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* **Corresponding author**.

kramavat@gitam.edu

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Enhance Auto and Cross-Correlation Properties to Detect Multiple Moving Targets in Radar using the Booths Algorithm

R Koteswararaonaik[1]*, G V K Sharma[1]

1 EECE Department, GITAM School Technology ,GITAM(Deemed to be University), Visakhapatnam, India

Abstract

Objective: To enhance multiple moving target detection of Radar by improving auto and cross-correlation properties of the digital signal received from the target. **Methods:** This study uses the Booths Algorithm to generate various groups of digital codes to test the auto and cross-correlation properties, and Doppler tolerance of the desired digital signal received from the target. Furthermore, Matlab is used to validate the investigated results. The side-noise of the presented digital codes is optimal which improves both static and moving target detection in multi-target environment. Standard length codes (i.e. 8, 16, 32, 64,128 and 256-bit) are designed. **Findings:** The designed group of digital codes discovers a broad range in smart 5th-generation battlefields to detect the target, in which multiple and fast-moving warfare including Unmanned Aerial vehicles will actively participate in the mission. To confirm the study, a comparison has been made between the proposed approach and the current art of work (vide figure A). **Novelty:** Simple novel and productive set of digital codes using the Booths Algorithm have been designed and tested in real-time applications; wherein, the side noise peaks have been reduced to a minimum when compared to the current art of work

Keywords: Booths Algorithm; Autocorrelation; Digital Codes; Target Detection; Cross Correlation

1 Introduction

Defense is the main focus of any nation to protect their territory, so it becomes necessary to make the territory secure. Various techniques have already been adopted to improve the security of the country in terms of automatic weapons, improvised fighting aircraft, UAVs, and surveillance equipment. However, on top of all developments, an initial and necessary step is to monitor the inward and outward movements of the warfare within the territory (i.e. air as well as ground). Thus the research community focused to work in the field of radar engineering to enhances surveillance systems to detect the target as it is the only equipment to investigate targets. Several theories and models[1,2] (i.e. range gate, finding auto and cross-correlation of PN code, minimization of noise, and windowing technique) have been explored to detect the position of the target. Moreover, maximum researchers of signal processing used Golay, Prouhet- Thue-Morse (PTM), over-sampled PTM, ternary codes, etc. to investigate the position of the target. However, these approaches are well suited when the targets are static or slow-moving, but these approaches fail to detect multiple and fast-moving targets.

To mitigate the gap of minimizing the side noise and finding multiple and fast-moving targets, researchers move towards windowing methodology. In this technique, the researchers tried to reduce the amplitude of the side noise peaks below the acceptable limit up to certain frequencies called frequency bands. The authors used a different arrangement of binary codes to create more windows within the desired frequency limit. At this juncture, the authors are improving the windows, but the overall throughput is reduced since code generation is complex and maximizes the delay. Furthermore, the auto and cross-correlation of the given codes showed side noise peaks, which degrade the target detection performance.

In this study, a simple and effective method of code digital code generation called Booths Algorithm of code generation (BACG) is developed to investigate the multiple moving targets with desired Doppler. The presented approach improved the auto and cross-correlation performance and can be used to investigate the probability of multiple target detection. The proposed approach includes

a) Design of initial binary codes using the Booths Algorithm.

b) Performing mathematical operations to improve the properties of these codes.

c) To analyze the auto, cross-correlation properties and Doppler tolerance of the final codes obtained.

The standard codes can detect only static targets and the recent researches in this field detect the moving targets with significant side noise and complexity. In the presented approach the code designed depicts optimal noise in auto and cross-correlation properties and provide clear windows for static and moving targets detection.

