34th Conf. on Radar Meteorology
October 5-9, 2009

P10.8

MODE OF DUAL POLARIZATION: PHASED ARRAY VERSUS PORABOLIC DISH

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ABSTRACT – This paper does not present any novel material whatsoever. Instead, it provides a succinct summary of the pros and cons induced by the modes of dual polarization and contrasts the differences for the two types of radar systems: (1) mechanically steered parabolic dish, such as in Weather Surveillance Radar 1988 Doppler (WSR-88D) and (2) electronically scanned phased array radar (PAR). Our goal is to highlight that PAR has a different set of pros and cons associated with its dual polarization capability compared to that of WSR-88D. The paper discusses why a certain mode of dual polarization on WSR-88D was chosen in the past, and presents ramifications that should be considered when choosing polarization mode on PAR in the future. These considerations may impact the decision making process.

1. INTRODUCTION

Dual polarization in meteorological radar has shown to provide indispensable information for echo classification and rainfall estimation (Ryzhkov et al. 2005, Ryzhkov 2007, Saffle et al. 2009, Melnikov et al. 2009). Dual polarization is referred to a capability of radar system to transmit/receive linear horizontally and vertically polarized waves in a *simultaneous* or *alternating* fashion. Four modes of dual polarization are possible: Simultaneous Transmit Simultaneous Receive (STSR), Simultaneous Transmit Alternating Receive (STAR), Alternating Transmit Simultaneous Receive (ATSR), and Alternating Transmit Alternating Receive (ATAR). These modes have been widely publicized and compared during the recent decade (Doviak at al. 2000, Wang and Chandrasekar 2006, Hubbert et al. 2009, to name a few). An increased interest in determining a preferable mode of dual polarization was driven by the decision that the U.S. Department of Commerce / National Weather Service (DoC/NWS) had to make for the upgrade of 166 Weather Surveillance Radars 1988 Doppler (WSR-88D) to dual polarization capability (Istok at al. 2009, Saffle et al. 2009). Eager to exploit the polarization benefits, NWS funded a study which concluded that STSR dual polarization mode was preferable for the upgrade. The findings of this study are highlighted in Section 2.1. Regardless of the mode chosen by the NWS, supporters of each mode continue debating about errors in polarimetric estimates, importance of associated applications, and overall cost-benefit trade-offs.

The gist of dual polarization for meteorological applications was known for many decades as evident from Giuli (1986) who summarized radar polarization studies from 1950s to late 1980s. Meischner et al. (1997) also noted the advantages of polarization diversity for meteorological observations and pointed that these need to be demonstrated and assessed in the operational environment. Today, we can observe the benefits and limitations offered by each polarization mode on many examples, among which the radar systems epitomized in Table 1.

While dual polarization systems were considered and evaluated, the phased array technology became accessible for civil applications. In 2003 a team of government, university, and industry partners collaboratively created the National Weather Radar Testbed (NWRT). NWRT is a ground for investigation of the passive phased array antenna technology in application to weather observations (Forsyth et al. 2009). Phased Array Radar (PAR) proved its expediency in weather detection (Heinselman et al. 2007). PAR lacks dual polarization and is an old 1970s phased array technology. The plans for a future meteorological radar expose aspiration for dual polarization capable PAR (BASC 2008, Smith and Marshal 2009). The aspiration to attain a PAR system capable of producing polarimetric measurements comparable to those of WSR-88D refuelled the debate on the preference of the polarization mode in terms of errors, feasibility, applicability of the existing suite of algorithms, calibration and cost (Weber et al. 2007, Crain and Staiman 2007, Zrnic 2009, Staiman 2009).

Table 1: Examples of S-band meteorological radars with dual polarization

Radar name and location	Mode of dual polarization
CAMRa – Chilbolton Advanced Meteorological Radar, Reading University, Chilbolton, United Kingdom	ATSR
S-Pol, National Center for Atmospheric Research, Boulder, Colorado, United States	ATSR STSR
CP-2, Australian Bureau for Meteorology, Brisbane, Australia	ATAR
KOUN, National Severe Storms Laboratory, Norman, Oklahoma, United States	STSR
SCU-CHILL, Colorado State University, Boulder, Colorado, United States	STAR, STSR

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In this paper we summarize and contrast the pros and cons induced by the mode of linear orthogonal dual polarization for mechanically steered parabolic dish versus electronically scanning phased array radars

