9.3 **Digital IF receiver – capabilities, tests and evaluation**

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1. INTRODUCTION

The current WSR-88D system configuration uses analog circuits to down convert the signal from intermediate frequency (IF) to base band. First, the IF signal is amplified and passed through a matched filter. Because dynamic range of weather signals is much broader than that of the A/D converters, the signal amplitude is adjusted by an automatic gain control (AGC) circuit to ensure that signal level remains within the range of A/D converter. Video signals are obtained by employing a synchronous detector, which removes the IF component and creates the in-phase (I) and quadrature phase (Q) components. This process, even though very effective, involves a large number of analog components which makes it prone to failures. In addition, because the sampling is fixed at *1.67* μs the system does not support implementation of novel data processing schemes which requires oversampling signals in range as well as a second receiver channel (Torres, Zrnić, 2001). At the same time, the advent of digital telephony and high-speed converters made commercial single board digital receiver available on the market. These devices are capable of sampling and processing signals at IF frequencies thus significantly reducing the number of components in the system and making it more reliable. This made the replacement of the analog receiver with digital technology feasible.

2. HARDWARE

The digital receiver chosen for incorporation into the WSR-88D RRDA (Research Radar Data Acquisition) system is ECDR-GC814 from Echotek corporation. It is a dual channel receiver with two 14 bit A/Ds that can operate at clock frequencies up to 105 MHz. Each channel is equipped with a down-converter chip, the Gray GC4016. It consists of four independent digital down converter channels and is specified to operate at rates of up to 100 mega samples per second. Pertinent characteristics of our application are listed next.

The down-converter chip accepts 14 bit data. Each down converter channel contains one Numerically Controlled Oscillator (NCO) and a mixer to convert the signal to its two baseband components. This is followed by a 5 stage Cascade Integrate Comb (CIC) filter and two stages of block averaging filters to isolate the desired signal. One stage of the CIC filter is equivalent to a uniformly weighted averaging filter (Hogenauer, 1981). Therefore five stages are equivalent to application of a moving average five times. There are no multipliers and, in the filtering process, signals are decimated in time. Decimation factor of CIC filter is programmable and can take values between 8 and 4096 (combining two channels can reduce the effective decimation by two). Hence, the least decimation after the CIC filter is 8 (4 when two channels are combined). The frequency transfer function of the CIC filter is

$$\frac{\left(1-e^{-j2\pi fTR}\right)^5}{\left(1-e^{-j2\pi fT}\right)^5}, \qquad (1)$$

where R is the decimation factor, and T is the sample spacing.

After the CIC filter there are two weighted moving average filters (tap filters), one with 21 taps the other with 63 taps. Each weight is programmable and each filter decimates by an additional factor of two which brings the minimum overall decimation factor to 32 (16 in a combined channel mode).

The underlying interconnect fabric in the RRDA signal processing subsystem is the RACE++ from Mercury corporation. Because the Echotek ECDR-GC814 features a built in RACE++ interface it provides efficient data delivery to RRDA digital signal processors.

3. DESIGN CONSIDERATIONS

Some of the design choices are inexorably tied to the specific intermediate frequency of the WSR-88D, f_{if} = 57.5491 MHz and the spacing of range resolution volumes (i.e., the gate spacing). The range gate spacing in the current WSR-88D is at 250 m (which is also the pulse depth) and is obtained from a count of $16 \times 6/f_{if}$. Therefore, to generate this sample spacing the clock frequency should be $n\, f_{if}/m$, where n, m are integers and m is either 2 or 3. To achieve the best possible resolution m is chosen to be 3. The highest possible n is 5 and produces the clock (i.e., sampling) frequency $F_{CK} = 5f_{if}/3$ = 96.95133 MHz. This choice aliases the sampled IF signal to $2f_{if}/3$ which, along with f_{if}, also becomes one of the NCO frequency choices. The clock frequency F_{CK} is produced by the hardware unit which accepts IF frequency as an input and performs the following divide and mix operations $2f_{if}/3 + f_{if}$. Consequently, timing of the digital receiver and the output of samples are in complete synch with the rest of the radar system. There are other choices for the clock frequency but these require re-sampling

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(available within the chip) to generate spacing of 250 m.

