P13.2 X-BAND SIMULTANEOUS HORIZONTAL AND VERTICAL TRANSMIT DATA AND CROSS-COUPLING

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1. INTRODUCTION

The simultaneous transmission and reception of H (horizontal) and V (vertical) polarized waves (called SHV mode) has become a very popular way to achieve dual polarization for weather radar (Doviak et al. 2000). Several papers have appeared in the literature analyzing and illustrating the effects of cross-coupling of the H and V electric field components. S-band measurements have been the focus of these papers (Wang and Chandrasekar 2006; Ryzhkov and Zrnić 2007; Hubbert et al. 2009a,b). Here, experimental X-band data from the new dual-polarized TEAM-R (Taiwan Experimental Atmospheric Mobile–Radar), owned and operated by National Central University, Taiwan, are used to demonstrate cross-coupling effects on differential reflectivity (Z_{dr}) and differential phase (ϕ_{dp}). Cross-coupling can be caused by either non-zero mean canting angle of the precipitation medium or by antenna polarization errors. Here we focus on the former. Both RHI scan data as well as vertical pointing data are used to investigate and demonstrate cross-coupling artifacts.

2. MODELING SHV CROSS-COUPLING

The scattering model used is described in Hubbert and Bringi (2003); Hubbert et al. (2009a,b). The transmit wave, the propagation medium, the backscatter medium and antenna errors are included. Here, the model is simplified and the backscatter medium is modeled with the 2×2 Sinclair matrix. The received voltages can be expressed (Bringi and Chandrasekar 2001)

$$\begin{bmatrix} V_h^r \\ V_v^r \end{bmatrix} = \begin{bmatrix} i_h & \xi_h \\ \xi_v & i_v \end{bmatrix} \mathbf{R}(-\theta) \begin{bmatrix} e^{\gamma} & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \mathfrak{z} & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} e^{\gamma} & 0 \\ 0 & 1 \end{bmatrix} \mathbf{R}(\theta) \begin{bmatrix} i_h & \xi_v \\ \xi_h & i_v \end{bmatrix} \begin{bmatrix} E_h^t \\ E_v^t \end{bmatrix} \quad (1)$$

where the matrices are (from left to right), the received voltages, antenna error, Cartesian rotation, propagation, backscatter, propagation, Cartesian rotation, antenna error and transmit electric fields. The backscatter and precipitation particles are aligned in the horizontal and vertical planes. $\gamma = (\lambda_1 - \lambda_2)$ is a complex number that accounts for differential propagation effects ($\lambda_{1,2}$ are the H and V complex propagation constants), $\mathfrak{z} = S_{hh}/S_{vv}$, and $\xi_{h,v}$ are complex antenna errors. Since we are only concerned with the differential quantities, SHV Z_{dr} and SHV ϕ_{dp}, proportionality constants and gains are omitted. For this study, the antenna errors are zero, i.e., $\xi_{h,v} = 0$ and cross coupling caused by non-zero mean canting angle, θ, is the focus.

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3. TEAM-R EXPERIMENTAL DATA

Shown in Fig. 1 is a RHI of TEAM-R SHV data. There is a small convective core at 12 km range. The melting level from the ρ_{HV} panel is around 4.5 km height. The ice phase begins at around 5 km height. Note the radial stripe of high Z_{dr} in the ice phase. It is interesting that the accompanying ϕ_{dp} along this radial shows very little phase shift. The Z_{dr} bias is likely due to a non zero mean canting angle of the precipitation in the ice phase along that radial. Modeling results below support and explain these signatures.

Figure 2 is TEAM-R vertical pointing data. The melting level is clearly seen in the ρ_{hv} data at about 5.2 km height and the total precipitation echo depth, taken as outer edge of the white color data in the Z panel, is 15 km. Note the locations of the maxima/minima of Z_{dr} data (light brown and green colors) and of ϕ_{dp} (green and purple). They do not coincide as one might "intuitively" think they should. The model data below explains this.

