

# ACHIEVING MINIMUM PEAK SIDE LOBE THROUGH PULSE COMPRESSION CODING TECHNIQUE ON SYNTHETIC APERTURE RADAR

Beatrice Sylvia V.I.<sup>1\*</sup> and A. Sumathi<sup>2</sup>

<sup>1</sup>Anna University, Chennai - 600025, Tamil Nadu, India;  
rush2syl@yahoo.com

<sup>2</sup>Department of ECE, Adhiyaman College of Engineering, Hosur - 635109,  
Tamil Nadu, India;  
sumathi\_2005@rediffmail.com

**Abstract:-** In the Electronic Warfare (EW) field, the interception of Radarsignals and retardation of Radar performance are of primary consequences. In this generation, a modern radar called Synthetic Aperture Radar (SAR) which is used to create two- or 3-dimensional images of objects and synthetically increases the antenna size or aperture to increase the azimuth resolution of the mapped area. To achieve a minimum peak side lobe and minimal main beamwidth, in this paper the radar waveform generator are developed using various pulse compression coding techniques which aims to achieve both better range resolution and high target detection capability. This radar waveform is implemented in the Matlab software tool.

**Keywords:** SAR, minimum peak side lobe, barker code, waveform generator

## 1. Introduction:

Synthetic Aperture radar has evolved into a potent and precious tool for monitoring our earth environment. SAR is a complex device that needs deliberate integration of sensors and platforms into a fully incorporated system so that the imaginary data it acquires are sufficiently accurate, both radiometrically and geometrically. The rapid progress of hardware and software has directed the SAR system [1] to produce excellent quality images like never before. The key to SAR is to attain the Doppler shifts embedded in the carrier frequency, by moving either the radar or the target being observed.

Depending upon the system configuration, SAR sensor can acquire data in three different modes: stripmap, scan, and spotlight. They are described as follows.

**Stripmap mode:** When operating as a stripmap SAR, the radar antenna pointing path is settled with respect to the stage flight track and the illumination footprint envelope a strip on the ground as the stage moves. The optimum azimuth determination is autonomous of the sensor– target range and is equivalent to half of the physical antenna length in the azimuth direction.

**Scan mode:** While operating as a ScanSAR, the sensor antenna beam is periodically stepped in range to

neighbor swaths referred to as sub-swaths. As a result the overall dimension of range swath is increased for each target. In the ScanSAR mode, the full antenna synthesis is not possible and the range swath width raises at the expense of the azimuth decision.

**Spotlight mode:** When operating as a spotlight SAR, the sensor steer its antenna beam to progressively illuminate the land patch being imaged. In this mode, finer azimuth resolution is achieved than in the stripmap mode using the similar physical antenna [2]. The spotlight mode offers efficient imaging of multiple smaller scenes while the stripmap mode images a long strip of terrain.

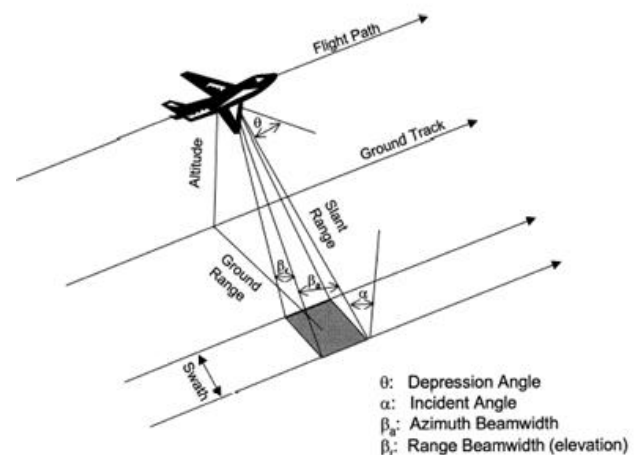


Fig. 1. Typical Synthetic Aperture Radar Imagery Geometry

The typical imaging geometry for Synthetic Aperture Radar is shown in Figure 1. SAR works in a surface appearing mode and a swath is imaged fine to one side of the aircraft. The depression angle ( $\theta$ ) is the angle between the horizontal and a line from the motor vehicle to particular spot on the swath. The depression angle or its complement, the incidence angle ( $\alpha$ ), are generally used to define range geometry. The incidence angle measurement is used for space borne vehicles and the depression angle measurement is used for airborne vehicles. Swath width is restricted by the range beamwidth and based on the altitude of the flight vehicle. The higher the altitude, the superior is the swath

width for a given  $\theta$  or  $\alpha$ . In the azimuth or along track direction, there is no necessary geometric distortion from motionless terrain objects, since every item is imaged at the point of the SAR vehicle.

