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SIMULATION OF A PULSE COMPRESSION RADAR TRANSMITTER RECEIVER

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ABSTRACT

The technique of Pulse Compression consists of transmitting a pulse which sweeps through a range of frequencies with a carefully designed relationship of frequency to time. The received reflected pulse is cross correlated with the digital representation of the transmitted pulse and the resulting waveform is a narrow pulse of large magnitude.

Pulses (chirp) which will compress into narrow, high magnitude peaks can be designed mathematically and will produce approximately 40 dB of gain under ideal conditions. The analogue circuits of the radar transmitter and receiver chain will distort the pulse and reduce the amount of gain. Poor design of the circuit can reduce the gain by 20-30 dB, so it is paramount to design the circuit with the chirp in mind. This paper discusses the use of a simulation tool to model the circuit and algorithms to ensure that the analogue components do not unnecessarily distort the pulse and reduce the benefits of pulse compression.

INTRODUCTION

The average transmitted power of a given radar may be increased by increasing the length of the transmitted pulse. However, this method decreases the range resolution capability of the radar by decreasing the bandwidth of the received signal. In order to provide increased pulse width without compromising range resolution, a technique is used that provides for the transmission of a long pulse that can be compressed into a short pulse length in the receiver. This technique is called Pulse Compression and is accomplished by frequency or phase modulating the transmitted pulse and then compressing the return pulse by using a time delay network whose velocity of propagation is a function of frequency. In this way, the higher frequencies “catch up” with the lower frequencies and thereby effectively shorten the pulse. Acker (1).

That was the method used 20 or so years ago. With the increase in processing power of digital signal processing (DSP), the pulse compression in the receiver is now accomplished digitally using the fast Fourier transform (FFT) and achieves a greater pulse compression ratio.

A block diagram of the process is shown in figure 1. The carrier wave (CW) signal is frequency modulated by a non linear function which makes the pulse sweep through a range of frequencies, often called a chirp. The modulation is implemented by generating the baseband sweep digitally and modulating the pulse with the IF using a conventional analogue quadrature transmitter. The conventional analogue quadrature receiver converts the received pulse to digital samples. The DSP section of the receiver computes the cross correlation of the received pulse with the transmitted pulse. The standard equation for cross correlation is shown below (1).

$$Z_k = \sum_{l=0}^{N-1} y_l x_{(l+k)} \quad (1)$$

For the radar system under design, the size of the correlation, N was 1024. When N is large then the number of computations is large, ie N^2 so it is computationally efficient to use the FFT. This entails taking the FFT of the both the complex transmitted pulse and the complex received pulse, multiplying the results together using the complex conjugate of the transmitted pulse, and doing the inverse FFT. The result is a large amplitude pulse, displaced in time by the time difference of the two pulses. The implementation of the radar system will use an array of DSP's to execute the FFT's. In practice the FFT of the transmitted pulse is not computed since it is the same pulse every time, instead it is a look up table in memory.

SIMULATION

Historically, the non linear frequency modulation curve had been designed by the mathematicians, and the analogue transmitter and receiver sections designed by the RF engineers. It was decided that with the availability of high level simulation tools, a tool could be used to consider the consequences of each discipline's design decisions.

SystemView by Elanix Inc was chosen to model the RF analogue and DSP sections for its following merits :

- Ability to model non-linear RF and Analogue components, including compression points and intermods.
- Ability to model DSP processes with user specified data widths and formats.
- Ability to model multiple sample rate systems so that RF circuits can be combined with DSP systems in the same model.
- Relative ease of use compared to other simulation tools.
- Ability to easily examine and document simulation results.

PERFECT PULSE COMPRESSION

The shape of the frequency modulation is shown in figure 2. This was defined to be approximately 10uS in length and have a bandwidth of approximately 10MHz. Simulation of the pulse compression of the received pulse when not considering the analogue section of the transmitter and receiver showed that the pulse had a peak magnitude of 40dB, depending on where you define the floor. The "perfect pulse" is shown in figure 3.

