Real Time Generation, Data Acquisition and Analysis of LPI Radar Signals

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Abstract:

With the rapid advancements in signal processing and VLSI areas, In the modern Electronic warfare scenario, ESM receivers development has taken a major leap in intercepting and analyzing the conventional radar signals in real time but at the same time, Radar technology has also been incorporated with EP features such as the Low Probability of Intercept(LPI).The radar uses Different methodologies to achieve the LPI feature, but most of them are centered around the various modulations that are impressed upon a radar waveform to mask its presence. So, to intercept and jam the LPI radar signals a thorough understanding and analysis of the signal characteristics is required. The present paper discusses the various LPI radar signals generation through arbitrary waveform generator, analysis of the generated waveforms through Real Time Spectrum Analyzer and acquisition of the signal samples using a digital receiver having high speed ADC for further analysis.

Key Words: LPI-Low Probability of Intercept, EW-Electronic Warfare, Intra Pulse Modulation, Arbitrary Waveform Generator (AWG) and Real Time Spectrum Analyzer (RTSA), Digital Receiver

I. INTRODUCTION

A covert radar operation in a Low Probability of Intercept (LPI) mode is and will be the most effective measure against the ESM detection, intelligent jamming and the Anti Radiation Missile (ARM) threat [1]. The function of Low Probability of Intercept (LPI) radar is to prevent its interception by an Electronic Support (ES) receiver. This objective is generally achieved through the use of a radar waveform that is mismatched to those waveforms for which an ES receiver is tuned. This allows the radar to achieve a processing gain, with respect to the ES receiver, that is equal to the time-bandwidth product of the radar waveform. This processing gain allows the LPI radar to overcome the range-squared advantage of the ES receiver in conventional situations. Consequently, a conventional ES receiver can only detect LPI radar at very short ranges «3 nm. Most LPI Radar concepts try to reduce the transmitted peak power by stretching the signal in time and frequency in order to camouflage the specific radar signal signature. The use of a narrow beamwidth together with a low sidelobe pattern leads to further reduction of the intercept probability. Some waveforms are intentionally designed to make the detection process nearly impossible. The paper discusses the major LPI radar signals and their generation approach, analysis methodology together with the real time signal acquisition using high speed hardware.

II. LPI RADAR SIGNALS

It is well known that the ability of anti-jamming is prime target for evaluating the characteristic of radar. To improve the ECCM performance of radar, Pulse compression techniques have been widely used in many modern radar systems. The transmitted pulse is modulated by using frequency (chirp) modulation or phase coding in order to get large time-bandwidth product[2]. In receiver side, the target echo signal is passed through a filter matched with the transmitted waveform and results in an extremely narrow impulse with a large peak value, thus the transmitted pulse is compressed in time domain. Pulse compression combines the advantage of high energy of a long pulse with the high resolution of a short pulse.

Most of the LPI radars use FMCW, Chirp signals which are frequency modulations employing pulse compression technique. The advantage of FMCW radars are their extremely high time bandwidth product which makes them very resistant to interception by ES systems. Large modulation bandwidth provides very good range resolution. Stepped, Ramp and Triangular frequency modulations come under Linear FM while Sinusoidal and Square FM comes under Non linear FM.

Pulse compression can also be implemented by using phase-coded waveform and applying the digital correlator as the matched filter. The complex envelope of the phase-coded pulse is given by

$$u(t) = 1/T\sum_{m=1}^{M} u(m)\,rect[t-(m-1)tb)/tb]$$

where um = exp $(j\varphi m)$ and the set of M phase $\{\varphi 1, \varphi 2, ..\ \varphi M\}$ is the phase codes associated with $u(t)$. The phase codes are chosen so that the autocorrelation function of the waveform has the larger peak signal to peak sidelobe ratio (PSR) for a certain code length. The PSR is bounded by the code length N, or can be expressed in dB as

$$\text{PSR (dB)} = 20 \log (N).$$

The binary Barker sequences are finite length, discrete time sequences with constant magnitude and a phase of either $\varphi_k = 0$ or $\varphi_k = \pi$. The main drawback of binary codes such as Barker code and m-sequences is their sensitivity to Doppler shift.

"Good" codes are defined as those having one main peak in their autocorrelation function and minimum residual or side peaks. "Optimum" binary sequences having a main peak-to-side-peak ratio equal to the sequence length have been found only for sequences having length 13 or less in the case of Barker coded signals.