The transmitted SAR wavelength, which commonly ranges between 1 cm and 1 m, relates with the roughness of the terrain according to a Rayleigh coarseness criterion. Generally, if the granularity of the rough terrain is more than 0.1 of the SAR wavelength, an important arrival will occur. Polarization of the SAR runs a task if a feature is united vertically or horizontally. Important arrival from the subsurface can happen also when cross-polarized SAR is used. The electrical conductivity or dielectric is vital for metal items since a high dielectric material reflects important backscatter (i.e., SARreturn).

### 1.1 Pulse Compression Techniques:

Pulse compression [3], otherwise called pulse coding, is a signal handling technique proposed to develop the sensitivity and range resolution of radar schemes. Pulse compression assigns to a group of methods used to enhance the bandwidth of radar pulses. In the radar recipient, these echo pulses are 'compressed' in the time space, bringing about a range determination which is better than that related with an uncoded pulse. Pulse Compression avoids the interference between the transmitter with reception. If the transmission is pulsed, neither the transferred signal nor transmitter noise is an issue, since the radar does not send and get at the same time. Further the targets range can be absolutely controlled by estimating the gone time between the transmission of a pulse and the reaction of the resonance of that pulse.

There are different types of Pulse Compression Coding Techniques which includes Barker Coding, Chrip Coding and Chrip like Phases Codind. Again the barker code has sub-division of Binary Barker Code Minimum Peak Side Lobe Codes and Polyphase Barker Coder. In this paper, barker codes are used for targeting Minimum Side Lobe Codes.

## 2. Literature Review:

AnamikaSharmila and R.P.Singh [4] suggested a High-resolution radar images which can be achieved by employing SAR technique. It is well known that SAR can provide several times enhanced image resolution than conventional radars. The exploration for proficient image denoising methods still remains a valid challenge for researchers. Despite the difficulty of the recently proposed techniques, mostly of the algorithms have not yet attained a pleasant level of applicability; each algorithm has its assumptions, advantages, and limitations. This paper presents a review of SAR. Behind a brief introduction in our work we are particularly targeting the noise called backscattered noise in SAR

terminology which causes the appearance of speckle prospective future work in the area of air flight navigation, mapping Weather Monitoring and during natural disaster like earth quake. The SAR having the capability, to make human visibility beyond optical vision, is also discussed.

S.Lokesh et al [5] have proposed to develop an FPGA-based (field programmable- gated-array) architecture for on-board processing of radar data. In particular, the hardware is intended for the high computational load in processing Synthetic aperture-radar. Pulse compression plays a major role in the design of the radar system. Pulse compression using linear frequency modulation techniques are very well-known in modern radar. The technique better resolves the opposition between the restriction of peak pulse power and range resolution in radar. Similarly Azimuth resolution is carried out by using Azimuth reference function.

Hong-Cheng Zenget al [6] proposed a general imaging formation algorithm for accurately and efficiently converging GNSS-based bistatic SAR data, which deflects the interpolation handling in traditional back projection algorithms (BPAs). Global Navigation Satellite System (GNSS)-based bistatic Synthetic Aperture Radar (SAR) now plays a more and more important role in remote sensing applications for its low-cost and real-time global coverage capacity. A two-dimensional point target spectrum model was initially presented, and the bulk range cell migration correction (RCMC) was therefore derived for minimizing (RCM) range cell migration and coarse focusing. As the bulk RCMC acutely changes the range history of the radar signal, a modified and much more efficient hybrid correlation operation was initiated for balancing residual phase errors. Simulation results were offered based on a general geometric topology with non-parallel trajectories and imbalanced velocities for both transmitter and receiver stages, showing a satisfactory performance by the proposed method.

Jingxiong Zhang and Ke Yang[7] Compressive testing or compressed sensing (CS) works on the assertion of the sparsity of the basic signal, depends on the trans-informational capability of the estimation network employed and the resultant estimations, works with advancement-based algorithms for signal reconstruction and is in this way proficient to finish data compression, while getting information, prompting sub-Nyquist sampling methodologies that empower productivity in data acquisition, while ensuring certain precision criteria. This paper tries to connect the gap in the interdisciplinary zone of CS, radar and data theory by assessing data flows in CS-radar from sparse scenes to estimations and deciding sub-Nyquist sampling rates basic for scene reconstruction inside certain distortion thresholds, given separeate scene sparsity and normal per-

sample signal-to-noise ratios (SNRs). Simulated studies were performed to adjust and approve the data-theoretic investigation. The joint approach proposed in this paper is valuable for information-theoretic orientated CS-radar framework analysis and execution assesment.

