Approach of Pulse Parameters Measurement Using Digital IQ Method

R. K. Niranjan and B. Rajendra Naik

***Abstract*—Electronic Warfare (EW) systems measuring the radar parameters using conventional method can't preserve phase information of the incoming Radio Frequency (RF) signals. Conventional methods does the measurement using detected video signal or envelope of the RF. Proposed method does the measurement using intermediate frequency (IF) signal which is the down converted signal of RF signal. This method preserves the phase information because the intrapulse and interpulse measurements are carried out using the IF signal. The Matlab simulation is carried out for the intrapulse analysis and results are presented and discussed. The comparison is given between conventional method and proposed method for Radar EW systems.**

***Index Terms*—EW systems, IF signal, intrapulse, interpulse, RF signal.**

I. Introduction

Conventional EW systems are good for the basic radar parameter measurements like frequency, pulsewidth (PW), pulse repetition frequency (PRF), pulse amplitude (PA) and direction of arrival (DOA) of incoming signal. The measurement of DOA technique is not discussed in this paper. In addition to above parameters it also measures the type of emitter based on the pulse width and scan type using pulse amplitude [1]. The conventional EW systems are not capable to measure the variations of parameters such as phase, frequency and amplitude within the pulse. The block diagram of conventional EW receiver is shown in Fig. 1. The frequency is measured based on the instantaneous frequency measurement (IFM) receiver and other parameters are measured based on the detector output.

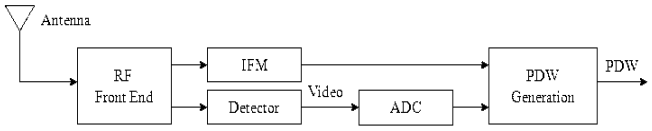


Fig. 1. Block diagram of conventional EW receiver.

Initially the measurement of radar pulse parameters being carried out using the envelope of the down converted IF or RF signal. This envelope is nothing but it is video signal. In the process of envelope detection, the phase information of the signal is lost. Therefore these methods are not useful where phase information is to be preserved.

The proposed EW receiver is shown in the Fig. 2. The next generation EW receiver is the superhet receiver. The superhet receiver downconverts the RF signal into the fixed IF signal of the required bandwidth. The bandwidth is varied depending upon the requirements. The superhet receiver has the advantage of sensitivity due to its limited bandwidth. The proposed method of intrapulse analysis works alongwith the superhet receiver. The IF generated from the superhet receiver is digitized. The frequency translation is carried out on these digitized IF samples and filtered out the highest component. This method measures the rise time and fall time and it also carries out measurement of parameter variations within the pulse.

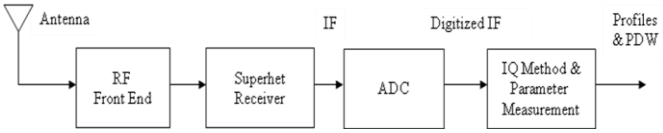


Fig. 2. Block diagram of proposed EW receiver.

The method presented in this paper has the advantage of both real time and intrapulse parameter measurements. The proposed method is implemented in Matlab. The measurements are based on the In-phase (I) and Quadrature-phase (Q) processing which gives the intrapulse parameter measurements for EW applications. It measures the instantaneous parameter like phase, frequency and amplitude for intrapulse analysis whereas pulse width and pulse repetition interval for inter pulse analysis. The various radar signal waveforms can be handled by the proposed method.

The I and Q components are generated using frequency translation. The output of frequency translation consist one upper and one lower frequency components. The upper frequency components are filtered out by the low pass finite impulse response (FIR) filter. At the output of filter the phase is computed using I & Q filtered outputs. The proposed digital IQ method is discussed in detail in the subsequent section.

Different types of radar signal waveforms are described in Section II. The design of digital IQ method and its implementation using Matlab is discussed in Section III. Matlab results are presented in Section IV and conclusions are given in Section V.

II. Signal Waveforms

The basic classification of radar signals is Pulsed or Continuous Wave (CW). If the signal is CW it may be simple

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CW and frequency modulated CW (FMCW) [2]. If it is Pulsed it may be simple pulsed or modulated pulsed signal. The modulations in the pulse may be chirp, barker coded and stepped FM. The variation in Frequency, PRF and PW on pulse to pulse basis also exists in the radar signals. Change in frequency based on pulse to pulse or scan to scan is known as frequency agility. Similarly, the change in PW is known as PW agility. The proposed method is capable to measure above signals.

III. Digital IQ Method

A typical signal in radar, communications and related fields is a bandpass signal. The time domain representation of continuous signal is obtained using complex notation. The signal is digitized by the technique called IQ sampling shown in Fig. 3. This analog method is difficult to implement without errors. Analog mixing of IQ sampling introduces some phase difference between the In-phase path and Quadrature-phase path. The continuous noise is also added to the signal due to the active low pass filter devices. To overcome these errors quadrature sampling with digital mixing is preferred.

