19.6 NEXRAD OPEN RADAR DATA ACQUISITION (ORDA) RECEIVER CHARACTERISTICS

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1. ABSTRACT

The Open Radar Data Acquisition (ORDA) system receiver path is significantly different than the legacy NEXRAD Radar Data Acquisition (RDA) receiver path. The ORDA system realizes improved performance and reliability through the integration of the SIGMET 72Mhz IF digital receiver that greatly reduces system component count. This paper will discuss system performance parameters including minimum detectable signal, dynamic range, matched filtering and other intrinsic receiver characteristics. The inter-relationship between these parameters and procedures for optimization will be discussed. A comparison against legacy performance will also be provided where appropriate.

2. INTRODUCTION

The NEXRAD ORDA enhancement program replaces proprietary hardware with open-platform commercial hardware, a digital IF receiver and Graphical User Interface based on open architecture software principles (Patel, 2004). This paper presents an analysis of the ORDA receiver path. A comparison of system performance parameters such as sensitivity and dynamic range will be presented with an explanation of differences from and enhancements to the legacy system.

3. LEGACY SIGNAL PATH

The legacy receiver signal path (Figure 1) consists of the receiver channel with an RF generator and an RF test signal generation and processing path.

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The receiver channel detects and converts the returned RF energy into a complex, phase-coherent analog (video) signal. The RF generator creates transmitter RF, test RF, STALO & COHO signals. The in-phase (I) and quadrature (Q-90^0 shifted) video contains the echo return amplitude and phase information needed for base data generation. Log video is used to provide a wide dynamic range automatic gain control (AGC) function and also supports the interference detection function. The I/Q and log video are sent to the A/D converter assembly where it is digitized, purged of ground clutter, and converted to radial base data.

The RF test signal generation sub-function sends samples of signals (in digital format) from various internal monitor points to the signal processor (HSP and/or PSP). The signal processor takes this data and calculates parameters needed for receiver calibration.

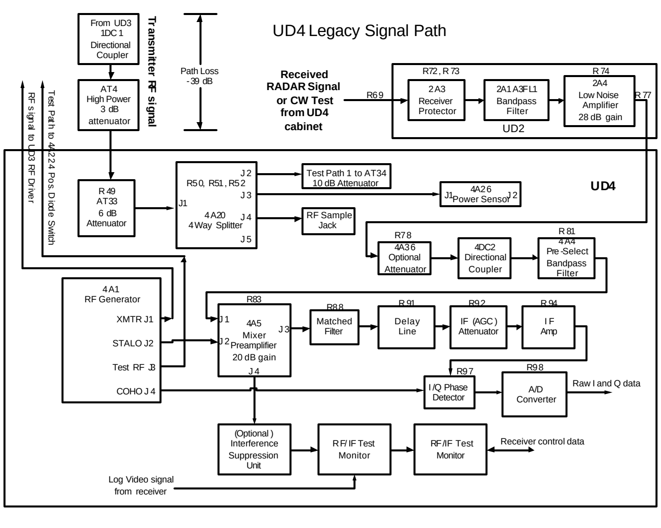

Figure 1, Legacy Receiver Signal Path

4. ORDA SIGNAL PATH

The ORDA design is functionally similar to the legacy receiver signal path; however, the

ORDA receiver signal path has replaced legacy matched filtering, A/D converting and signal processing with a SIGMET Intermediate Frequency Digitizer (IFD) and signal processor (RVP), as shown in Figure 2. The ORDA design digitizes IF signal while maintaining all minimum WSR-88D receiver characteristics (such as dynamic range and sensitivity). This reduces noise while improving receiver performance and reliability.

