CALIBRATION OF DIFFERENTIAL REFLECTIVITY ON THE X-BAND WEATHER RADAR

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1. INTRODUCTION

The doppler weather radar with polarimetric upgrade will improve the appearance of precipitation estimation and hydrometeor classification. The polarimetric parameter of differential reflectivity (Z_{DR}) is valuable for detecting the mean size of raindrops, which is useful for knowing drop size distribution (DSD) of precipitation. It need high accuracy to apply Z_{DR} for rainfall estimation, for example, rainfall estimator tested by Ryzhkov et al. (2005) has a bias error of 18% if the bias of Z_{DR} is 0.2 db. Therefore, Calibration of Z_{DR} must be done very carefully.

Bias of Z_{DR} comes from three main part of radar system: transmitter, receiver and feed line system. For the radar that transmits simultaneous horizontal and vertical polarizations(SHV mode), transmitter usually has one power divider to split power generated by klystron into two outputs as horizontal and vertical polarization transmission power. The loss difference between two outputs of power divider is main bias of transmission chain. The radar with SHV mode usually has two receivers which simultaneously receive horizontal and vertical polarization echoes. The unbalance gain between two receivers isn’t static and unique over full dynamic ranges, which generate bias into echoes. Feed lines consist of waveguide, circulator, rotary joints, feeder, etc. The loss difference of feed lines also produces bias during transmission and receiving. The bias can be expressed as:

$$Z_{DR(BIAS)} = L_{tr} + G_{re} + 2L_{fl}$$

L_{tr} denotes loss difference of transmitter, G_{re} denotes gain difference of receiver, L_{fl} denotes loss difference of feed lines.

There are many existing methods for Z_{DR} calibration(Melnikov 2003): test signals, solar radiation, and precipitation, etc.

In this paper, we will

- implement and test existing calibration method on the X-band polarimetric weather radar built at the Key Laboratory of Atmospheric Sounding in Chengdu of Sichuan province(abbr. XD radar).
- improve test signal method to calibrate active receiving chain that is not static and unique over full dynamic range.
- design procedure to correct Z_{DR} based on calibration .

2. CALIBRATION IMPLEMENTATION

The XD radar located in Chengdu University of information technology is dual-polarimetric doppler weather radar. The XD radar adopts SHV mode. Fig 1 below introduces basic diagram of XD radar. The XD radar has only one transmitter. The power generated by klystron is split into H and V transmission by power splitter. The radar has dual-channel receiver which simultaneously receive H and V polarization echoes. The existing Z_{DR} calibration methods such as test signal solar calibration and weather target calibration are implemented in this radar.

