POLARIMETRIC CALIBRATION FOR A SYNTHETIC APERTURE FM-CW RADAR

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1. Introduction

Since the principle of radar polarimetry is applicable to a wideband FM-CW radar, it is necessary to calibrate the polarimetric radar system, taking into account of the band width. If the operating frequency becomes high, a precise alignment and calibration of radar system become difficult because of shorter wavelength. This paper describes one method to calibrate a polarimetric and synthetic aperture FM-CW radar operative at the *Ku* band (14.5-15.5 GHz). First, a polarimetric calibration methodology is outlined using a corrugated metallic plate which is specially designed to act as a linear target over the operational band. The advantage of the proposed linear target is large RCS with simple structure. Referring to a calibration technique[1], the measured scattering matrices containing error were calibrated. The calibrated scattering matrix yields the corresponding polarimetric signatures together with the Co-Pol max polarization state. It is shown that the radar acts as a highly precision polarimetric and synthetic aperture radar system.

2. Calibration Procedure

Theoretical Sinclair scattering matrix [S] with relative power and phase for a 45° oriented dipole or wire target is given as

$$[S]_{45^\circ dipole} = \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} = \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix}. \tag{1}$$

It is possible to obtain a scattering matrix by a polarimetric and synthetic aperture FM-CW radar. A scattering matrix measured by the radar, however, contains error. The error can be roughly classified into two categories; 1) the Co-Pol channel imbalance, and 2) the X-Pol channel imbalance.

In a 2-dimensional imaging system, the Co-Pol channel imbalance is caused by a difference in antenna pattern in the polarimetric channels. For example, H-H (horizontal transmitting and horizontal receiving) pol and V-V pol should yield the same scattering matrix element ($S_{hh} = S_{vv}$) for the 45° oriented dipole. However, the difference in antenna pattern (beam coverage) in the H-pol direction and V-pol direction causes different amplitude and phase for S_{hh} and S_{vv} in the synthetic aperture processing. This factor can be incorporated into a measured scattering matrix [Z] expression as

$$[Z] = \begin{bmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{bmatrix} = [R][S][T] = \begin{bmatrix} 1 & 0 \\ 0 & f_1 \end{bmatrix} \begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & f_1 \end{bmatrix}, \tag{2}$$

where [T] and [R] are system transfer function matrices of transmitter and receiver, respectively. The term f_1 is associated with the Co-Pol channel imbalance.

For the X-Pol channel problem, the element S_{hh} should be equal to S_{hv}. Usually, this condition is not satisfied for a measured scattering matrix due to the same reason in the Co-Pol channel imbalance case. Since the polarization isolation level is less than - 30 dB in our FM-CW radar system, the isolation problem may be neglected. The factor to resolve the X-Pol channel imbalance, which accounts for the situation and is suited for a mathematical expression, is an introduction of f_2 in the scattering matrix as

$$\begin{bmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{bmatrix} \Rightarrow \begin{bmatrix} S_{hh} & f_2 S_{hv} \\ f_2 S_{vh} & S_{vv} \end{bmatrix}. \tag{3}$$

Therefore, the mathematical expression for a measured scattering matrix [Z] containing the Co- and X-Pol channel error becomes

$$[Z] = \begin{bmatrix} Z_{hh} & Z_{hv} \\ Z_{vh} & Z_{vv} \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & f_1 \end{bmatrix} \begin{bmatrix} S_{hh} & f_2 S_{hv} \\ f_2 S_{vh} & S_{vv} \end{bmatrix} \begin{bmatrix} 1 & 0 \\ 0 & f_1 \end{bmatrix}. \tag{4}$$

The purpose then turn out to obtain f_1 and f_2. If these factors are obtained, it becomes possible to calibrate measured scattering matrix [Z] and to calibrate the polarimetric FM-CW radar system as well.