It is worth discussing intuitively the type of pulse necessary to achieve a infinite pulse of zero width, ie an impulse. To get an impulse out of an inverse FFT (IFFT), then the input must be a non zero constant. To multiply two signals together and achieve a constant, both inputs must be a non zero constant. To get a non zero constant output from a forward FFT, then the input must contain an equal amount of all frequencies (ie the impulse). Now we know that it is impossible to create a perfect impulse with electronics, so we have to achieve the closest approximation possible, and that is a pulse which sweeps across the widest bandwidth possible. In practice the radar is limited in bandwidth by the available spectrum and the bandwidth of the DSP section.

SIMULATION MODEL

The model had to include the analogue components that would be in the transmitter and receiver systems, the non linear amplifiers, active mixers, phase splitters, power splitters, power combiners and low pass filters. The analogue section is shown in figure 4. The transmitter consisted of a pair of 10MHz, 12 bit digital to analogue converters (DAC), low pass filters (sometimes called reconstruction filters) to remove the higher frequency images of the signal, active mixers, a power combiner, and amplifier. The local oscillator was set at 40MHz, although the radar would use a much higher centre frequency than this, for modeling purposes the frequency can be scaled down. This keeps the simulation time short (less than 2 minutes). The transmission path is modeled by a power loss and time delay. The receiver consists of a pre-amp, power splitter, active

mixers, local oscillator, low pass filters and 10MHz 12 bit analogue to digital converters (ADC). The IQ inputs to the ADC's have noise added, which helps to improve the correlation process.

SIGNAL DISTORTION

The analogue components would cause signal distortion and noise. The main cause for concern was the distortion and how this would affect the power gain and width of the pulse after compression. The non linear amplifiers would produce harmonics of the input bandwidth of $\pm 5\text{MHz}$. The harmonics would be outside the bandwidth of the receiver so they would not affect the pulse compression, therefore it was not necessary to model the high power amplifier of the transmitter.

The major cause of distortion was the phase distortion caused by the non linear group delays of the reconstruction and anti-alias filters. A large change in group delay over the bandwidth of the pulse causes the pulse to have a slow rise time and decay at the end, see figure 5, this shows an overlay of the input to the quadrature DAC (black) and the output of the low pass (reconstruction) filter (grey). The diagram shows that the impulse response of the filter across the chirp bandwidth causes the pulse envelope to have a slow rise time and long decay. What is not very clear is that the change in group delay causes the waves to "bunch up" at the higher frequencies. The low pass filters used were 6 pole Chebyshev, with a -3dB point at 4MHz. The group delay of the filter is shown in figure 6.

All of this distortion affects the pulse compression and reduces the pulse compression gain. The compressed pulse from using the Chebyshev low pass filter in the DAC reconstruction filters and ADC anti-alias filters is shown in figure 7. It can be clearly seen when comparing the pulse with the pulse in figure 3, that the gain has been reduced to about 20 dB from 40 dB, and there is a second spike after the main pulse about 15dB below the main pulse. The pulse is also slightly wider. This will reduce the operating range and range resolution of the radar. The second spike could cause a spurious target detection.

FINAL DESIGN

The SystemView simulation software includes a filter design package, capable of designing Finite Impulse Response (FIR), Infinite Impulse Response (IIR) and Elliptic filters. The IIR section was used to model Bessel, Butterworth, Chebyshev, and linear phase low pass filters. The software calculates the group delay of each filter design. It was found by experimenting with different low pass filter designs in the model, that a Bessel filter gave the highest power, narrowest pulse after compression. The filter used was a 9 pole filter with a -3dB point at 5MHz. The advantage of the Bessel filter is that it has a flat group delay (linear phase) in the pass band, however it does not have a fast roll off compared to the Chebyshev. To make the roll off as steep as needed, a 9 pole filter was required. The compressed pulse from a model of the final design is shown in figure 8. It can be seen that the pulse is narrower and higher than the pulse using the Chebyshev filters.

CONCLUSIONS

Most of the design decisions could of been made using the old methods. However, when it comes to a more complex system where the integrity of the waveform is paramount and the mathematics are complex, it becomes increasingly more important to simulate.