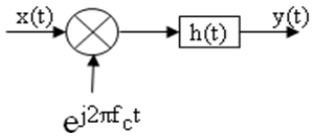


Fig. 3. Analog mixing with low pass filtering.

The above disadvantages can be avoided with digital mixers and digital filters. The mixing signal frequency f_c is chosen one fourth of the sampling rate [3]. The digital mixing process is shown in Fig. 4.

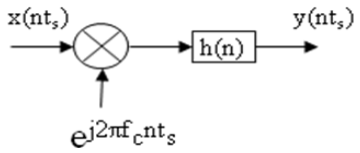


Fig. 4. Digital mixing with low pass filtering.

A. Noise Estimation

The weakest signal that can be detected is known as minimum detectable signal. The incoming signal is compared with the threshold. If the incoming signal is greater than the threshold level, the single is detected. Two types of threshold are used. One is fixed threshold, whereas other is noise riding threshold. The fixed threshold is decided in advance. Whereas the noise riding threshold is computed based on the noise estimation before the pulse, i.e. during signal absence. The noise is estimated for finite duration in real time.

If the output signal exceeds the threshold, the target is declared as present. The threshold level is very critical since it affects the detection probability of the receiver and thus directly affects its performance. If the threshold is too high, then the receiver misses the weak signals and if it's too low the receiver picks up false signal.

The initial equation to calculate noise riding threshold is the standard deviation of the period N in discrete form and can be written as

$$\sigma = \sqrt{\tfrac{1}{N}\sum [x(nts) - x(avg)]^2} \quad (1)$$

where, σ is the standard deviation, x(nts) is the digitized samples and x(avg) is the average value of the x(nts) for the period of number of samples (N). The x(avg) is written as

$$x(avg) = \frac{x(0)+x(1)+.....+x(n-1)}{N} \quad (2)$$

To estimate noise threshold, the method is shown in Fig. 5.

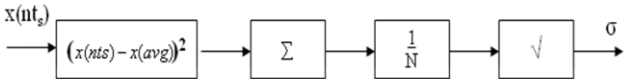


Fig. 5. Noise riding threshold.

The equation to compute noise riding threshold in real time for the period N in discrete form can be written as

$$\sigma' * \varepsilon = \frac{1}{N}\sum |x(nts)| \quad (3)$$

To estimate noise threshold in real time, the method is shown in Fig. 6. The standard deviation computed using this method (σ') is almost equal with standard deviation computed using previous method (σ). If there is little difference that is corrected using threshold correction.

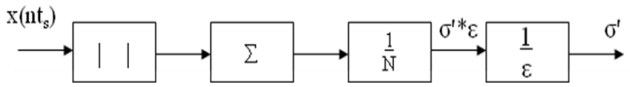


Fig. 6. Noise riding threshold in real time.

The multiplication error constant ε can be computed priori. In this method there is no need to compute the square and average of digital sequences. Apart from time it computes the threshold for a given time period N in real time. Whereas in other method, after computing average of sequence only, further difference of average and original sequence and squaring of this difference is carried out. The above method is implemented in Matlab.

After computing the value of standard deviation, the value of threshold can be decided. If the threshold is equal to one sigma, then 68.27% is the probability of detection. If the threshold is equal to two sigma, the probability of detection is 95.45%. If the threshold is equal to three sigma, the probability of detection is 99.73% [4]. Practically many people, choose threshold equal to two sigma. The probability density function with respect to standard deviation is shown in Fig. 7.

The above figure shows the probability density function of the guassian distribution function. The noise is said to be

guassian in nature and it is spread in the full band.

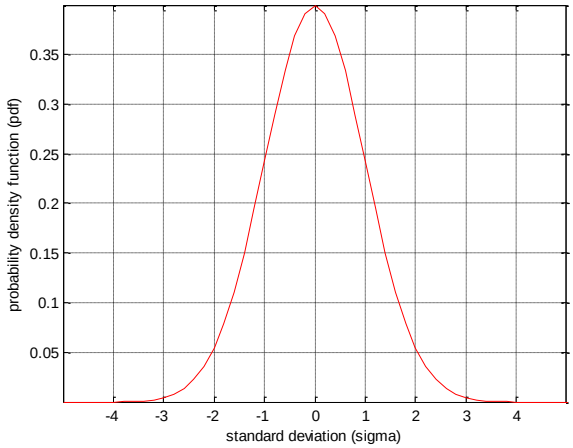


Fig. 7. Probability density function plot.

