DESIGN AND DEVELOPMENT OF SIGNAL PROCESSING ALGORITHMS FOR GROUND BASED ACTIVE PHASED ARRAY RADAR.

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Abstract—**This is a graphical user interface (GUI) model which provides a platform for analyzing basic signal processing algorithms for ground based active phased array radar. This paper presents a ground based active phased array radar simulation framework and model structure based on signal processing algorithm such as pulse compression, cell averaging constant false alarm rate, moving target indicator approach and analyze the detection of radar through a set of radar parameters. By changing the parameter user can check effect on detection performance using matlab software.**

Index Terms— Signal processing algorithms, pulse compression, constant false alarm rate ,moving target indicator, ground based active phased array radar.

I. INTRODUCTION

Radar technology has been continuously developing over the last 80 years starting from the late 30s of the last century when radar was first invented for defense applications .Active phased array uses TR modules, there is separate TR modules with each of the antenna element. Due to separate TR modules active phased array can have multiple beams. Active phased array is focused for this work. The task of signal processing is the detection, location and parameter estimation of targets within the specified observation space. The received echo signals are superimposed by noise and external disturbance signals. After detection an estimation of target parameters as accurate as possible, follows. The simulation generates random targets. For each radar pulse the simulation calculates the returns that the radar will receive from all the targets according to the radar formula. The simulation calculates the amplitude& phase of the return signal .The radar builds a vector of its samples as complex signals and adds it to complex random RF noise. The vector goes through a LPF representing the receiver BW and then add another complex random noise representing the radar's thermal noise. The radar saves several reception periods to a buffer and then processes the entire buffer. The radar can perform a match filter over the received signal. The radar analyzes each range cell in the buffer in search of a target. Detection threshold can be fixed or dynamic according to the buffer statistics. In case Moving Target Indicator (MTI) is used the target detection is done in the frequency plane of the complex signal. Each detected target is plotted on the main radar display.

II. WORK OF GENERIC RADAR SIGNAL PROCESSOR

Figure illustrates one possible sequence of operations in a generic radar signal processor. The sequence is not unique, nor a set of operations exhaustive. In addition, the point in the chain at which the signal is digitized varies in different systems . The operation can be grouped into signal conditioning & interference suppression, imaging, detection and post-processing.To design a successful signal processor, the characteristics of signal to be processed must be understood. Relevant characteristics include signal power, frequency, polarization, angle of arrival, variation in time and randomness. The radar range equation will give a means of predicting nominal signal power. Doppler phenomenon will predict received frequency. Complexity of real world give rise to very complex variation in radar signal, this will lead to the use of random processes to model the signal and to pdf that match measured behavior well.

