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Measuring the linear depolarization ratio simultaneously with the other polarimetric variables

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1 Introduction

The linear depolarization ratio (L_{DR}) is a measure of the amount of rotation received for a given transmitted pulse imparted by the scattering process. As electromagnetic energy scatters off objects in the atmosphere, a rotation is imparted onto the polarization state. As a result, energy that was purely horizontally polarized will have a slight vertical component and similarly energy that was purely vertically polarized will have a horizontal component upon scattering. The magnitude of the rotation is highly dependent upon the size, shape, and orientation of the objects from which the energy is scattered. As such, L_{DR} is very useful in hydrometeor classification, particularly when paired with other polarimetric variables. Figure 1 shows the hydrometeor phase diagram with respect to L_{DR} and the differential reflectivity (Z_{DR}), and Figure 2 shows the phase diagram with respect to reflectivity (Z) and Z_{DR}. In Figure 1, there is no overlap between the different hydrometeor types, yet in Figure 2 there is significant overlap. Figure 2 is the well established relationship with respect to hydrometeor classification with the polarimetric variables. Thus, one can clearly see the benefit of measuring the linear depolarization ratio simultaneously with the other polarimetric variables.

Current designs of polarimetric radar (Zrnic, 1996; Bringi, 2001; Alford, 2002) do not allow the measurement of L_{DR} simultaneously with the other polarimetric quantities (Z_{DR}, ρ_{hv}, Φ_{DP}, K_{DP}). To measure L_{DR}, one polarimetric channel transmits energy and both polarimetric channels receive the resultant scattered energy. This measurement procedure inhibits the measurement of the other polarimetric variables that require both polarimetric channels to transmit simultaneously. To overcome this limitation of the L_{DR} measurement, a method of uniquely coding the signals in each polarization channel can be used to allow the identification of cross-polar contributions of the received signal.

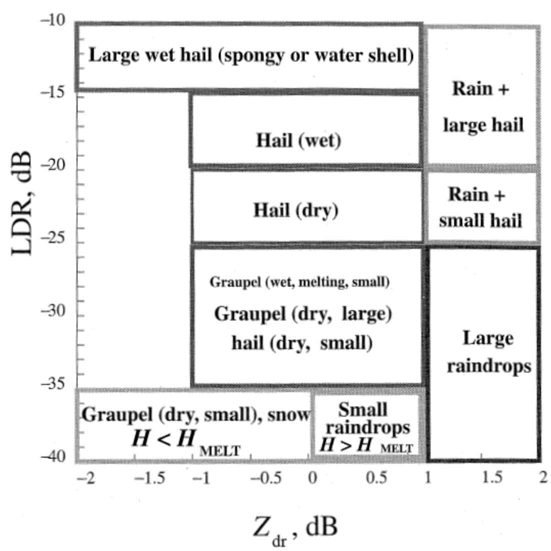

Fig. 1. Hydrometeor diagram in $L_{DR} - Z_{DR}$ space. Note, there is no overlap of hydrometeor types. (Bringi 2001)

A recent trend in weather radar has been to extend the range of high PRF transmission, thereby overcoming the Doppler Dilemma through the use of *phase coding* (Frush, 2002; Hubbert, 2002; Hubbert, 2003; Joe, 1997; Sachidananda, 1999; and Siggia, 1981). Phase coding is accomplished by varying the phase from pulse to pulse, uniquely identifying each pulse. Once each pulse can be identified uniquely, its contribution to the received signal can be recognized. This same concept, when applied to the polarimetric channels, will allow the transmitted pulse from one channel to be uniquely extracted in the other channel. As cross channel contributions to the received signal can be uniquely identified in the received signal, moments quantifying the cross channel contributions, namely L_{DR}, can be measured.