4. MODEL DATA

In the following plots, the backscatter medium has a Z_{dr} of 0.5dB. SHV Z_{dr} and SHV ϕ_{dp} are plotted in polar coordinates as a function of the principal plane ϕ_{dp} (0° to 8°) of the propagation medium and θ, the rotation angle. The differential attenuation is 0.03 dB/deg, a typical value for X-band. The transmit phase difference, $\arg\{E_v^t E_h^{t*}\}$, is a parameter. For all plots, $|E_v^t| = |E_h^t|$. Note again from the experimental data of Fig. 2 that the

Z_{dr} and ϕ_{dp} maxima/minima do not line up along radar radials. This can be attributed to SHV operations and a phase difference between the H and V transmit waves. Shown in Figs. 3,4,5 and 6 are SHV Z_{dr} (left column) and SHV ϕ_{dp} (right column) with transmit differential phase as parameter: $\arg\{E_v^t E_h^{t*}\} = 0, 45, 90, -90$ for Figs. 1,2,3,4 respectively. $\theta = 0°$ corresponds to vertical and is measured clockwise positive. ϕ_{dp} principal plane is the radial independent variable. To mimic the experimental data plots and for better data viewing, an offset of $5°$ was added to the ϕ_{dp} principal plane values. This causes the seen inner circle of blank data. The plots demonstrate that radial lines of maxima and minima of SHV Z_{dr} and ϕ_{dp} do not coincide. Consider the radial in Fig. 5 marked by the black line. The increase in SHV ϕ_{dp} is only $1.7°$ along this radial while the SHV Z_{dr} increases to about $1.15\,\mathrm{dB}$. Since the intrinsic Z_{dr} is $0.5\,\mathrm{dB}$, this represents a bias of about $0.6\,\mathrm{dB}$. Thus, the model demonstrates how significant SHV Z_{dr} bias can be observed while simultaneously the accompanying accumulation in SHV ϕ_{dp} is small. Note the principal plane ϕ_{dp} accumulation is by necessity much larger than the measured accumulation in SHV ϕ_{dp}, though both are relatively small.

Finally, Fig. 7 shows modeled SHV Z_{dr} bias with the mean canting angle of the propagation medium as a parameter (see paper 9A.3 in these proceedings). For the left panel, $\arg\{E_v^t E_h^{t*}\} = 0°$ (i.e., $45°$ linear transmit polarization) and for the right panel, $\arg\{E_v^t E_h^{t*}\} = -90°$ (i.e., circular transmit polarization). For the left panel, $10°$ principal plane ϕ_{dp} can accumulate and the SHV Z_{dr} bias is kept within about $0.1\,\mathrm{dB}$. In contrast, the right panel shows that only $3°$ or $4°$ ϕ_{dp} need to accumulate before significant Z_{dr} bias will be seen. This then shows that very little ϕ_{dp} needs to accumulate in the ice phase before significant SHV Z_{dr} bias is observed such as the Z_{dr} bias stripe seen in Fig. 1.

5. CONCLUSIONS

Simultaneous transmission of H and V polarization waves (termed SHV mode) is now a popular way to construct dual-polarization radar systems. The technique is based on the assumption of 1) zero-mean canting angle of the precipitation medium and 2) negligible antenna polarization errors. Zero-mean canting angle is a good approximation for rain but not for the ice phase of storms. Experimental X-band data from the new dual-polarized TEAM-R (Taiwan Experimental Atmospheric Mobile–Radar), owned and operated by National Central University, Taiwan, were used to demonstrate cross-coupling effects on differential reflectivity (Z_{dr}) and differential phase (ϕ_{dp}). Interesting artifacts were seen in both a RHI scan and vertical pointing data. A model was used to simulate the observed SHV Z_{dr} and ϕ_{dp} signatures. The model showed that cross-coupling of the H and V transmitted wave caused by non zero mean canting angle of the propagation medium will cause the observed artifacts. The nature of the SHV Z_{dr} and ϕ_{dp} signatures is a strong function of the differential transmit phase. Understanding of these demonstrated biases is vital for correct microphysical interpretation of SHV data.

