P4.R15 Clutter Censoring Theory and Application for the WSR-88D

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1. ABSTRACT

This paper examines the increase in WSR-88D system noise due to large input signals. The Open Radar Data Acquisition (ORDA) frequency domain clutter filter, GMAP, nominally achieves 10dB more clutter filtering than the Legacy 5-pole elliptic IIR filter. The increased clutter removal reveals the effect of large input signals on the noise floor. To remove the noise biased data, clutter censoring must be applied after clutter filtering. The ORDA technique discussed in this paper minimizes weather removal when clutter censoring is applied. Finally, a comparison between Legacy clutter suppression and ORDA clutter suppression is presented.

2. INTRODUCTION

In a radar system, noise comes from many sources. For the WSR-88D, the predominant noise in the absence of signal is thermal noise. However, when a signal is present, additional noises are introduced. This additional signal-induced noise is inconsequential when the signal is present; however, when signal is removed by clutter filtering, the resulting residue is noise-like and exceeds thermal noise levels. As a result, post clutter-filter censoring must be applied to remove the noisy returns.

3. NOISE SOURCES

The following list identifies the predominant noise sources of the WSR-88D system. Other noise sources such as shot noise, flicker noise, and jitter noise from A/D sampling are minimal and therefore inconsequential in the WSR-88D system.

3.1 Thermal Noise

Thermal noise comes from heat, i.e., thermal agitation of atoms. It is computed as N = kTB, where k is Boltzman's constant, T is temperature in Kelvin, and B is the noise bandwidth of the receiver. Thermal noise is the predominant noise source in the WSR-88D system. This noise source is constant and is based upon hardware characteristics. Typically, the WSR-88D system thermal noise is measured to be -114dBm in short pulse referenced to the input of the Receiver Protector.

3.2 Phase Noise

Phase noise comes from the transmitter itself. It is a characteristic of the transmitted pulse; therefore, it is only present in a radar return. WSR-88D phase noise is approximately -64dBc.

3.3 Quantization Noise

This noise comes from the A/D converter and is the noise added by quantization of a signal. Quantization noise depends on the resolution of the A/D converter. In the WSR-88D Legacy system, quantization was an important noise component because of the Automatic Gain Control (AGC) (quantization noise increased when the AGC threshold was overcome). In the Legacy system the 12-bit A/D converter quantization noise was 10.8dB below thermal noise for a signal below the AGC threshold.

In ORDA, the 14-bit A/D converter is at IF Frequency. In ORDA, quantization noise is constant and significantly less than the system thermal noise. Quantization noise measures approximately -165dBm referenced to the input of the Receiver Protector.

3.4 Window Noise

The windowing function used in frequency transformation also creates "noise". This noise is not typical white noise, but represents window sidelobes. Essentially it is an unwanted artifact of signal processing. ORDA signal processing uses

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a Blackman window with sidelobes approximately -60dB below the signal.

4. NOISE DEPENDENCE ON SIGNAL

All the noise sources (except windowing noise) mentioned above are white noise sources; that is, the noise power is spread evenly across the spectrum. Therefore, white noise, i.e., an incoherent signal, has a random velocity and a high spectrum width.

Figure 1 plots noise power versus signal level showing noise power dependence on the input signal. For both signal and noise, the values shown are referenced to the WSR-88D receiver front end, that is, the input to the Receiver Protector (see Figure 3 for details).

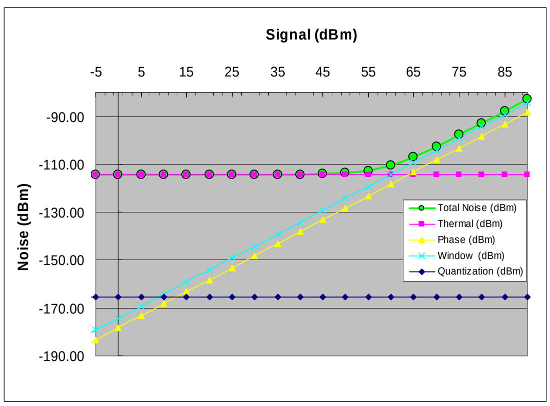

Figure 1: Noise Power vs. Signal Level

As can be seen from Figure 1, there is no appreciable effect from noises other than thermal noise for input signals below approximately 50dB. However, as the signal increases, the noise level rises. Above approximately 70dB SNR, the noise power increases 1 dB for each additional dB of signal power.

Figure 2 shows similar information by plotting total noise power versus input signal levels. The data is referenced to the WSR-88D Receiver Protector.

