An Operational Guide to WSR-88D Reflectivity Data Quality Assurance

Joe N. Chrisman
Engineering Branch
and
Cynthia A. Chrisman
Operations Branch

WSR-88D Operational Support Facility (OSF)
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Introduction. Several parameters and influences, both electronic and meteorological, affect the quality of the base data estimates. The single most important aspect regarding base data accuracy is system calibration. Even though the field site electronics technician staff perform overall off-line checks of system calibration every 3 months, intervening changes in the operating characteristics of the radar may result in reflectivity estimation errors. These changes are reflected in a change in DELTA SYSCAL (reported as CALIB on the Unit Control Position (UCP)). Not all changes in DELTA SYSCAL, however, result in reflectivity errors. The goal of this paper is to provide a simple procedure that will enable the on-duty meteorological staff to quickly ascertain which changes in DELTA SYSCAL will affect the accuracy of the base reflectivity estimates. Armed with this knowledge, the meteorological staff can modify their interpretation of the reflectivity and reflectivity-derived products until corrective maintenance action can be completed.

Background. The reflectivity estimates are determined by measuring returned power and accounting for the power loss due to the range to the target, effects of atmospheric phenomenon such as signal attenuation, reflection of the hydrometeors, etc. (Probert-Jones radar equation), and signal loss through the antenna/receiver/signal processor signal path. For any given returned power value, the range to the target is known and effects of atmospheric phenomenon are understood and corrected for in software by use of the Probert-Jones radar equation. Therefore, system calibration (SYSCAL) is the only remaining variable that can affect the reflectivity estimate.

Calibration. To initially set up SYSCAL so that the required reflectivity accuracy of $\pm$ 1 dBZ is obtained, all of the path losses in the test signal critical path are measured and entered in the RDA adaptation data. The power measuring devices are also carefully calibrated. The resultant SYSCAL is then entered as the baseline value of SYSCAL in the RDA adaptation data.

To maintain a reflectivity accuracy of $\pm$ 1 dBZ, automated calibration is performed during the retrace between each volume scan using test signals as shown in Figure 1. From the known parameters of the generated test signals, "expected" reflectivity values are calculated (using the Probert-Jones radar equation). Then, the test signals are processed by the signal processor and "measured" reflectivity values are calculated. The "expected" reflectivity values are compared to the "measured" reflectivity values and the SYSCAL is adjusted to force the "measured" values to equal the "expected" values. This ***new*** SYSCAL will be used during the next volume scan to "correct" the weather data reflectivity values for current system operating conditions.

The quantity which is displayed, DELTA SYSCAL (reported as CALIB on the UCP), is the difference between this baseline SYSCAL and the value of the ***new*** SYSCAL calculated by the latest on-line automated system calibration process. After manual calibration, the DELTA SYSCAL value should initially be very close to zero. Any subsequent departure from zero is an indication that something has changed from the benchmark calibration conditions.

This process for correcting the weather signal strength assumes that the test signal characteristics do not change and that the transmitted power is measured correctly. Any deviations from this ideal situation will cause inaccuracies in the determination of DELTA SYSCAL and therefore result in reflectivity estimation errors.

