P11.8 RADAR RECEIVER CORRECTION OF POLARIZATION

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1. ABSTRACT

In radar meteorology, it is desired to have various forms of polarization diversity in transmission and reception. In this paper, we consider a phased array radar whose radiating elements are crossed dipoles or equivalent such that relative phase and amplitude will create any form of transmitter polarization. The crossed dipoles are associated with transmit/receive (TR) modules where phase/amplitude control provides beam steering and desired polarization. We consider the construction such that the receive paths from the orthogonal dipoles are separated from the transmit paths (by RF switches or circulators). Errors in polarization can be corrected upon reception where power levels are low, reducing demands on transmitter specifications.

With reception of orthogonal polarization components, these can be appropriately phase and amplitude controlled to produce the effect of having transmitted and received any form and combination of polarizations. All of the receiver correction may be done at coherent base band (I + jQ) with digital signal processing and all of the desired polarization combinations may be achieved simultaneously from the same pair of transmitted orthogonal components. Any transmitter errors can be corrected digitally in the receive paths.

Calibration will be needed over many steering angles in the field of view and requires a calibration sphere or its equivalent in the far field. The relationships for correcting amplitudes and phases are presented in the paper and are easily accomplished with digital processing.

2. INTRODUCTION

A polarimetric radar system transmits and receives signals with two orthogonal polarization to obtain important characteristics of hydrometeors. There is high expectation that dual polarization will lead to improved understanding of the physical processes in storms and other meteorological phenomena. In a radar with a dish antenna, production of the desired polarization is well understood and, since scanning is mechanical, the polarization properties are not affected by the direction of the antenna beam. In a phased array, however, beam steering is done by element phasing. This results in polarization properties that are, in general, dependent upon the steering direction. Heretofore, the control or production of desired polarization properties has concentrated on the transmission aspect; that is, by controlling, as far as practically feasible, the nature of the transmission. This means controlling the amplitude and phase characteristics of antenna element at high power levels, with all the attendant physical difficulties and expense.

This paper shows that it is possible to correct the received EM waves by appropriate phasing and amplitude correction so that the received wave behaves as if circular, or fairly arbitrary, polarization had been transmitted. To do this, however, a separate receiving path is provided for each T/R module. The reason for a separate receiving path is that the receive path corrections would be made at low power. The economics of a separate receive path for each T/R module are yet to be explored, but costs should not be significantly increased. The reason is that, with receiver module correction, the accuracy of phase and amplitude characteristics upon transmission at high power would not be as stringent as would otherwise be required. This can therefore provide the effect of transmitted circular polarization, even if the actual transmitted polarization is not circular. The advantage is that correction is done upon the received energy and, therefore, at low power where methods of amplitude and phase correction are simpler and more economical.

The principle of polarization correction is explained at first for a single T/R element; the extension to an array of elements follows. The principle is based upon the observation that a perfect reflector (e.g., a conducting sphere) returns a wave with the opposite sense of polarization and, therefore, the received wave would be extinguished with the receiver at the same polarization. So whatever transmitted and received polarization is desired, the criterion of correct transmission and reception is the extinguishment of the reflection from a perfect reflector.

3. APPLICATION TO A SINGLE T/R MODULE

Figure 1 shows an embodiment of a T/R module that could be used in a phased array without special correction properties. Components such as power amplifier, low noise amplifier, etc. are not shown. The figure caption explains its action.

Figure 1(a) shows the module in the transmit configuration while Figure 1(b) shows the module in the receive configuration. The difference lies in the switch positions. The circulator in the figures also serves as an RF switch.

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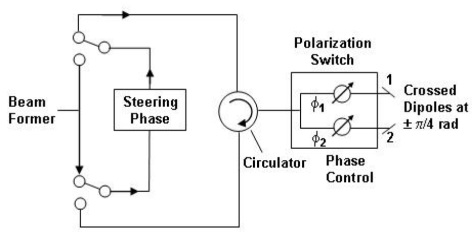
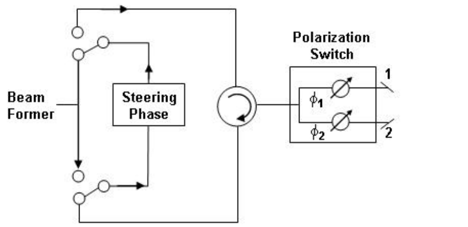
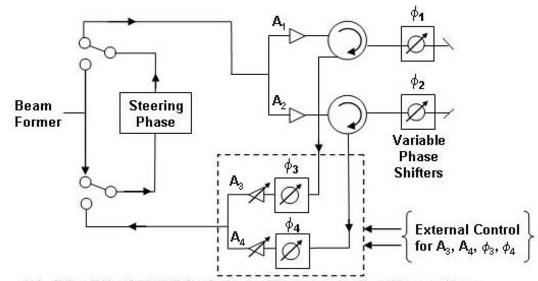


