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CLUTTER SUPPRESSION MEASUREMENTS THAT ACCURATELY EVALUATE A RADAR SYSTEM'S END-TO-END CAPABILITY

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1. INTRODUCTION

The weather radar market has a growing desire for superior Clutter Suppression (CS) driven by end-user requirements for better data. Manufacturers answer this need for superior CS by refining their designs and publishing data specifying their enhanced CS values. The end-user must evaluate the accuracy of the published CS values published for the selected radar. The process of testing CS is a complex task and perceived to be impossible by some end-users. As a result of addressing CS testing in the lab and in the field, EEC has designed a CS measurement technique that is free from the interference anomalies seen in actual clutter. This technique is nonjudgmental, can be used on all radar systems, and may well become the standard for the industry.

De-Modulation is key in the detection of clutter, when it involves two signals that are very close in frequency. The two signals produced are I and Q (Alford, 2001). Both include second harmonic terms. Through filtering the harmonics are removed leaving only the base band statements. The most important characteristic is that the transmitted frequency f_T component is gone. The deletion of the f_T component is necessary if we are to process the Doppler or f_d information.

The "I" and "Q" elements describe the phase component of the received signal. A change over time in the phase component has a direct relationship with the Doppler shift or f_d. The received signal is relative to f_T but may contain a Doppler shift if the target is moving. The rate of change of the phase angle is f_d. The following describes the phase relationship:

$$I = \frac{\cos(\theta)}{2} \qquad Q = \frac{\sin(\theta)}{2}$$

2. THE PROBLEM WITH REAL CLUTTER

Phase noise $\Delta 6$ is an unwanted property of the I and Q signals caused by influences other than weather. From the following we can calculate the CS with respect to phase noise.

CS $= -20 \log \Delta 6$
where $\Delta 6$ is in radians

The dilemma is seen when trying to evaluate the CS of a radar with real clutter, because the evaluator has no control over the atmosphere, elements within it, or the actual clutter movement. Today's weather radars have filters with depths of over 50dB. These filters require a signal stability of 0.18 degrees. It is difficult to achieve this stability in a laboratory environment and is extremely difficult to accomplish in an operational environment. In the past, the radar community has attempted to perform CS testing using "real" clutter. However, due to the number of uncontrollable parameters found within the received signal from clutter the CS value is virtually impossible to measure accurately when it exceedes -45dB. Other parameters that the evaluator has no control over are: tower movement, radome flexion, and signal degradation from obstacles within the radiated signal path (large obstacles like trees/birds/insects and small obstacles like smoke/dust/water). It is important to remember that -45dB of CS equates to 0.32 degrees of phase noise.

EEC resolved this concern in 1992 by designing a technique to delay the transmitted signal through the use of Bulk Acoustic Wave (BAW) delay lines as shown in Figure 4. Our first BAW delay lines were very expensive and difficult to fabricate, as a result, they were only used in our factory. Our early units provided a delay of only 2.6 microseconds but supplied a purer signal than the old style echo boxes that had delays of 3 to 5 microseconds. We have made advances in its design and its cost is much less, plus the new units provide a delay of 30 microseconds. The BAW delay lines supply a practical simulation of clutter at a low cost to the end user. Everyone in the weather radar industry would like to be able to use "real" clutter for suppression testing, however, as of today no one has a valid method using "real" clutter in this process. EEC is confident that the only method to validate a system in a non-judgmental manner is through the use of a delay line, which supplies simulated clutter.

3. CLUTTER SUPPRESSION MEASUREMENT

Clutter suppression is like a chain made with a number of links. The strength is dependent on the weakest link. The only way to test the capability of the chain is to expose it to a stress. So it is with CS. An

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end-to-end test is the only way to evaluate the true performance. In the past dynamic targets were used, this was adequate until the CS and system stability exceeded the stability of the returned signal. At this point EEC developed a method of generating a signal that was coherent with the receiver sub-system and injecting this signal back into the receiver. This was an extensive test of the receiver, signal processor and workstation, however, it is not an end-to-end test because the transmitters f_T or radiated signal is not used.