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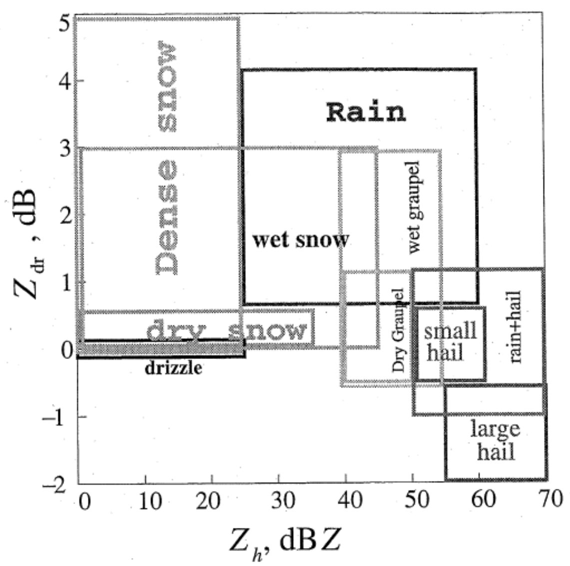

Fig. 2. Hydrometeor diagram in Z – Z_{DR} space. There is significant overlap of hydrometeor types. (Bringi, 2001)

The remainder of this paper discusses the modifications required to the standard polarimetric radar configurations in order to measure L_{DR} simultaneously with the other polarimetric variables and summarizes the theory of signal extraction.

2 System Modifications

Current designs of polarimetric radar typically have some mechanism to allow the measurement of L_{DR}. Some systems, such as the COBRA system in Japan (Nakagawa, 2004) and Florida State University's Seminole Hurricane Hunter (Ray, 2003), are dual transmitter configurations. The determination of L_{DR} using these systems involves allowing only one transmitter to operate, but both receivers process the return signal. Figure 3 shows a block diagram showing the typical configuration of a dual transmitter system. Other systems use a single transmitter and a power divider. These systems employ waveguide switches to determine the transmit path for the pulse energy. The receivers are always in operation and are not affected by the waveguide switches. Figure 4 shows a single transmitter implementation on an EEC Simultaneous Dual Polarization (SIDPOL) weather radar system. Figure 5 shows the configuration that explicitly describes the waveguide switching network required to measure L_{DR}. Performing phase coding on the each polarimetric channel of the radar will require modifications that are specific to each configuration.

Considering Figure 5, the easiest configuration to modify is the dual transmitter. In this configuration no significant modifications are required, only the removal of the waveguide switches. For a Traveling Wave Tube (TWT) or klystron based systems such as COBRA, low power pulse signals are injected into each klystron for amplification. By coding the reference signals with different orthogonal codes, the contributions from each transmit channel can be extracted from the received signal.

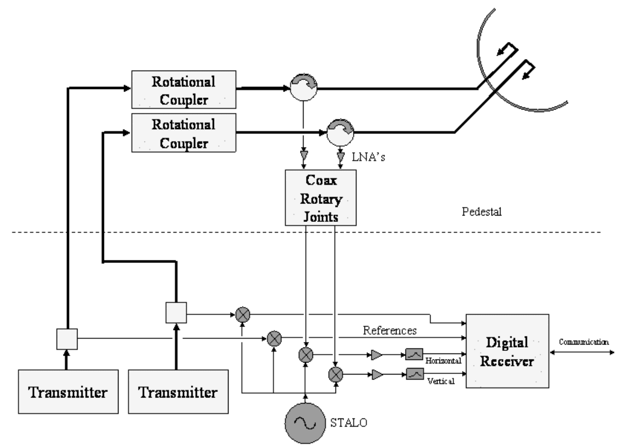

Fig. 3. Typical dual transmitter simultaneous dual polarization radar system

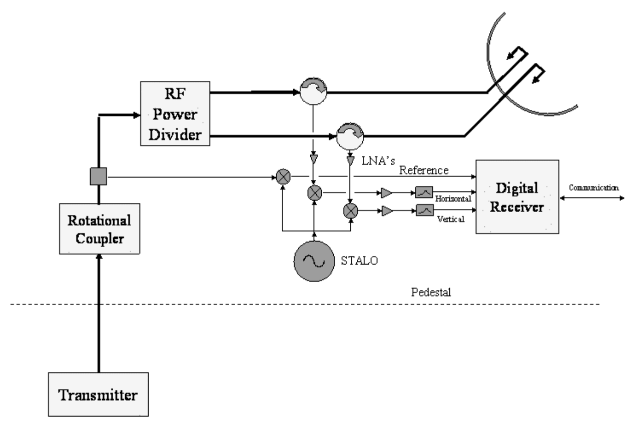

Fig. 4. EEC implementation of simultaneous dual polarization radar.

