Analysis of Range Ambiguity Effects in a Gated Linear FM Homodyne Receiver

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Abstract

Radar systems that use pulsed waveforms for detection can be adversely affected by target returns whose round-trip time of flight is longer than the radar's interpulse period. Unless techniques such as pulse repetition frequency (PRF) jitter or pulse phase encoding are employed, the receiver has no way of determining whether a target's range is accurate. If this radar system is being used to collect radar cross section (RCS) data, the range ambiguities may exhibit themselves as clutter and cause unacceptable levels of data contamination. A Gated Linear FM Homodyne (gated LFMH) radar modulates its transmitted signal during the time of an individual chirp, or frequency sweep, which leads to two distinct PRFs; the chirp PRF and the interchirp pulse PRF. The chirp PRF is typically very low, on the order of tens to hundreds of chirps per second, and therefore insignificant with respect to range ambiguities. It is the interchirp pulse PRF that is typically of sufficient rate to factor significantly in the processing of data collected with range ambiguities present. This paper provides analysis of the effects of range ambiguities in a typical gated LFMH radar that occur during wideband RCS data collections. In addition, a method for optimizing the radar system parameters through the prediction of the range ambiguities will be shown.

Keywords: Linear FM, PRF, Radar, Range Ambiguity, RCS Measurements

1.0 Introduction

Linear FM Homodyne (LFMH) Radars have been utilized for the collection of wideband radar cross section (RCS) data for years [1]. These systems can easily produce the wide bandwidths necessary for standard 1-, 2- and 3-dimensional RCS imaging. This paper describes the basic concepts of a linear FM homodyne (LFMH) radar and the effect of range ambiguities that arise when the system is gated.

2.0 Basic LFMH System

Figure 1 depicts a simplified LFMH radar system. The core of this radar architecture is a continuously swept frequency source which produces a linear sweep, or chirp, from a start frequency to a stop frequency. A sample of the transmitted waveform is fed to a mixer in order to down-convert the received waveform to baseband.

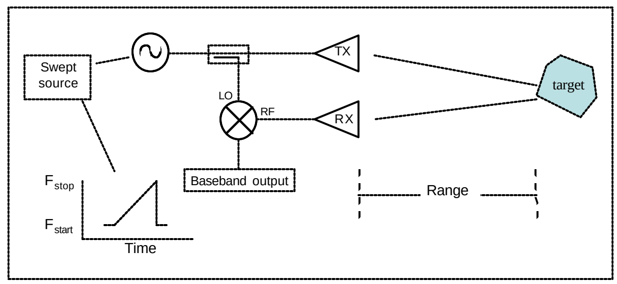

Figure 1 – Basic Linear FM Homodyne System

Because the transmit waveform sample is fed directly to the mixer, a time lag will occur between it and the received waveform. Figure 2 shows the timing relationship between transmitted and received waveforms and the resultant baseband frequency dependence on sweep rate and range to target.

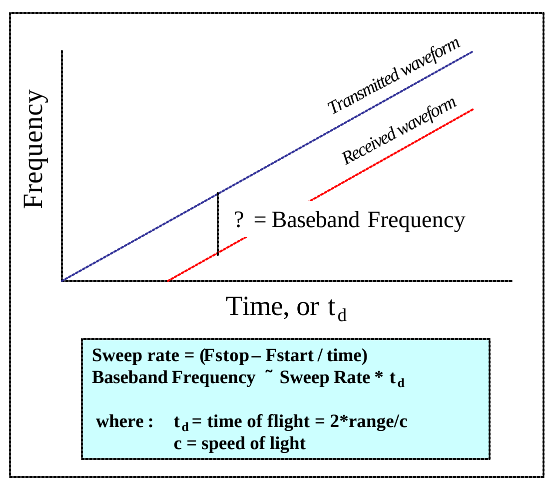

Figure 2 – Determination of Baseband Frequency

Figure 3 below shows the measured response of a single target echo. In this case, an LFMH radar system was configured with a delay line to simulate a target echo at range (amplitude deviations in the baseband signal are due to system power fluctuations across the frequency sweep). Because the echo is at a fixed range, a single frequency baseband signal, or tone, is produced over the entire frequency sweep.