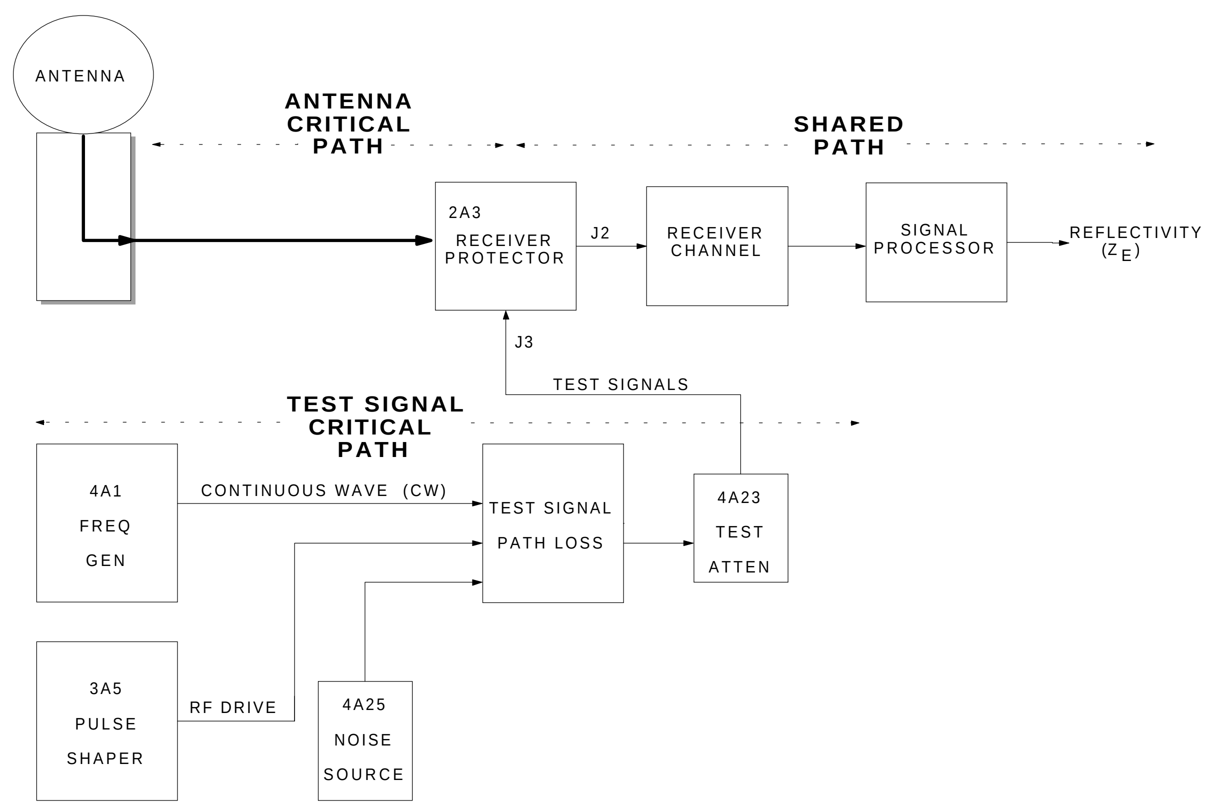

Figure 1: WSR-88D Weather Signal and Test Signal Paths

A closer examination of Figure 1 reveals that there are actually three signal paths that must be considered when discussing reflectivity calibration.

Antenna Critical Path. This is the path that ***only*** the weather signal passes through. The path is from the radar antenna through the waveguide and into the receiver front end. Since the path losses in this path are mainly a function of the physical parameters of the antenna and waveguide, changes in this path are small and are not considered in the analysis that follows.

Test Signal Critical Path. This is the path that ***only*** the test signals pass through. This path is from the test signal generation and calibration components to the receiver front end. Changes in these path losses will directly cause reflectivity errors and are a major concern.

Shared Path. This is the path from the receiver front end through the receiver and on to the signal processor that the two signals (weather and test) share. Changes in the path losses through the Shared Path are corrected by DELTA SYSCAL and do not result in reflectivity errors.

> NOTE: In addition to the path losses shown in Figure 1, reflectivity accuracy is also affected by the following two factors:
>
> Transmitted Power Measurements. Since the transmitted power is a component of the Probert-Jones radar equation, inaccuracies in the measurement of this parameter will cause reflectivity errors.
>
> Antenna Pointing Accuracy. Inaccuracies in the pointing precision of the antenna, while not directly affecting the calculation of the reflectivity estimate, do cause problems with the WSR-88D products. The pointing accuracy of the antenna is checked as a standard Preventive Maintenance Inspection item every 28 days.

Reflectivity Error. There are several things that can cause a change in SYSCAL. Some changes are properly corrected by DELTA SYSCAL, preserving reflectivity accuracy, while other changes improperly alter DELTA SYSCAL, causing reflectivity errors. The following table details these changes.

Change	***Result***
Transmitted power (Pt) (correctly measured)	Reflectivity estimates corrected by DELTA SYSCAL. No resultant reflectivity error.
Transmitted power (Pt) (incorrectly measured)	Reflectivity estimates improperly altered by DELTA SYSCAL causing reflectivity error.
Shared Path (SP) Loss	Reflectivity estimates corrected by DELTA SYSCAL. No reflectivity error.
Test Signal Critical Path	Reflectivity estimates improperly altered by DELTA SYSCAL causing reflectivity error.

Of the 4 classifications, two (changes in the transmitted power (Pt) (correctly measured) and Shared Path loss) are corrected by DELTA SYSCAL and ***do not*** result in operational reflectivity data inaccuracies. However, the other 2 classifications (changes in the transmitted power (Pt) (incorrectly measured) and changes in the Test Signal Critical Path loss) ***do*** cause reflectivity errors and result in inaccurate base reflectivity products and in fallacious reflectivity-based, algorithm-derived products.