Polyphase codes have no restriction on code elements, and are normally derived from the phase history of frequency-modulated pulse. The Frank code and the P1 and P2 codes, the modified version of Frank code, are derived from the frequency stepped pulses. These three codes are only applicable for perfect square length ($M = L^2$) and can be expressed as[2]

Frank: $$\phi_{i,j} = 2\pi / M[(i-1)(j-1)]$$

P1:

$$\phi_{i,j} = -\pi / M[M-(2j-1)][(j-1)M+(i-1)]$$

P2: $$\phi_{i,j} = -\pi / 2M[2i-1-M][2j-1-M]$$

Another two well known polyphase codes are P3 and P4 codes derived from the linear frequency modulated pulse. Unlike Frank, P1, and P2 codes, the length of P3 and P4 codes can be arbitrary. P3 and P4 codes can be expressed as

$$\text{P3: } \phi_i = -\pi / N_c (i-1)^2$$

$$\text{P4: } \phi_i = -\pi (i-1)^2 / N_c - \pi (i-1)$$

It has been observed that Frank, P1, and P2 codes are more Doppler-tolerant than binary phase codes and P3 and P4 codes are even better. However, when the relative velocity between the radar and the target is relatively large comparing with the velocity of signal propagation and is not negligible, the received signal is Doppler distorted and does not match with the matched filter. This mismatch will result in the signal loss and the sidelobe increasing in the compressed pulse, therefore the Doppler-tolerant waveform with the minimum signal loss under different Doppler environments is always desired. With this objective, random phase coded radars signals are under research today. One criterion for the selection of a good ‘random’ phase coded waveform is that its autocorrelation function should have equal time-side lobes. Also, one of the common objectives in waveform design is to achieve clear areas in the distribution of ambiguity [3].

For the intercept receiver to demodulate the waveform, the particular modulation technique must be known (which is typically not the case).So, a detailed analysis of these above waveforms is done by generating the signals through the arbitrary waveform generator and signal data has been acquired for further analysis in MATLAB and implementation in FPGA based processing hardware.

III. GENERATION ANALYSIS & ACQUISITION OF LPI RADAR SIGNALS

Generation: Modern radar design has created complicated pulses that present significant generation challenges. In the modern world of "software defined" radar, modulated pulses, chirps, and other waveforms are often created not with traditional analog circuitry, but with Digital Signal Processing, DSP, and Direct Digital Synthesis techniques that digitally synthesize complicated signals directly at IF or RF frequencies [4]. These only become analog when the synthesized digital data is put through a D/A converter. The above said LPI radar waveforms i.e. Chirp, FMCW, Barker, Polyphase (P1-P4), have been generated using the Tektronix AWG7122C arbitrary waveform generator having the advanced DSP and DDS features coupled with software called RFXpress. Some of the generated waveforms have been shown below.

Fig 1: 7 Bit Barker signal generated from the AWG

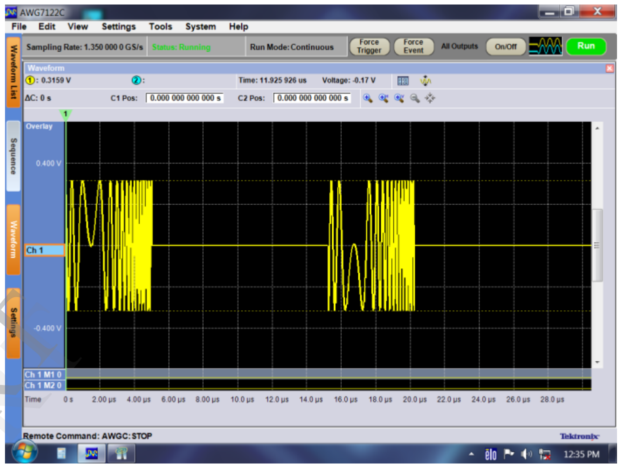

Fig 2: Chirp Signal generated from the AWG

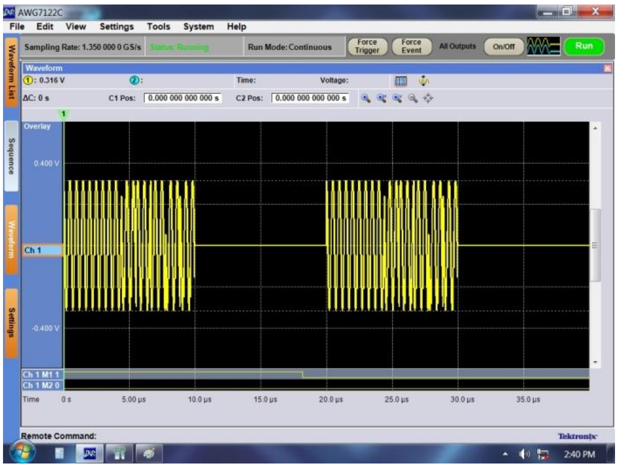

Fig 3: 4 Bit (16 phase) Frank signal

Analysis: During the verification of the design of radar, there is a need to assure that the transmitted signal is correct, that the receiver responds to correct signals, and that there are no unexpected signals emitted from the transmitter. Unexpected outputs can range from unintended signals that are related to the desired pulse (such as harmonics, sub-harmonics, image mixing products, etc.), as well as spurious outputs unrelated to the desired pulse, such as radiation of internal local oscillators, coupling from digital clocks, spurious oscillations within RF circuitry, pulse errors, etc. A single incorrect computer instruction can create momentarily incorrect RF output. This can play havoc when filtered, amplified, and transmitted. Spurious emissions can interfere with other services as well as provide a distinctive signature if they are specific to a particular transmitter design.