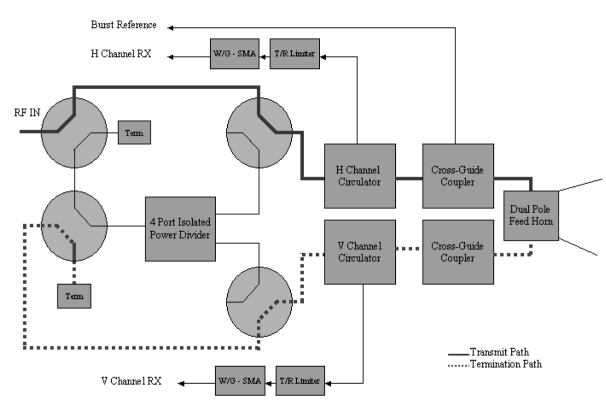

Fig. 5. Waveguide network showing switching required with current simultaneous dual polarization radar system measuring L_{DR}.

If the klystrons share the same STALO, the phase coding can be performed via digital phase shifters before injection into the klystron tube for amplification. Magnetron based systems like the Seminole Hurricane Hunter can run freely, without any sort of explicit phase coding, since by their nature magnetrons transmit with a phase that varies randomly from pulse to pulse.

Modifying a single transmitter configuration is more difficult. The switches will no longer be required, so they may be removed. The coding of the transmitted signals must be performed after the power splitter, so that each channel is coded separately, therefore a high power phase shifter should be employed. Figure 6 is a block diagram of a representative single transmitter configuration for implementing L_{DR} measurement simultaneous with the other polarimetric variables.

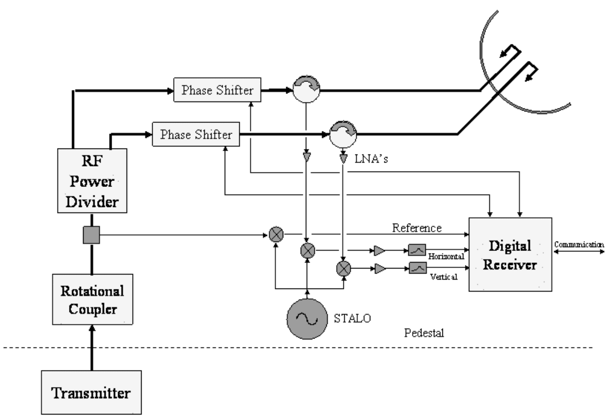

Fig. 6. Block diagram for single transmitter configuration for measuring L_{DR} simultaneously with the other polarimetric variables

3 Extracting cross-polar signals

This section describes the mathematical techniques for extracting the cross-polar signal from the received signal after simultaneous transmission is described. To those versed in the phase coding theory for extending the unambiguous range, the discussion will be hauntingly familiar for the techniques are the same.

To simplify the discussion without a loss of generality, we will assume that the code applied to the signals is orthogonal. Mathematically, two functions are considered orthogonal over an interval [a,b] if the integral over this interval is zero, i.e.

$$\langle h(x) | v(x) \rangle = \int_a^b h(x)v(x)\mathrm{d}x \equiv 0 \quad (1)$$

Given that the signals are orthogonal, then the extraction of cross-polar components is simplified.

For some notation, the transmitted signal is described as a vector with horizontal and vertical contributions,

$$\mathbf{S}_T = H_T\hat{\mathbf{H}} + V_T\hat{\mathbf{V}}. \quad (2)$$

Similarly, the received signal will be described as a vector with received horizontal and vertical components,

$$\mathbf{S}_R = H_R\hat{\mathbf{H}} + V_R\hat{\mathbf{V}}. \quad (3)$$

Due to the rotation of polarization state of the scattered signal from the transmitted, each component of the received signal will in fact be linear combinations of the transmitted components,

$$H_R = \alpha H_T + \beta V_T, \quad (4a)$$

$$V_R = \delta H_T + \gamma V_T. \quad (4b)$$

The idea is to extract the cross-polar component, i.e. V_T from the H_R signal and similarly the H_T from the V_R signal.