Jiang et al[3] proposed a method to detect radar targets using conventional neural networks (CNN). The approach is well suited for static targets because a huge database is created to match the target which increases the delay and may not be the optimum solution for multiple and moving target detection. Long et al[4] presented a comparative analysis of various types of high-resolution radar (HRR). Here the author focused on issues and solutions related to detection, but no attention was given to reducing side noise peaks to facilitate multiple-moving target detection. Abratkiewicz, K[5] discussed a schemeusing Fourier transform to improve the probability of signal retrieval, however the approach is complex and fails to catch fast-moving targets. Alotaibi, M[6,7] modified the existing hex codes to improve the performance of the existing target detecting scheme, undoubtedly the author maximizes the target detection probability but still, the author fails to remove all side noise peaks and may not be the optimum solution of high-Resolution Radars. Aleem et al[8] proposed ASCI code of some special characters in which they tried to develop a set of coding schemes to test the target detection. Here the author got better results in terms of ambiguity but the performance of the designed codes reduces at the cost of auto and cross-correlation. Therefore, hiding targets cannot be detected and fails to solve real-time problems of multiple-moving target detection. Unissa et al[9] present long binary codes to improve the performance of the auto and cross-correlation to detect high-speed targets, however, the design process of code generation is too complex which needs more time to process it and increases the delay. Bhure R K D and Manjunathachari K[10] designed a method using trills coding approach in which the authors combined the trills bits at various levels to make the stream in a standard form and later they used combinational circuitry to generate more number of bits to investigate the target detection probability. Here the presented model showed good results up to a stream of 48 bits soon after it degrades performance because delay in the designed system increases more caused by more usage of combinational circuitry.

2 Methodology

The presented approach is unique as it is using a step-by-step procedure to generate the codes and mathematical operations are performed to minimize the noise and improve target detection. As no additional hardware is required for the proposed method the complexity is optimal and hence system performance is enhanced.

2.1 Proposed Approach

The fundamental string of integers employed to generate radar testing codes has been developed from 0-15 hex decimal numbers. However the concatenation series must follow an equal number of zeros and ones when represented in hex code, moreover, we are required to follow the decimals which are multiples of 3. Thus mathematically can be represented as

$$f_{\text{int.str}} = \prod_{p}^{q} 3p \quad 1 \leq p \leq q \& \text{q} = 4 \tag{1}$$

where '$f_{int.str}$' is the fundamental string of integers and has values 3, 6, 9, and 12. Therefore the same series can be represented in hex code as

$$\left.\begin{array}{l} 3 = 0011 \\ 6 = 0110 \\ 9 = 1001 \\ 12 = 1100 \end{array}\right\} \tag{2}$$

Now the radar testing codes have been developed using Booths Algorithm and termed Radar code generation using Booth Algorithm (RCGBT).

2.2. Radar code generation using the Booth Algorithm (RCGBT) to measure auto-correlation

In this method of code generation initially we multiply each element of the series by '3' using the Booths algorithm. Later, we combine all the bits of Accumulator 'A' and Multiplier 'Q' row-wise. Figure 1 represents the algorithm of the proposed approach to generate a fundamental code matrix.

For simplicity purposes, we represent 3x3 multiplication using the Booths algorithm to generate the initial codeword (see Table 1). To test the target interpretation, we analyze the auto and cross-correlation of the designed code word. Similarly, all other multiples of 3 of the series i.e. 3x6, 3x9, and 3x12 can be developed.

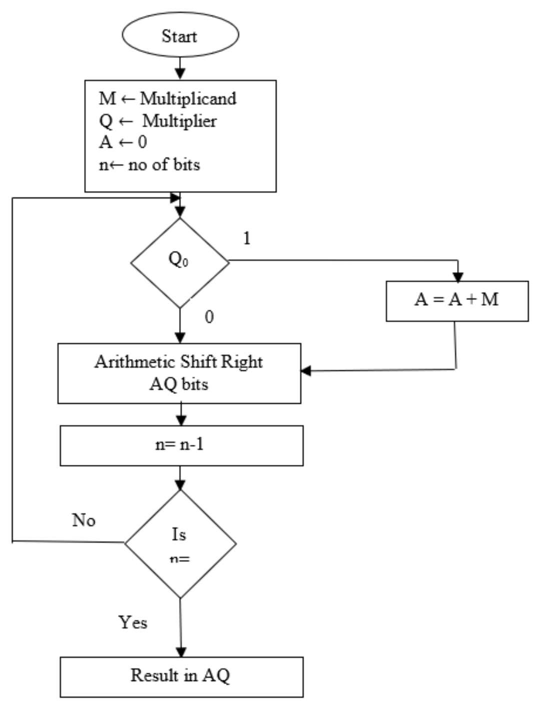

Fig 1. Flow chart of the initial Radar code generationusing the Booths Algorithm

The autocorrelation of the generated codeword is more or less the same as that of existing models. So to optimize autocorrelation the codeword generated is further modified by principles of digital logic and can be represented as 'M_{CW}'. Mathematically the modified codeword can be generated by Complement the bit position of 6 i.e. Total weight of the codeword – the weight of one's (8-2 = 6). Therefore