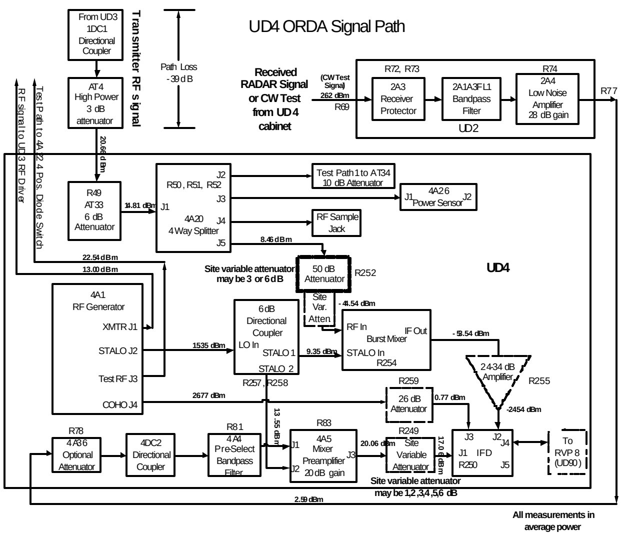

Figure 2, ORDA Receiver Signal Path

4.1 Digital Receiver

A 14-bit Analog to Digital (A/D) converter in the IFD captures and digitizes the IF energy and the transmit pulse burst sample at 72MHz. Using a digital receiver eliminates the need for AGC circuitry, DC Bias adjustment and I/Q phase alignment. Digitized data is transferred from the IFD to Receiver Circuit Card Assembly (Rx CCA) in the RVP for matched filter processing and conversion to I/Q data.

Configurable matched filtering provides significant improvement over the fixed legacy hardware matched filter, especially in long pulse (4.57 µs) operation. The matched filter is configured to duplicate the bandwidth of the legacy, matched filter.

4.2 Matched Filter

The digital Matched filter has many advantages: low filter power loss, adjustable bandwidth and filter length, and DC Bias control. The WSR-88D uses 2 pulse widths, and therefore requires 2 different matched filters for optimal performance. Short pulse is filtered at 600KHz, and Long pulse is filtered at 200KHz. The matched filter used is a Finite Impulse Response (FIR) filter.

The filter selected has wide implications on the receiver's performance. As noted above, the bandwidth affects the noise floor, and therefore the receiver sensitivity. However, a filter narrower than the pulse width causes signal loss. In the WSR-88D, the 600kHz short pulse matched filter causes approximately 0.6dB signal loss. The 200kHz long pulse matched filter results in approximately 0.2dB signal loss.

4.3 Signal Levels

A transmitted pulse sample is used to generate a burst pulse, which is used for phase reference in the IFD. Typical field values for signal level through the receiver path are given in Figure 2.

The maximum input signal for the IF and burst input is +6.5dBm. An attenuator is used at the input of the IFD to adjust our signal levels to meet the IFD specifications.

4.4 Test Path

To maintain system calibration, the WSR-88D system uses four built-in test signals as shown in Figure 3. Typical values through the receiver path are provided in this figure for these test signals. The NOISE test source is used to measure system noise temperature. CW signal is used to measure system linearity and dynamic range. The KD test signal is used for clutter suppression measurements and provides a general measure of system phase stability.

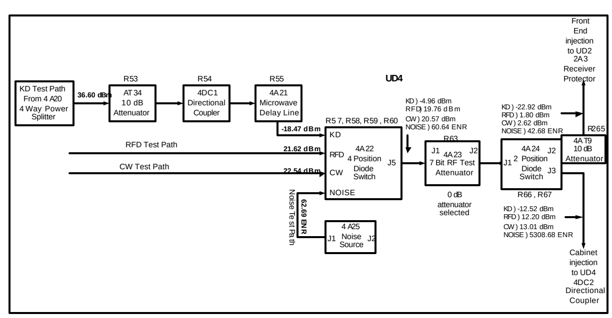

Figure 3, ORDA Test Path

5. RECEIVER PERFORMANCE

The ORDA receiver signal path meets or exceeds legacy receiver path performance as measured by the following parameters:

- System Noise Level
- System Dynamic Range
- System Sensitivity
- System Linearity

PARAMETERS	ORDA	LEGACY
System Noise short pulse long pulse	-80 dBm -85 dBm	-57dBm
Dynamic range	93 dB	92 dB
Matched filter loss	-0.6dB	-1.5dB
Sensitivity	-114dBm	-113dBm

5.1 Noise Level

Many types of noise contribute to a receiver, but for the WSR-88D the predominant noise is thermal. Active components in the receiver, namely, the Low Noise Amplifier and the Mixer/Preamp, add phase noise, shot noise and non-linearities. The IFD adds quantization noise and sampling noise from the A/D converter and the input clock. These noise quantities are all orders of magnitude less than the thermal noise contribution through the entire transfer range of the receiver. Quantization noise affects remain constant for the IFD as opposed to the variations induced by the AGC circuitry in the legacy receiver signal path. Therefore, the thermal noise is the dominant contributor to any variations in the measured system noise floor.