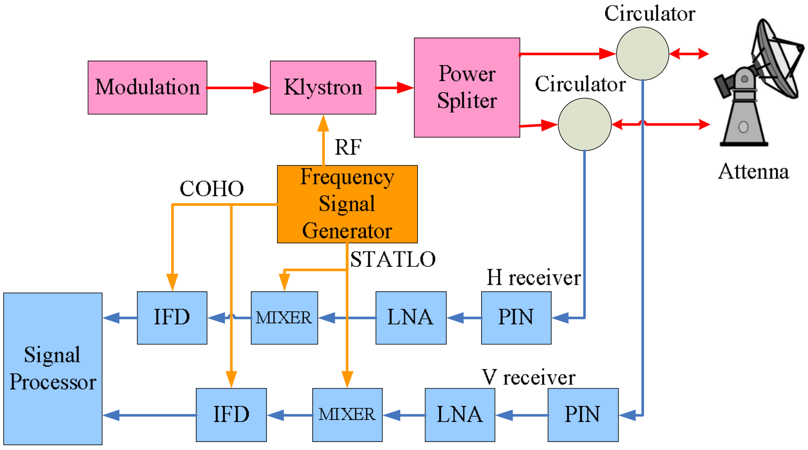

Fig 1.Basic diagram of XD radar

The XD radar has a built-in test signal calibration system which is used to conventional noise calibration, dynamic range calibration, radio frequency driven calibration (RFD), klystron driven calibration (KD) and so on. RFD and KD are single channel test in XD radar, they aren't suitable for measuring system differential reflectivity in-transmit. In coming technical upgrade, dual-channel transmitted power can be monitored by adding directional coupler after power splitter. Currently, built-in test signal is only used in receiving chain polarimetric calibration. CW test signal produced by frequency generator firstly get through digital-control attenuator and phase shifter, then is split into two channel by power splitter and separately injected into low noise amplifier (LNA) of H and V receiver. Finally, signal processor calculates gain difference G_{re} between H and V active receiving chain. In experiment, we discovered that G_{re} is not static over time and not unique over full dynamic range of receiving. Fig 2 shows the result curve. It shows that mean G_{re} is less than 1dB but is variable via input power variation. Considering the standard deviation of statistic G_{re} should be less than accuracy of 0.2 dB, the scale of input power is mainly distinguish as three parts: strong power range (up to saturation), linear amplified range and weak power range(down to receiving sensitivity). Each range has its own mean G_{re}. Sometimes active part of receiver isn't stable, the standard deviation of G_{re} in the linear amplified range surpasses the accuracy of 0.2dB. The linear amplified range should be distinguished as detailed range to calculate corresponding gain difference.

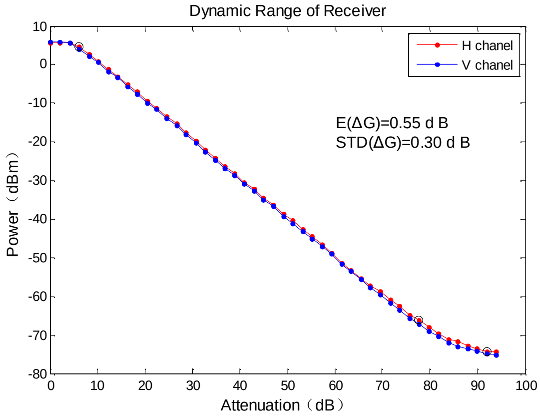

Fig 2.dyanmic range of dual-receiver

Loss difference of feed lines L_{fl} can be calculated from factory specification of each part of feed lines, and is adjusted close to zero dB when radar is deployed. However, it is unavoidable that L_{fl} varies via longtime aging. The XD radar utilizes solar calibration method to monitor the variation of L_{fl}. It has been proved that solar calibration method can be used to measure system differential reflectivity in-receiving including feed lines and receiver. The measured Z_{DR} from solar echoes consists of L_{fl} and G_{re}.The measured Z_{DR} minus G_{re} is L_{fl}, where G_{re} is obtained from test signal method. The XD radar need antenna scanning to search position of peak SNR of solar echoes. Fig 3 shows the H and V solar echo power variations as antenna scanning, the system differential reflectivity in-receiving is 0.52dB at maximum SNR ,the value is very close to active receiver signal test result of 0.55dB at same time and at same SNR level(approximately SNR of 5dB after filtering). It indicated that the L_{fl} of XD radar is about -0.03 dB less than the accuracy of 0.2dB.

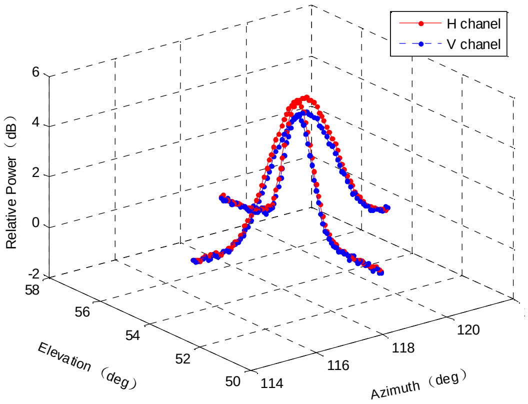

Fig 3. Power variation of solar echoes via elevation and azimuth

The weather target method can calibrate system differential reflectivity including entire transmission chain and receiving chain(Bringi and Chandrasekar 2001). If the weather target are spherical, the measured Z_{DR} should be zero, if not there are differences in receiver gains and transmitted powers. So, Z_{DR} calibration with appropriate weather can monitor the differences of receiver gain and transmitted power differences. RYZHKOV et al (2005) concluded that Z_{DR} measurements in rain will decrease as elevation lifting. Their measurement show that the value of Z_{DR} for severe hailstorms varies between 0 and 0.1 dB above elevation of 85°. If for light rain the value will be much less. Meanwhile, antenna needs to be rotated 360° in azimuth to average Z_{DR} for eliminating periodic variation (Bringi and Chandrasekar 2001). XD radar lift antenna up to 85° elevation and operate PPI scanning mode. Fig 4 shows a PPI measurement of a moderate rain captured on April. 17, 2008 at 1404 UTC. Bright band can be easily found from fig 4. The freezing line is about 100 to 300 meters above bright band. Dry snow can be found above freezing line which is suitable as weather target of calibration. Fig displays histogram of Z_{DR} and H received power collected above freezing line. The collected data are averaged in azimuth. The value of Z_{DR} in the mean is about 0.51 dB and the standard deviation of Z_{DR} is about 0.2 dB. The value minus G_{re} and double L_{fl} is L_{tr}. The L_{tr} calculated is about 0.02dB which is also less than the accuracy of 0.2dB.