$$M_{CW} = 00001101 \tag{3}$$

The side noise peak of the designed codeword is 1. Therefore, the Main peak to noise peak reduction ratio (PRR) at a code length of 8 bits can be given as

$$\text{PRR(dB)} = 20\log(1/8) = -18.06 \text{ dB} \tag{4}$$

Table 1. Generation of initial codeword using Booths Algorithm

Iterations (n)	Carry bit (C)	Accumulator bits (A)				Multiplier bits (Q)				Multiplicand bits (M)				Operation
						Q3	Q2	Q1	Q0					
4 (as total bits are 4)	0	0	0	0	0	0	0	1	1	0	0	1	1	initialization
	0	0	0	1	1	0	0	1	1					As Q0 = 1 Then A = A+M
3	0	0	0	0	1	1	0	0	1					Shift Right AQ
	0	0	1	0	0	1	0	0	1					As Q0 = 1 Then A = A+M
2	0	0	0	1	0	0	1	0	0					Shift Right AQ
1	0	0	0	0	1	0	0	1	0					As Q0 = 0 So Shift Right AQ
0	0	0	0	0	0	1	0	0	1					As Q0 = 0 So Shift Right AQ
Generated codeword (bits of AQ) 00001001														

Moreover, to test the target at 16, 32, and 64 code lengths, the generation of the desired codes is developed by Matrix Creation Method (MCM). The first row and column of the matrix can be generated by using equation (3), and the remaining bits of the matrix can be developed using the EX-OR operation of row and column as characterized in Table 2. ⊕E, E= E⊕E and E = E⊕E

Table 2. Generation of codes using MCM

0	0	0	0	1	1	0	1
0	E_{22}	E_{23}	-	-	-	-	E_{2n}
0	E_{32}	-	-	-	-	-	-
0	-						-
1	-						-
1	-						-
0	-						-
1	E_{n2}	-	-	-	-	-	E_{nn}

$$\left.\begin{array}{l}\text{where } E_{22} = E_{21} \oplus E_{12}, E_{23} = E_{21} \oplus E_{13} \text{ and } E_{2n} = E_{21} \oplus E_{1n} \\ E_{n2} = E_{n1} \oplus E_{12} \text{ and } E_{nn} = E_{n1} \oplus E_{1n}\end{array}\right\} \quad (5)$$

To test the 16-bit codeword first two rows of Table 2 are concatenated to each other to form a desired codeword i.e.$E_{11} \ldots E_{1n} E_{21} \ldots E_{2n}$ = 0000110100001101inwhich the value of the side noise peak is '5' which is again nearly the same as reported earlier in the literature. So to make the code ideal we complemented the bit positions containing multiple of 3 values (i.e. 3, 6,9,12, and 15-bit positions. Therefore the novel 16-bit code generated can be signified as

$$C_{16NB} = 0010100110011111 \quad (6)$$

The codeword has only a noise peak of amplitude 2

For 32 bit test, we divided the elements of Table 2 into equal parts i.e. upper part 32 bits and the lower part 32 bits. During the test, the upper part showed a maximum noise peak equal to 23 and the lower part illustrated a noise peak of 8 and can be represented as

$$C_{32B} = 11110010111100100000110111110010 \quad (7)$$

However, to get the optimized value of the maximum noise peak, the codeword is further modified by complimenting the bit positions of multiples of 3 up to the limit given in equation (8) of bit positions.

$$\frac{\sum_{i=1}^{n} i}{S_{dvs}} \quad (8)$$

where $1 \leq n \leq 4$ and S_{dvs} = Starting decimal value of the initial series (i.e. 10/3 = 3.3333, so limit the complimenting process up to 3rd multiple) and the innovative codeword generated can be represented as

$$C_{32MB} = 11010110011100100000110111110010 \tag{9}$$

This generated codeword has a maximum noise peak of 4

In 64 bit test, all the row of Table 2 are concatenated to form a 64-bit codeword and is represented as

$$C_{64B} = 0000110100001101000011010000110111110010111100100000110111110010 \tag{10}$$

The codeword has a maximum noise peak of 8.