The actual noise level measured by the signal processor is based on the thermal noise temperature at the front end, the system bandwidth, receiver gain and the thermal noise temperature contributed by the receiver components.

$$Noise_{dBm} = 10\log(kB(T_{ant} + T_{Rx})) + g + 30 \quad (1)$$

Where k is Boltzman's Constant, B is the receiver bandwidth, T_{ant} is the thermal temperature at the front end, T_{Rx} is the noise contribution of the receiver and g is the receiver gain from the receiver protector to the IFD.

With the 14-bit, 72MHz IFD, the noise level with the input terminated at 50O is nominally given as –85dBm/Mhz. With a 600KHz bandwidth, this translates into a noise level of approximately –87dBm (N_{IFD}) at the IFD input. Terminated at the antenna, the system noise floor in short pulse is approximately –81dBm (N_{FE}). The Long pulse noise floor is approximately –85dBm. The primary contributor to the difference in the noise floor between short pulse and long pulse is the differences in bandwidth, 600KHz for short pulse and 200KHz for long pulse.

5.2 Sensitivity

Sensitivity for the WSR-88D receiver is referenced to the receiver front end input. It is directly related to the noise floor so that a quieter receiver will have a better sensitivity.

Sensitivity is therefore directly related to thermal noise, matched filter bandwidth, and receiver noise figure.

With the removal of analog IF and video components, ORDA has a slightly improved noise figure, 0.1 to 0.2dB. The digital matched filter is better than the legacy's analog filter, gaining as much as 1dB. This means ORDA is approximately 1dB more sensitive than legacy.

Sensitivity is measured for both systems at the 0dB S/N ratio, where signal input power equals the noise power, i.e., the point 3dB above the noise floor. This is defined as Minimum Discernible Signal (MDS), but is not actually the smallest coherent signal detectable. As Figure 4 shows, the signal is easily discernible to approximately 5-6dB below MDS.

5.3 Dynamic Range

The dynamic range is defined as the difference between the MDS, where the S/N ratio is 0dB, and the IFD's 1dB compression point, where the signal deviates 1dB from linear. The legacy dynamic range was typically measured to be 91dB to 92dB (Sirmans, 2000).

The IFD's normal compression point is +6dBm, giving a dynamic range of 87dB. However, SIGMET uses a statistical linearization technique for signals above compression, thereby recovering another 6dB of signal. This gives a dynamic range of 93dB to 94dB for the ORDA receiver signal path.

Figure 4 shows the ORDA off-line linearity and reflectivity test measurement display. This calibration test computes the system noise floor, compression point, minimum detectable signal, linearity and dynamic range and shows the results in a graphical window. This test was done in short pulse at the KCRI channel 2 test bed system in Norman, OK. As shown here, the dynamic range from 0dB S/N to 1dB compression is given as 95 dB.

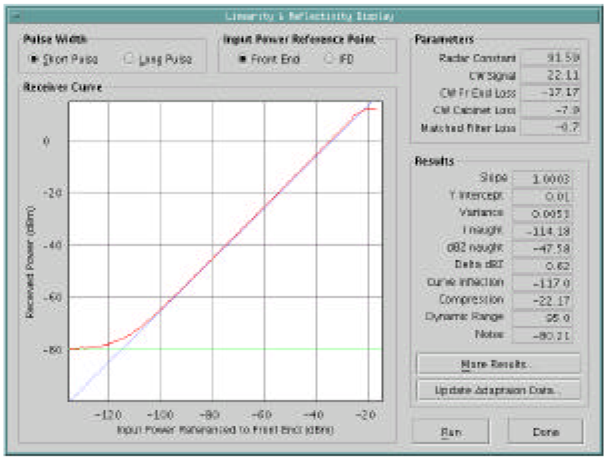

Figure 4, Receiver Transfer Curve

5.4 Linear Transfer Curve

The linear slope of the receiver over the IFD's dynamic range is 1.00 (measured power equals input power). Computation of the linear slope is a performance check that confirms the IF's expected and measured values are within tolerance.