To emulate the WSR-88D legacy hardware the digital receiver is set up to supply one complex sample every *1.67 μs* (i.e., one sample per range gate). Because introduction of additional autocorrelation along range is not desired just the first of the two programmable FIR filters is used. Consequently, only one of the second FIR filter programmable 63 taps is set to a value different from zero. An example cfir_34 (GC4016 Data Sheet) coefficient set is chosen for the first filter. This configuration results in the overall frequency response that has a 3dB bandwidth of approximately 600kHz (i.e., reciprocal of the legacy sampling time), and is shown in Fig. 1 a).

The second configuration allows oversampling in range by a factor of five. To achieve this, the CIC filter output rate is increased five times, while the FIR filters settings remained the same. This resulted in the frequency response of the same shape as in the previous case while the 3dB bandwidth increased fivefold to 1.5 MHz (Fig. 1 b). In the case of oversampling in range the increase in system bandwidth is necessary, as introduction of additional correlation along range by the digital filtering will prevent achieving the maximum variance reduction obtained by averaging spectral moments in range. For the given case, it was verified that, for the wide bandwidth noise input, the autocorrelation of the output complex samples is insignificant at all lags except zero.

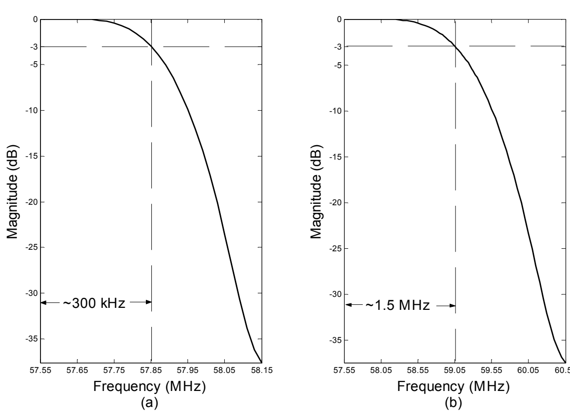

Figure 1. The overall frequency response for (a) matched filter, and (b) oversampling mode.

4. RECEIVER DYNAMIC RANGE

The combination of sampling and digital filtering increases the signal to noise ratio at the output of digital receiver. Consequently, the dynamic range is defined as the ratio of signal power at the output to the noise power present at the receiver input, given that the supplied signal peak value equals the maximum A/D converter input value, and the noise power is either equal to or less than the minimum value detectable by the converter (Zrnić, 2001). Because in weather radar the receiver must be capable of handling strong ground clutter echoes as well as meteorological signal returns, the dynamic range in excess of 90 dB is desired.

A simple way to experimentally ascertain the dynamic range of the system is to provide the variable test signal to the input of the receiver and measure the output. Using this approach the dynamic range of the ECDR-GC814 (for a matched filter configuration) was first measured in the low noise test environment where the input signal was supplied by the signal generator (Fig. 2 a). The amplitude of the input sine wave was set to a maximum allowable value while not saturating the A/D converter. This was verified by amplifying the signal which has shown the full saturation to occur at 1.2 dB above the signal level. The dynamic range from the 0 dB attenuation point to 1 dB above noise level was measured to be 98 dB. Additionally, the known noise power was subtracted from each measurement to further extend the linear region resulting in a 105 dB dynamic range with less than 1 dB deviation from a linear transfer function. The receiver was then connected to the WSR-88D and the built-in programmable attenuator was used. This attenuator has the capability of attenuating the internally generated test signal from 0 to 103 dB in 1 dB steps. In this configuration, dynamic range from zero attenuation point to 1 dB above noise level was 94 dB, and after noise subtraction the 1 dB deviation linear range was 96 dB. The loss of dynamic range in the WSR-88D environment could be attributed to the increased noise power at the input of the digital receiver. Nevertheless, it is still larger than 90 dB, and thus satisfactory for weather radar applications.

