P1.16 MEASUREMENT ISSUES CONCERNING ZDR OFFSET

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## 1. INTRODUCTION

Measurement of received radar signals in different polarization modes provides additional information used in a variety of measurements including hydrometeor classification. This possibility arises due to radar models assuming a spherical target (raindrops, hail, graupel, etc) that are in fact not spherical. For example, a falling raindrop is an oblate spheroid, extended in the horizontal and compressed in the vertical. The result is that horizontally polarized returns from rain will have a slightly greater power than vertically oriented returns.

Ideally the transmitted power is independent of polarization modes. However, in a real radar system where polarized pulses are transmitted via their own horns, waveguides, and couplers and switched by an RF switch (which may itself not be perfectly balanced), transmission of exactly matched radiation is impossible to attain. To compensate a user defined quantity called the $Z_{DR}$ offset is defined.

This paper summarizes different methods of measuring this offset and the issues associated with accurately measuring the offset. We will begin our discussion with a brief review of measurement error analysis.

## 2. MEASUREMENT ERROR ANALYSIS

As with all measurements, there will be errors inherent in the measurement that need to be considered. For example, the power meter thermistor mount, HP478A, has a maximum SWR of 1:1.13 at 5700 MHz. This translates to a reflection coefficient of 0.06 implying a percentage of error of ± 3 %. Let us demonstrate the impact of this error.

In performing the transmitted power measurement with an HP478A, after signal attenuation (with a maximum attenuator variance of ± 1.0 dB), the power level is measured at 3.00 dB. Including the ±3 % error, the signal power measurement is 3.00 ± 0.09 dB. The latter term, the ± 0.09 dB describes the accuracy of the meter, not the precision. Precision is a measure of the systemic errors whereas accuracy is a measure of random errors Baird (1994). For example, if a meter is always indicates a deviation from the true value of +3.0 dB, it is not very precise but the accuracy of the measurement is still ± 0.09 dB. The measurement envelope indicates the accuracy of the measurement, and the location of the peak with respect to the true or actual data value indicates the precision. Figure 1 demonstrates this graphically.

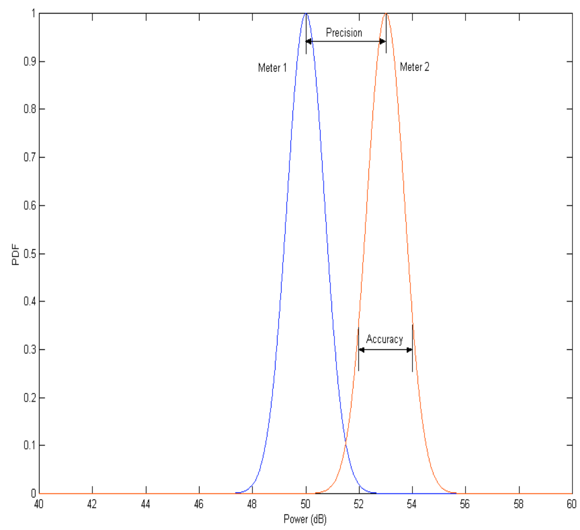


Figure 1. Measurement envelopes for two identical meters with an accuracy of ± 1 dB. The level being measured is at 50.00 dB so it is clear that Meter 1 is very precise, but Meter 2 is not precise. The precision of Meter 2 can be improved via calibration. However, its accuracy cannot be improved without a redesign.

The true value in this figure is 50.00 dB. One meter is reading a value of 53 dB and another reads a value of 50 dB. The accuracy of the meters is ± 1 dB. For meter 1, the measurement is 50 ± 1 dB and for meter 2, it is 53 ± 1 dB. Meter 1 is more precise than meter 2, but their accuracies are the same. The precision error in meter 2 can be mitigated through calibration, but the accuracy issues cannot be easily mitigated. To increase the accuracy, the functional design of the meter must be changed to utilize higher accuracy components or the meter's design must incorporate better measurement techniques.

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These errors can have a profound effect on the accuracy and precision of a relative measurement such as the difference in power levels between two ports. For example, suppose we used the two meters described above to measure the forward power between horizontal and vertical modes. Say meter 1 (horizontal) read 84 ± 1 dB and, meter 2 (vertical) reads 87 ± 1 dB. This means that the true value (ignoring precision issues) in the horizontal mode is in the interval [83 dB, 85 dB] with a certainty of 68% or within the interval [84 dB, 86 dB] with a certainty of 95%. Similarly, the 68% confidence interval for the vertical mode is in the interval [86 dB, 88 dB]. The difference between these two will be in the interval given by the differences between meter 1's minimum and meter 2's maximum and meter 1's maximum and meter 2's minimum, i.e. [(83 dB - 88 dB), (85 dB - 86 dB)] = [-5 dB, -1 dB]. This translates to a difference of (or a relative measurement of) -3 ± 2 dB. Note, this is the same as (84 ± 1 dB) - (87 ± 1 dB). Let us look at a more realistic example, i.e. the determination of the $Z_{DR}$ offset from the forward power measurements and the antenna gain.