The input signal $x(t)$ is digitized at a sample rate of $f_s=4f_c$ is shown in Fig. 5. The discrete samples are represented as $X(nt_s)$. The quadrature mixing with $f_c=f_s/4$, to centre the input signals in-phase and quadrature phase components about zero hertz, is performed digitally with the results of the in-phase replicated components, and the low pass filtered in-phase and quadrature-phase components are obtained. Using this, the difficulties in signal path phase and amplitude matching are eliminated because only one A/D converter is used. In addition, the DC bias problems associated with analog signal mixing to zero Hz are avoided [5]. The block diagram shown in Fig. 8 shows the conversion of input signal into complex signal alongwith the parameter measurement.

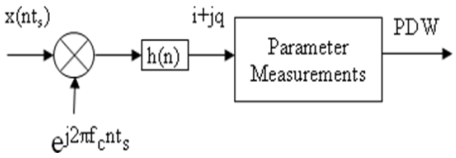


Fig. 8. PDW generation using digital approach.

B. Pulse Descriptor Word

The threshold computed using noise estimation is applied for pulse detection. Once pulse is detected, the parameters are measured. The pulse parameter constitutes the PDW as shown in Fig. 9.

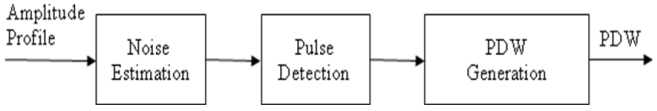


Fig. 9. PDW generation.

PDW consists of frequency, PW, PA and PRF. The minimum, maximum and average value in stable region for frequency and amplitude is also measured.

C. Matlab Implementation

The input digitized sequence is generated in Matlab. The complete parameter measurement approach using digital IQ is implemented. The block diagram of parameter measurements is shown in Fig. 10.

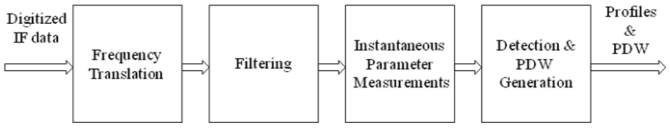


Fig. 10. Block diagram of parameter measurements.

The incoming IF signal is digitized using analog to digital converter. The digitized IF signal $x(nt_s)$ is multiplied by the numerically controlled oscillator (NCO) outputs and its 90^0 phase shifted outputs. Thus the incoming signal is converted into complex signal. The detailed block diagram of profiles generation is include phase, frequency and amplitude profiles. The amplitude profile is used for detection. The frequency profile is used to find out the frequency. The block diagram of phase, frequency and amplitude profiles generation is shown in Fig. 11.

The various instantaneous parameters [6] have been measured by the proposed method. The received signal parameters measured includes phase, frequency, amplitude, pulsewidth, signal type and time of arrival or Pulse repetition interval of the signal pulses.

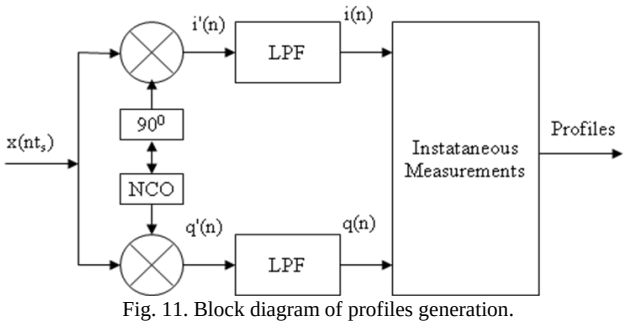


Fig. 11. Block diagram of profiles generation.

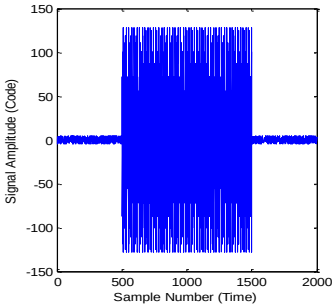
The low pass sampling is only considered in this case. Even though little higher sampling rate is required for IQ method. The quadrature sampling also can be carried out [7]. The quadrature sampling advantage is that it needs two ADCs with sampling rate of twice the signal bandwidth. But it introduces analog mixer error which doesn't occur in Digital IQ method.

Each of the above parameters is having their significance. The instantaneous phase tells us phase variation within the signal presence. If at all it is there it reflects in the frequency profile. The frequency is computed based on the phase differentiation. The instantaneous amplitude tells us the radar is scanning or it is fixed apart from the distance of it.

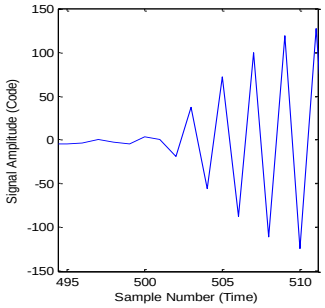
Initially based on the pulse width it can be decided whether the signal is pulsed or it is continuous. If the pulse width is higher from some certain limit, it is said to be continuous otherwise it is pulsed and pulse width is measured. The pulse repetition interval of the signal is derived from the time of arrival of the pulse.