Impacts of Reflectivity Errors. Reflectivity estimate accuracy is of prime importance to warning meteorologists and hydrologists because of the estimate's impact on reflectivity-based algorithm performance. Of particular note is the sensitivity of the Hail Detection Algorithm (HDA) and Precipitation Processing System (PPS) to errors in base reflectivity estimates.

The primary input to the HDA is the maximum reflectivity of a storm's two dimensional (2D) components. It is impossible to anticipate the exact effect of a reflectivity estimate error on the HDA since the HDA output for each storm depends on the storm's vertical reflectivity profile, the heights of the 0 and -20 degree Celsius levels, and, to a lesser extent, the range from the radar.
However, we can make the general statement that a negative reflectivity error will result in a decrease in HDA's estimates and a positive reflectivity error will result in an increase in HDA estimates. It should be noted that test cases have shown that even reflectivity estimate errors as small as 1 dB may affect all three of the HDA's outputs (i.e., the Probability of Hail (POH), Probability of Severe Hail (POSH) and Maximum Expected Hail Size (MEHS) estimates).

Unlike the ambiguity of the impact on HDA performance, PPS performance impacts can be approximated. During a significant rainfall event, reflectivity estimation errors caused by small variations in radar calibration can negatively impact product accuracy and forecast and warning decisions. Consider the following:

> A 40 dBZ return has a -1 dB reflectivity error. Using the $Z = 300R^{1.4}$ relationship, this error would cause the precipitation accumulation algorithm to estimate a .48 in/hr rainfall rate instead of the .57 in/hr rate that is actually occurring. Though this underestimation

of almost .10 in/hr may seem relatively small, the cumulative effect over time can result in significant precipitation accumulation underestimation over the life of an event.

If the same return (40 dBZ) had a -4 dB reflectivity error, the precipitation accumulation algorithm would estimate a .48 in/hr rainfall rate instead of the .93 in/hr that is actually occurring. In this case, the actual rainfall would be almost 2 times the radar-estimated rainfall accumulation. The cumulative effect of this type of accumulation error can compromise warning and forecast decisions (e.g., rainfall is estimated at 2.00 inches over a watershed where the actual amount is almost 4 inches).

Use of a tropical Z/R relationship ($Z = 250R^{1.2}$) exacerbates the problem. The same 40 dBZ return with a -4 dB reflectivity error would result in a .85 in/hr rainfall rate instead of the 1.83 in/hr rainfall rate that is actually occurring. This results in an underestimation of approximately 1.00 inch per hour, which becomes extremely significant over time.

On the other side of the coin, the radar can experience a positive reflectivity error (+X dBZ) which would result in overestimated precipitation accumulation errors. For example, a 40 dBZ return with a reflectivity error of +4 dB would result in an actual rainfall accumulation of approximately ½ of the radar-estimated accumulation amount using the $Z = 300R^{1.4}$ relationship.

Calculating the Reflectivity (Z) Error. Since there is not an automated function to determine reflectivity accuracy in real time, some operators turn to the DELTA SYSCAL value to provide insight into the radar's calibration. A small DELTA SYSCAL (-1.5 dB to +1.5 dB) is a good indication that the reflectivity estimates are okay. However, if the DELTA SYSCAL value exceeds ± 1.5 dB, a significant change from the baseline condition has occurred. Large DELTA SYSCAL values may be due to factors which do not cause reflectivity estimation errors. On the other hand, a larger than normal DELTA SYSCAL value may indicate system path loss changes that do result in reflectivity errors. In either case, relying on DELTA SYSCAL alone does not provide enough information to determine the effect on the accuracy of the reflectivity estimates.

NOTE: A DELTA SYSCAL outside the range -1.5 dB to +1.5 dB should be investigated by the electronics maintenance staff.

The reflectivity error component of a larger than normal DELTA SYSCAL is the quantity that determines reflectivity accuracy. Knowing the reflectivity error quantity provides valuable operational insight into product interpretation and application of reflectivity and reflectivity-derived products to the forecast and warning processes. Unfortunately, the system does not automatically calculate this value.

Fortunately, however, a simple procedure for solving for this quantity has been developed by the

Operational Support Facility. The procedure to calculate the estimated reflectivity error while the WSR-88D system remains operational is fairly straightforward and takes less than a minute. This procedure has an accuracy of $\pm$ 1 dB, provided that the system has been previously calibrated correctly and that no RDA Maintenance Mandatory Alarms exist. (Both are generally good assumptions.)