To get the optimum value we complemented the residue of the 3-bit position (i.e. residue of 3=1) of this code we can reduce the noise peak to 5 (see Figure 2 (a). The modified codeword generated can be represented as

$$\mathrm{C}_{64\mathrm{MB}} = 1000110100001101000011010000110111110010111100100000110111110010 \tag{11}$$

Two more code words of length 128 and 256 bits have been tested to optimize multiple moving target detection. The 128-bit codeword is developed by concatenated C_{32B}-C_{64MB}-C_{32B} code words respectively and the expanded code word can be represented as

$$\begin{aligned} C_{128B} = &1111001011110010000011011111001010001101000011010000110100001101111111001 \\ &0111100100000110111110010111100101111001000001101111110010 \end{aligned} \tag{12}$$

The maximum noise peak of 'C_{128B}' is 30, so to optimize the maximum noise peak further at 128-bit length we complement multiple of 3 positions up to the limit given in equation (13).

$$S_{Avfc} = \sum_{i=1}^{k} 3i, \quad 1 \leq k \leq 4 \tag{13}$$

Where 'S_{Avfc}'is the sum of all values of the fundamental code represented in equation (1). Therefore from equation (13), the value of 'S_{Avfc}' = 30. Hence limit the complementation process of multiples of 3-bit positions up to 30 and the required codeword generated can be represented as

$$\begin{aligned} C_{128MB} = &11010110011000000100100110100101000110100001101000011010000110111111001 \\ &0111100100000110111110010111100101111001000001101111111000 \end{aligned} \tag{14}$$

The maximum noise peak of 'C_{128MB}' is 12

Similarly, 256 codeword's are developed by considering the 16-bit code of equation (6), furthermore, this code is used to generate the 16*16 bit matrix i.e. 256 bits, and can be characterized as

$$\begin{aligned} C_{256B} = &0010100110011111001010011001111111010110011000000001010011001111111101011 \\ &0011000000001010011001111100101001100111111101011001100000110101100110000 \\ &00001010011001111100101001100111111101011001100000110101100110000011010 \\ &1100110000011010110011000001101011001100000 \end{aligned} \tag{15}$$

Here the Maximum noise peak is 30 for only a few seconds and for the rest of the time interval, the noise peak is 16 (see Figure 3 (a)). The noise peak of 30 can be tolerated, as in Doppler versus amplitude test analysis, the noise amplitude is below 0.2 dB and has a clear window within the entire range of frequency (see Figure 4 (b)).

Note that the complement of each final code designed gives the same auto-correlation value.

2.3 Design of a codeword to evaluate Cross-correlation

Cross-correlation is the measure of similarity between two different signals this is the next method that has been adapted to measure the noise peak value. To verify the multiple target detection process using cross-correlation at 8, 16, 32, 64,128, and 256-bit length code words. The first codeword (signal value) of all the given codes at different lengths (i.e.8, 16, 32, 64,128, and 256) is considered the same as characterized in section 3.1 (Autocorrelation). However, the 2nd codeword for all the above-mentioned codeword lengths is developed with different logic investigations to check the performance of the detection system.

The initial design of the 8-bit codeword is developed by concatenation of alternate bits of equation (2) (i.e. the bits formed by 3 and 9) and the bits are 00111001. The cross-correlation amplitude obtained is 3.