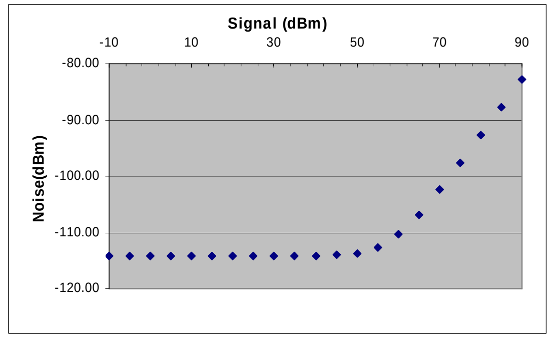

Figure 2: Total Noise vs. Signal

5. REFERENCE LEVELS

Figure 3 below shows the reference points in the WSR-88D receiver path.

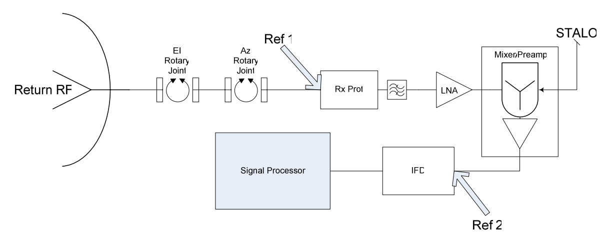

Figure 3: WSR-88D Receiver Path

To convert from one reference to the other, the following parameters are applied:

1. From the Receiver Protector Input to the IFD (Reference 1 to Reference 2 in Figure 3), Receiver Gain of approximately 35dB is applied.
2. In the IFD, Matched Filter Loss is approximately -0.6dB.
3. In ascope, the reference level is +6dBm.

Therefore, -114dBm power level at the input to the Receiver Protector would be equivalent to an ascope power level of approximately -85.6dB

6. DELAYED KLYSTRON TEST

6.1 Clutter Filter

The ORDA clutter filter used operationally and for these tests is the Gaussian Model Adaptive Processing (GMAP) filter, a frequency domain clutter filter that actively seeks the correct filtering width and reconstructs data across the zero isotach. Its maximum suppression for clutter signals, those signals with narrow spectrum widths centered on the zero isotach, is greater than the Infinite Impulse Response (IIR) filter used in the legacy WSR-88D. Hence, GMAP typically filters to the noise level without leaving any signal residue on the zero isotach.

6.2 KD Test Data

The delayed klystron (KD) test signal, a 10 μs delayed sample of the transmitter output, was used as an input signal to show affects of increased signal on noise. Data shown was captured using SIGMET's ascope utility with the number of samples set to 128, the Blackman window selected, a range resolution of 250m, FFT processing, and a PRF of 1000.

The KD signal is an "ideal" clutter signal, having a zero velocity and extremely narrow spectrum width. This low spectrum width affects the performance of the spectral window, and extremely low phase noise systems can make a system appear ideal. The system used in the tests has enough phase noise to show the affects of windowing and phase noise.

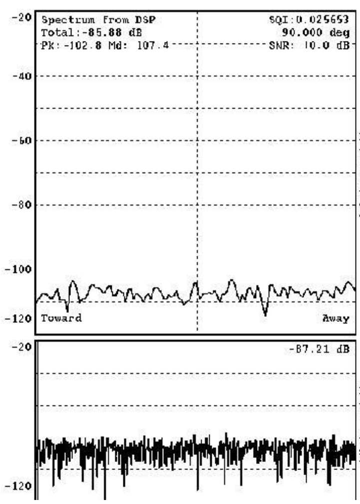

Figure 4: No Input Signal (i.e., Noise)

Figure 4 shows that without any input signal, the system noise power is approximately -85.88dB. This is very close to computed values for normal operational system of -85.6dB. Figure 5 shows the KD input with 30dB attenuation, that is, a relatively small input signal with peak power of only -45dBm (approximately 50dB above noise). When GMAP clutter filtering with a search width of 0.7m/s is applied (see figure 6), there is not an appreciable effect on the noise floor.