B. Zakeriet al [8] have proposed P4 polyphase code is renowned in microwave pulse compression technique. There are different reduction techniques to lessen the sidelobes of P4 code. This paper shows a new sidelobe reduction procedure which its results are great. To valid our work, other sidelobe reduction techniques such as Woo filter and altered forms of Woo filter are examined and compared with the technique presented in this paper. Results show that the technique introduced in this paper delivers improved (PSL) peak side lobe ratio and integrated side lobe ratio (ISL) than other solutions.

Amirmokhtar Akbaripour and Mohammad H. Bastani [9] have introduced new filter structure to restrain the sidelobes of radar signals that result from standard matched filtering. The proposed filter is suitable for any type of binary coding signals. Several techniques are utilized to estimate the filter coefficients such as Wiener filter technique, linear programming (LP) algorithm, and Lagrange multiplier method. Also, a weighting function is used to shape the sidelobe energy in a constant manner that will yield more sidelobe reduction. Comparison of the proposed filters and the matched filter illustrates that at the expenditure of insignificant loss in signal-to-noise ratio (LSNR), sufficient mainlobe-to-peak-sidelobe ratio (MSR) can be achieved.

### 3. Proposed Solution:

In order to achieve high resolution with minimum peak side lobes, this paper proposes a efficient pulse compression coding technique in Synthetic Aperture Radar. The SAR waveform is responsible for the accuracy, resolution, and ambiguity of determining the range and radial velocity of the target. The respective SAR signal will be selected based not only on the desired delay and Doppler resolution but also in where the competing targets are located in the delay-Doppler plane.

#### 3.1 Ambiguity function plot with a GUI:

A MATLAB code [10] equipped for making the ambiguity function of a wide range of SAR signals is initiated. This program makes use of Matlab's sparse matrix activities, and stays away from loops. The code frames it possible to enter various signals and gives control over numerous plot parameters. This program also permits over sampling of the signal with significantly better resolution than required for finding the delayed signal. This makes it probable to process a diluted picture (fewer delay – Doppler grid points) of the ambiguity function with low computational exertion

while testing the signal with an adequately large sampling rate.

Due to the symmetry of the AF (Ambiguity Function) concernig the origin, the code plots just two of the four quadrants. This gives a chance to show the Zero-Doppler cut of the AF, which is the extent of the autocorrelation function. Another figure with subplots of three characteristics of the signal: Amplitude, Delay, and Frequency.

There are five parameters in the GUI (Ton, BW, N, k, m) [11]. Of those, the main parameter that influences the signal and not just the plots is N. Since the signal is characterized by a vector, with a definite length (number of element), it is often necessary to increase the number of samples (repeats) during each of these elements. At any time you change the value of N, you need to click on "Update" button to recalculate the signal. At exactly that point you can tap on any of the alternate buttons to get the different plots. The radar on/off radio button choose the type of waveforms whether the MPS waveforms or the RADAR waveforms. The parameters k and m are the number of grid points on the positive delay axis and Doppler axis of the plot.

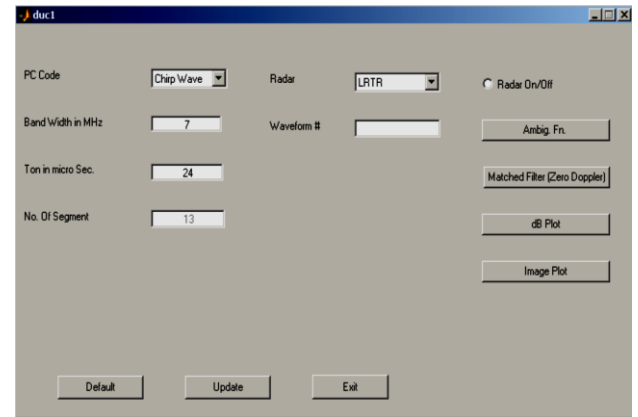


Fig. 2. Matlab GUI development for Radar Wave form Analysis

Each Code has been compared with the four main functions of the waveforms called the ambiguity function, Matched filter with zero doppler, DB plot and the image plot.

#### Ambiguity function:

The ambiguity function, which is expressed as  $|\chi(\tau, f)|$ , is basically used to earn an understanding of how a signal processor behaves, or responds, to a given replied signal. As indicated in the data, the independent variables of the ambiguity function are time ( $\tau$ ) and frequency ( $f$ ). The time variable is normally related with target series and the frequency variable is normally related with target Doppler.