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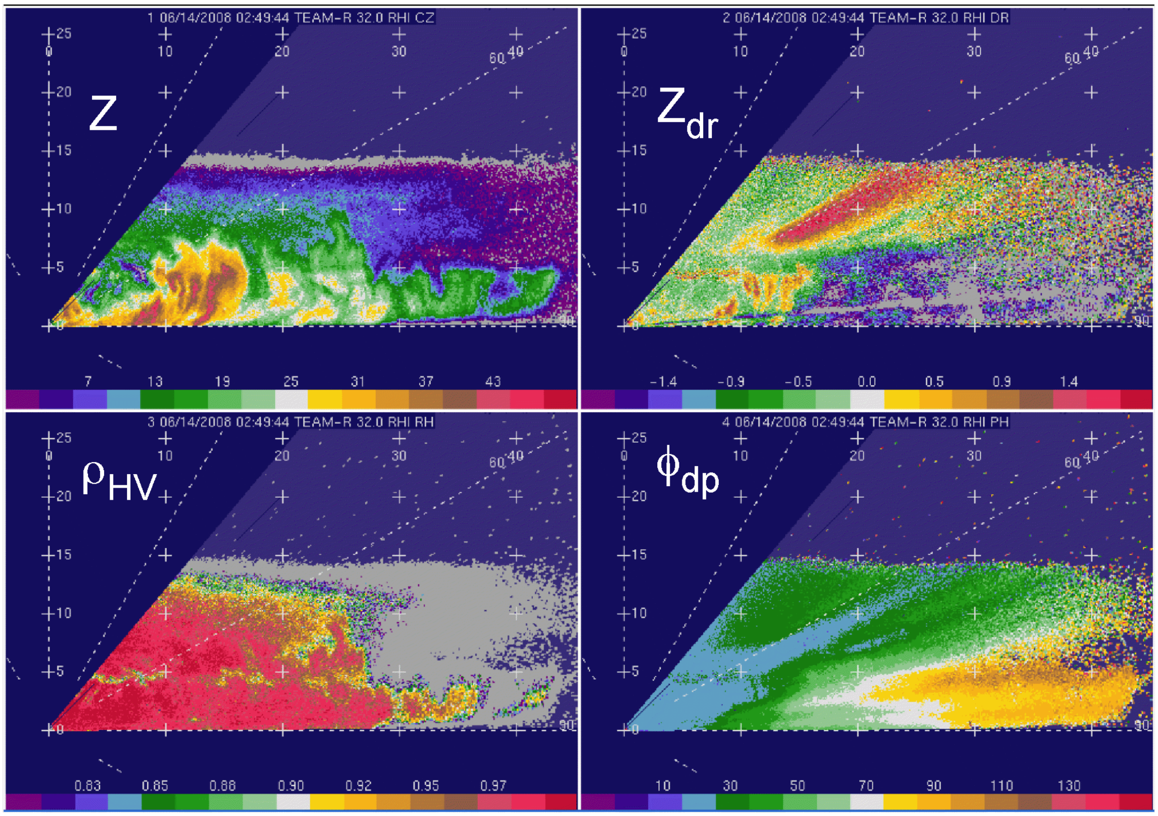