It is theoretically known that a 45° wire has a scattering matrix (1) and has characteristics such that

$$\left| \frac{S_{vv}}{S_{hh}} \right| = 1, \quad \left| \frac{S_{hv}}{S_{hh}} \right| = 1, \quad \arg\left(S_{hh}^{*} S_{vv} \right) = 0, \quad \arg\left(S_{hh}^{*} S_{hv} \right) = 0. \tag{5}$$

This condition leads f_1 and f_2 to

$$| f_1 | = \left| \frac{Z_{vv}}{Z_{hh}} \right|^{1/2}, \quad \arg(f_1) = \frac{1}{2} \arg\left(Z_{hh}^{*} Z_{vv} \right), \tag{6}$$

$$| f_2 | = \left| \frac{Z_{hv}}{Z_{hh} f_1} \right|, \quad \arg(f_2) = \arg\left(\frac{Z_{hh}^{*} Z_{hv}}{f_1} \right). \tag{7}$$

3. Calibration Target

One of the most simple targets is a wire. A single wire has a small RCS which makes the measurement difficult in a sense that a noise level of an instrument becomes relatively large compared to the small RCS. In this paper, we propose a linear target for the calibration which acts as a wire with large RCS as shown in Fig.1. It consists of corrugated metallic plates with their edges are aligned and parallel in a plane. Since the radar system sweeps a certain frequency band, the proposed target must work as a linear target within the band. In order to satisfy this frequency characteristics requirement, the interval of the metallic plates is set less than the half-wavelength of the highest frequency. This continuous spacing constructs many parallel plate waveguides aligned in a plane which reflect a wave whose polarization direction is parallel to edges completely due to cut-off condition within the waveguide. On the other hand, a wave with the polarization orthogonal to edges proceeds into the parallel waveguide and reaches an electromagnetic wave absorber behind. In this way, the proposed corrugated metallic plates is expected to act as a linear target.

4. Calibration Result

Figure 2 shows a span image of the 45° oriented linear target after the 2-dimensional synthetic aperture processing. The number of pixels in this image is 64×64, each having its own scattering matrix. By averaging more than 20 pixels pertaining to the target at the center, a representative scattering matrix is derived. A polarimetric signature in the Co-Pol channel is depicted in Fig.3 using the measured scattering matrix. It is seen that the pattern and the Co-Pol maximum polarization state is distorted by errors. Fig.4 shows the calibrated polarimetric signature (= theoretical one).

Next, the target was oriented with respect to a scanning direction in an imaging plane, and was imaged by the polarimetric FM-CW radar. The orientation angle was chosen to be 60, 30, 0, -30, and -60 degrees. The Co-Pol maximum polarization state for the target after the calibration, corresponding to the polarization state which gives the maximum attainable power, is listed in Table I as a function of the orientation angle. The polarization state is represented as a set of the ellipticity angle ε and the tilt angle τ. It is seen that the polarization state is very close to the theoretical one and that the FM-CW works as a full polarimetric radar.

5. Conclusion

The proposed corrugated metallic plates has proved to work as a linear target, especially suited for a wideband measurement. Using the linear target, it is possible to calibrate the polarimetric radar system. Once the calibration factors are obtained, they can be applied to other orientation angle configurations. It was shown that the radar acts as a highly precise polarimetric imaging system.

References

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[2] Y. Yamaguchi, T. Nishikawa, M. Sengoku, W. -M. Boerner, and H. J. Eom,"Fundamental study on synthetic aperture FM-CW radar polarimetry," *IEICE Trans. Communications*, vol. E77-B, no.1, pp.73-80, Jan. 1994

[3] Y. Yamaguchi, T. Nishikawa, M. Sengoku, and W. -M. Boerner, "Two-dimensional and full polarimetric imaging by a synthetic aperture FM-CW radar," *IEEE Trans. Geoscience Remote Sensing*, vol.33, no.2, pp.421-427, Mar. 1995