#### 3.2 Barker Code:

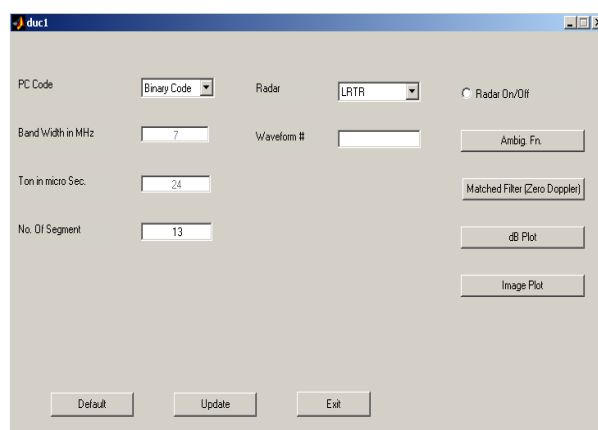
As the name involves, in this type of coding, the radio frequency phase of the transferred pulses are modulated, and the modulation is complete as in incremental frequency modulation in finite increments. Here, though, just two increments are used: 0 degree and 180 degree. The radio frequency phase of certain segments is shifted by 180 degree, according to a predetermined binary code. A ordinary shorthand process of representing the coding on paper is to signify the segments with 1 or 0. An unshifted segment is defined by 0 and a shifted division is represented by 1.1 which are shown in Figure 4, Figure 5 and Figure 6.

### 3.2.1 Binary Barker Code:

A barker code of length  $n$  is meant as  $B_n$ . There are just seven known Barker Codes that offer this exceptional property: they are mentioned in the table. Note that B2 and B4 have corresponding structures that have similar qualities. All the identified binary sequences yielding a peak-to-peak side lobe ratio of  $N$  were reported.

**Table 1.** All known Binary Barker Codes

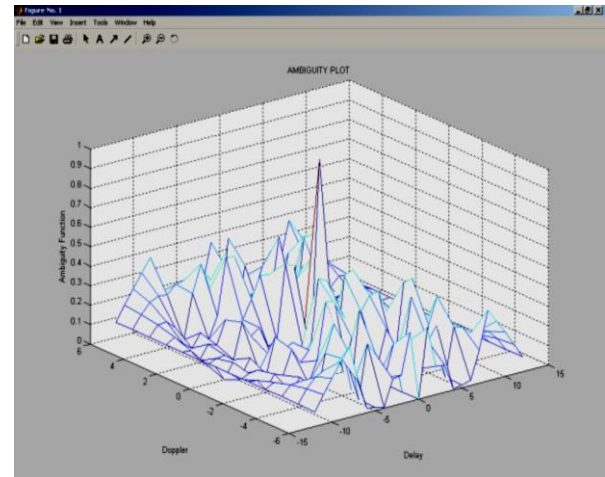
Code Length	Code
2	11 or 10
3	110
4	1110 or 1101
5	11101
7	1110010
11	11100010010
13	1111100110101



**Fig. 3.** GUI Selection for the Barker Coded Radar Waveform

To improve the signal to noise ratio (SNR), modern radarsystems often employ the matched filter in the receiver chain. The ambiguity function of a waveform represents exactly the output of the matched

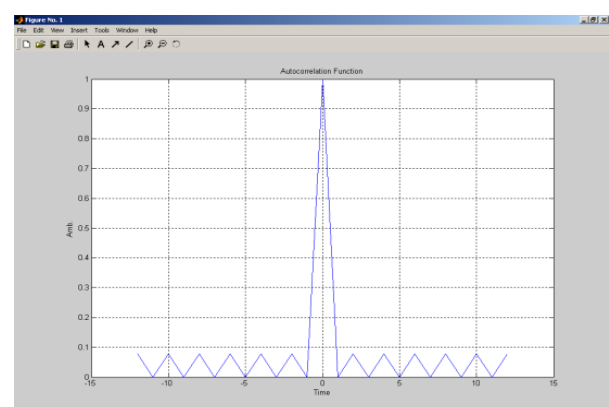
filter when the specified waveform is used as the filter input.



**Fig. 4.** Ambiguity Plot

The above plot explain the ambiguity function of the barcode radar waveform. The ambiguity function peaks at  $\tau = 0$ , and  $f = 0$  and the ambiguity is zero elsewhere ideally. The pulse width is 24 micro sec, and the Bandwidth is 7 MHz (3D view).

In the above result of barcode radar waveform type, the additional delay ( $\tau$ ) and an additional frequency shift ( $f$ ), from the result shows, the ambiguity function is not symmetric. Only at the maximum ambiguity function place at (0,0), had got the maximum peak value to find the target. However, in the existence of target Doppler, this peak is drifted. This causes a fault in the delay. Hence the Doppler shift will be returned as a fault in the range. Thus a modification in Doppler will return a change in range. Thus, the Range Doppler Coupling affect the Barcode type of Radar waveform.