2. LINEAR ORTHOGONAL DUAL POLARIZATION OPERATION MODES

2.1 The choice of STSR mode for WSR-88D

Over a decade ago NSSL performed a trade study for the NWS to determine which of the polarization modes was preferable. A report documenting results of this study indicates that the benefits of STSR outweighed the benefits of ATAR mode (Section 3.1) (Doviak and Zrnic 1998 page 75-76). For example, Ryzhkov and Zrnic (1998) compared errors of theoretical estimates for one of the polarimetric variables *differential phase* for different modes of dual polarization. They concluded that STSR provides a better accuracy, reduced statistical fluctuation, and gives advantages if the normalized Doppler spectral widths that are larger than 0.1, typical for severe storms. In addition, STSR mode promised to have no impact on the existing suite of algorithms, and allowed for an independent addition of the suite for polarimetric variables estimation. Only a minor threshold adjustment was required to address the 3 db sensitivity loss cased by splitting the power between the two polarization channels. A new thresholding scheme was developed at NSSL to improve data quality and address the 3 dB sensitivity loss (Ivic et al. 2008). NSSL documented signal processing techniques for polarimetric oversampling, range velocity ambiguity mitigation techniques, clutter filtering, censoring and estimation of polarimetric variables in STSR dual polarization mode (Zrnic et al. 2008). Several sets of equations for estimation of polarimetric variables and discussions on preference of one set to the other are summarized in NSSL's report (Zrnic and Melnikov 2007).

The echo classification schemes were developed for the polarimetric STSR data. Currently, 6 variables (*reflectivity*, *differential reflectivity*, *specific differential phase*, *correlation coefficient*, and textures of *reflectivity* and *differential phase*) are used to determine 10 classes of scatterers: 1. clutter and anomalous propagation; 2. biological scatterers; 3. dry snow; 4. wet snow; 5. crystals; 6. graupel; 7. big drops; 8. light rain; 9. heavy rain; and 10. hail (Ryzhkov 2007). The number of classes is increasing; for example, smoke plumes were found to produce a distinct polarimetric signature (Melnikov 2009).

A number of S-band research radars use Linear Depolarization Ratio (LDR) to classify atmospheric particles. LDR is a variable acquired in ATAR and STAR mode, when radar transmits a horizontally polarized wave, but receives both co-polar and cross-polar horizontally and vertically polarized waves. However, Doviak et al (2000) stated that LDR is not a robust parameter to quantify properties of precipitation; and for some hydrometeors, LDR is highly correlated with the correlation coefficient and can be found from it using a simple formula (Doviak et al 2000).

Reliability and maintainability of radars for ATAR and STSR modes is not the same. Often in operational environment there is a low tolerance to a radar-down-time caused by maintenance and repair of the expensive high power polarization switch specific to ATAR mode. In these situations, a preference is given to STSR mode even though this mode gives polarimetric measurements with larger errors (Keeler 2009).

In conclusion, authors believe that the STSR mode was chosen for the WSR-88D upgrade because it offered minimal disturbance to operations of the current system.

2.2. A come-back of the alternating mode

Wang and Chandra (2006) derived theoretical cross polarization requirement that would satisfy error requirements in current weather radar system. They declared that an isolation performance of slightly below −20 dB is acceptable in *alternating* mode, however it must be significantly less than −30 dB in *simultaneous* mode. Knowing that a current WSR-88D system has a specification requirement of –30 dB (OST SEC 2007), it is evident that errors in polarimetric variables should be expected. Wang and Chandra (2006) stated that *simultaneous* mode in current configuration might have an unacceptable level of polarization errors. Hubbert et al (2009) exposed these errors providing examples of differential reflectivity fields depicting biases in the ice-phase of storms and attributed these to a non-zero mean canting angle of the ice particles. Similar finding were reported by Ryzhkov and Zrnic (2007): zero-mean canting angle is a good approximation for rain but not for the ice particles in storms. It is, however, understood that the conditions favorable for this huge errors do not occur on a daily basis.

3. COMPARING POLARIZATION MODES

3.1. Comparing polarization modes for WSR-88D

Table 2 highlights some of the facts used that may have influenced NWS' decision in determining a preferable polarization mode for the WSR-88D (Doviak and Zrnic 1998 page 75-76). The scores here are for an example purpose only and do not represent the actual scoring. Columns 3 and 4 expose that STSR mode scored higher than ATAR mode.

Data acquired in *simultaneous* mode enables total compatibility for current WSR-88D processing schemes such as range-velocity ambiguity mitigation and clutter filtering procedures. *Alternating* mode is unsuitable for batch mode, staggered/variable pulse repetition frequency modes. *Alternating* mode need twice the time for data acquisition compared to *simultaneous* mode. *Simultaneous* mode enables a direct estimation of correlation coefficient at lag zero, and differential phase with unambiguous interval twice that in the *alternating* mode. In *simultaneous* mode there is no need for a costly high-power ferrite switch, and no associated power loss that might exceed 1.5 dB in the *alternating* mode. However, *Alternating* mode allows measuring depolarization ratio. The cross polarization isolation is better in *alternating* mode due to mechanical switching. The switch has a relatively short lifetime and generates excessive acoustic noise. In *simultaneous* mode the receivers must be perfectly matched and a very good level of cross polarization isolation is required. Even so, large propagation errors still are possible behind the ice-phase of storms.