The 16-bit codeword is developed by concatenating all the bits of equation (2) such as 0011011010011100. Meanwhile multiple of 3 positions are complementing up to 12 (i.e. using equation 16).

$$D_{BC} = \frac{S_{Avfc}}{2} - I_{f_{\text{int.str}}} \tag{16}$$

where'D_{BP}' is the decimal value of the bit position in a codeword up to which complement needs to be done and '$I_{f_{int.str}}$' is the initial decimal value of the string represented in equation (1). Hence the modified 16-bit codeword can be represented as

$$\text{Snd}_{16BC} = 0001001000001100 \tag{17}$$

Where 'Snd_{16BC}' is the 2nd 16-bit code word used to check the cross-correlation. The maximum noise peak of 'Snd_{16BC}' is 5 . For 32-bit code generation equation (17) is concatenated with its complement, so the 32-bit code word can be represented as

$$\text{Snd}_{32BC} = 00010010000011001110110111110011 \tag{18}$$

The maximum noise peak we achieved from 'Snd_{32BC}' is 8. To test the cross-correlation of a 64-bit length codeword, simply we concatenate '$Snd_{32BC}Snd_{32BC}$' to get a 64-bit codeword. Here we got a maximum noise peak of 14 (see Figure 2 (b)) and the codeword can be designated as

$$\text{Snd}_{64BC} = 0001001000001100111011011111001100010010000011001110110111110011 \tag{19}$$

Moreover, for 128-bit length code word initially the hex values of series 3, 9,6,12 are concatenated and is represented as 'H_V' = 3, 9, 6, 12(i.e. 0011100101101100). Then multiple of 3 has been complimented to get a 32-bit codeword in the form of 'pH_V' such as '00011101111111100111001011011000', furthermore this process continues till the length will be equal to 128 bits, and can be represented as

$$\text{Snd}_{128BC} = pH_V pH_V \text{..till 128 bits} \tag{20}$$

So the final code can be represented as

$$\text{Snd}_{128BC} = 0001110111111110001110010110110000011101\\1111111000111001011011000001110111111110001110010110\\11000001110111111110001110010110110 0$$

In this code word, we got a maximum noise peak of 20

Finally, for 256-bit generation 'H_V' is concatenated 16 times to develop 256-bit code and can be represented as

$$S_{nd}d_{256BC} = 0011100101101100001110010110110000111001 0\\110110000111001011011000011100101101100001110010 1101\\100001110010110110000111001011011000011100101101 1000\\011100101101100001110010110110000111001011011000011 10\\010110110000111001011011000011100101101100001110010 11\\0100$$

In this code word, we got a maximum noise peak of 29 (see Figure 3 (b))

2.4 Doppler Tolerance of the Codes

The obtained codes are tested for the Doppler tolerance, as Doppler shift degrades the performance of the matched filter, the signals sent for target detection must be more Doppler tolerant. The codes having fewer bits are less Doppler tolerant when compared with the codes having more bits. Figure 6 depicts the ambiguity function of the designed codes of lengths 128 and 256 respectively. From the figures, we can observe the clear windows for certain frequencies, as the noise amplitudes for these frequencies are 0.2 dB and below which is an acceptable threshold limit value. Clear windows from Doppler graphs represented in Figure 4 (a) for 128 bits and Figure 4 (b) for 256 are 4-8 kHz, 9-60 kHz, and 0-60 kHz respectively.

3 Results and Discussion

In this section, we validate the performance of the desired and developed codeword's using Mat-Lab. Figures 2 and 3 represent the auto and cross-correlation of different code lengths to validate the proposed approach. Furthermore, Figure 4 (a) & (b) represents the ambiguity function of 128 and 256-bit length codes respectively to validate the designed codes at various Doppler frequencies.

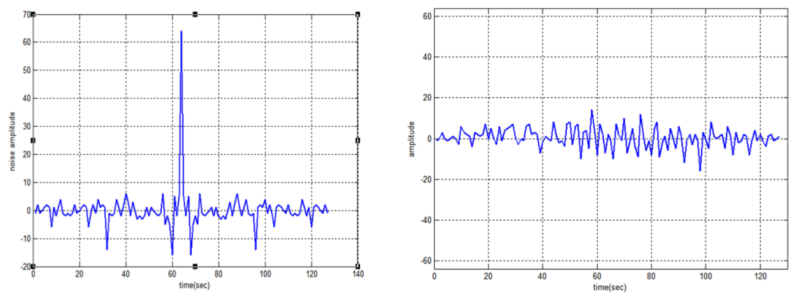

Fig 2. (a) Auto-correlation property of 64-bit (b) Cross-correlation property of 64 bit