**Fig. 5.** Match Filter Output With Zero Doppler

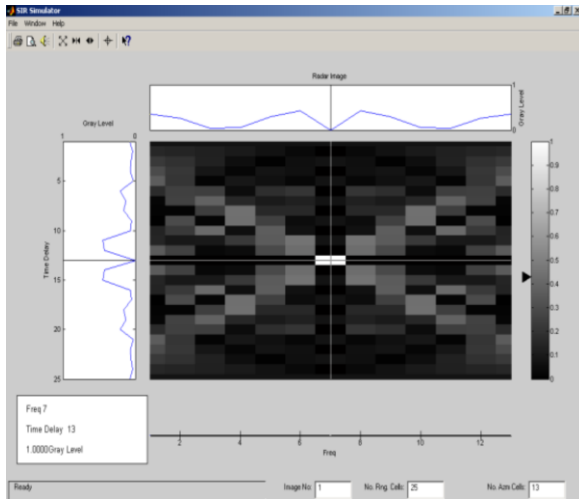


Fig. 6. Simulator Plot

The Barker code has the Doppler Intolerance and there is no binary barker code exist for  $13 < N < 1$  where the peak side lobe ratio is defined by  $N$ . This becomes the demerit for the selection of Barker code with minimum value of  $N$ .

The Simulator Plot shows the ratio of main lobe amplitude to the side lobe amplitude as well as the pulse compression ratio increases.

### 3.2.2 Minimum Peak Sidelobe Codes:

A binary code that yield minimum peak side lobes, but do not meet the Barker condition is called as Minimum Peak Side lobe Codes (MPS Codes).

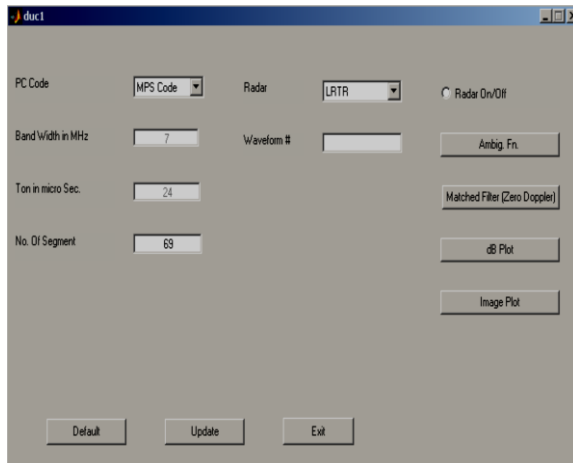


Fig. 7. GUI Selection for MPS Code Radar Waveform

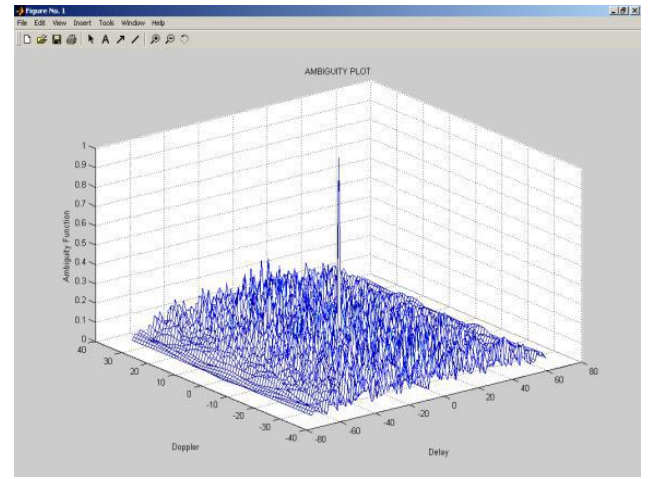


Fig. 8. Ambiguity Plot

Figure 7 shows the MPS Code Results up to  $N \leq 69$  were reported here. Codes with a peak side lobe of 2 were reported for  $N \leq 28$ . The MPS codes reported for  $28 < N < 48$  and  $N = 51$  have a side lobe level of 3, and the MPS codes of length  $N = 50$  and  $52 \leq N \leq 69$  have side lobe level of 4. It seems that for any peak side lobe level there is a boundary of the greatest value of  $M$  for which a binary sequence with that side lobe level exists.