Linear system response is vital to ensure system accuracy. The excellent linearity of the WSR-88D receiver is seen in Figure 4, where the slope is 1.0003, the variance is a negligible 0.0053, and all the data points in the linear region conform to the curve. The receiver displays excellent linearity to within 1-2dB of 1dB compression. The low end, where the noise floor affects the signal, shows expected behavior with no anomalies.

5.5 Sensitivity vs. Dynamic Range

In a digital receiver, sensitivity and dynamic range form a parametric relationship so that optimizing for one reduces the other.

The tradeoff between sensitivity versus dynamic range is based upon the noise ratio of the receiver to the IFD (N_{FE}-N_{IFD}). The WSR-88D receiver has an excellent noise figure of around 3dB. To maintain the WSR-88D sensitivity, the IFD operates at approximately 6dB above the IFD noise floor, reducing the dynamic range by 7dB and the sensitivity by 1dB.

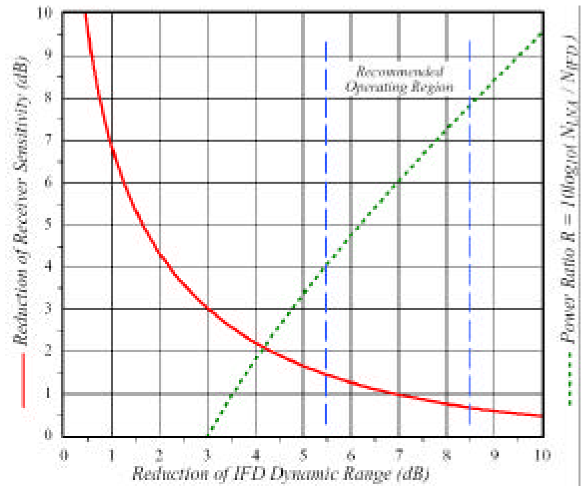

Figure 5, Sensitivity-Dynamic Range Trade Off

5.6 Reliability

ORDA has replaced several legacy components with COTS equipment. The new components have a high mean time between failure (MTBF), low noise figures, and costs much less than the previous legacy components. The component reduction realized with the ORDA architecture minimizes downtime and provides higher reliability.

Removal of the analog components for AGC and I/Q detection eliminates the receiver channel alignment. All the receiver channel setup is now done in software and does not need to be done periodically, only upon component replacement. This setup consists of matched filter configuration for short pulse and long pulse and burst pulse configuration.

A minor consideration for reliability is the reduced power needed for the new receiver. The new ORDA receiver components require approximately 10 watts, compared to several hundred for the removed legacy components.

5.7 Reflectivity Equation

The performance parameters determine system calibration and its ability to accurately measure reflectivity, velocity and spectrum width. Reflectivity is computed with equation 3.

$$dBZ = 10\log\left(\frac{P_R - N}{N}\right) + 20\log(R) - A \times R + dBZ_0 \quad (3)$$

Where P_R is the return signal power, N is the Noise value corrected for elevation, R is range, A is the two-way atmospheric loss and dBZ_0 is the system calibration constant, computed using equation 4. dBZ_0 represents the reflectivity of a 0dB Signal-to-Noise target at a range of 1km, and includes all the constants in the radar equation (Rinehart, 1997).

The receiver has no effect on Range or Atmospheric Loss, but its accuracy is critical for the other values. The Return Signal Power depends on the receiver's linear response, especially at low power levels where noise has a large affect.

Accurate measurement of the Noise depends upon the receiver's ability to accurately model the fluctuations in noise, so the proper noise value is used in the equation. The dBZ_0 calibration constant requires an accurate measurement of the system's MDS to determine the conversion factor from power to reflectivity.

6. CONCLUSION

ORDA implementation of Sigmet's IFD and RVP has improved the overall performance of the NEXRAD radar. The replacement of several legacy components with ORDA components has reduced the system noise while increasing the linearity and dynamic range. The new Sigmet equipment has software adjustable filters, which can closely match both pulse widths. This provides for a better filter for eliminating spurious signals and background noise from the I and Q data.

7. ACKNOWLEGEMENTS

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Note: The views expressed are those of the author(s) and do not necessarily represent those of the National Weather Service.

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