By simulating, the mathematician and RF disciplines could integrate their designs and easily observe the interaction of each other's design decisions. Doing this before prototype build saved engineering effort trying to see why the pulse is not the same shape as expected by the mathematicians.

SystemView by Elanix Inc, provided an easy to use, comprehensive tool for modeling both the analogue RF and DSP sections of the system.

REFERENCES

(1) A. Acker, "How to speak Radar", 1974 Basic Fundamentals of Radar, page 10.

FIGURES

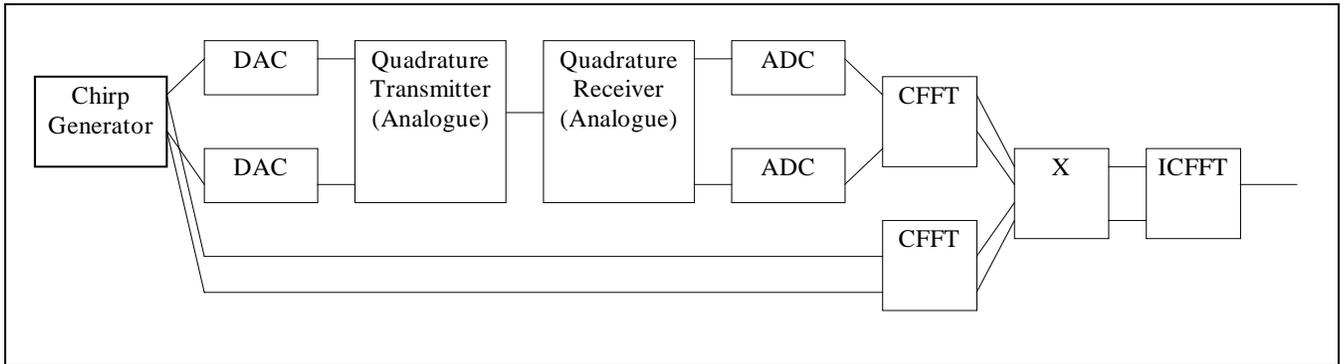


Figure 1 - Block diagram of digital pulse compression process.

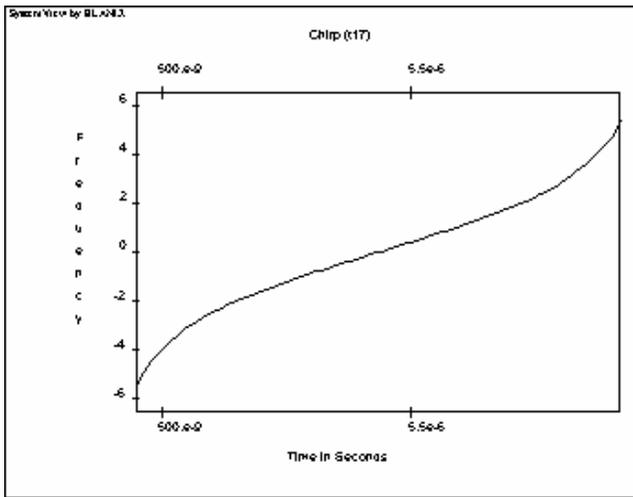


Figure 2 - Frequency modulation curve

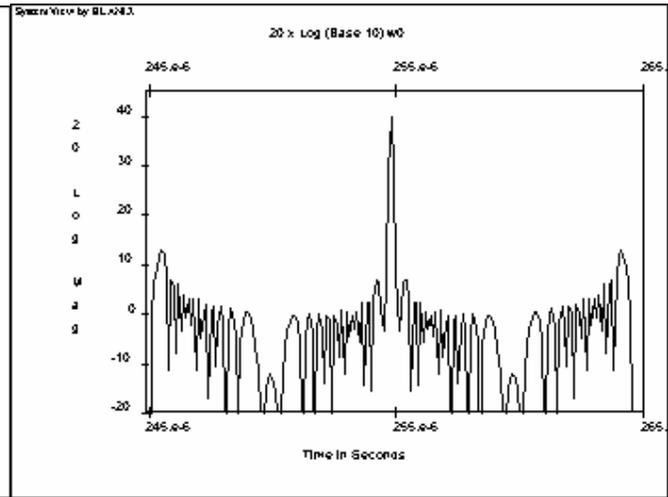


Figure 3 - Compressed Pulse (no analogue)