(a) T/R Module in Transmit Configuration

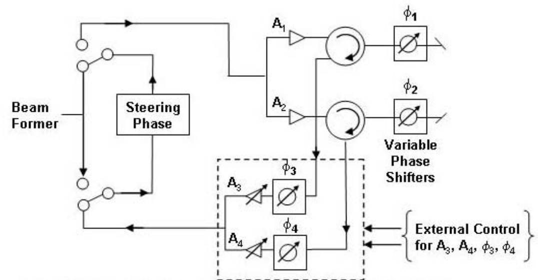


(b) T/R Module in Receive Configuration

Fig. 1. T/R module. In the polarization switch, power is divided equally to the phase shifters. Looking outward, dipole no. 1 is canted from upper left to lower right. Dipole no. 2 is perpendicular to dipole no. 1. For right circular polarization, $\phi_1 - \phi_2 = \pi/2$ rad. For left circular polarization, $\phi_2 - \phi_1 = \pi/2$ rad. For vertical polarization, $\phi_1 = \phi_2$. For horizontal polarization, $\phi_1 = -\phi_2$.



(a) Modified T/R Module in Transmit Configuration



(b) Modified T/R Module in Receive Configuration

Fig. 2. Modified T/R module. The multipliers A_3, A_4 and phase shifters ϕ_3, ϕ_4 serve to correct errors in the transmit path. The gains and phases must satisfy equations (1) – (4).

This transmission of the desired polarizations as indicated in the figure caption depends upon the realizations of the phase relations as shown and also upon the accurate division of power into the two arms of the polarization switch. If the power split is not equal and/or the phase relations are not accurately given by the requirements of Figure 1, the proper desired polarization will not be achieved. Correction of the gains and phases of the paths to and from the crossed dipoles may be accomplished as indicated in Figure 2. In the transmit configuration, the receive path is open (upper figure). In the receive path, the outputs of the crossed dipoles are fed to the correctors A_3, ϕ_3 and A_4, ϕ_4 shown in the lower part of the figure. The amplifiers (or attenuators) are used to compensate for gain imbalance in the transmit path. The necessary phase relationships to achieve the effect of a desired polarization state are given below. The criterion for the proper phase and amplitude relations is that the received signal from a perfect reflector be extinguished.

<u>Right Circular Polarization</u>

$$(\phi_1 + \phi_3) - (\phi_2 + \phi_4) = \pm \pi, \; A_1A_3 = A_2A_4 \qquad (1)$$

<u>Left Circular Polarization</u>

$$(\phi_1 + \phi_3) + (\phi_2 + \phi_4) = \pm \pi, \; A_1A_3 = A_2A_4 \qquad (2)$$

<u>Vertical Polarization</u>

$$(\phi_1 + \phi_3) - (\phi_2 + \phi_4) = 0, \; A_1A_3 = A_2A_4 \qquad (3)$$

<u>Horizontal Polarization</u>

$$(\phi_1 + \phi_3) + (\phi_2 + \phi_4) = 0, \; A_1A_3 = A_2A_4 \qquad (4)$$

4. CORRECTION AT THE ARRAY OR SUBARRAY LEVEL

Heretofore, corrections have been considered to be applied individually to each T/R module in an array. However, individual T/R module receive outputs are ordinarily not available. In addition, the individual signal levels may be too small for effective correction. This argues for corrections to be made to the sum of module outputs in the form, usually, of subarray outputs. The reason for correcting subarray outputs rather than the entire array is that there are other desired outputs, such as outputs from subarrays for monopulse.

The collection of subarray outputs is illustrated in Figure 3. It is noted that the signal collections are done at the RF level and generally there would be separate collections for the different subarrays. Figure 3 differs from figure 2 in several respects.

1. Steering Phase: In Figure 2 the steering phase is applied to each module through what is known as a “common leg circuit” and the signal path on both transmit and receive goes through the common leg circuit through which the steering phase is applied. In Figure 3, the transmit and receive paths are distinct so the steering phase must be applied separately to these paths, although it is of the same value for both paths.
2. Signal Collection: The entire array would be in proper phase for transmission in a given direction. Signal collection, on the other hand,

can be made in the form of subarrays so that monopulse would be supported as would interferometry for crossbeam wind measurement [1]. Signal collection would provide the necessary signal levels to be amplified through the receiver to provide the low noise signal levels for low loss analog-to-digital (A/D) conversion.

3. A/D Conversion: The granularity of the received signals would determine the dynamic range to be achieved. In addition, because the A/D granularity controls the signal granularity, the phase corrections ϕ_3 and ϕ_4 could be very fine. For example, if the A/D converter supplied 8 bits, the phase granularity would be

$$\frac{2\pi}{256} = 0.0245 \text{ radians}$$

4. Amplitude and Phase Correction: Amplitude and phase corrections would be applied to A_3, A_4 and ϕ_3 and ϕ_4 to achieve the desired effective polarization. The requirements to achieve specific polarization are given by equations (1) – (4).

5. Simultaneous Polarization Combinations: It is feasible to provide, simultaneously, A_3, ϕ_3 and A_4, ϕ_4 combinations, to achieve any of the polarizations. Figure 4 shows these possibilities.