Figure 1: *TEAM-R RHI SHV data.*

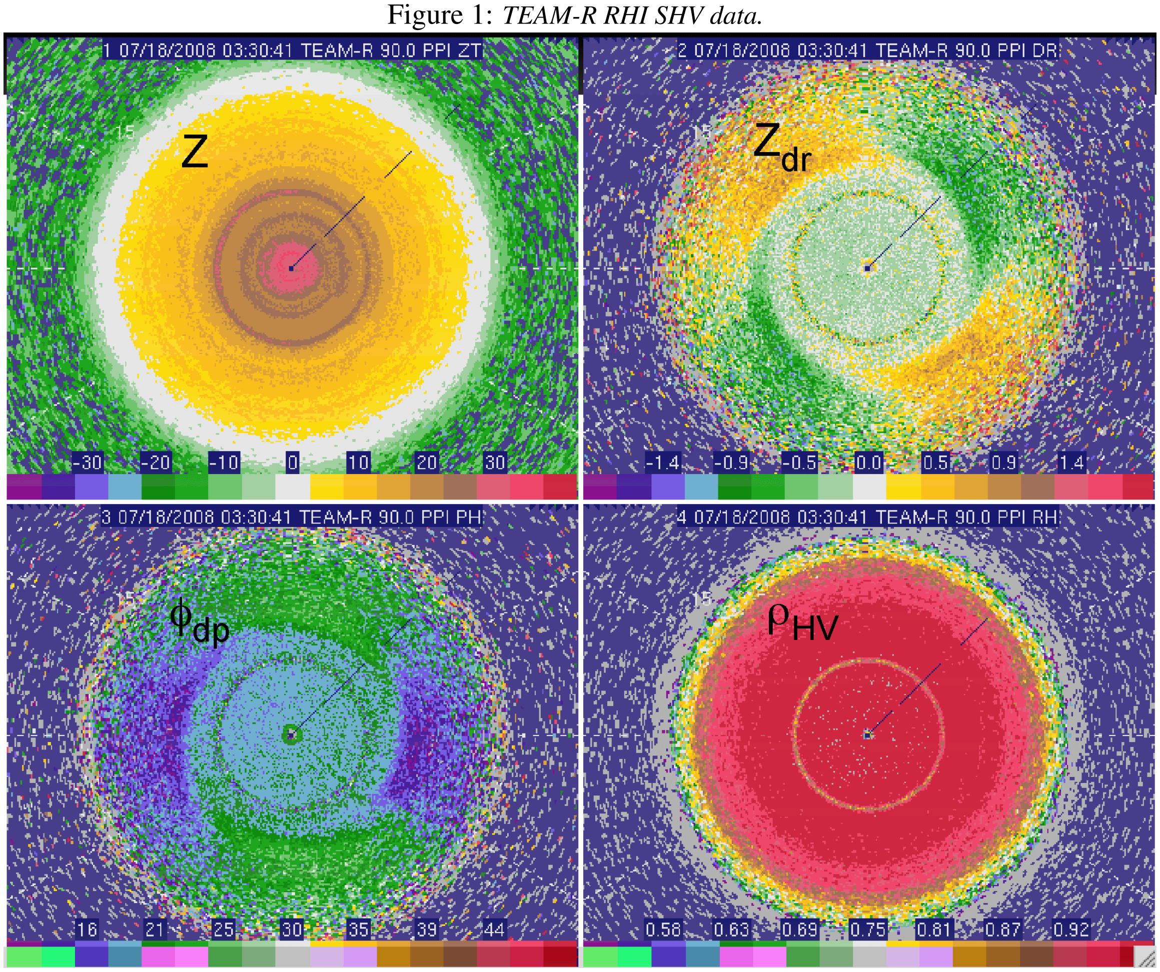

Figure 2: *Vertical pointing TEAM-R data.*

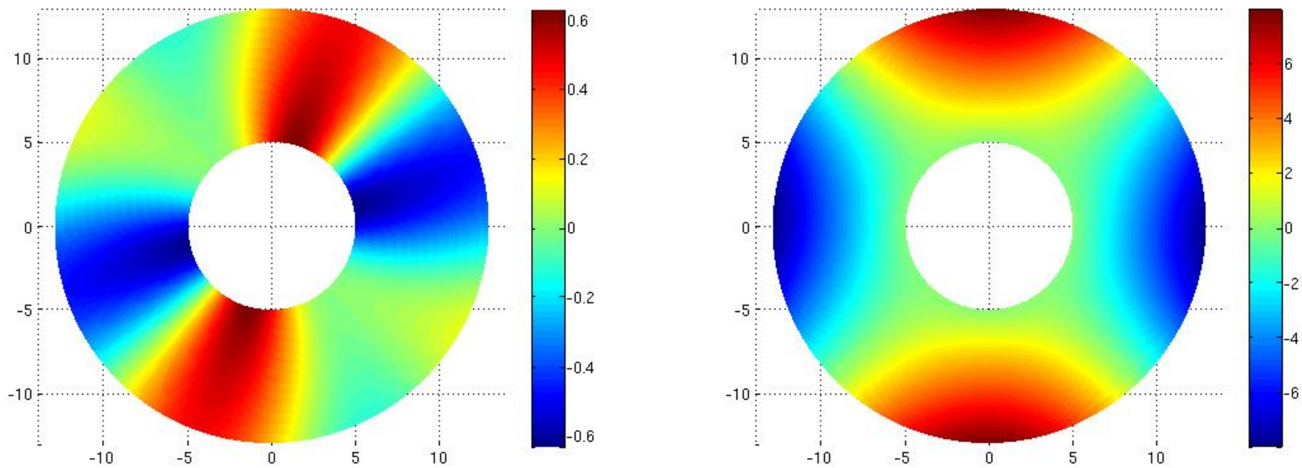

Figure 3: *SHV modeled data. The left panel is Z_{dr} (dB) and the right panel is SHV ϕ_{dp} (degrees).* $\arg\{E_v^t E_h^{t*}\} = 0°$. *The polar angle