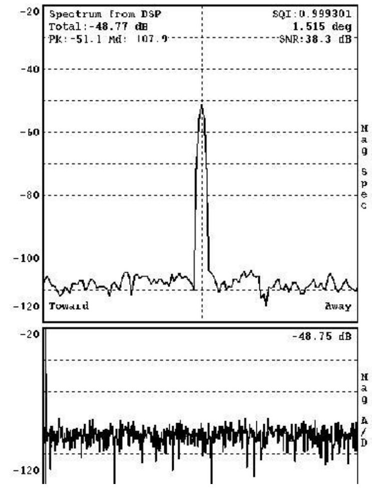

Figure 5: KD with 30dB attenuation

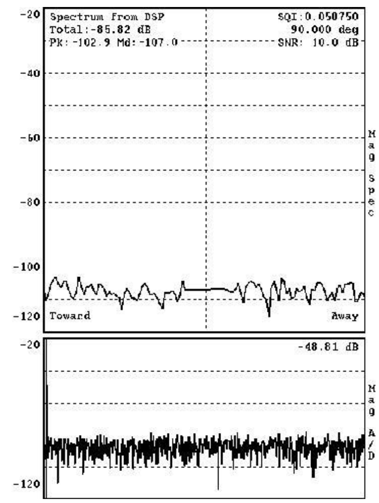

Figure 6: KD, 30dB, GMAP applied

However, once a large signal is injected, the effect on the noise floor becomes quite obvious. Figure 7 shows the KD pulse with only 10dB attenuation injected at the receiver front end. A peak KD of -30dB increases the noise floor about approximately 4dB as shown in Figure 8. With another 10dB of input signal the noise floor increases by another 10dB as is evident from Figure 9. These tests prove the non-linear relationship between noise power and input signal for high input signal values as shown in Figure 1.

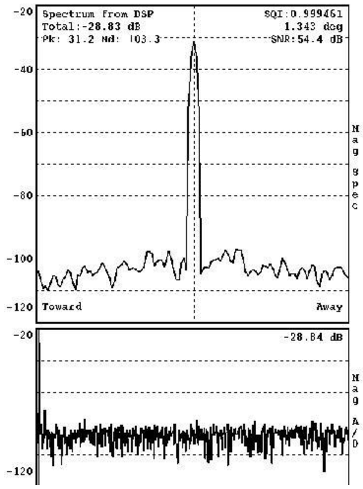

Figure 7: KD with 10dB attenuation

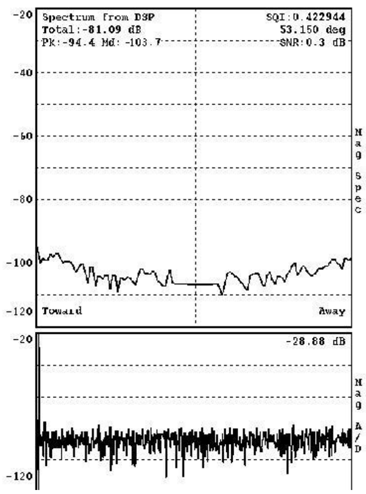

Figure 8: KD, 10dB, GMAP applied

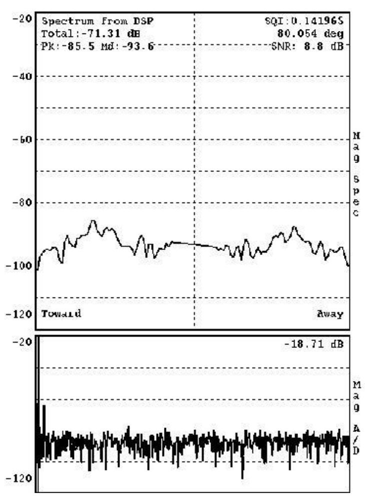

Figure 9: KD, 0dB, GMAP applied

As shown in the above ascope images, the noise floor increases with large input signals. When the input signal level reaches a level where the phase noise is larger than the thermal and quantization noise, the signal to noise ratio does not increase with input signal but remains at signal to phase noise level. Test results of this phenomenon are shown in Figure 10.

As the signal level increases, the noise floor is constant and equal to the thermal noise until the signal to noise ratio reaches approximately 45dB. From 45dB to 55dB SNR, the noise floor increases 3dB above the thermal noise level. Afterwards, the noise floor increases 1dB for each additional dB of input signal.

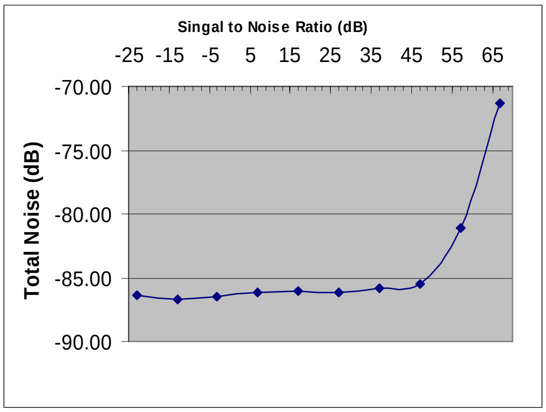

Figure 10: Noise versus KD Signal

7. CLUTTER CENSORING

The increased noise power that remains after clutter filtering is termed clutter residue. This residue is then removed through clutter censoring. Different methods of clutter censoring can be applied, e.g., CSR, Log-for-Log, Clutter Mapping, and Adjusted Noise.