We know all too well that the "real" clutter is unpredictable at times. Plus the characteristics of the atmosphere between the radar and the target can change the phase of the received signal. System coherence is key to CS. Within a radar, various subsystems can be coherent, and a Fidelity Monitor will test them in a stand-alone environment (Alford, 1999). However, the Fidelity Monitor did not address the CS testing concern. The Fidelity Monitor was enhanced by incorporating a delay line, which enabled the device to make an end-to-end CS measurement. The delayed signal is as close to perfect clutter as one can make. By using the Fidelity Monitor, instrumented with the delay line, all subjective measurements and ambiguities of the received signal from the target are removed. This solution supplies the radar engineer with the required tool to test both radar components and the end-to-end CS.

The Fidelity monitor cannot test all digital receivers, signal processors and workstation because of unavailable signals. These sub-systems have proven to be some of the primary concerns for our end users. To remove this limitation EEC designed a selectable BAW delay line, which can be added to any radar. In the case of EEC's equipment, code used in the Fidelity Monitor was added to the workstation, which produces a time series display. As shown in Figure 1, the time series display shows coherence of the raw I and Q signals from the preprocessor as calculated through the arc tangent function. It is displayed on the workstation, but is not altered by the workstation software. When a delayed f_T signal is used the buyer sees the true end-to-end performance of the transmitter, analog/digital receiver, and signal processor through the time series display.

Questions from the end user concerning clutter filter operation are commonly asked. A method was developed using the BAW delay line to resolve these types of questions. It employs the selectable BAW delay line and the use of Clutter CORrection (CCOR) Threshold. A decibel value of CCOR is set by the end user within the workstation. This CCOR value is compared to the ratio of a filtered signal Z to the same signal but unfiltered U. In most signal processors both Z and U values are converted to decimal and a ratio is calculated Z/U. The ratio is compared to the decimal value of the CCOR. If the ratio is less than the

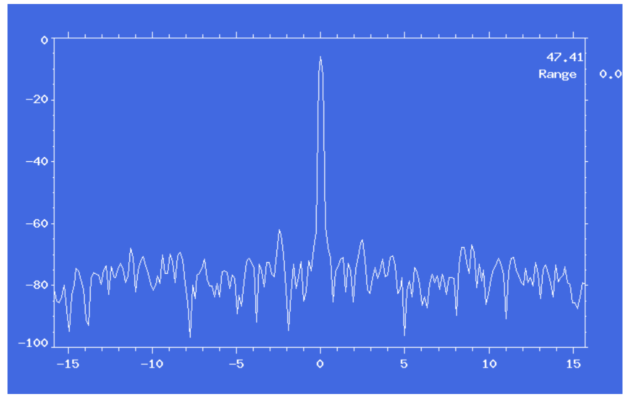

Figure 1 Time series display showing a system coherence of over 47dB.

CCOR, the Z signal is not passed to the filtered signal display. As shown in Figure 2, the value of CCOR is –45dB and the delayed f_T signal is not displayed in the Z product on the workstation the systems end-to-end CS is 45dB or greater. In this manner CCOR is used to set a threshold of CS that is based on the effectiveness of the clutter filter. The filter is only as good as the phase detection of the radar.

The BAW delay line is the key element in this method. The use of CCOR is not new and most Doppler weather radars employ CCOR. No special software or firmware is required to support this method. Before this method was developed the buyer and OEM were at an impasse. This technique of coupling CCOR with the delayed f_T produces an absolute non-judgmental measurement of systems end-to-end CS. The CCOR threshold will not allow bias from the OEM or the buyer. The delayed f_T signal is either filtered or it is passed, there is no discussion and therefore no impasse between the OEM and the end user.

4. CAUTIONS

All receivers have a performance curve plotting the output with respect to the input as shown in Figure 3. The lower end of this curve is Minimum Discernable Signal (MDS) and the upper end is the compression point. There are two points of caution that must be made with regards to CS and linearity. First the injected delayed f_T signal must be above the MDS by at least the CCOR value. If this is not the case the evaluator may think that the CCOR value is the CS value and this may not be the case. Clutter can't be suppressed below the MDS. If the system MDS is –114 dBm and the CS value to be evaluated is 45dB then the injected f_T signal must be equal to or greater (–114 dBm + 45dB) or -67dBm. The second item can be seen in some digital receivers that employ *statistical linearization*, (Zrnic, 2001). *Statistical linearization* is used to extend the compression point. When a system uses *statistical linearization* the true CS seen in the extended region may not be consistent with the CS measured in the linear region of the curve. Even with the fastest A/D converters available to today's engineers, this effect occurs due to the nonlinear nature of saturation, (Debauchies, 2001). EEC designers recognize this limitation of *statistical linearization* and achieve a linear dynamic range of greater than 100 dB without *statistical linearization*.