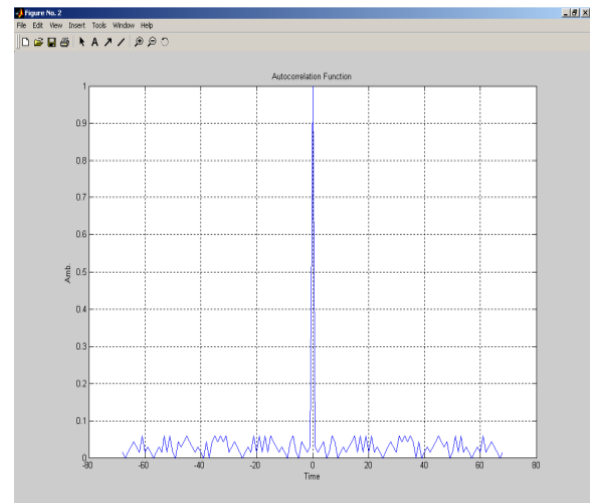


Fig. 9. Match Filter Output With Zero Doppler

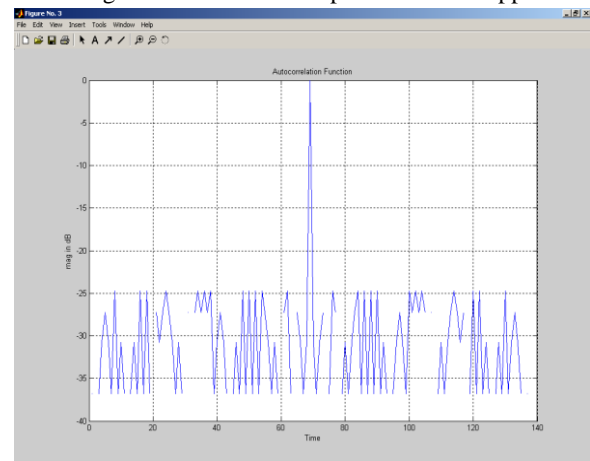


Fig. 10. dB Plot

Figures 8, 9, 10 show the Ambiguity Plot, Match Filter Output with Zero Doppler and dB plot of minimum peak sidelobes code which represents the the minimum integrated side lobes. This MPS code is comparatively small complexity (no multiplications are required at the receiver.

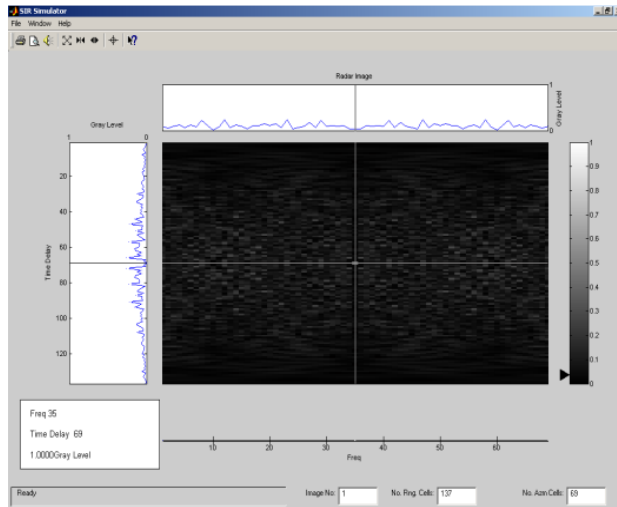


Fig. 10. Wave Simulator

The Result with the centre portion of the ambiguity function with the target detection is seen in the above simulator plot (3D View). The response of the signal processor with the received waveform has minimal complexity with no multiplications needed at the receiver end. The simulated code has the minimum integrated side lobes, but these MPS technique exist for the limited value of  $N$ .

### 3.2.3 Polyphase Barker Code:

Granting any phase values can direct to lower side lobes. However, the outmost side lobe is always 1. The poly phase series with minimum peak-to-peak side lobe ratio excluding the outmost side lobe is called general Barker sequence or poly phase Barker.

In many functions, the phases are limited to values that are the  $k$ th roots of unity. If such limitations are made on the values of the general Barker sequence, there seems to be a boundary on the maximal length  $N$ , depending on  $k$ , for such sequences (e.g.,  $N=13$  for  $k=2$ ). The magnitudes of all other side lobes are fewer than 1. Also that the autocorrelation function in the poly phase case is complex valued.