is θ, the rotation angle, with zero degrees being vertical. The radial independent variable is principal plane ϕ_{dp} in degrees.*

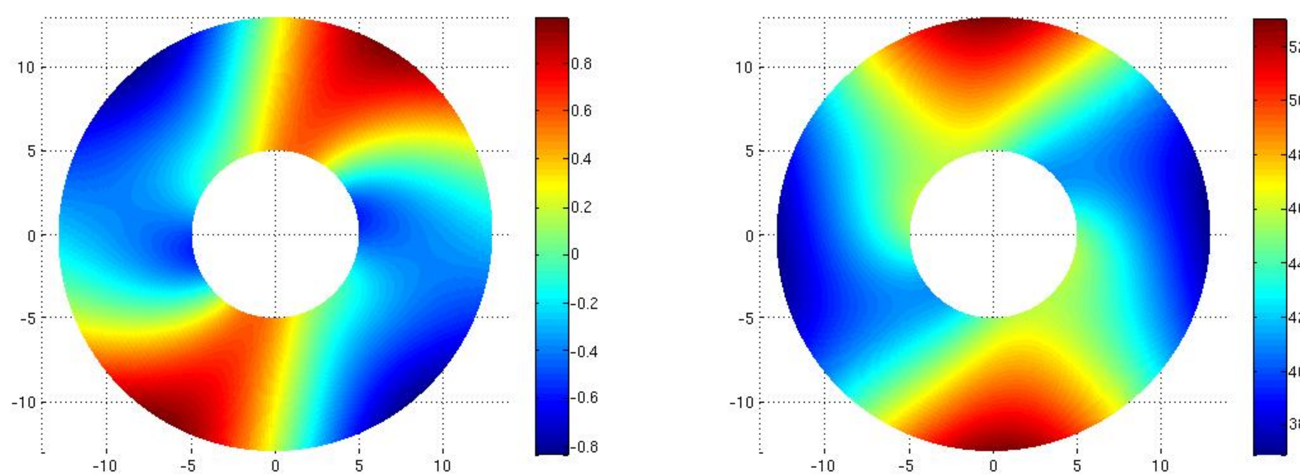

Figure 4: *SHV modeled data. The left panel is Z_{dr} (dB) and the right panel is SHV ϕ_{dp} (degrees).* $\arg\{E_v^t E_h^{t*}\} = 45°$