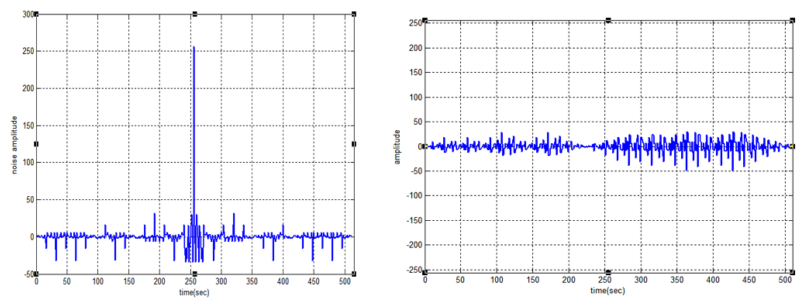

Fig 3. (a) Auto-correlation property of 256-bit (b) Cross-correlation property of 256 bit

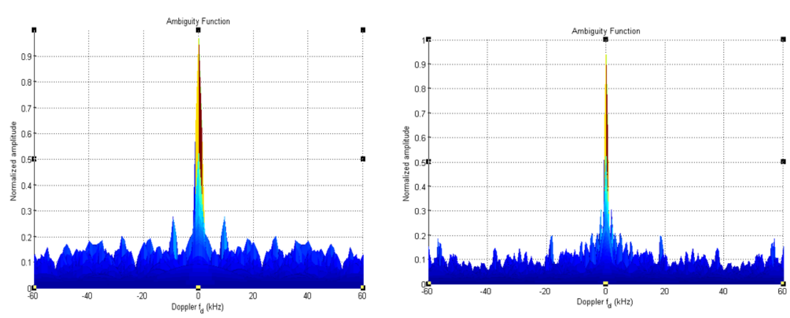

Fig 4. (a) Ambiguity function of 128 bits (b) Ambiguity function of 256 bits

The summary of all graphs is represented in Tables 2 and 3

Represents the summary of all the designed codes relating to Auto correlation, cross-correlation, and clear window frequency range at various code lengths.

Table 3. Summary of all the figures

Number of bits	Auto-correlation Max. Noise peak	Cross-correlation Max. peak	Clear windows from Doppler graphs (in kHz)
8	1	3	-
16	2	5	-
32	4	8	40-55
64	5	14	10-23, 43-60
128	12	22	4-8, 9-60
256	16	29	0-60

4 Comparative Analysis and Discussion

Figures 5 and 6 represents the comparative analysis of noise peaks of the proposed approach and current art of work with respect to auto correlation and ambiguity.

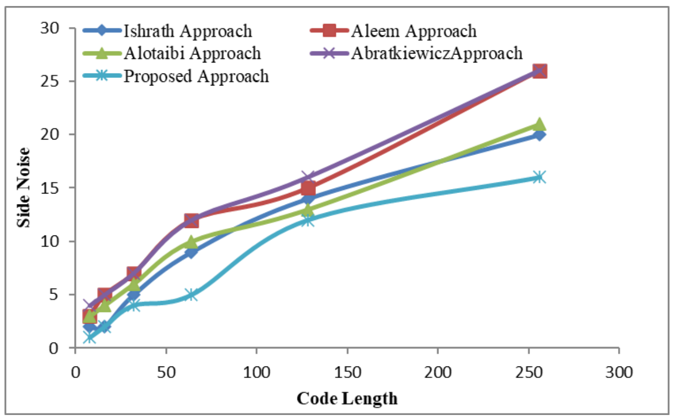

Fig 5. Autocorrelation property of Proposed and Existing Approaches (Code Length Versus Side Noise)

From the figures, it has been observed that the proposed approach depicts the enhanced results when compared to the current literature. Furthermore, the developed codes are simple to design and effective to analyze multiple fast-moving targets. The proposed approach is energy efficient, because the code design process required minimum hardware to run the desired detection procedure, in addition to this only two output devices (i.e. either A- Scope or Plan Position Indicator (PPI)) will cover the entire range of the target and minimizes the visualization cast and human effort.