The major inhibition in measuring the $Z_{DR}$ offset is that the offset is typically quite small on the order of tenth's of a dB. The problem with measuring such a small difference is that the effect is on the order of or smaller than the possible error in the test equipment. This presents a major problem, how do we know if the effect we measure is true or simply due to measurement errors? We cannot. An additional artifact of these results is that the cumulative error in the measurement of the offset may encompass a significant percentage of the entire data range.

## 3. TRANSMIT POWER MEASUREMENTS

The $Z_{DR}$ offset can be determined solely from measurement of the power levels of transmitted energy in both polarization modes and the antenna gains for horizontal and vertically transmitted signals.

The first step in determining the $Z_{DR}$ offset is to measure the power at the coupled port of the coupler at the antenna for both the horizontal and vertical polarization modes. Other information required is the antenna gain factors for horizontally and vertically polarized signals. This data should be provided by the antenna manufacturer with the antenna pattern.

To determine the offset, we add the horizontal contributions and subtract the vertical contributions, and multiply the result by 2 (transmission and reception losses), i.e.

$$offset = 2\times(P_H + G_H - P_V - G_V) \qquad (1)$$

where $P_H$ and $P_V$ are the forward power measurements in the horizontal and vertical directions respectively, and $G_H$ and $G_V$ are the antenna gain measurements in the horizontal and vertical directions respectively.

Table I is typical data from a dual polarization system. The attenuator used to reduce the forward power into the appropriate range of the meter is specified to ± 1 dB. The possible attenuator error is added into the forward power measurement error.

| **Value** | **Horizontal (dB)** | **Vertical (dB)** |
|---|---|---|
| Forward Power | 83.67 ± 1.09 | 83.67 ± 1.09 |
| Antenna Gain | 45.0 ± 0.1 | 45.2 ± 0.1 |
| **Total** | **128.67 ± 1.19** | **128.87 ± 1.19** |

Table I. Measurement of Horizontal and vertical transmitted power in a dual polarization system.

When the power values are summed, the errors in the power measurement also summed. Similarly, if we subtract, the errors will add (subtraction is really an addition operation with a negative number). Thus, the difference between the horizontal and vertical totals is 0.20 ± 2.38 dB. This is the one way difference. To get the two-way difference, we multiply this by two. The error gets multiplied by 2 also, so

$$off = 2\times(0.02 \pm 2.38) = 0.40 \pm 4.76 dB \qquad (2)$$

So in this example, our offset is less than half of a dB, but the error is nearly 5 dB. Since the effect is so much smaller than the possible error, how can we know for sure that the measured offset is the true offset or just an artifact of measurement error? In addition, the error is approximately one-half the entire data range. The implication is that the 99.5% confidence interval (three times the error) is greater than the data range, a measure that is simply unacceptable.

## 4. RECEIVED DATA MEASUREMENT

The Received Data Measurement procedure for determining the $Z_{DR}$ offset involves injecting a signal from a calibrated test signal generator into the coupler antenna port and measuring the reflectivity for each polarization mode.

Figure 2 is a diagram demonstrating a possible $Z_{DR}$ measurement configuration. In this configuration, the signal being injected from the test signal generator goes through a power splitter, transferring equal amounts of energy to each of the couplers.

Injecting the signal into the couplers, we need to account for the possible error in the test signal generator (0.5 dB), the power splitter (0.01 dB), in the attenuation factors of each coupler (0.01 dB), and the error associated with the differential reflectivity

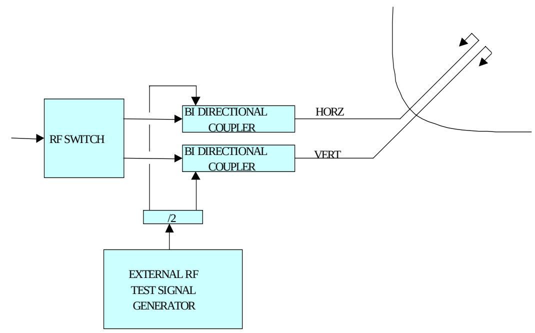


Figure 2. $Z_{DR}$ test configuration. The output from the test signal generator is split and inserted into the bidirectional couplers for each polarization mode.