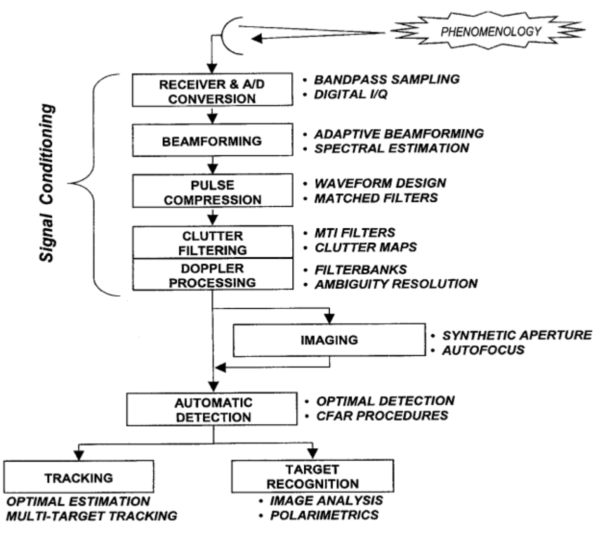

Fig 1:Example of generic radar signal processor flow of operations

A. Signal conditioning & interference suppression

Purpose of this is to improve the SIR of the data prior to detection, parameter measurement of imaging operations. This is done in general with a combination of fixed and adaptive beam forming, pulse compression, clutter filtering, and Doppler processing. Beam forming is applicable when the radar antenna is an array. Beam forming can be fixed or adaptive. Pulse compression is a special case of matched filtering. Many radar system design strive both high sensitivity in detecting targets and high range resolution. But it has proven that there is tradeoff between sensitivity and resolution. Pulse compression provides a way out of this dilemma by decoupling the waveform bandwidth from its duration, thus allowing both to be independent specified. This can be done by designing a modulated waveform. A very common choice is linear frequency modulated waveform. The instantaneous frequency of a LFM pulse is swept over a desired bandwidth during the pulse duration. Frequency may be swept either up or down, but the rate of frequency change is constant. The matched filter is a filter in the radar receiver designed to maximize the SNR at its output. Clutter filtering and Doppler processing are closely related. Both are techniques for improving detect ability of moving targets by suppressing interference from clutter echoes, usually from the terrain in the antenna field of view, based on differences in the Doppler shift of the echoes from the clutter and from the target of interest. The techniques differ primarily in whether they are implemented in time or frequency domain. Clutter filtering usually takes the form of MTI which is simply pulse to pulse high pass filtering of the radar echoes at a given range to suppress constant components, which are assumed to be due to non moving clutter. Extremely simple very low order digital filters are applied in the time domain samples taken at fixed range but on successive transmitted pulses. The term Doppler processing generally implies the use of FFT to explicitly compute the spectrum of echo data for a fixed range across multiple pulses. Due to their different Doppler shifts, energy from moving target is concentrated in different parts of spectrum from clutter energy, allowing detection and separation of the targets. Doppler processing obtains more information from the radar signals than does MTI filtering. The cost is more required pulses, thus consuming energy and timeline, and greater processing complexity.

B. Detection

The most basic function of radar signal processor is detection of the presence of one or more targets of interest. Information about the presence of targets is contained in the echoes of the radar pulses. These echoes compete with receiver noise, undesired echoes from clutter signals, and possibly international unintentional jamming. The signal processor must somehow analyze the total received signal and determine whether it contains a desirable target echo and if so at what range, angle and velocity. It will be seen that in most cases can be obtained using the technique of threshold detection. In this method magnitude of each complex sample of radar echo signal is compared to a pre-computed threshold. If the signal amplitude is below threshold it is assumed to be due to the interference signal only. If it is above the threshold it is assumed that the stronger signal is due to the presence of target echo in addition to interference, and a detection is declared. Because they are result of a statistical process, threshold detection decisions have finite probability of being wrong. For example, a noise spike could cross the threshold, leading to a false target detection, called as false alarm. These errors are minimized if the SIR is as large as possible, in this case the threshold can be set relatively high resulting in a few alarms while detecting the most targets. The matched filter maximizes the SIR, thus providing the best threshold detection performance. Thus, furthermore, the achievable SIR is monotonically increasing with the transmitted pulse energy E, thus encouraging use of longer pulse to get more energy on target. Since longer simple pulses reduce range resolution, the technique of pulse compression is also important so that high resolution can be obtained while maintaining good detection performance. There are numerous significant details in implementing threshold detection. Various detector designs work on magnitude, squared magnitude or even log magnitude of complex signal samples. The threshold is computed from knowledge of the interference statistics are rarely known accurately enough to allow for pre computing a fixed threshold. Instead, the required threshold is estimated using interference statistics estimated from the data itself, a process called CFAR detection.

III. Theory of Various Signal Processing Algorithms

In this paper various basic signal processing algorithms such as pulse compression, constant false alarm rate, moving target indicator have been used for detection and range determination of target. Then it has been compared with the mini-map of generated targets. Theory for different signal processing algorithms is given in following part of paper.

A. Pulse Compression

High range resolution as might be obtained with a short pulse, is important for many radar applications. But there can be limitations to the use of a short pulse. Large bandwidth can increase system complexity, make greater demands on the signal processing and increase likelihood of interference to and from other users of electromagnetic spectrum. A serious limitation to achieving long ranges with short duration pulses is that a high peak power is required for a large pulse energy. A long pulse can have the same spectral bandwidth as a short pulse if the long pulse is modulated in frequency or phase. The modulated long pulse with its increased bandwidth B is compressed by the matched filter of the receiver to a width equal to 1/B. This process is called pulse compression. Pulse compression allows a radar to simultaneously achieve the energy of a long pulse and the resolution of a short pulse without the high peak power required of a high energy duration pulse.