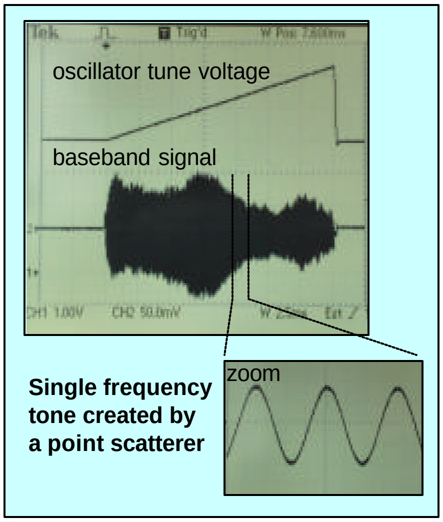

Figure 3 – Measured Waveforms (4 GHz sweep; 250 MHz/ms sweep rate)

After the received RF signal is down-converted to baseband, it is usually passed through a lowpass anti-alias filter before being sampled by an analog to digital (A/D) converter. By filtering the baseband signal, frequencies which are present due to far range echoes are eliminated prior to sampling. In a balanced system design, the A/D sample frequency is set equal to twice the baseband filter cut-off frequency, thereby ensuring that no baseband signals are sampled at less than Nyquist rates.

For a typical sweep repetition rate, or chirp PRF, of 100 Hz (10ms period), the LFMH radar is unambiguous in range out to many hundreds of miles, although the cut-off frequency of the baseband filter and the A/D sample rate will determine the maximum range of the system

Range resolution is performed by the application of a Fourier transform to the sampled baseband signal. Individual target echoes separated in range will have correspondingly different baseband frequencies which will be separated by the Fourier transform process. Software gating techniques can then be used to "filter" the baseband signal to a smaller frequency bandwidth in order to achieve a smaller range window.

3.0 Gated LFMH Signals

Pulse gating is usually employed in a LFMH radar to increase the isolation between the system's transmitter and receiver sections. Pulse gating may also be used to reduce the effects of localized clutter sources (i.e. a chamber back wall).

The pulse gating is performed by RF switches which are located in the transmit and receive component chains and are continually pulsed during the time of the frequency sweep, as shown in Figure 4.

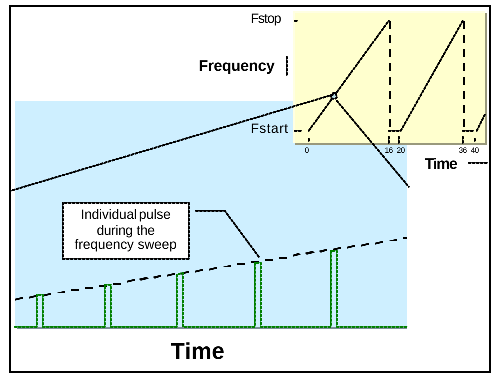

Figure 4 – Pulse Gating During a Frequency Sweep

First, a short transmit pulse is produced and sent toward the target. When the desired received echo returns, the receiver is opened up to allow the pulse to enter. In a LFMH radar, to receive the entire target zone echo the receiver must be left open for a time equal to twice the electrical length (i.e. a target length of 100 ft has an electrical length of roughly 100 ns, so 2*100 ns) of the target zone plus the transmit pulsewidth.

The gating essentially performs an RF sampling which can be seen in the down-converted baseband signal as shown in Figure 5.