Authors suggest to the research community to compare the performance of radars from Table 1. Of the particular interest would be the performance analysis for four radars in four polarization modes, i.e., CAMRa in ATSR, CP-2 in ATAR, KOUN in STSR and SCU-CHILL in STAR. Such comparison would enable meteorological and engineering community to truly assess how much each mode gives for the money and what is the best trade.

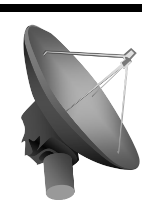
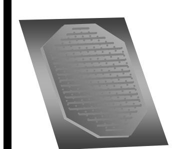
3.2. Comparing polarization modes for PAR

In this section authors score the same items as in Section 3.1 but considering a phased array antenna instead of a parabolic dish reflector. Table 2 columns 5 and 6 expose that ATAR mode scored higher than STSR mode in this assessment.

PAR conceptually allows for a more rapid scan than WSR-88D. PAR's STSR mode is twice faster than ASAR. In addition to rapid scan, in simultaneous mode there is direct compatibility with current NEXRAD algorithms, and with current NWRT set up. However, large propagation errors behind the ice-phase of storms could occur. There are several challenges. Among the most important ones are meeting cross polarization requirements, matching the two beams, calibrating the polarimetric variables as a function of electronic beam steering. Alternating mode allows for a slower scan, provides compatibility with existing NCAR algorithms, depolarization ratio can be measured, no need to match the two receivers because there is only one. In addition, there is no challenge in cross polarization isolation, low propagation errors in ice phase, low power switch, good performance, and long life. The fact that this mode is unsuitable for batch mode, staggered/variable PRF still holds.

Knowledgeable readers are invited to modify the scoring system exemplified by the authors to clarify which items are critical and most beneficial for meteorological applications. From the presented scoring, ATAR might be a favorable choice for the meteorological missions of the future multifunction PAR for civil applications.

Table 2: Example of scoring when considering dual polarization mode in parabolic dish reflector and phased array antennas

					
		STSR	ATAR	STSR	ATAR
1	Data acquisition time, rapidness of a scan	+1	-1	5	+1
2	Data acquisition compatibility with WSR-88D and its signal processing	+5	-1	5	-1
3	Maximum unambiguous velocity depends on sample spacing only	+1	-1	+1	-1
4	Velocity estimate is decoupled from f_{DP}	+1	-1	+1	-1
5	f_{DP} unambiguous interval is twice that in alternating mode	+1	-1	+1	-1
6	Need for a costly high-power ferrite switch	+1	-5	+1	+1
7	Power loss or No power loss >1.5 dB due to switch	+1	-1	0	0
8	Need a second receiver	-5	+1	0	0
9	The two receivers must be matched	-1	+1	-1	+1
10	Low power switch, good performance	0	0	0	+5
11	The cross polarization isolation must be good (<<–30dB)	-1	+1	-5	+5
12	Total compatibility with current WSR-88D processing,	+1	-1	+1	-1
13	Enables R-v mitigation, clutter filtering	+1	-1	+1	-1
14	Suitable for batch mode, staggered and variable PRT	+1	-1	+1	-1
15	$\|r_{hv}(0)\|$ and f_{DP} can be estimated directly,	+1	-1	+1	-1
16	Propagation errors due to ice-phase of storms and non-zero canting angle	-1	+1	-1	+1
17	Depolarization ratio can be measured	-1	+1	-1	+1
18	Fewer errors because of number of samples for the same dwell time	+1	-1	+1	-1
19	Automatic suppression of overlaid echoes from even trip reflectivity	-1	+1	-1	+1
20	Excessive acoustic noise generated by the high power polarization switch	0	-1	0	+1
21	Lifetime	0	-1	0	+5
	Score:	**6**	**-12**	**10**	**13**

4. CONCLUSION

The paper discussed why a certain mode of dual polarization on WSR-88D was chosen in the past, and presented ramifications that should be considered when choosing polarization mode on PAR in the future. These considerations may impact the decision making process. The pros and cons induced by the modes of dual polarization are summarized and scored for the two types of radar systems: mechanically steered parabolic dish and electronically scanned phased array radar. Presented scoring indicates that preferable dual polarization mode for PAR is different than that for WSR-88D.

AKNOWLEGEMENT

The authors acknowledge the administration of Lockheed Martin MS2 *Strategic Research and Technology Development* and *Advanced Systems* for support. The authors appreciate Byron Tietjen for his review and valuable advice.

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