The simulation is carried out using Matlab. The input signal is generated with the amplitude of ±125 code and the noise level of ±5 code. Considering the 8-bit ADC with 1 volt reference voltage, the least significant bit (LSB) of the ADC is equivalent to 3.9 mV (milli volts). The ±125 ADC code is equivalent to ±0.488 V and ±5 code is equivalent to ±19.5

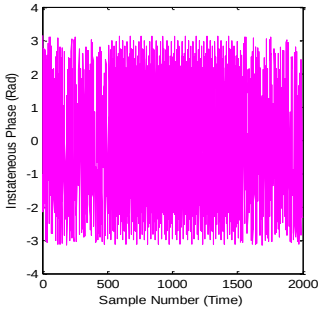
mV. The noise is taken as Gaussian and it is spread during the signal presence also. The incoming signal frequency is considered 160 MHz and sampled at a rate of 500 MS/s. The Matlab simulation results are presented in Fig. 12.



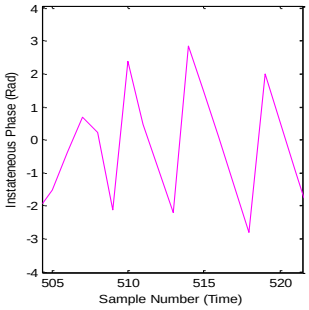
(a) Signal Amplitude Plot.



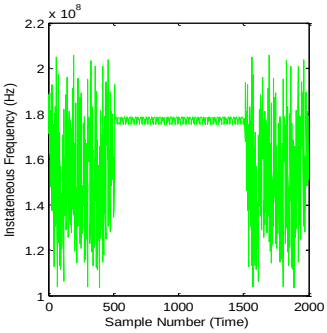
(b) Zoomed Signal Amplitude Plot.



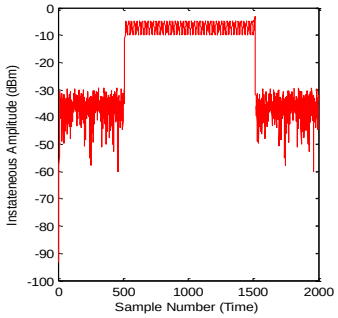
(c) Instataneous Phase Plot.



(d) Zoomed Instantaneous Phase Plot.



(e) Instantaneous Frequency Plot.



(f) Instantaneous Amplitude Plot.

Fig. 12. Matlab simulation results.

Fig. 12(a) shows the signal amplitude plot. The sine wave of 160 MHz frequency is generated. The signal is sampled at the rate of 500 MS/s. Fig. 12(b) shows its zoomed version of the signal amplitude plot. Fig. 12(c) shows the instantaneous phase plot measured at each 2 ns. Fig. 12(d) shows the zoomed version of instantaneous phase plot. Fig. 12(e) shows the instantaneous frequency plot and Fig. 12(f) shows the instantaneous amplitude plot. Both frequency as well as the amplitude is also measured at each 2 ns.

TABLE I: COMPARISON BETWEEN CONVENTIONAL METHOD AND DIGITAL IQ METHOD

Parameter	Conventional Method	Digital IQ Method
Approach	Analog	Digital
Bandwidth	Wideband	Narrowband
Frequency Accuracy	1 MHz	0.5 MHz
Exact Duplication of components	Not Possible	Possible
Pulse width Accuracy	100 ns	20 ns
PRI Accuracy	20 ns	10 ns
Capability to measure intrapulse parameters	No	Yes

Comparison study has been carried out between Digital IQ method and conventional method. The comparison results are tabulated in Table I. The convetional method was analog whereas proposed method is digital. Digital IQ method is having number of advantages over conventional method. The major advantage of this method is duplication. Since all components are digital components, so they can be duplicated without any errors [8].

IV. CONCLUSION

The measurements carried out based on Digital IQ method have certain advantages. The components with similar functionality can be realized as it is. Like the multiplier required for frequency translation, the exact nature of multiplier, filters can be realized without any error. Two identical digital low pass filters also can be realized with similar response. This is not possible in analog world.

The conventional methods can't preserve the phase information because these methods use the video signal which is a detector output for processing. Hence these methods can't do the intrapulse measurements.

The intrapulse measurements are carried out using digital IQ method. The intrapulse features includes the type of modulation present in the pulse. Since this method preserves the phase, the any variations in the instantaneous phase can be detected. The detected phase variation tells whether the phase is linear or varying within the pulse. The variation in the instantaneous phase profile reflects variation in amplitude profile and frequency profile as abrupt changes.

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