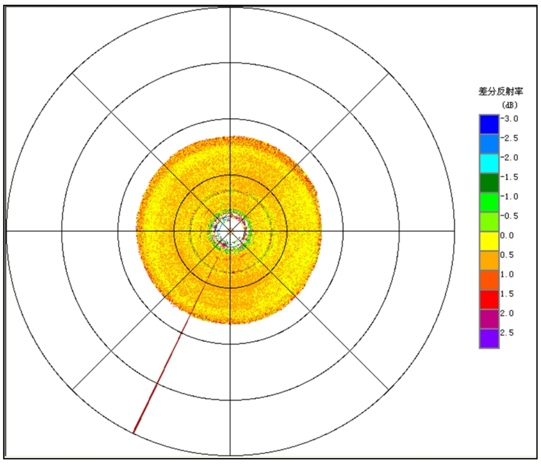

Fig 4. PPI of a moderate rain at elevation of 85°, on April. 17, 2008 at 1404 UTC.

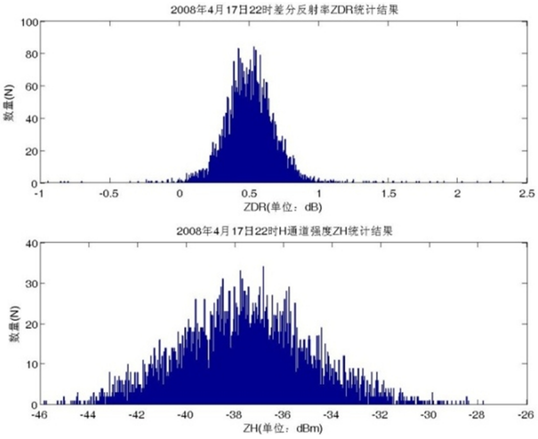

Fig 5. Histogram of Z_H and Z_{DR} above freezing line at elevation of 85°, on April. 17, 2008 at 1404 UTC.

The experiment was taken from April to

June in 2008. The measurement indicated that the G_{re} is main factor of system differential reflectivity and G_{re} varied from 0.4 to 0.7 dB at that time. The sum of L_{tr} and L_{fl} is usually less than 0.1 dB and relatively static. Neglecting tiny variation of L_{tr} and L_{fl} in short time (several days or weeks), test signal is valid measure for monitoring the variation of system differential reflectivity. Test signal method is operated during interval of volume scanning in XD radar.

3. COMPENSATION OF Z_{DR}

Base on calibration, there are two ways correcting Z_{DR} measured: hardware way and software way. The hardware way is a set of devices that are used to adjust the amplitude and phase of H receiving channel. XD radar doesn't utilize hardware way to correct Z_{DR}. Because correction value is usually tiny (less than 1dB) and need to be stable, which aren't easy to reach at for hardware. Besides, correction value set by hardware is unique along full dynamic range of receiver, while test signal calibration suggests that correction value should vary via SNR variation of echoes. Therefore, XD radar develop a software method to correct Z_{DR} measured. The basic procedures of software correcting are:

- Based on test signal calibration, full dynamic range is distinguished as SNR range which has its own G_{re}.
- Calculating the SNR of H received echoes.
- Judging which SNR range the echoes belong to.
- Adding corresponding compensation value into Z_{DR} measured.

4. CONCLUSION

The XD radar is an X-band Doppler dual-polarization weather radar in Chengdu, China. Three existing differential reflectivity (Z_{DR}) calibration methods are tested on the XD radar, which use test signal from built-in radar generators, solar echoes and weather scatters at high elevation. The measurement displays that the variation of system differential reflectivity is mainly arisen by active part of receiver, which can be calibrated with test signal.

Test signal measurement displays that the standard deviation of gain difference of active receiver is usually more than 0.2 dB for full dynamic range. The dynamic range of receiver need to be distinguished as SNR range, in which standard deviation of Z_{DR} is less than 0.2 dB. Each SNR range has its own gain difference in the mean. Calibration of test signal is operated during interval of volume scanning.

In real operational environment, the XD radar develop a software correcting method which is suitable for tiny, stable and multi-value adjustment of Z_{DR} measured.

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