So, after the generation of the LPI Radar signals using the arbitrary waveform generator the verification and validation and analysis of these waveforms has been done by using the Real Time Spectrum Analyzer (Model RSA 6114A).

In the Real Time Spectrum Analyzer There are several ways to analyse different modulations within a pulse apart from traditional Spectrum analysis. They are

i. DPX Spectrum
ii. Amplitude-versus Time Plot
iii. Phase-versus Time Plot
iv. Frequency-versus Time Plot

The DPX Spectrum shows in real time the frequency concentration of the modulated signal which can't be measured using the traditional spectrum analyzers.

Amplitude versus Time is a single parameter measurement. It operates on a sample-by sample basis. The amplitude measurement plots the magnitude envelope detection. Here the magnitude is calculated for each sample by squaring both In-phase (I) and Quadrature (Q) values for each sample, summing them and then taking the square root of the sum.

The Frequency vs. Time graph gives a detailed view of the time frequency representation of the signal i.e. how the frequency of the signal is varying over time and also the gives the frequency at any instant of time. This graph is very useful and is used for the analysis of the Chirp waveform.

The Phase vs. Time graph gives a detailed view of how the phase of the signal is varying over time and also the gives the instantaneous phase. This graph is very useful and is used for the analysis of the all the phase coded waveforms i.e. for Barker, Polyphase (P1-P4). Some of the analysis plots (Frequency vs. Time, phase vs. time and amplitude vs., time, DPX spectrum, phase deviation, frequency deviation views) of the waveforms generated using the AWG and analyzed using the Real Time Spectrum Analyzer are shown below.

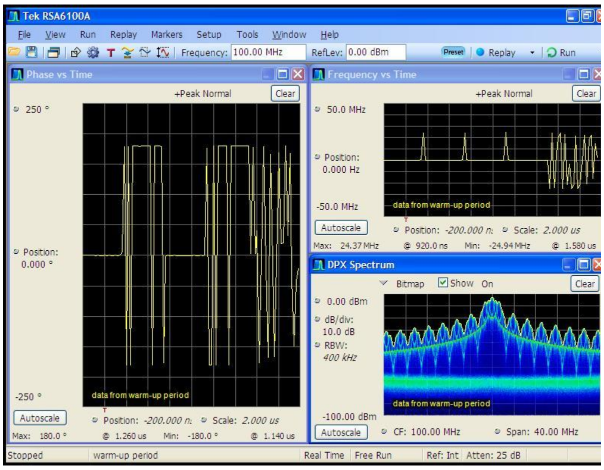

Fig 4: Phase vs. Time, Frequency vs. Time and DPX

views of a 13 bit Barker Coded pulse.

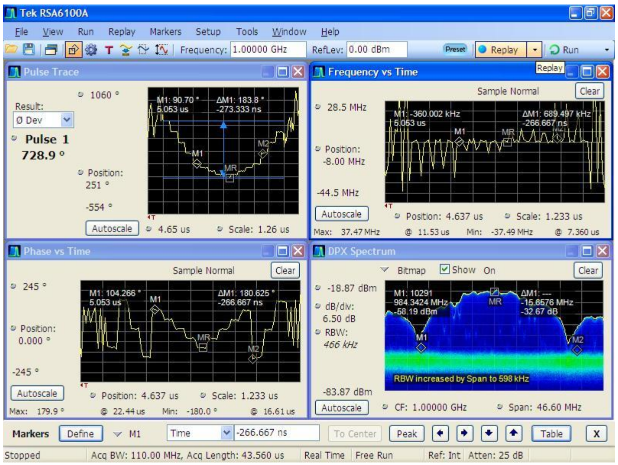

Fig 5: Phase deviation, Phase vs. Time, Frequency vs.

Time and DPX views of a P1 polyphase code.