measurement. Calling the coupler attenuation factors $A_H$ and $A_V$ for horizontal and vertical respectively, the relation for the $Z_{DR}$ offset is,

$$offset = Z_{DR} - 2\times\left(G_H - G_V\right) + \left(A_H - A_V\right) \qquad (3)$$

The error associated with the differential reflectivity measurement depends upon the resolution and data range of the processor. Eight bit output from the signal processor returns 256 levels of data. If the differential reflectivity data range is from -8.0 to 8.0 dBZ, the associated $Z_{DR}$ measurement error is,

$$\varepsilon = \pm\frac{8.0dBZ - (-8.0dBZ)}{256} = \pm 0.0625dBZ \qquad (4)$$
$$\approx \pm 0.06\,\mathrm{dBZ}$$

Suppose the $Z_{DR}$ value we measure is 0.31 dBZ, and the system parameters are as described in Table II.

| Value | Hor (dB) | Vert (dB) | Diff (dB) |
|---|---|---|---|
| **Coupler Atten** | 29.96 (0.01) | 29.72 (0.01) | 0.24 (0.02) |
| **Antenna Gain** | 45.0 (0.1) | 45.2 (0.1) | -0.2 (0.2) |

Table II. System parameters for measuring the $Z_{DR}$ offset via signal injection. Values in parentheses are the error terms.

We see that the $Z_{DR}$ offset is,

$$Z_{offset} = (0.31 \pm 0.06)$$
$$- 2\times(-0.2 \pm 0.2) + (0.24 \pm 0.02)$$
$$= 0.015 \pm 0.48\,dBZ$$

without the inclusion of the signal generator and power splitter error terms.

Again, from the perspective of error analysis, the data obtained via these measurements are meaningless. We cannot know if the measured value is true or an artifact of measurement error.

The coupler attenuation and hence its error can be removed by injecting the signal into the waveguide directly at the horns rather than the couplers. Provided the amount of energy entering each feed horn is identical (no deviation, hence error here), the coupler is removed from the equation. However, in the above example, the coupler error was in fact the minimal error contributor, thus eliminating its error may not have a profound effect on the result.

## 5. WEATHER DATA MEASUREMENT

The Weather Data Measurement procedure for determining the $Z_{DR}$ offset is straightforward, but requires nature to cooperate. During a rainstorm with little wind, point the antenna straight up, elevation 90° and turn off the azimuth servo. Then measure the offset directly.

The error associated with this method is based upon the error associated with the signal processor and the display software. For example 8-bit output from the radar signal processor will give an error of ±0.0625 dB (data range from –8.0 dBZ to +8.0 dBZ). As an example, suppose we read the $Z_{DR}$ value as 0.1 dBZ. Then, the offset is 0.1 ± 0.0625 dB. The value inserted into the software would be 0.1.

## 6. CONCLUSION

Ideally, the signal power transmitted in a dual polarization weather radar system would be independent of the polarization mode. However, this not the case due to separate waveguides, couplers, feedhorns, and differences in the antenna gains based upon polarization orientation. To compensate for these factors in the processing of $Z_{DR}$ data, a correction factor, $Z_{DR}$ offset is used. The $Z_{DR}$ offset is simply the difference in the system losses between horizontally and vertically polarized signals.

Several techniques were described to determine this offset, each with advantages and disadvantages. The Transmitted Data Measurement uses the transmitted power and antenna gain to determine the offset. The second technique, the Received Data Measurement, uses a calibrated signal generator and the display workstation to measure the offset. The third technique is the Weather Data Measurement technique uses the display workstation and weather to measure the corresponding offset together.

The major inhibition in measuring the $Z_{DR}$ offset is that the offset is typically quite small, on the order of tenth's of a dB, yet the possible error associated with the measurement is typically on the order of a few dB's. Obtaining accurate measurements of a very small effect, well within the possible error bounds, is problematic. For how do we know the offset we measure is truly the offset and not a statistical fluctuation?

We can get an accurate measurement for $Z_{DR}$ offset using the Weather Data Measurement Technique. In this method the $Z_{DR}$ offset is measured directly via the signal processor and display system. Test instrument errors are removed (except for the system error of course), and an accurate measure is obtained for the system in question. The major drawback is scheduling the proper weather conditions.

## 7. REFERENCES

D. Baird, 1994: **Experimentation: An introduction to measurement theory and experiment design**, Prentice-Hall, pp. 224.