Encoding the transmitted signals with the code denoted by $\mathbf{\Psi}_H$ for the horizontal code and $\mathbf{\Psi}_V$ for the vertical code, the orthogonality condition requires,

$$\mathbf{\Psi}_H^{-1}\mathbf{\Psi}_V = \mathbf{\Psi}_V^{-1}\mathbf{\Psi}_H = 0, \quad (5)$$

and the transmitted signal can be written as,

$$\mathbf{S}_T = \mathbf{\Psi}_H H_T\hat{\mathbf{H}} + \mathbf{\Psi}_V V_T\hat{\mathbf{V}}. \quad (6)$$

The received signal will have the same form as described in (3), however the horizontal and vertical components of the received signal may be written thus,

$$H_R = \alpha\mathbf{\Psi}_H H_T + \beta\mathbf{\Psi}_V V_T, \quad (7a)$$

$$V_R = \delta\mathbf{\Psi}_H H_T + \gamma\mathbf{\Psi}_V V_T. \quad (7b)$$

Therefore, the coding that allows the identification of the transmitted polarized state is contained within the components of the received signal.

By applying the inverse code (decoding) to the received signal components described in (7), the co-polar and cross-polar contributions to the received signal may be extracted from each polarization channel. Decoding the received horizontal signal, we obtain,

$$\mathbf{\Psi}_H^{-1}H_R = \mathbf{\Psi}_H^{-1}\alpha\mathbf{\Psi}_H H_T + \mathbf{\Psi}_H^{-1}\beta\mathbf{\Psi}_V V_T = \alpha H_T, \quad (8a)$$

$$\mathbf{\Psi}_V^{-1}H_R = \mathbf{\Psi}_V^{-1}\alpha\mathbf{\Psi}_H H_T + \mathbf{\Psi}_V^{-1}\beta\mathbf{\Psi}_V V_T = \beta V_T. \quad (8b)$$

Similarly, decoding the received vertically polarized signal, we obtain,

$$\mathbf{\Psi}_H^{-1}V_R = \mathbf{\Psi}_H^{-1}\delta\mathbf{\Psi}_H H_T + \mathbf{\Psi}_H^{-1}\gamma\mathbf{\Psi}_V V_T = \delta H_T, \quad (9a)$$

$$\mathbf{\Psi}_V^{-1}V_R = \mathbf{\Psi}_V^{-1}\delta\mathbf{\Psi}_H H_T + \mathbf{\Psi}_V^{-1}\gamma\mathbf{\Psi}_V V_T = \gamma V_T. \quad (9b)$$

Once the cross-polar and co-polar components of the signals are extracted from the received polarimetric waveforms, the estimation of L_{DR} is the application of the definition, i.e. the ratio of the cross-polar contribution to the signal to the co-polar contribution of the signal. Mathematically, this can be written as,

$$\ell_{DR_H} = \frac{\beta V_T}{\alpha H_T}, \quad (10)$$

for the horizontal channel in linear units. Logarithmic units the value is,

$$L_{DR_H} = 10\log\left(\frac{\beta V_T}{\alpha H_T}\right) = 10\log(\beta V_T) - 10\log(\alpha H_T). \quad (11)$$

Similarly, the linear depolarization ration as obtained from the vertical channel is given by,

$$\ell_{DR_V} = \frac{\delta H_T}{\gamma V_T}, \quad (12a)$$

$$L_{DR_V} = 10\log\left(\frac{\delta H_T}{\gamma V_T}\right) = 10\log(\delta H_T) - 10\log(\gamma V_T). \quad (12b)$$

In summary, by encoding the transmit signals with an orthonormal function; the co-polar and cross-polar components in the received signal of each polarization channel may be extracted via decoding of the received signal. Once the co-polar and cross-polar components are extracted, their ratio then defines L_{DR}.