B. Moving Target Indicator (MTI)

In air surveillance type of radars, most of the clutter power can be removed if the near-zero Doppler spectrum is filtered out. Techniques for implementing clutter filtering are the basis of moving-target indicator (MTI) radars. The required high-pass response is determined by the spectrum of the clutter.The clutter from a stationary target doesn't provide any Doppler shift as there is no relative motion between radar and target. So, its spectrum is a line at zero frequency as shown in below

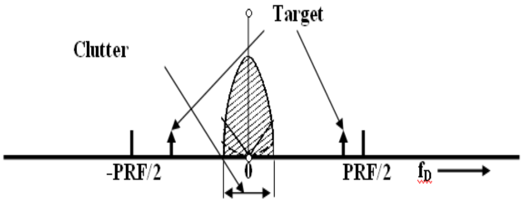

Fig 2: MTI filter

So an FIR Filter is used to cancel the unwanted clutter. This FIR Filter has binomial coefficients. These MTI Filters are called as "Delay line cancellers".

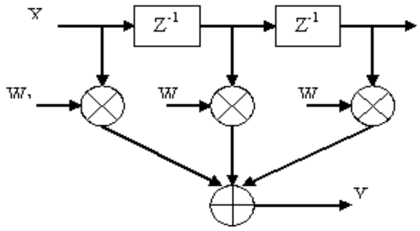

Fig 3: MTI filter

The response of the Double Line Canceller is

$$|H(\omega)| = \left|4\sin^2\left(\frac{\omega t_p}{2}\right)\right| = \left|4\sin^2\left(\frac{2\pi f_D t_p}{2}\right)\right| \quad (1)$$

$$|H(\omega)| = \left|4\sin^2\left(\frac{\pi f_D}{f_p}\right)\right|$$

C. Constant False Alarm Rate Processor

Here in this paper CA-CFAR is used for detection purpose. A CFAR obtained by observing the noise or clutter background in the vicinity of target and adjusting the threshold according to the measured background. The block diagram of CA-CFAR processor is shown in the figure 4 below. It is assumed that the detection decision has to be obtained for the Cell Under Test (CUT). In order to accomplish this first consider the (N+1) range cells surrounding the CUT, where N is the size of the reference window and can be chosen depending upon the processor.

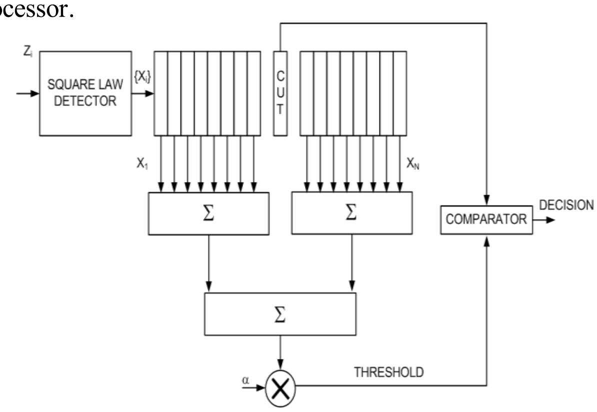

Fig 4:Block diagram of Cell-Averaging CFAR (CA-CFAR)

To decide upon the presence of target, we perform the following operations.

1. All the video output magnitude in the reference window other than CUT is summed up.
2. The summed up value is multiplied with a scaling factor α to get threshold. This α is found from the formula given in equation (2)

$$\alpha = \left(\frac{1}{P_{FA}}\right)^{-1} - 1 \quad (2)$$

3. The product of α and the sum is then compared with the value of video output in the CUT.
4. If the value in the CUT is greater than the threshold then target is declared to be present. Else no target is present.

IV. Simulation Results

This section presents a number of plots which result from the implementation of different signal processing algorithms. By comparing the detected plot with generated mini-map one can check the accuracy of particular signal processing algorithm along with various parameters.