Calculating the reflectivity error only requires four parameters and a scientific calculator. Of these parameters, CALIB, SHORT PULSE LIN CHAN NOISE, and ANT PK PWR are available from the Unit Control Position (UCP) RDA Status menus. The fourth parameter, expected Microwave Loss (M/WAVE LOSS$_{(expected)}$), is a constant value for your site that was determined during site acceptance and is available from the electronics technician staff.

Once the required 4 parameters are collected, the 5 simple calculations listed below will provide an estimated reflectivity error.

Ratio = Antilog ([M/WAVE LOSS$_{(expected)}$] / 10)
Ant Peak Power$_{(expected)}$ = 700 KW / Ratio
Transmitted Power (Pt) Error = 10 log(Ant Peak Power$_{(expected)}$ / ANT PK PWR$_{(measured)}$)
Shared Path (SP) Error = 10 log(0.200E-5 / SHORT PULSE LIN CHAN NOISE)
Reflectivity Error Estimate = CALIB - Pt Error - SP Error

Applying the Reflectivity (Z) Error Estimate in Routine Hydrologic Operations. **The meteorological staff can use this calculated reflectivity error estimate to mentally adjust their radar data interpretation to compensate for the overestimation or underestimation in reflectivity estimates.** Although this process is applicable to all reflectivity-derived products, it is extremely valuable when used to adjust precipitation estimates. Even though the effect of reflectivity errors on precipitation accumulation estimates is not linear for all reflectivity values, it can be closely approximated and applied in a table to assist the forecaster adjusting the accumulation rates based on the calculated reflectivity error. As illustrated in Table 1 below, a simple "fudge factor" can be used to mentally adjust precipitation accumulation estimates once any reflectivity error is known.

Table 1 Precipitation Accumulation "Fudge Factors" to Compensate for Estimated Reflectivity Errors		
Estimated Reflectivity Error	Fudge Factor for $Z = 300\ R^{1.4}$	Fudge Factor for $Z = 250\ R^{1.2}$
- 4 dB	rain rate will be 52% actual (multiply accumulation by 2)	rain rate will be 44% actual (multiply accumulation by 2.25)
- 3 dB	rain rate will be 60% actual (multiply accumulation by 1.7)	rain rate will be 55% actual (multiply accumulation by 1.8)
- 2 dB	rain rate will be 72% actual (multiply accumulation by 1.4)	rain rate will be 67% actual (multiply accumulation by 1.5)
- 1 dB	rain rate will be 85% actual (multiply accumulation by 1.2)	rain rate will be 80% actual (multiply accumulation by 1.25)
$\pm$ 0 dB	No calibration-based rain rate error (multiply accumulation by 1)	No calibration based rain rate error (multiply accumulation by 1)
+ 1 dB	rain rate will be 118% actual (multiply accumulation by .85)	rain rate will be 125% actual (multiply accumulation by .8)
+ 2 dB	rain rate will be 140% actual (multiply accumulation by .7)	rain rate will be 150% actual (multiply accumulation by .65)
+ 3 dB	rain rate will be 166% actual (multiply accumulation by .6)	rain rate will be 183% actual (multiply accumulation by .55)
+ 4 dB	rain rate will be 192% actual (multiply accumulation by .5)	rain rate will be 225% actual (multiply accumulation by .45)

To facilitate operational implementation of calculating the reflectivity error estimate, a detailed procedure for this process is included in Attachment 1. The procedures in Attachment 1 will determine whether the error is isolated to the Shared Path, where it is compensated for by DELTA SYSCAL or, if not, provide suggested corrective action guidance. An example case using the procedures in Attachment 1 are included in Attachment 2.

Additionally, Mr. Dave Floyd and Mr. Don Rinderknecht, OSF Operations Training Branch (OTB), have provided an easy to use windows program that automatically performs these calculations (see Attachment 3 for an example of the program output). To use the program, simply input the required 4 parameters. The Transmitted Power (Pt) Error, Shared Path (SP)

Error and final Reflectivity Error Estimate are then calculated and displayed. To obtain the executable file or source code, visit the OSF OTB Homepage (http://www.osf.noaa.gov/otb/papers/z-error/).