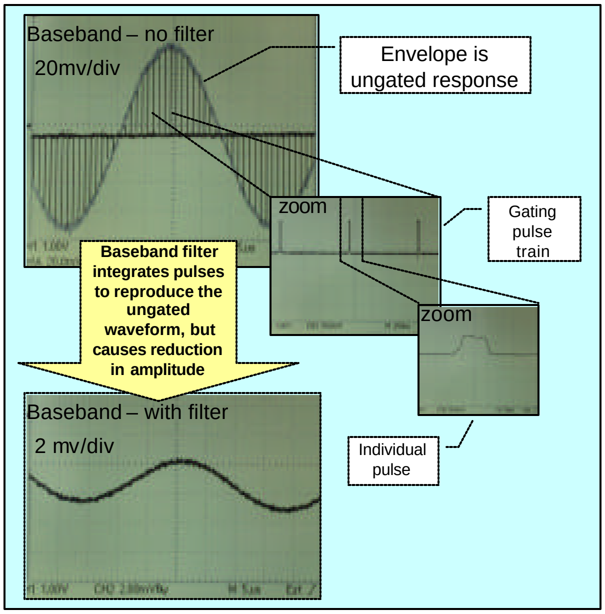

Figure 5 – Pulse Gating Effect on Baseband Signal

As seen above, the pulse gating creates a pulse train in the baseband signal which describes the same envelope as an ungated signal. After filtering, the frequency content of the gated signal is identical to the ungated signal, but an amplitude loss occurs due to the gating duty cycle.

As with traditional digital sampling, the RF sample frequency, or interchirp PRF of the pulse gating must meet the Nyquist criteria for the highest baseband signal present. For example, a LFMH radar using a frequency sweep rate of 250 MHz/ms will have a baseband frequency of 250 KHz for an echo received from a range of 500 feet. As long as the interchirp PRF is 500 KHz or higher, the echo will be down-converted correctly. Higher interchirp PRFs are typically desired because they reduce the duty cycle amplitude losses.

4. Range Ambiguities and the LFMH Receiver

Traditional pulsed radars are based on the premise that all echoes from a single transmit pulse are received before a second pulse is transmitted. Range ambiguities normally occur when a receive pulse is delayed in time for long enough so that one or more subsequent transmit pulses (2nd, 3rd, 4th, etc.) are produced before the first receive pulse returns.

In a gated LFMH receiver, any delay in a received pulse creates a greater baseband frequency at time of down-conversion. This means that a LFMH receiver can correctly process the delayed receive echoes mentioned above, provided that the interchirp PRF is high enough to adequately sample them. The interchirp PRF must be at least twice the frequency of the highest baseband component. Signals that are not adequately sampled will become aliased when they are reconstructed in the baseband filter, thus producing an incorrect baseband frequency which in turn creates an erroneous range response.

The issue of insufficient RF sampling arises when the physical limitations of a measurement setup prevent high RF sample frequencies. This is the case typically encountered in an outdoor scenario where the distance to target is long enough so that the 2-way transit time of a transmitted pulse and corresponding receive echo is the determining factor for the maximum interchirp PRF.

For a 100 ft target centered at a range of 250 feet, the round trip transit time to the target center is roughly 500 ns. Using a 100 ns transmit pulsewidth, the required receive gate would need to be 300ns long. Because the target is centered at 250 ft, one half this is added to the 500 ns to give a round trip transit time to the far end of the target zone of 650ns. Assuming no additional system overhead, the maximum interchirp PRF becomes 1/650 ns, or roughly 1540 KHz.

If a LFMH radar system is configured for an interchirp PRF of 1540 KHz, then the highest baseband signal that can be Nyquist sampled is 770 KHz, which equates to an echo at a range of roughly 1500 ft. Target echoes from ranges farther than this will create an aliased baseband response, which depending on the amount of aliasing may show up as erroneous echoes in the desired target zone.

5. Ambiguity Prediction

The next step in the analysis of range ambiguity effects in a gated LFMH receiver is to determine where far range echoes will alias. As stated in the previous section, the interchirp PRF determines the final baseband frequency of the aliased echoes. Baseband frequencies which exceed the Nyquist sampling frequency of ½*interchirp PRF will begin to alias and appear lower in frequency, continuing towards DC as the received baseband frequency increases. At DC, the aliased signal will then begin to increase in apparent frequency until it again reaches the Nyquist frequency. This pattern continues to repeat indefinitely.

