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Design of Bi-phase codes for radar applications using Genetic algorithm

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***Abstract*— In radar applications, pulse compression is a commonly utilized technique. This approach is used to combine a short pulse's high resolution with a long pulse's high energy. It is achieved through frequency modulation or phase coding of the transmitted pulse. Bi-phase and polyphase are the two types of phase coding techniques. Due to the ease of implementation of bi-phase codes they are more preferred over the latter. An optimal bi-phase code is one that has minimum side lobes in its autocorrelation function. For an N-bit code there are 2^N possible states and as the length increases the number of states also increases. Hence searching for an optimal code among these possibilities becomes difficult and time consuming. To overcome this, optimization techniques are used. This paper presents the usage of one such method called genetic algorithm to find out the optimal code for longer length sequences from 100 to 105.**

Keywords—Pulse compression, Autocorrelation, Bi-phase code, Genetic algorithm.

I. INTRODUCTION

RADAR (RAdio Detection And Ranging) is a system used for detection and location of objects present in the vicinity. It works by transmitting electromagnetic signals towards the target and examines the echoes received from them. Some of the areas where radar is widely used are in Military, Air Traffic Control, Ship Navigation and Remote sensing. The range resolution capabilities and the radar's capacity to detect objects at longer distances define the radar performance. Range resolution refers to the radar's ability to distinguish between two or more targets that are close together. The pulse width of the waveform determines this. The range resolution improves as the pulse width narrows. When the pulse width is narrow, however, the energy of the pulse is reduced. Due to this range detection gets reduced. So these two factors are conflicting in nature. In radar, pulse compression techniques are utilized to solve this problem.

Pulse compression[1] involves modulation of a long pulse in frequency or phase. This way, it allows the radar to attain both the resolution of a short pulse and the energy of a long pulse at the same time. The radar system primarily employs bi-phase pulse compression. In this, the signal that is transmitted is 0^0 relative to +1 in the binary code and 180^0 for -1.One of the preferable property in a bi-phase code is that it should have low side lobes in its autocorrelation function so as to prevent the weaker targets from being hidden in the side lobes of the stronger one. The lower the side lobes are in relation to the main lobe peak, the easier it is to recognize the main peak and as a result the better the associated code. Barker codes[1] are popular bi-phase codes having lowest side lobe peaks but they are available only for a code length of 13.As most of the radar applications requires longer length sequences, search for such optimal codes becomes essential[2].

Many researches have been conducted to address the issue discussed above. In 1975, Linder [3] found the binary length sequences with best PSL value up to a length of 40 using computer search method. Cohen et al.[4] increased the length of the results to 48 by using recursive algorithms. S.Tyler and R.Keston[5] in their study used some initial guesses and then they were modified until no further changes resulted in a better code to find out binary codes for lengths ranging from 28 to 64. Hu et al.[6] were able to generate binary sequences with lengths up to 100 using neural network technique.

There are six sections in this study. After the introduction in section I, the merits that are required to be minimized in the bi-phase codes are explained in section II. Section III describes genetic algorithm which is used to determine optimal codes in detail. For simulation Python 3.7.9 is used and the procedure that was employed is discussed in section IV. The results of the algorithm are shown in Section V. In section VI the investigation's result is underlined.

II. MERIT MEASURES

In radar systems, sequences with good autocorrelation function(ACF) qualities are employed as transmit signals[7]. The performance metrics that can be used to assess the quality of a proposed sequence is discussed in this section.

Consider a binary code 'p' of length L whose sequence can be written as $\{p_1, p_2, p_3, p_4,\dots,p_L\}$ where p_i can be either 1 or -1. The ACF of the code is given by:

$$ACF_n(p) = \sum_{i=1}^{L-n} p_i \;\; p_{i+n} \qquad where\ n = 0,1,2,\dots,L-1 \quad (1)$$

A good waveform should have one prominent central peak which is known as the "mainlobe" at n = 0 that is $ACF_0(p)$ and for all other values of n the autocorrelation function must be zero. But a notable problem is that the ACF is not impulsive in nature as it contains side lobes that are evenly distributed on both the sides of the main lobe. The term “sidelobe” refers to any non-zero value of $ACF_n(P)$ for $n \neq 0$. High sidelobes if present can be mistaken for a target and it also prevents the detection of weak target present near a strong target. The lower a code's sidelobe level, the more likely it is to be chosen for any radar application.

Two metrics are used for the sidelobe measure[8]. The first metric as shown in equation (2) is the Peak sidelobe level(PSL). The PSL is the highest sidelobe in the ACF of the code. It is given by equation (2).

$$PSL = max|ACF_n(p)| \qquad when\ n \neq 0 \qquad (2)$$

For an optimal bi-phase code peak sidelobe has to be minimum.

Integrated sidelobe level (ISL) is the second metric and is given by the equation (3). It is defined as the total power contained within the sidelobes.

$$ISL = 2\sum_{n=1}^{L-1} ACF_n^2(p) \qquad (3)$$

III. GENETIC ALGORITHM

Genetic algorithms (GA) are a form of optimization approach for finding the best solutions to a computational issue that maximizes or minimizes a specific function. This algorithm was developed by John Holland[9] and his students at the University of Michigan. GA is a search heuristic that imitates the biological process of natural selection and reproduction which was described by Charles Darwin. By generations the best and the fittest solutions are kept as survivors while the remainder of the possibilities is discarded. Once again the best solutions evolve on a constant basis as the natural test ground becomes more demanding. This is a continuous process for determining the best possible outcome.