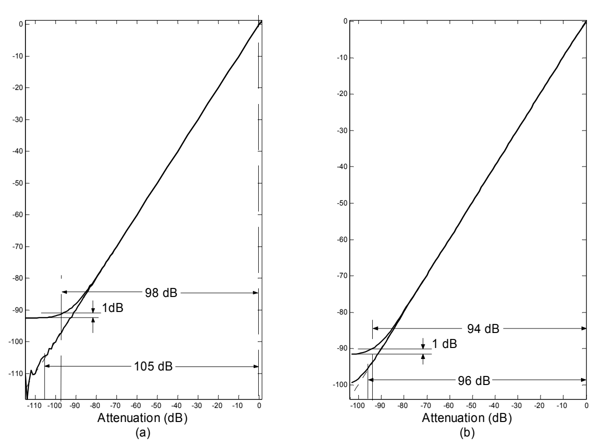

Figure 2. The matched filter mode plot of the dynamic range measurement in (a) the test, and (b) the WSR-88D environment.

The digital receiver was then configured for oversampling mode and the same set of measurements was carried out. The results obtained are shown in Fig. 3. When compared to the matched filter mode plots the increase in noise level is evident. This is expected as the bandwidth in the oversampling mode is five times larger; hence the increase in noise power degrades the SNR. Consequently, the noise level based dynamic range for the test and the WSR-88D environments was measured to be 90 dB and 89 dB, respectively. This is a decrease of 8 dB and 5 dB from the matched filter mode. If the noise power is subtracted from the results the 1 dB linear dynamic range extends to 106 dB and 100 dB. This, however, is an increase of 1 dB and 4 dB compared to the matched filter case. An explanation of this effect would require further investigation and is out of the scope of this paper. Nevertheless, one can speculate that the increased noise level can enhance the A/D conversion and digital filtering performance given that the noise distribution is uniform (similar to dithering). Higher noise levels, however, require increase in the number of samples used for estimation if the same variance is to be maintained. As large number of samples (3×10^5 for each step) was averaged to obtain each result, the higher noise power in the oversampling mode could be the cause of the 1 dB linear dynamic range increase.

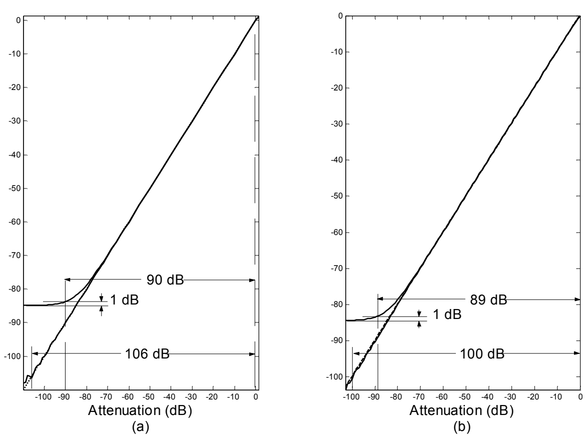

Figure 3. The oversampling mode plot of the dynamic range measurement in (a) the test, and (b) the WSR-88D environment.

5. SUMMARY

The Echotek ECDR-GC814 digital receiver device is incorporated into the WSR-88D RRDA system. This device features two channels each equipped with one 14 bit A/D converter and digital down converter integrated circuit (Gray GC4016). The digital receiver allows for efficient data delivery to the RRDA signal processing subsystem using an on-board RACE++ interface. Digital filtering is flexible as the Gray GC4016 supports various configurations. Two configurations are employed. One that mimics the current legacy WSR-88D signal processing, and the other that oversamples the signals in range by a factor of five. The dynamic range was measured for both configurations to verify that it meets the weather radar application requirements.

6. REFERENCES

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