7.1 Legacy Adjusted Noise

The Legacy WSR-88D software used an Adjusted Noise variable to increase the noise floor based on input signal power for each 1km data bin.

$$Noise_{adj} = Noise_{thermal} + \left(Noise_{quiescent} \times \left(\left(Power_{avg} \Big/ Threshold_{cutoff} \right) - 1 \right) \right)$$

$Noise_{adj}$ replaces computed thermal receiver noise floor in all signal processing computations. In essence, based on the input surveillance echo power, the thermal noise floor is unilaterally increased for signal processing and base moment computations. The Legacy method operates on 1km data bins and is applied regardless the amount of clutter filtering. That is, even for small clutter targets, the noise floor is increased by a small amount. The adjustment in the noise floor is proportional to the input signal level.

7.2 Clutter Mapping

A simple way to remove clutter residue is to use a clutter map to show where clutter is expected. The clutter power removed by the clutter filter is compared to the clutter power in the clutter map, and if they're equivalent, the cell is censored. This works well for fixed clutter without scintillation. The clutter map needs to be derived on a clear day to get an accurate map of the clutter field. The Terminal Doppler Weather Radar (TDWR) uses this technique, and it works well for the fixed clutter field. It does not work for Anomalous Propagation, and depends on a fixed clutter field. Any changes in the clutter require a new map. This would be needed at least seasonally due to vegetation, and anytime major construction is done within the site's ground clutter regime. Since it depends on characteristics of the clutter and must take into account clutter variations, and doesn't depend on the return signal, it can also remove weak weather signals.

7.3 CSR

Another method to censor residue data after clutter filtering is by using a CSR threshold, i.e., Clutter to Signal Ratio. In this method, the total unfiltered power minus the filtered power is used to determine a threshold for when censoring is applied. That is, when the difference between unfiltered power and filtered power exceeds the CSR value, that particular data bin is censored.

This feature is available in the ORDA signal processor. This method is more precise than the legacy adjusted noise method because it is applied on 250m bin data and is applied only when the difference exceeds the CSR threshold.

However, since large clutter signal increases the noise floor, the total power after clutter filtering is higher than it would be without the presence of the large input clutter signal. Therefore, in order to adequately censor all clutter residue, a small CSR threshold must be applied. As a result, in order to effectively remove all clutter residue, an aggressive censoring (CSR threshold) has to be applied; thereby increasing the chance of removing small, relevant weather information.

7.4 Log-for-Log

The method used in ORDA data processing is termed the Log-for-Log threshold. This method combines the concepts of both the Legacy Adjusted Noise method and the CSR threshold method. The Log-for-Log threshold operates on 250m bin data, thereby increasing the granularity of censored data.

The log signal threshold value is increased depending on the amount of clutter filtering, not on the input clutter signal strength. Therefore, unlike the Legacy method which adjusts the noise floor based on the input signal strength, the Log-for-Log method only uses the difference between filtered power and unfiltered power. This is a tremendous advantage over the Legacy method.

In the Log-for-Log method, an initial starting point or cutoff threshold is selected. For the ORDA data processing, this cutoff point is set to 50dB. That is, until the difference between filtered and unfiltered power exceeds 50dB, no adjustment to the log signal threshold is applied. For example, ff the clutter power is equal to weather signal power for a given bin, the delta between the filtered power and unfiltered power is only 3dB. Therefore, no adjustment to the log signal threshold would be applied.

If greater than 50dB of clutter filtering was applied, the log signal threshold would be increased ($Offset_{initial}$ + 1 dB) for each additional dB of clutter filtering. To compensate for the initial offset shown in Figures 2 and 10, $Offset_{initial}$ is set to 3 dB for the ORDA system.

8. CONCLUSION

There are many sources of noise in a radar system. The effects of different noises can be masked by signals; when those signals are removed the noise becomes dominant. Censoring unwanted noise from clutter filtered returns is vital to display and product processing of radar data.

GMAP is an effective, strong clutter filter, easily capable of removing clutter to the noise level. Four methods were identified to reduce the remaining noise, and the Log-for-Log method is the best of those discussed. CSR and adjusted noise remove too much weather, and the mapping technique is not good for anomalous propagation and scintillating clutter.

The results of Clutter Censoring with Log-for-Log reveal excellent clutter suppression, with no noise-like returns in clutter fields. Further, small weather events are minimally biased and are not censored.

9. 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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