmit simultaneously, the radar cross section of the target then becomes 23.4 dBm^2. A spatial resolution size of 10 m^2 (10 dBm^2) [3] for an airborne L-band SAR and a cross-polarized backscattering coefficient of -20 dB for soil and rocks and short vegetation [4] must be reasonable assumptions. The radar cross-section of the surface is thus around -10 dBm^2, so a signal-to-background ratio of about 30 dB would be expected, even if a 3-dB loss is taken into account in the calculations for the calibration target. No amplifiers will be needed to calibrate an air SAR according to estimation of signal strength in the link. Thus, a V-H depolarizing target can behave as a target with either the first or second scattering matrix required for the algorithm of [1], depending on the polarization of the incoming wave. The third scattering matrix is provided by, as described previously, rotating each element of the array by 45 degrees. The two targets are thus sufficient for the TTA polarimetric calibration of an air SAR.

In the space SAR case, however, the situation is different from the air SAR case. The spatial resolution is of the order of several hundred square meters or even more, i.e. around 30 dBm^2. Assuming a cross-polarized backscattering coefficient of -20 dB, as for airborne SAR, the radar cross section of the background thus becomes 10 dBm^2. To accurately calibrate an SAR, we need a sufficiently high signal-to-background clutter ratio. If we assume that the same value is needed for spaceborne as for airborne SAR, it is then necessary to increase the radar cross-section of the target by about 20 dB. Thus we have to insert an amplifier with a 20-dB gain in each connection route of the target. This increases the radar cross-section of the target by about 40 dBm^2, and the signal-to-background clutter ratio is now about 30 dB. The value is almost the same as for the air SAR. With amplifiers, however, the target can only act as a V-to-H or H-to-V reflector according to the direction of amplification, but not in the passive target for the air application. We still need three targets for space SAR calibration. One disadvantage of the present active target is that twice as many amplifiers are needed as in the conventional designs. Another concern is the polarization discrimination ratio of each antenna element. Since each element is used to transmit and receive simultaneously, the cross-polarization discrimination ratio has to be greater than the loop gain, to stabilize the target's operation. In our experience the polarization discrimination ratio of a microstrip patch antenna, for example, is typically around 20 dB, so at least 20-dB amplification in the connection route is critical. A further effort to increase the cross-polarization discrimination ratio of the element is needed to ensure more stable operation of the target.

4. Summary

This paper presents an experimental plan for polarimetric calibration of air and space SAR's. Application of the Van Atta array concept results in a novel and effective design for the targets to be used in polarimetric calibration. The system's advantages are its source tracking capability and slim and lightweight structure which allows easy handling in the field. A passive design which is applicable to the calibration of air SAR can be used for depolarization both from horizontal to vertical and vertical to horizontal polarizations, depending on the polarization of the incoming wave. The addition of 20-dB gain amplifiers in both connection routes of each target makes the system applicable to the calibration of spaceborne SAR. One major disadvantage of the present target is its requirement for twice as many amplifiers as are needed in a conventional active radar calibrator.

An experiment is planning for calibrating PALSAR onboard the ALOS satellite. Further fundamental study of the novel target itself and a verification study on air SAR will be performed first.

References

[1] A. Freeman et al., Polarimetric SAR calibration experiment using active radar calibrators, IEEE Trans. Geosci. Remote Sens., Vol.28, pp.224-240, 1990.
[2] M. Fujita, A novel depolarizing target of Van Atta array design for polarimetric calibration, paper presented at IEICE General Conference, March 2000, Hiroshima Univ.
[3] H. Wakabayashi et al., Airborne L-band SAR system: Characteristics and initial calibration results, paper presented at IGARSS'99, June-July 1999, Hamburg, Germany, pp.464-466.
[4] F.T. Ulaby and M.C. Dobson, Handbook of radar scattering statistics for terrain, 357pp., Artech House, 1988.