Table 1 : Simulation platform parameter

Parameter	Value	Unit
PRI	0.8	Millisecond
Stagger	1	
PW	16	Microsecond
Amplitude	10^10	Volt
Antenna velocity	Pi/3	Rad/sec
CFAR threshold	2	
Sampling rate	50	KHz
Radar bandwidth	0.02	MHz
Pulses in buffer	32	
No. of targets	4	
No. of clutter	3	
Target RCS	100	
Digitizer noise	10^-9	
Electromagnetic noise	10^-13	

A. Without any signal processing algorithm

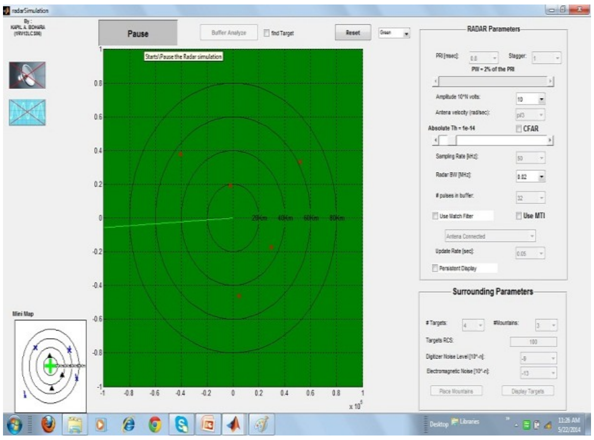

Fig 5: Detection outcome without any signal processing algorithm

Here in this case as shown in mini-map a radar target pattern has been generated which consists of 3 clutters and 4 actual radar targets which has to be detected. When no signal processing algorithm has been used radar finds out 5 targets out of which 3 clutters are mistaken as radar target. For proper detection clutter should be discriminated from actual targets. But here in this case there is no clarity between clutter and targets. In order to efficiently detect rest two missed one has to change radar parameters or use signal processing algorithms such as moving target indicator, constant false alarm rate, matched filtering as shown in figure 4 and figure 5.

B. Output after CFAR

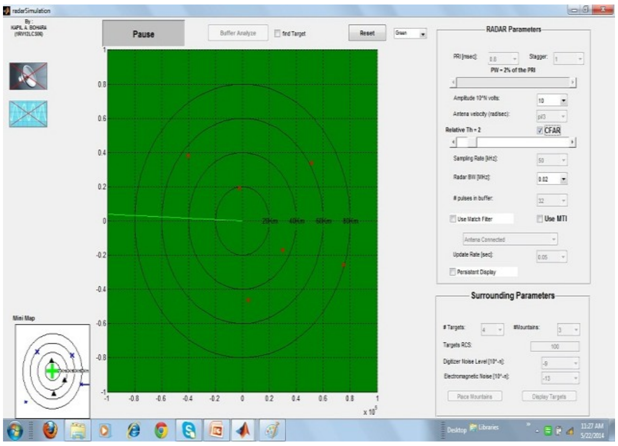

Fig 6: Detection outcome after CFAR algorithm with threshold as 2.

It is been shown that when CFAR is used 6 targets have been detected out of which 3 clutters and the only one target is missed. One target is missed because it is out of range. Here more number of targets have been detected compared to the case where none of the signal processing algorithm is used. But still with the help of CFAR one cannot check whether targets are stationary or moving target and moreover still there is no discrimination between clutter and actual radar target. As no detection is possible beyond the range of 100 km the only missed target can not be detected by any combination of signal processing algorithm. User can also change the threshold set for CFAR and check what is the effect of CFAR on detection.

C. Output after CFAR, MTI and pulse compression

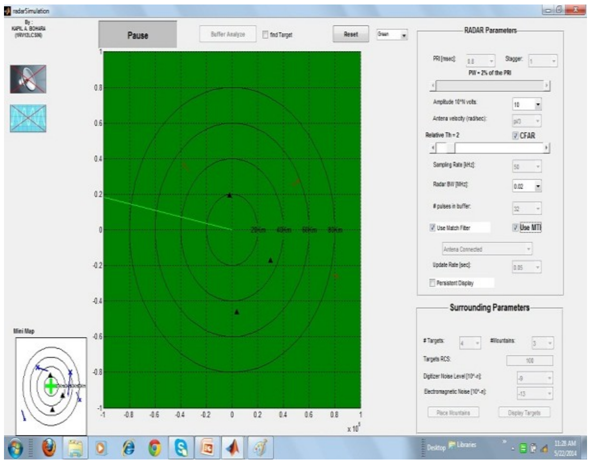

Fig 7: Detection outcome after using matched filter, moving target indicator, constant false alarm rate algorithms.