5. CONCLUSION

Within our industry, CS test concepts range from extensive to almost nonexistent. As digital receivers become more prevalent, CS testing must not be overlooked by the OEM for either new systems or upgrades of older radars. This technique empowers the buyer and ensures that the industry has a standard that can be reference to time after time. By using the BAW delay line and workstation coupled with its CCOR threshold the total system's CS is fully evaluated.

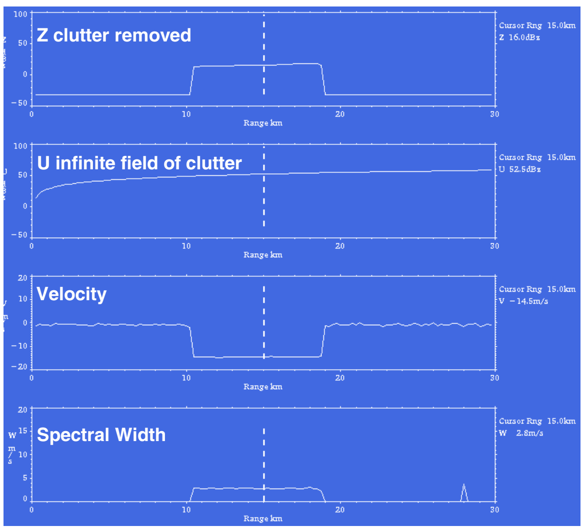

Figure 2 is an actual display showing sub-clutter visibility using simulated weather within an infinite field of clutter. In the Z window the clutter is removed leaving only the weather.

If the system does not support the OEM's published suppression of clutter the delayed injected f_T will be displayed in the Z product. This method removes ambiguities of the past and, therefore, the true CS is shown. The end user and the OEM have no question as to the end-to-end clutter suppression of the purchased radar system or upgrade.

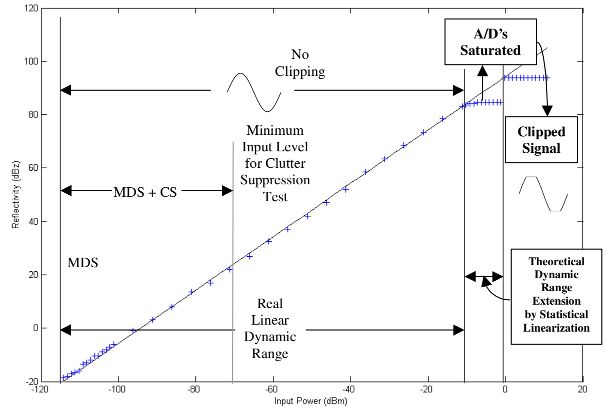

Figure 3 Graph of typical EEC receiver MDS = -114dBm, saturation occurs at -9.2dBm linear dynamic range = 105 dB

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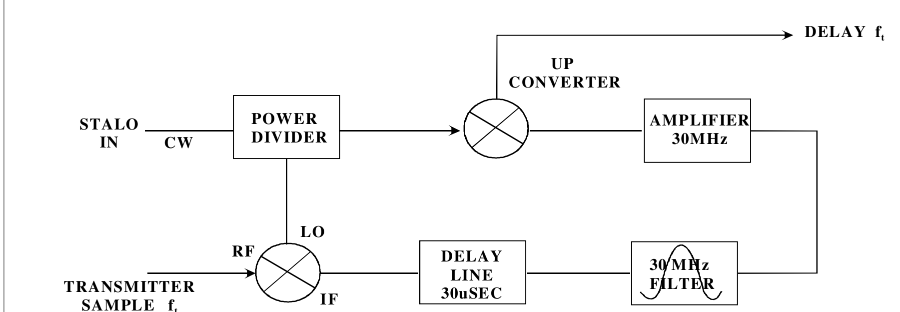

Figure 4 Bulk Acoustic Wave (BAW) delay line schematic