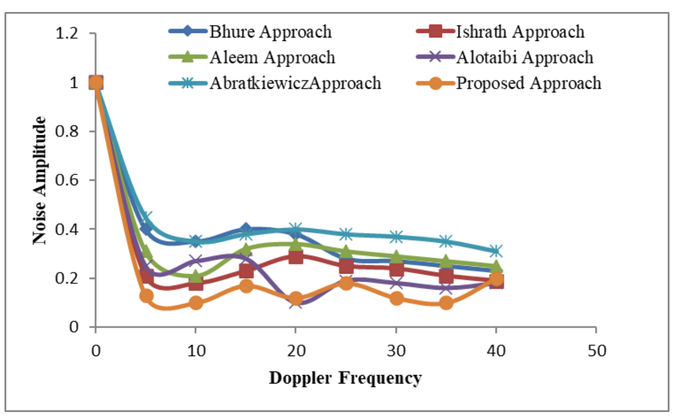

Fig 6. Ambiguity property of Proposed and Existing Approaches (Doppler frequency Versus Noise Amplitude)

5 Conclusion

An easy and efficient stream of codes has been obtained to investigate the target detection probability of the radar system. The designed codes are optimized to have minimal noise with improved auto-correlation, cross-correlation, and Doppler tolerance properties. The designed coding schemes demonstrated improvement in the results when compared to the current art of work as represented in section 4. Furthermore, the proposed technique will enhance the knowledge of the research community which is working in the field of radar signal processing. The proposed model has been validated using Matlab

References

1) Hunde A. Multi-Target State and Extent Estimation for High Resolution Automotive Sensor Detections. *Sensors*. 2022;22(21):8415. Available from: https://doi.org/10.3390/s22218415.
2) Zarai K, Cherif A. Improved Multi Target Tracking in MIMO Radar System Using New Hybrid Monte Carlo–PDAF Algorithm. *IoT Applications Computing*. 2022. Available from: https://doi.org/10.5772/intechopen.95948.
3) Jiang W, Ren Y, Liu Y, Leng J. A method of radar target detection based on convolutional neural network. *Neural Computing and Applications*. 2021;33(16):9835–9847. Available from: https://doi.org/10.1007/s00521-021-05753-w.
4) Long T, Liang Z, Liu Q. Advanced technology of high-resolution radar: target detection, tracking, imaging, and recognition. *Science China Information Sciences*. 2019;62(4). Available from: https://doi.org/10.1007/s11432-018-9811-0.
5) Abratkiewicz K. Radar Detection-Inspired Signal Retrieval from the Short-Time Fourier Transform. *Sensors*. 2022;22(16):5954. Available from: https://doi.org/10.3390/s22165954.
6) Alotaibi M. Multi-Criteria Decision Making to Detect Multiple Moving Targets in Radar Using Digital Codes. *Sensors*. 2022;22(9):3176. Available from: https://doi.org/10.3390/s22093176.
7) Alotaibi M. Correction to: Low noise moving target detection in high resolution radar using binary codes. *EURASIP Journal on Advances in Signal Processing*. 2021;2021(1). Available from: https://doi.org/10.1186/s13634-021-00721-x.
8) Aleem MD, Singh RP, Ahmad SJ. Enhance Multiple Moving Target Detection in Doppler-Tolerant Radar Using IRAESC Technique. In: Lecture Notes in Networks and Systems;vol. 33. Springer Singapore. 2019;p. 417–426. Available from: https://doi.org/10.1007/978-981-10-8204-7_42.
9) Unissa I, Ahmad SJ. Long Binary Sequences with Good Auto and Cross-Correlation Properties LAP. Saarbrücken, Germany, 2021. LAMBERT Academic Publishing. 2021;p. 978.
10) Bhure RKD, Manjunathachari K. Design Of Digital Code Using Trellis Code to Improve Multiple Moving Target Detection in Doppler Radar. *Indian Journal of Science and Technology*. 2021;14(46):3407–3415. Available from: https://doi.org/10.17485/IJST/v14i46.1771.