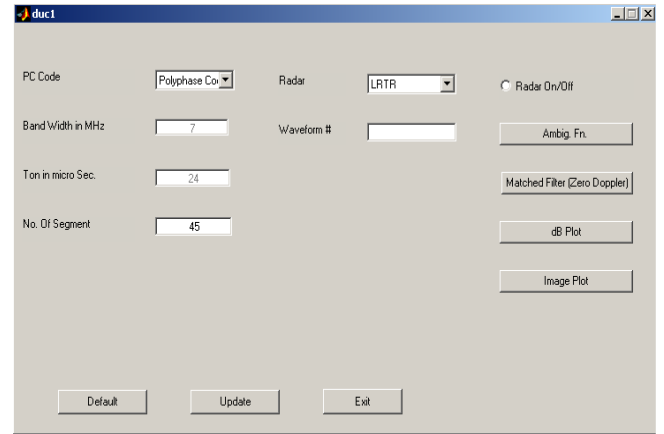


Fig. 11. GUI Selection for the Polyphase Radar Waveform

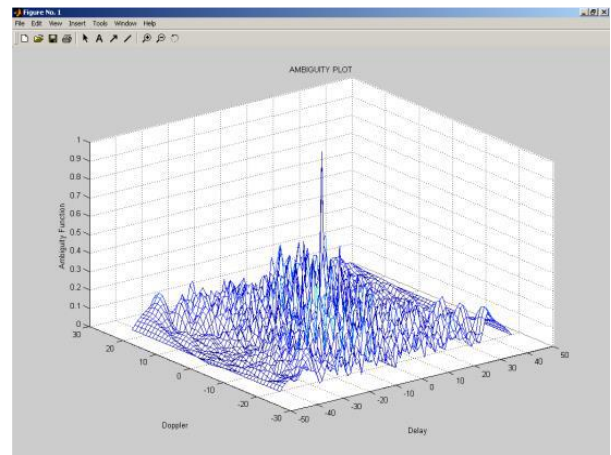


Fig. 12. Ambiguity Plot

The above plot, is the ambiguity function of a train of  $N$  coherent stepped frequency pulses shows the departure between the pulses is bigger than the length of the individual pulses. The cut along the doppler and delay axes results with spiky. The ambiguity function of the Polyphase frequency radar, has a tilt when compared to the other radar modulated waveforms above.

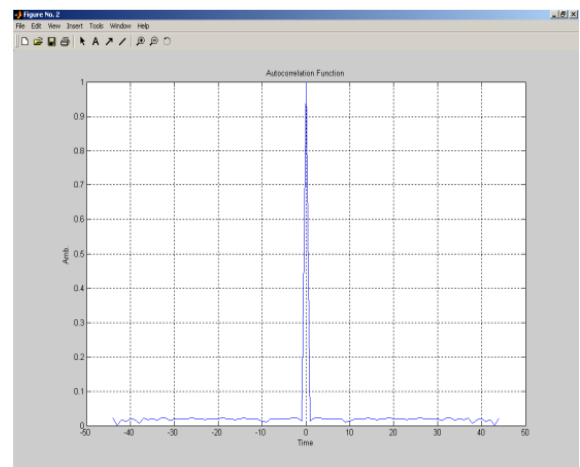


Fig. 13. Match Filter Output With Zero Doppler

The polyphase frequency pulse train or the polyphase waveform code with zero doppler cut is described in the above figure. The burst have  $N$  pulses at the frequencies



of  $f_n$  and the amplitude of  $A_n$  where  $n = 1, 2, 3, \dots, N$ . The entire coherent time or period is  $NT_R$ , where  $T_R$  is the pulse repetition interval.

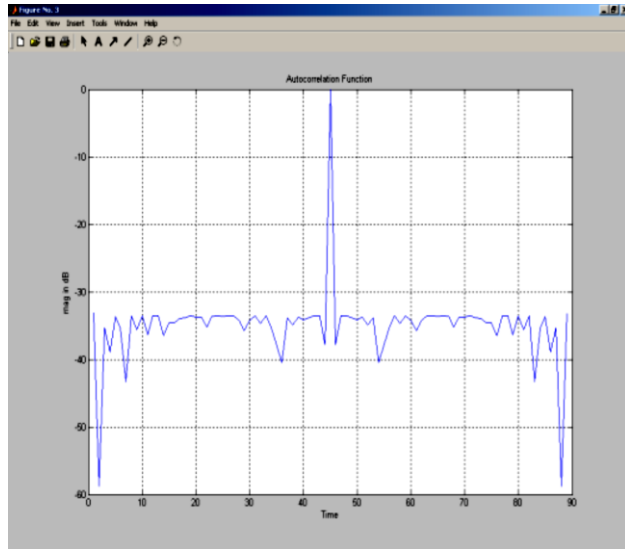


Fig. 14. dB Plot

The above plot shows the cut along the delay and doppler axes, with the central point of the polyphase frequency waveform is slanted. Comparing with the other radar waveforms, ambiguous spikes decreases quickly as compared to the MPS coded waveform.

Along the delay axis, the null to null width of each spike is  $2/N\Delta f$  as compared to  $2t_p$ , for the constant frequency pulse, thus making it probable to reduce the effective pulse of the polyphase radar waveform by rising  $N$  or  $\Delta f$ .