Summary. Using the procedure described in this publication, operational meteorological personnel can quickly calculate an estimated reflectivity error in real time. By knowing the reflectivity error being incorporated into the reflectivity estimates, the meteorological staff can mentally adjust their radar data interpretation of reflectivity and reflectivity-derived products to compensate for the overestimation or underestimation in reflectivity data values. Additionally, this estimated reflectivity error can be used to notify the electronics maintenance staff that a change in system performance has occurred. This notification can be made well in advance of when it might have been detected by routine maintenance activities.

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ATTACHMENT 1

OPERATIONAL REFLECTIVITY ERROR ESTIMATE PROCEDURE

(Extracted from the NWS EHB 6-510, paragraph 6-6.28.1.4.3)

Data Collection:

1. From the electronics technician staff obtain the M/WAVE LOSS$_{(expected)}$ +_________
This quantity is the sum of several RDA adaptation data parameters as detailed in the RDA Maintenance Manual NWS EHB 6-510, paragraph 6-6.28.1.3

    (NOTE: This should be a constant value and should not change until major maintenance action is performed on the RDA waveguide assembly)

2. Ensure the system is operating in VCP 21.

3. From the UCP, display the RDA RECEIVER SIGNAL PROCESSOR STATUS menu (ST,RD,R) and record the values of the following two parameters:

    CALIB __________
    SHORT PULSE LIN CHAN NOISE __________

4. From the UCP, display the RDA TRANSMITTER STATUS menu (ST,RD,TR) and record the values for the following parameter:

    ANT PK PWR$_{(measured)}$ __________

Reflectivity Error Calculation:

(NOTE: For the following steps, round off the dB calculations to the nearest hundredth.)

5. From Step 1 above, enter the absolute value of the M/WAVE LOSS$_{(expected)}$ +__________
    Note: The M/WAVE LOSS$_{(expected)}$ value is a constant value for your site.

6. Calculate the expected ratio of transmitter power to antenna power as follows:

    Ratio = Antilog (M/WAVE LOSS$_{(expected)}$ / 10)
    Ratio = __________

7. Calculate the Ant Peak Power$_{(expected)}$ as follows:

Ant Peak Power$_{(expected)}$ = 700 kW / Ratio
Ant Peak Power$_{(expected)}$ = 700kW/_____
Ant Peak Power$_{(expected)}$ = _________ kW

8. Calculate the Transmitted Power (Pt) error as follows:
Pt Error = 10 log(Ant Peak Power$_{(expected)}$ / ANT PK PWR$_{(measured)}$ from Step 4)
Pt Error = 10 log(__________ kW / __________ kW)
Pt Error = ______ dB

If the Pt error is outside the range of -0.3 dB to +0.3 dB, inform the electronics maintenance staff of the Pt error value. The transmitter output power and/or the power monitors need to be checked and /or repaired if the Reflectivity Error Estimate is outside the range of -1.0 dB to +1.0 dB. If the Reflectivity Error Estimate is within the range of -1.0 dB to +1.0 dB, corrective efforts can be accomplished during normal scheduled maintenance.

An error caused by a change in Pt *is* corrected by DELTA SYSCAL and *does not* result in inaccurate reflectivity estimates. However, an error in Pt caused by a faulty power monitor is not detectable by the system, *is not* corrected by DELTA SYSCAL, and results in inaccurate reflectivity estimates.

9. Calculate the change in Shared Path (SP) Error as follows:

SP Error = 10 log(0.200E-5 / SHORT PULSE LIN CHAN NOISE from Step 3)
SP Error = 10 log(0.200E-5 / _________________)
SP Error = __________ dB

If the SP Error is outside the range of -0.8 dB to +0.8 dB, notify the electronics maintenance staff. The receiver needs to be checked and /or repaired if the Reflectivity Error Estimate is outside the range of -1.0 dB to +1.0 dB. If the Reflectivity Error Estimate is within the acceptable range, corrective efforts can be accomplished during normal scheduled maintenance.

A change in Shared Path Loss (SP Error) *is* corrected by DELTA SYSCAL and *does not* result in inaccurate reflectivity estimates.

10. Calculate the Reflectivity Error Estimate as follows:

Reflectivity Error Estimate = CALIB (Step 3) – Pt Error (Step 8) – SP Error (Step 9)

Reflectivity Error Estimate = _______ dB – _______ dB – _______ dB

Reflectivity Error Estimate = dB

The Reflectivity Error Estimate should be within the range of -1.0 dB to +1.0 dB.