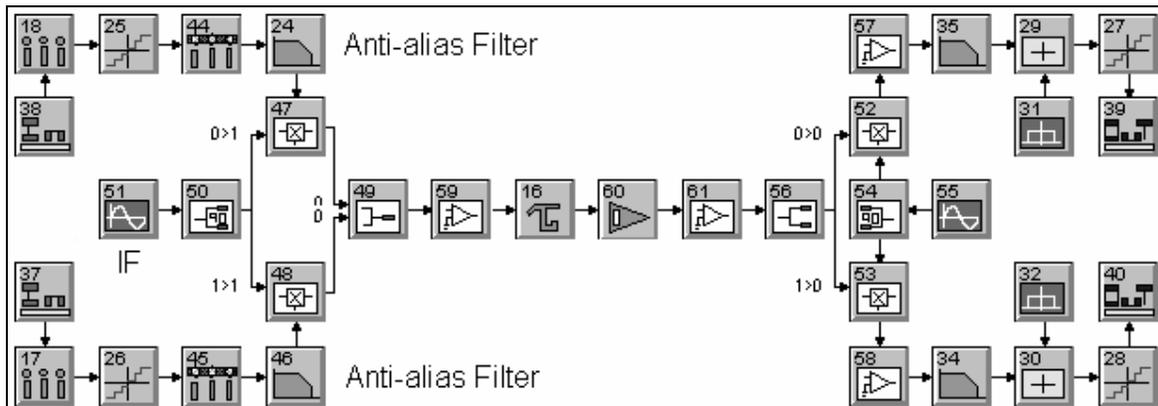


Figure 4 - Analogue section of transmitter and receiver model

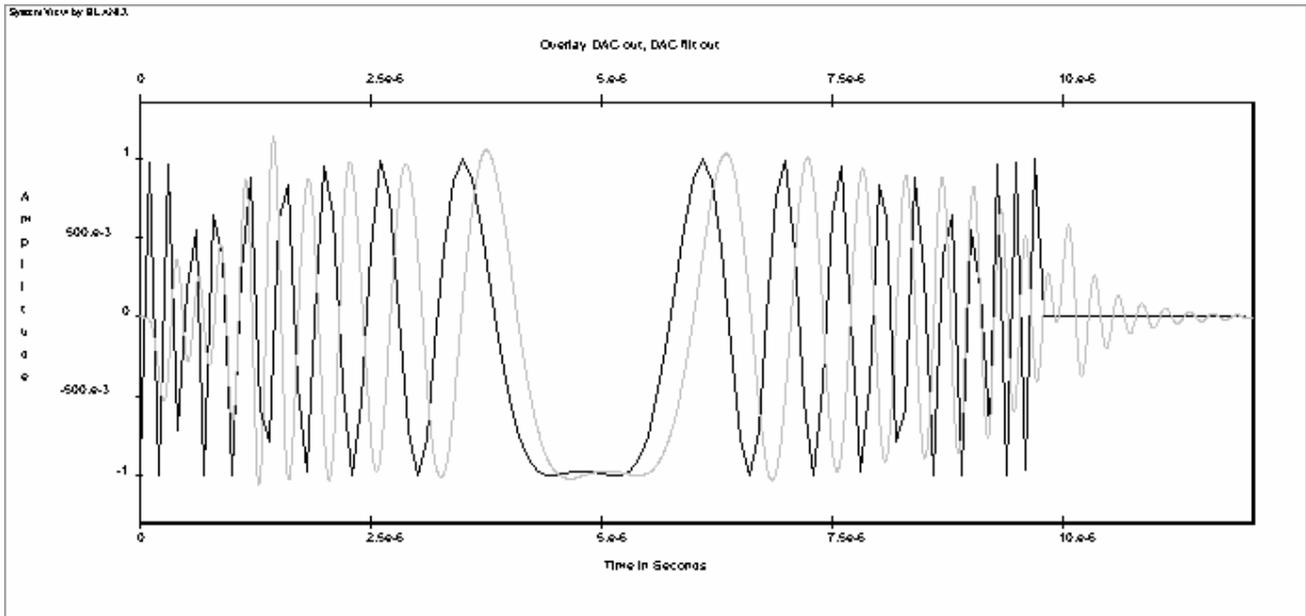


Figure 5 - Overlay of DAC input and low pass filter output

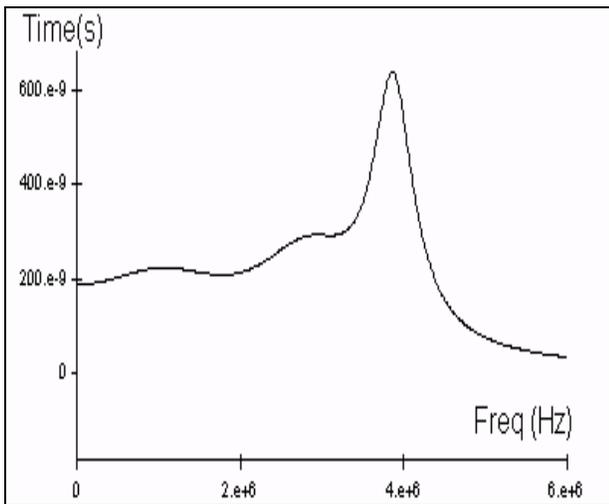


Figure 6 - Group delay of 6 pole Chebyshev

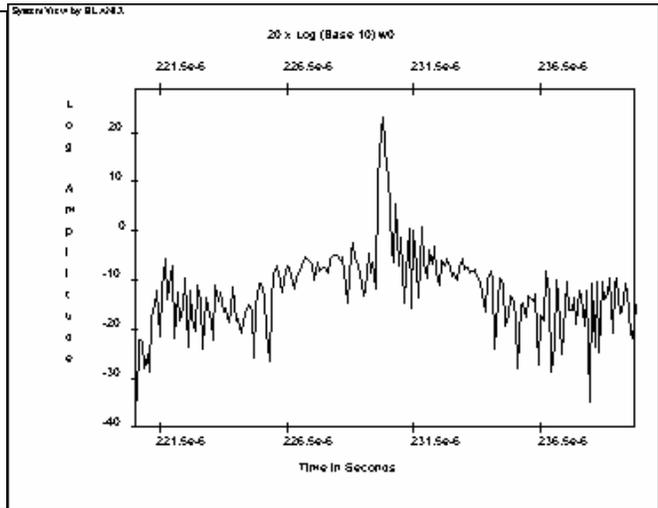