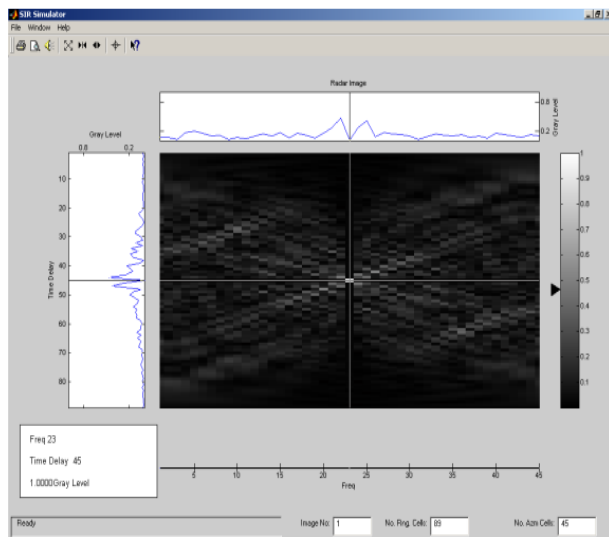


Fig.15. Simulator Plot for the Polyphase Waveform Code

The simulator plot of the poly phase radar wave form describes clearly the Range – Doppler Coupling. The peak portion of the signal outcome of the matched filter is the sign of the delay, then a rebound, shifted in Doppler, will cause an erroneous belated peak. Close to the zero Doppler, that added delay will be a linear function of the Doppler shift. The Simulator image

shows the peak of the ambiguity function will communicate well to the incorrect delay in which the sin argument is zero. The polyphase radar waveform results that the Doppler shift is attached to the delay. This code comprises of  $M$  frequency steps and  $M$  samples per frequency, which are obtained using double side band detection with the total oscillator at the band center.

#### 4. Conclusion:

Synthetic Aperture Radar (SAR) is a main tool for remote sensing. It's image quality measurements play a major role in the progress of SAR image digital processing methods. To achieve a minimum peak side lobe and minimal main beam width, in this paper, the radar waveform generator are developed using various pulse compression coding techniques. MPS Codes achieve both better range resolution and high target detection capability through minimum peak side lobe level as well as minimal main beam width.

#### REFERENCES

- [1] Andreas Reigber, Pau Prats-Iraola, Thomas Jagdhuber, Konstantinos P. Papathanassiou, Esteban Aguiera, Stefan Baumgartner, Anton Nottensteiner, and Alberto Moreira, "Very-High-Resolution Airborne Synthetic Aperture Radar Imaging: Signal Processing and Applications", pp.1-25, 2012.
- [2] Shridhar D. Jawak, Tushar G. Bidawe, Alvarinho J. Luis, "A Review on Applications of Imaging Synthetic Aperture Radar with a Special Focus on Cryospheric Studies", scientific research publishing, pp.163-165, 2015.
- [3] Wen-Qin Wang and Huaizong Shao, "Radar-to-Radar Interference Suppression for Distributed Radar Sensor Networks", remote sensing, ISSN 2072-4292, pp.740-755, 2014.
- [4] Anamika Sharmila, Dr.R.P.Singh, "A Review On Synthetic Aperture Radar", International Journal of Innovative Research in Advanced Engineering (IJIRAE), Issue 12, Volume 2, pp.57-60, December 2015.
- [5] S.Lokesh, M.Mohanapriya and Naseema.S.B, "Implementation of Strip Map Algorithm for Synthetic Aperture Radar (Sar)", Ijartet, Pp.87-91, 2016.

- [6] Hong-Cheng Zeng, Peng-Bo Wang, Jie Chen, Wei Liu, LinLinGe and Wei Yang, "A Novel General Imaging Formation Algorithm for GNSS-Based Bistatic SAR", Sensors 16, 294, pp.1-15, 26, February 2016.

- [7] Jingxiong Zhang and Ke Yang, “*Informational Analysis for Compressive Sampling in Radar Imaging*”, *Sensors*, ISSN 1424-8220, pp.7136-7155, 15,2015.
- [8] B. Zakeri, M. Zahabi, and S. Alighale, “*Sidelobes Level Improvement by using a New Scheme Used in Microwave Pulse Compression Radars*”, *Progress In Electromagnetics Research Letters*, Vol. 30, pp.81-90, 2012.
- [9] Amirmokhtar Akbaripour And Mohammad H. Bastani, “*Range Sidelobe Reduction Filter Design for Binary Coded Pulse Compression System*”, Vol. 48, ISSN 1, pp. 348-359, January 2012.
- [10] Pingping Huang and Wei Xu, “*ASTC-MIMO-TOPS Mode with Digital Beam-Forming in Elevation for High-Resolution Wide-Swath Imaging*”, *Remote Sensing*, ISSN 2072-4292, pp.2952-2970, 7,2015.
- [11] Sainath P. Aher, Shivaji B. Khemnar, Shambhaji D. Shinde, “*Synthetic Aperture Radar in Indian Remote Sensing*”, *International Journal of Applied Information Systems (IJ AIS)*, ISSN : 2249-0868, Volume 7– No. 2, pp.31-34, April 2014.