Currently this technique is being evaluated via simulation.

4 Conclusion

The advantages of the Linear Depolarization Ratio for hydrometeor classification and bright-band detection cannot be underestimated. Yet, this one polarimetric variable cannot be measured simultaneously with the other polarimetric variables. Rather, to measure L_{DR} in current polarimetric radars, the microwave energy must be transmitted in one polarization only and received in both polarizations. The value of L_{DR} is then the ratio of the cross-polar component received to the co-polar component.

This paper described a patent pending method by which L_{DR} may be measured simultaneously with the other polarimetric variables. The key to the technique is to provide unique features in the signal within each channel, allowing the identification of original polarization state. This unique coding of the signal can be performed in many ways, but the most recognizable manner is the idea of phase coding, currently used to mitigate multitrip echoes. Once the means to uniquely identify the orientation of the transmitted components within the received signal, then the entire back scattering matrix can be identified and hence all of the polarimetric variables measured simultaneously.

References

Alford, J.L., J.J. Stagliano, J. Helvin, 2002: Commercial Simultaneous Dual Polarization Radar, *Preprints of the 6th Symposium on Integrated Observing Systems, 12 – 17 January, Orlando, Florida, USA.*

Bringi V.N and V. Chandrasekar, 2001: *Polarimetric Doppler Weather Radar*, Cambridge University Press, 662 pp.

Doviak, R. J. V. Bringi, A. Ryzhkov, A. Zahrai, and D. Zrnic, 2000: Considerations for Polarimetric Upgrades to the Operational WSR-88D Radars, *J. Atmos. Oceanic Technol.*, **17**, 257 - 277.

Frush, C., R.J. Doviak, M. Sachidananda and D.S. Zrnić, 2002: Application of the SZ Phase Code to Mitigate Range-Velocity Ambiguities in Weather Radars, *J. Atmos. Oceanic Technol.*, **19**, AMS.

Hubbert, J.C., G. Meymaris, 2002: NEXRAD Range-Velocity Mitigation: Performance Evaluation of the SZ(8/64) Phase Coding Algorithm for Experimental Data, *NCAR Annual Report to the Radar Operations Center, Norman, OK, USA.*

Hubbert, J.C., G. Meymaris and R.J. Keeler, 2003: Range-Velocity Mitigation via SZ Phase Coding with Experimental S-Band Radar Data, *Preprints of the 31st International Conf. on Radar Meteorology, Seattle, WA, USA, 5 – 12 August*..

Joe, P., D. Hudak, J. Scott, R. Passarelli, and A. Siggia, 1997: Operational evaluation of range ambiguity resolution by phase diversity, *Preprints of the 28th Conf. on Radar Meteorology*, Austin, TX, pp. 250-251.

Katsuhiro Nakagawa, K., H. Hanado, N. Takahashi, S. Satoh, T. Iguchi, K. Fukutani, 2004: "Polarimetric Rainfall Observation with COBRA in the Rainy Season", Preprints, *Sixth International Symposium on Hydrological Applications of Weather Radar*, *Melbourne, Australia*, *2-4 February 2004.*

Ray, P., 2003: The Seminole Hurricane Hunter, *Preprints of the 31st Conference on Radar Meteorology, Seattle, WA, 5 – 12 August*.

Sachidananda, M. and D.S. Zrnic, 1999: Systematic Phase Codes for Resolving Range overlaid Signals in a Doppler Weather Radar, *J. Atmos and Oceanic Technology*, **16**, 1351-1363.

Siggia, A.D., 1981: Master's Thesis, MIT.

Zrnic, D.S., 1996: Simultaneous Differential Polymetric Measurements and Co-Polar Correlation Coefficient Measurement, *United States Patent 5,500,646*.

Zrnic, D. S. and A. Ryzhkov, 1999: Polarimetry for Weather Surveillance Radars, *Bulletin of the AMS*, **80**, 389 - 406.