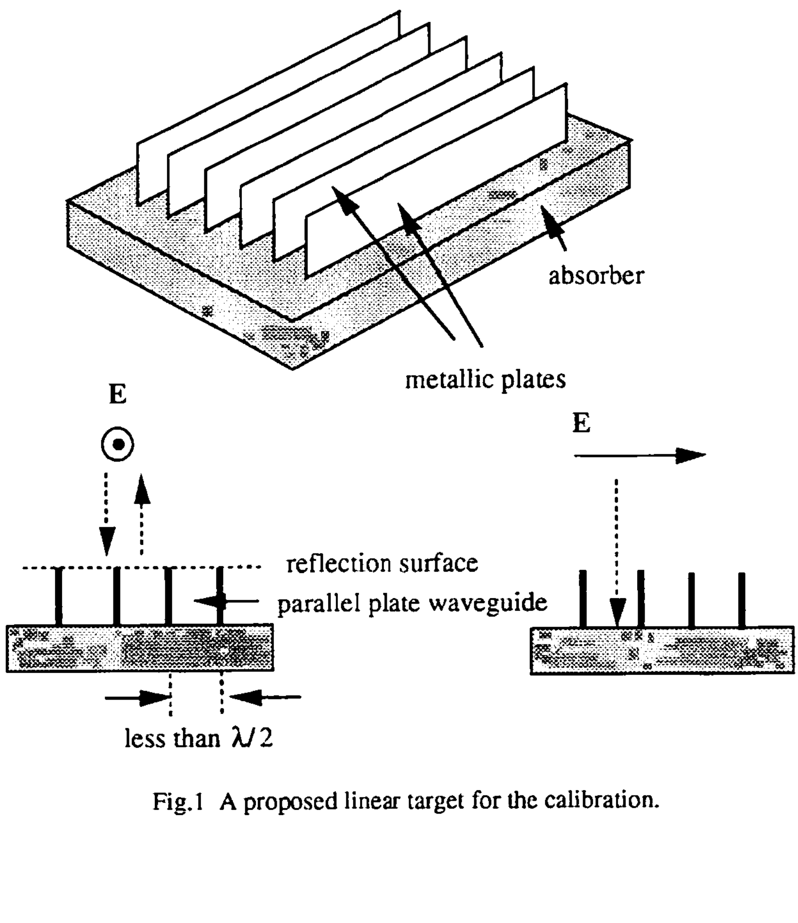

Fig.1 A proposed linear target for the calibration.

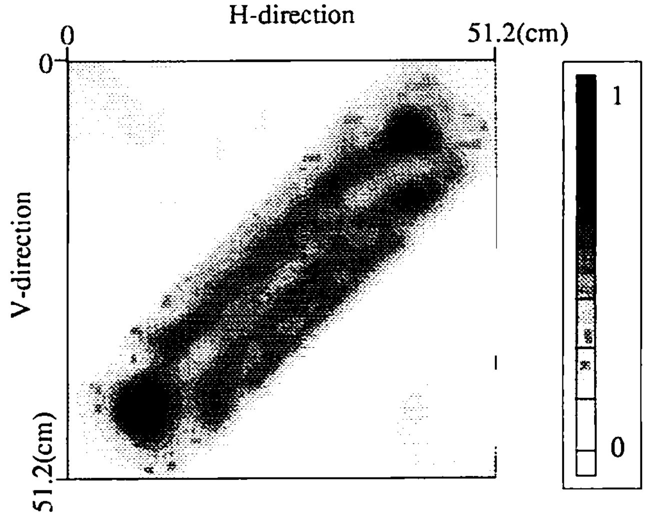

Fig.2 A span image of the 45° oriented linear target

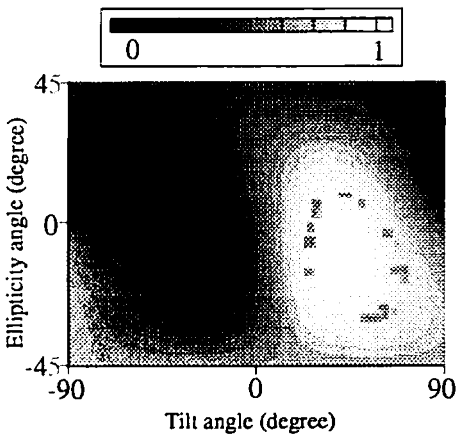

Fig.3 A measured polarimetric signature

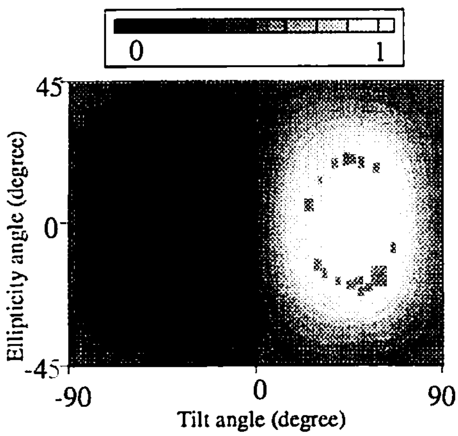

Fig.4 The calibrated polarimetric signature

Table I Co-Pol max polarization states corresponding to oriented linear target

	Co-Pol max	
orientation angle (degree)	ε (degree)	τ (degree)
60	1.2	60.3
30	1.3	29.9
0	-0.5	-0.2
- 30	-2.6	-32.4
- 60	3.8	-62.0