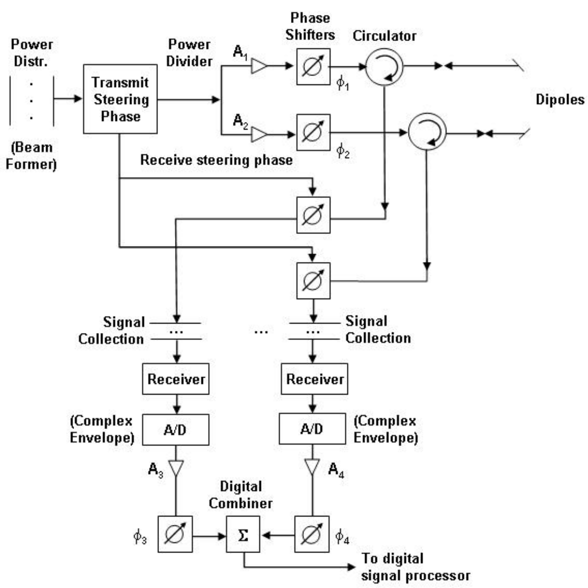


Fig. 3. Polarization correction/calibration based upon digital correction at the array/subarray level. This embodiment is compatible with monopulse and interferometry [1]. The gains and phases must satisfy equation (1) - (4), depending upon desired polarization.

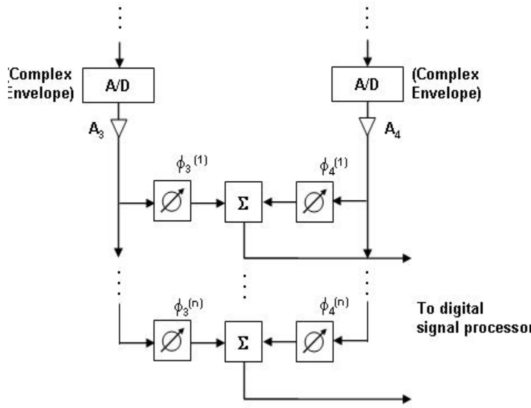


Fig. 4. Simultaneous achievement of several polarization combinations. A_3, A_4 and $\phi_3^{(1)}$, $\phi_4^{(1)}$ would satisfy (1) – (4). Other polarization combinations are similarly achievable.

5.0 CALIBRATION

The correction of polarization must be accomplished over the entire effective angular field of the array. For a planar array, the angular field could be ±45° in azimuth and 0° to near 90° in elevation. It is even possible that the lower limit in elevation could be negative, perhaps as much as −10°. This means that the calibration must be done over a fairly large number of angles in the field. If the correction is to be done at the T/R module level a large number of control paths will be necessary one for each T/R module. However, once the calibration is done these control commands remain fixed. A recalibration would be necessary only when a significant number of modules would have to be replaced. In any case, there is the disadvantage of having control circuitry in each and every module, substantially affecting the cost. On the other hand, calibration based upon the digital output of many array elements, as illustrated in Figures 3 and 4 is easily and economically accomplished, having no impact on the T/R modules.

The criterion for calibration is stated in Section 2 and 3, namely that the echo from a perfect reflector be extinguished or cancelled upon reception. To accomplish this, equations (1) – (4) must be satisfied. These requirements are re-stated in Figures 3 and 4. Once the correction values have been determined, they would be stored in a digital memory controlled by the desired steering angle.

6. CONCLUSIONS

I have shown how transmission polarization errors can be corrected upon reception. The essential features are:

1. Radiating elements that can transmit two orthogonal linear polarizations. A crossed dipole pair, with the dipoles canted at ±45°, is such a radiating element.

2. The same elements would be the receiving elements, but the reception paths through the system would be separated from the transmission paths.

3. The receiving paths would be gain and phase adjusted to produce the desired received polarization.

4. The methods of gain and phase adjustments in the receiving paths are at low power so that desired gain and phase values are easier to obtain.

5. Possible embodiments are:

   a) Correction done at the T/R module level. This implies a correction and calibration procedure that would depend upon a form of “search” so that the subarrays for each group of elements would exhibit the proper output.

   b) Collection of array or subarray received signals, reduction to coherent digital baseband, and correction performed upon the resulting digital signals. At this level, correction could be made very fine, depending on the digital word length.

   c) A variation of (b) consists of parallel/ simultaneous corrections for any desired polarization properties. Figure 4 illustrates this embodiment.

Embodiment 5(c) is the preferred embodiment. The criterion for obtaining the appropriate polarization effects is the extinction of the echo from a perfect, symmetrical, reflector, such as a sphere.

Calibration is to be accomplished over a large number of angles in the antenna’s field of view. The resulting gain and phase values for each angle would be stored in a read-only memory whose output values are controlled by the desired steering angle.

The concepts described in this report are compatible with the operation of subarrays for azimuth and elevation monopulse and for interferometry for cross-beam wind measurement. (Doviak et.al., 2004).

7. REFERENCE

Doviak, R.J. et.al., 2004: “Crossbeam wind measurement with phased array Doppler radar: Theory,” Proc. IEEE 2004 Int’l Radar Conf., Philadelphia, PA, April, 2004, pp. 312-316.