> Note: The Reflectivity Error Estimate is incorporated into all reflectivity

ATTACHMENT 2

OPERATIONAL REFLECTIVITY ERROR ESTIMATE PROCEDURE

(Extracted from the NWS EHB 6-510, paragraph 6-6.28.1.4.3)

Example

Data Collection:

1. From the electronics technician staff obtain the M/WAVE LOSS$_{(expected)}$ +__2.6_____
This quantity is the sum of several RDA adaptation data parameters as detailed in the RDA Maintenance Manual NWS EHB 6-510, paragraph 6-6.28.1.3

   (NOTE: This should be a constant value and should not change until major maintenance action is performed on the RDA waveguide assembly)

2. Ensure the system is operating in VCP 21.

3. From the UCP, display the RDA RECEIVER SIGNAL PROCESSOR STATUS menu (ST,RD,R) and record the values of the following two parameters:

   CALIB ___+2.5________
   SHORT PULSE LIN CHAN NOISE ___0.235E-05___

4. From the UCP, display the RDA TRANSMITTER STATUS menu (ST,RD,TR) and record the values for the following parameter:

   ANT PK PWR$_{(measured)}$ ___177KW_____

Reflectivity Error Calculation:

(NOTE: For the following steps, round off the dB calculations to the nearest hundredth.)

5. From Step 1 above, enter the absolute value of the M/WAVE LOSS$_{(expected)}$ +___2.6____
   Note: The M/WAVE LOSS$_{(expected)}$ value is a constant value for your site.

6. Calculate the expected ratio of transmitter power to antenna power as follows:

   Ratio = Antilog (M/WAVE LOSS$_{(expected)}$ / 10)
   Ratio = ___1.82_______

7. Calculate the Ant Peak Power$_{(expected)}$ as follows:

Ant Peak Power$_{(expected)}$ = 700 kW / Ratio
Ant Peak Power$_{(expected)}$ = 700 kW/_1.82__
Ant Peak Power$_{(expected)}$ = __384.61_ kW

8. Calculate the Transmitted Power (Pt) error as follows:

Pt Error = 10 log(Ant Peak Power$_{(expected)}$ / ANT PK PWR$_{(measured)}$ from Step 4)
Pt Error = 10 log(__384.61__ kW / __177___ kW)
Pt Error = _+3.37__ dB

If the Pt error is outside the range of -0.3 dB to +0.3 dB, inform the electronics maintenance staff of the Pt error value. The transmitter output power and/or the power monitors need to be checked and /or repaired if the Reflectivity Error Estimate is outside the range of -1.0 dB to +1.0 dB. If the Reflectivity Error Estimate is within the range of -1.0 dB to +1.0 dB, corrective efforts can be accomplished during normal scheduled maintenance.

An error caused by a change in Pt *is* corrected by DELTA SYSCAL and *does not* result in inaccurate reflectivity estimates. However, an error in Pt caused by a faulty power monitor is not detectable by the system, *is not* corrected by DELTA SYSCAL, and results in inaccurate reflectivity estimates.

9. Calculate the change in Shared Path (SP) Error as follows:

SP Error = 10 log(0.200E-5 / SHORT PULSE LIN CHAN NOISE from Step 3)
SP Error = 10 log(0.200E-5 / __.235E-05____)
SP Error = __-.70___ dB

If the SP Error is outside the range of -0.8 dB to +0.8 dB, notify the electronics maintenance staff. The receiver needs to be checked and /or repaired if the Reflectivity Error Estimate is outside the range of -1.0 dB to +1.0 dB. If the Reflectivity Error Estimate is within the acceptable range, corrective efforts can be accomplished during normal scheduled maintenance.

A change in Shared Path Loss (SP Error) *is* corrected by DELTA SYSCAL and *does not* result in inaccurate reflectivity estimates.

10. Calculate the Reflectivity Error Estimate as follows:

Reflectivity Error Estimate = CALIB (Step 3) **-** Pt Error (Step 8) **-** SP Error (Step 9)

Reflectivity Error Estimate = __+2.5___ dB **-** _(+3.37)__ dB **-** _(-.70)__ dB

Reflectivity Error Estimate = __- .17 __dB

The Reflectivity Error Estimate should be within the range of -1.0 dB to +1.0 dB.

Note: The Reflectivity Error Estimate is incorporated into all reflectivity

Notice that in this example the DELTA SYSCAL is high (+2.5 dB), but the resultant reflectivity error is only -.17 dB. The major reason for the large DELTA SYSCAL is 3.37 dB change in transmitted power from the baseline transmitted power (Pt Error calculated in step 4).

ATTACHMENT 3

Printout of the Operational Reflectivity Error Estimate Program Output