Figure 7 - Compressed Pulse using Chebyshev

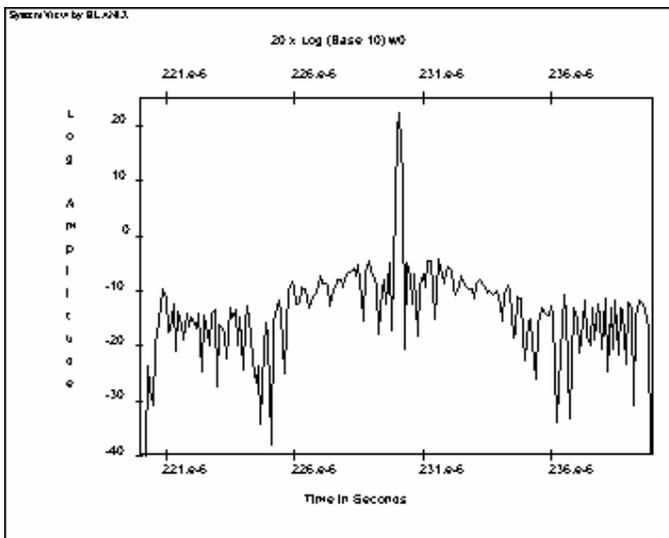


Figure 8 - Pulse using 9 pole Bessel with 5MHz cutoff

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Revised: March 27, 2008

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Printed in USA, November 14, 2003
5989-9520EN



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