Because the radar is pulse gated, it receives echoes not only from the desired target range, but also at ranges that have time delays which are multiples of the interchirp PRI (PRI = 1/PRF). These multiples correspond to receive echoes returning to the radar after subsequent transmit pulses have been emitted. These receive echoes are known as "n-time around" echoes because they have a time relationship that is equal to N*PRI, where N is 1, 2, 3, etc. Figure 6 shows a simulation tool that graphically depicts the relationship of the desired target zone (N=1 region) to these n-time around echo zones for an interchirp PRF of 1540 KHz.

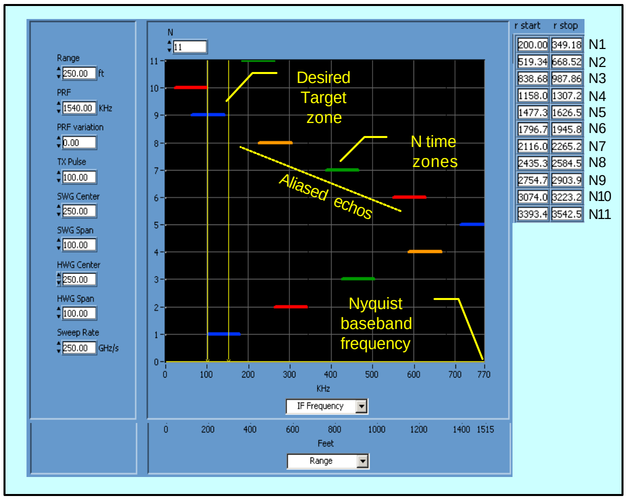

Figure 6 – Interchirp PRF Simulation at 1540 KHz

The width of the n-time zone indicators represents the amount of range extent received for each transmit pulse and is determined by the parameters entered on the left of the GUI. With a sufficiently high interchirp PRF, many of the first n-time echoes are adequately sampled and unaliased. If a 250 KHz anti-alias baseband filter is used, the LFMH system will have a range of roughly 500 ft. N-time zones at baseband frequencies higher than 250 KHz, either aliased or unaliased, will be eliminated by the filter. Only those n-time zones that fall within the desired target zone (in this case, N=9) can corrupt the target data.

Figure 7 shows the effect of lowering the interchirp PRF to 1300 KHz in order to move all of the N<12 echoes out of the desired target zone. At 1300 KHz, the N=11 echo is at a range of over 4000 ft.

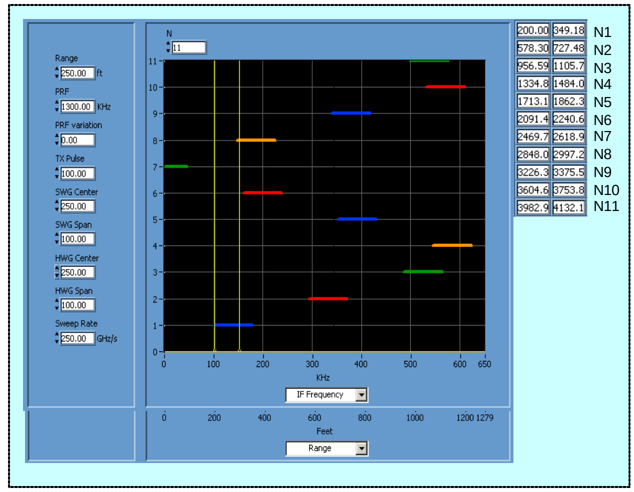

Figure 7 – Interchirp PRF Simulation at 1300 KHz

The simulation is interactive to allow the user the ability to change the radar parameters, primarily the interchirp PRF, and see the effect on the n-time echo zones. In this way an optimum interchirp PRF can be chosen to either eliminate or diminish the effect of unwanted aliases.

6. Conclusions

The analysis of range ambiguity effects in a gated LFMH receiver shows that when dealing with far range echoes, this receiver type has several unique characteristics compared to traditional pulsed radars that must be understood in order to configure the system for optimal performance. The adjustment of the interchirp PRF is a critical step to ensuring high quality data.

7. References

[1] Dean L. Mensa, High Resolution Radar Imaging, Artech House, Inc.,1981, Chapter 3.

8. Acknowledgments

The authors wish to thank Paul Degroot of The Boeing Company for his technical assistance.