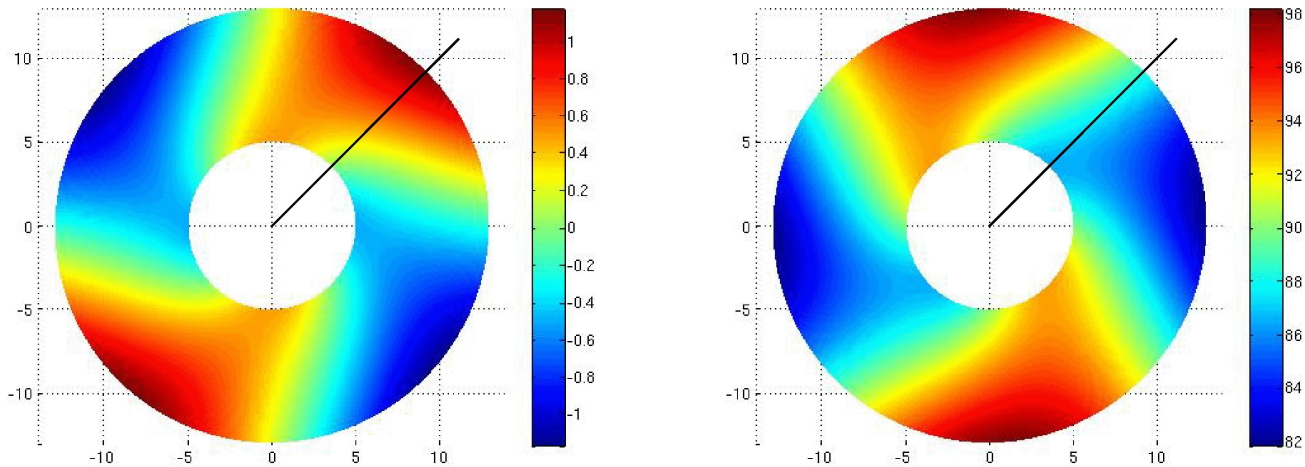

Figure 5: *SHV modeled data. The left panel is* Z_{dr} *(dB) and the right panel is SHV* ϕ_{dp} *(degrees).* $\arg\{E_v^t E_h^{t*}\} = 90°$

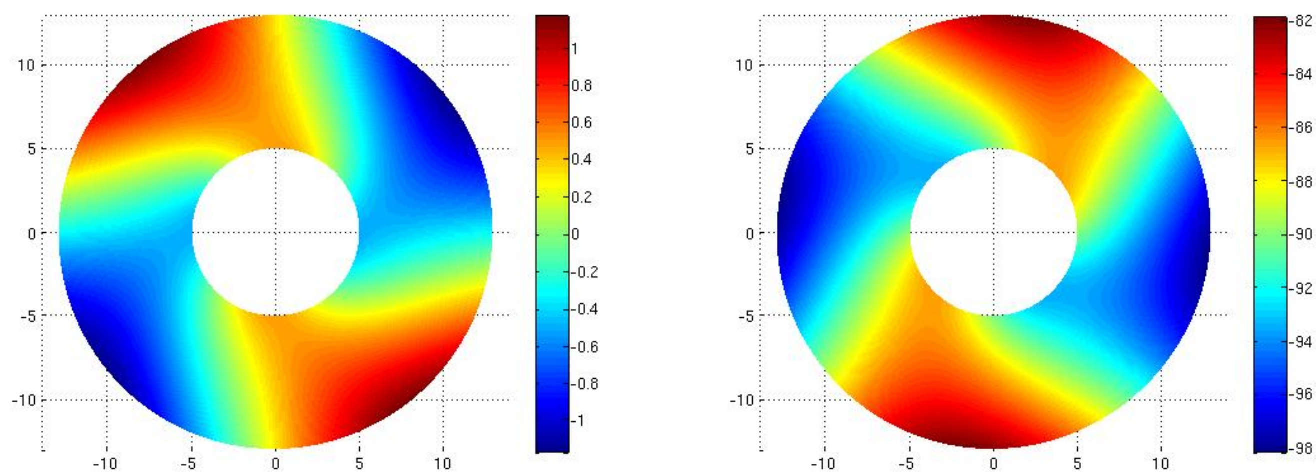

Figure 6: *SHV modeled data. The left panel is* Z_{dr} *(dB) and the right panel is SHV* ϕ_{dp} *(degrees).* $\arg\{E_v^t E_h^{t*}\} = -90°$