In this figure of detection different signal processing algorithms are used along with each other. After using all the algorithms such as moving target indication, constant false alarm rate, pulse compression simultaneously same clutters which were showing as targets are now indicated as clutter only. Thus now there is clear indication between clutter and targets. As shown in figure black triangles indicates as clutter and red cross marked with a line represents that it is a moving target. Detection also tells us about the motion of moving targets with range. In this way by making use of all 3 signal processing algorithms one can efficiently detect most of the targets with its motion and range and effectively differentiates clutter from false detection of considering it as radar target.

D. Output after matched filtering

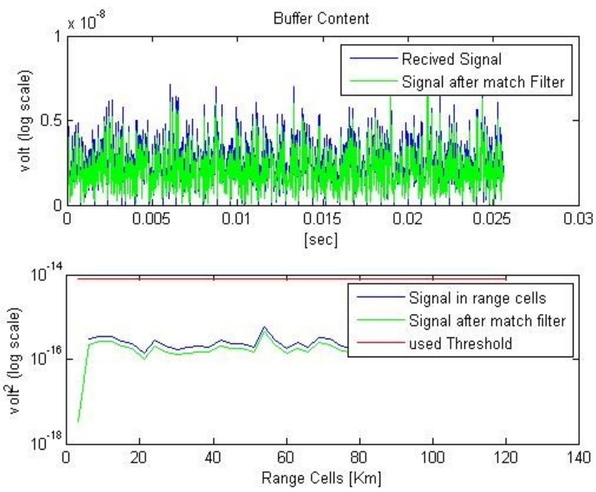

Fig 8: Contents of received signal stored in buffer after matched filtering

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E. Buffer contents

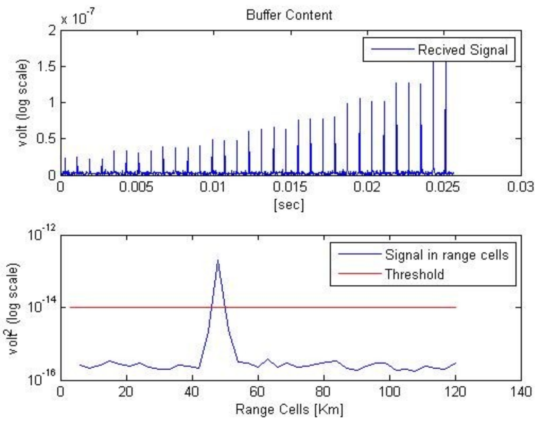

Fig 9 : Plot for content in buffer with time and range cells

First plot gives idea about the buffer content. Buffer of a particular size is defined and whole received signal is stored in buffer and observed at different time instants. After that the signal has further been processed using various signal processing algorithms.Second plot tells us about the signal level in different range cells. As in shown case threshold of 10^{-14} is set for constant false alarm rate. Principle for detection is that whenever the signal strength of received signal is less than threshold it is considered that there is no target while signal is present whenever signal strength in range cell is beyond the threshold set. Thus here possible range for target is in between 45-53 km.

V.CONCLUSION

A comprehensive graphical user interface (GUI) model which takes into account various radar parameters and different signal processing algorithm is developed. The behavior of this model in different radar environment with randomly distributed target is considered. The accuracy of the developed signal processing algorithm for ground based active phased array radar is further increased by using moving target indicator (MTI) , pulse compression, Constant false alarm rate (CFAR) simultaneously. The effect of radar parameter such as pulse width, pulse repetition interval, stagger, sampling rate, radar bandwidth, noise is observed. Various signal processing algorithms have been used and result after this simulation is compared with mini-map of actual radar target structure.

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