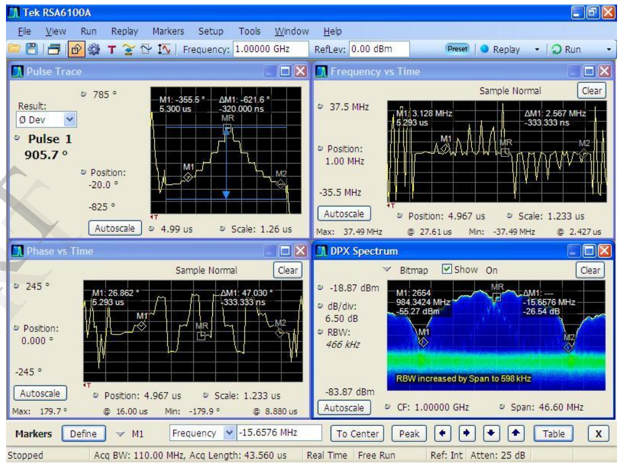

Fig 6: Phase deviation, Phase vs. Time, Frequency vs.

Time and DPX views of a P3 polyphase code.

Data Acquisition: The present day Radar signals can be processed in real-time if the time taken by the system to process signals is equal to the time taken by the system to acquire the data, especially if a radar signal is converted to digital data by using high speed ADC with sampling frequency of the order of GHz. In order to get real-time response, the rate at which the data is processed should match the ADC data rate[5] .To achieve this and for further algorithm verification, the signals generated using the Arbitrary waveform generator have been acquired using a single channel digital receiver hardware consisting of high speed ADC i.e.AD8D1500 ADC and Virtex-4 FPGA. Real-Time data Captured from an 8 Bit ADC with a sampling frequency of 1.35 GHz using Virtex-4 FPGA is shown in the figure below. Top portion of the figure shows the bus plot and the bottom portion of the figure shows waveform plot using Chip Scope Pro Tool. The digitized data from the ADC will be interfaced to an FPGA and is imported to a file onto a PC for further algorithm verification. The test setup for the data acquisition is shown below in figs 7, 8.

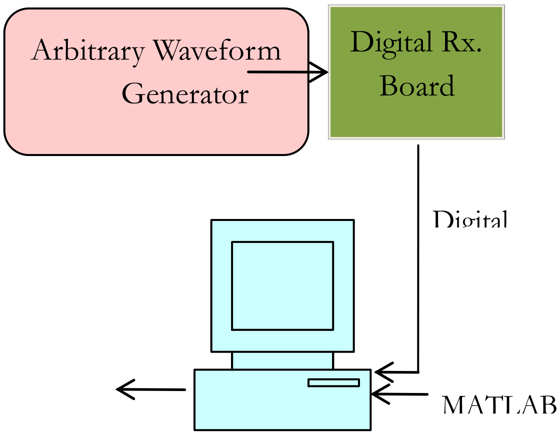

Fig 7: Real Data Acquisition and Analysis Process

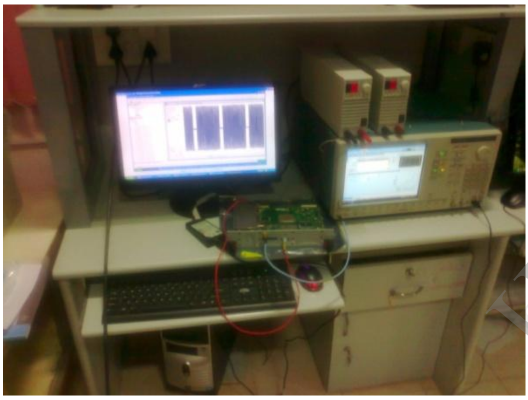

Fig 8: Laboratory test setup for Data Acquisition

IV CONCLUSION

The paper outlined the major LPI radar signals and their generation approach, analysis methodology together with the real time signal acquisition. Today more and more LPI radars are being inducted into modern weapon systems and platforms with different techniques such as Unpredictable main lobe pointing and the agility of the signal parameters such as transmit frequency, pulse width, pulse interval and scanning techniques which will further increase the difficulties of ESM receivers in signal classification and processing. So, Modern electronic intercept systems must perform the tasks of detection, classification, identification and exploitation in a complex environment of high noise, interference and multiple signals. Therefore, by investigating the design constraints imposed on the LPI Radar designer and understanding the ultimate requirement to detect and track targets of different cross section and velocity, there are options for the ESM designer to intercept and jam the LPI Radar signals.

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REFERENCES

[1] Heiner Kuschal, *Trends And Tendencies in LPI Radar*, Proceedings of Environmental factors in EW related to EW, Italy,1995.

[2] Philip E Pace, *Detecting And Classifying LPI Radar*, Second Edition,Artech House, Inc., Norwood, Massachusetts, 2009.

[3] W.-K. Lee and H.D. Griffiths, Development of modified polyphase P codes with optimum sidelobe characteristics, IEE Proc.-Radar Sonar Navig., Vol. 151, No. 4, August 2004.

[4].Fundamentals of Radar Measurements, Primer, S No.37W_22065, Tek

[5].V V S R N Raju, R Pavan Kumar, A K Singh, K Subba Rao, Detection, Identification and Classification of LPI radar signals, second International Conference in Electronic Warfare, Feb 2012, India.