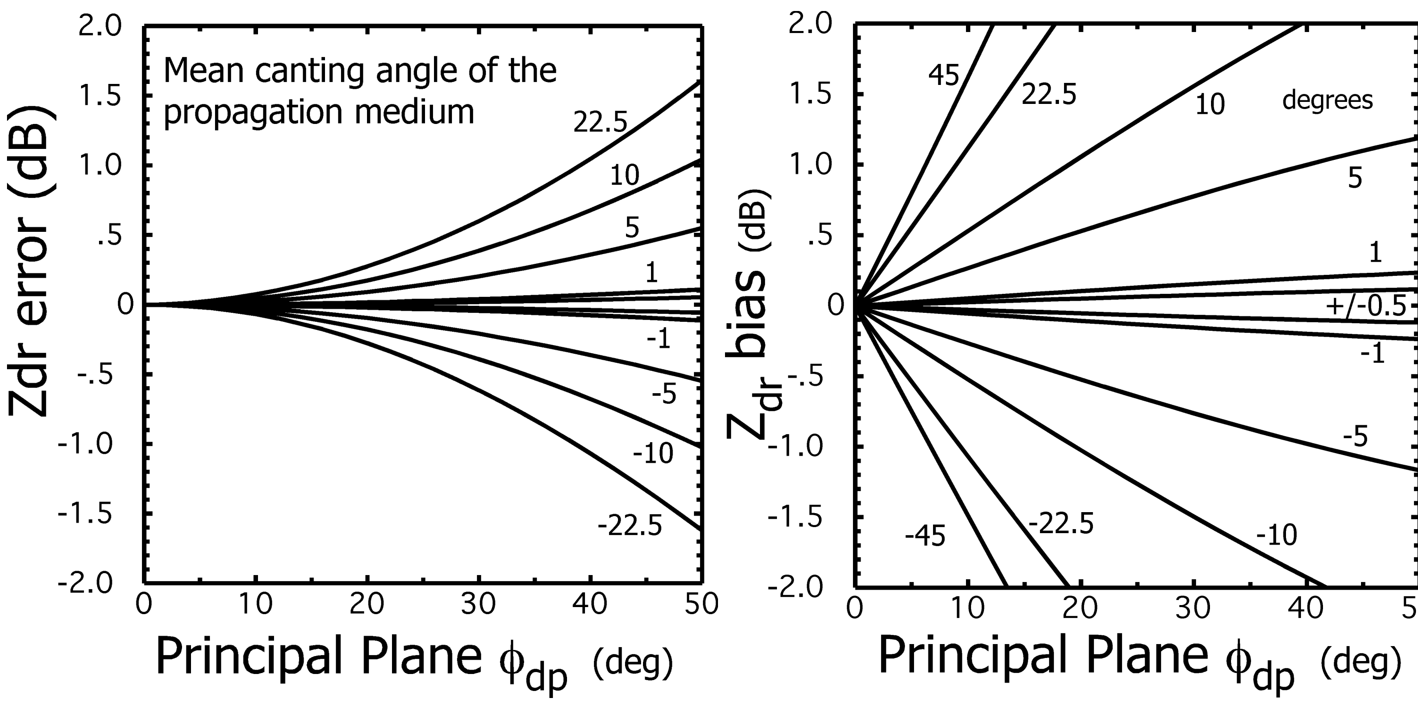

Figure 7: *Modeled SHV Z_{dr} bias with mean canting angle of the propagation medium as a parameter from paper 9A.3 in this proceedings. Left panel:* $\arg\{E_v^t E_h^{t*}\} = 0°$. *Right panel:* $\arg\{E_v^t E_h^{t*}\} = -90°$