In GA, a chromosome is a solution and each chromosomal element is referred to as a gene. Allele refers to the value that a gene takes to a specific chromosome. The search is carried out for various generations in order to arrive at the best option.

The steps involved in genetic algorithm are given below[10]:

1. *Initialize the population:* The initial population is generated randomly. The total number of chromosomes necessary in each generation is referred to as population size. The chromosomes can be real numbers or can be coded to binary form. The binary representations of N chromosomes are randomly initialized.

2. *Fitness function assessment:* The objective function of all the chromosomes in the population is evaluated. It is the function that the algorithm is attempting to optimize.

3. *Selection:* Chromosomes with good fitness value are selected and then allowed to pass their genes to the next generation. The binary tournament selection method is utilized in this paper to pick an individual from the population. In this, two individuals are randomly chosen from the population, and the chromosome with the highest fitness value is chosen as parent 1. This process is done another time to select parent 2.
4. *Crossover:* In crossover, the parents selected using binary tournament selection are combined together to form new chromosomes. The assumption behind crossover is that if the new chromosome receives the best qualities from both parents, it will be superior to both. It is of two types: Single point crossover or two point crossover.

   In single point crossover, a point is randomly chosen, and all genes following that point are swapped between the two parent chromosomes to produce two children. Two points are randomly picked in two point crossover, and the genes between them are swapped between the two parents to produce two offspring. This procedure is performed using a probability known as crossover probability, which indicates how frequently crossover will be carried out.

5. *Mutation:* It’s a genetic operator that randomly flips individual bits in the chromosomes. It is used to preserve genetic diversity [11] in a population of chromosomes from one generation to the next. In binary representation a randomly chosen bit is changed from 0 to 1 and vice versa.

6. *Recombination and Selection:* The fitness value of each chromosome is evaluated by combining the existing and offspring populations. The best chromosomes are chosen and passed down to the next generation based on their fitness value. Figure 1 shows the flow chart for a genetic algorithm procedure.

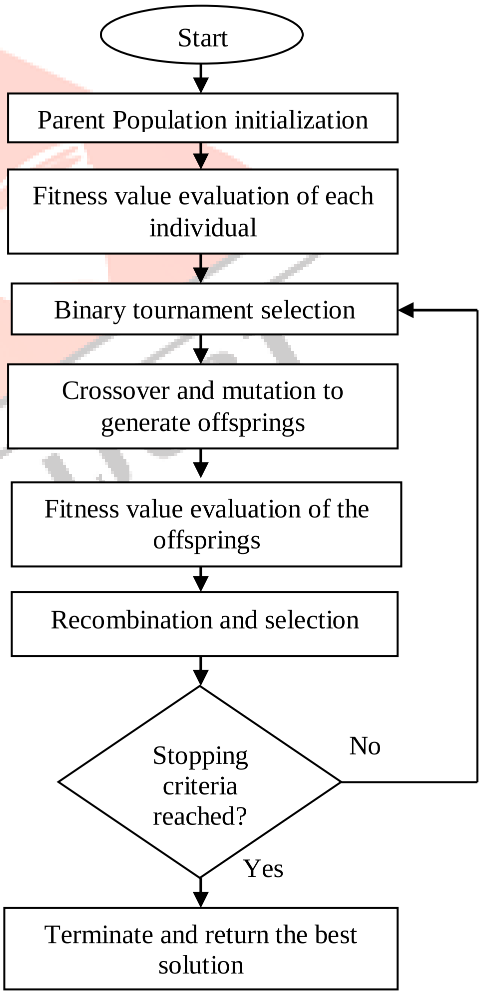

Figure 1: Flowchart of genetic algorithm

IV. SIMULATION PROCEDURE

GA is used to minimize the objective functions PSL and ISL separately. Bi-phase codes are generated for lengths varying from 100-105.Some of the basic steps in the generation of the bi-phase code are as follows:

1. The algorithm begins with the generation of N number of chromosomes randomly. These chromosomes are made of binary bits 1 and -1 and they serve as the first generation.
2. The size of the population is set to 500 and number of generations is taken as 500.
3. The ACF and PSL are evaluated for each chromosome.
4. Parents are selected using binary tournament selection.
5. Offspring are generated using genetic operators. The crossover and mutation probability are set to 0.9 and 0.01.
6. The parent and offspring populations are merged, and the best chromosomes are chosen for the following generation.

The process continues until desired number of generations is met. The same procedure is used for minimization of ISL using genetic algorithm.

V. RESULTS

Minimum values of PSL and ISL are used as the criteria to select the best codes for a given code length. Tables 1 and 2 show the results obtained. The autocorrelation function is also plotted in Figure 2,3,4,5,6,7,8,9,10,11,12 and 13.

Table: 1

Length of the sequence	PSL	Sequences
100	6	0110011111101001100100100011111100001010011111001011101000011010001000001000010100110101101110001101 1
101	7	001001101001110111010110111000001111000010111111011111101110101101001010000100010111000100000001110001 10
102	6	100001011000111010110000100101101110001100110001011100001001111111100001110101010011110101110010010 010
103	7	1100010110111010100100101011000001110100101111111110011010000110011100110010111000001010001100101000 0110
104	7	011000100010101110010100110101001010011101001111100011111001001100101011100100001011001110011100101 10001
105	6	110101100100110100101000001100001000100110110011000111001000111010000101100111111110000001010111000011 0011

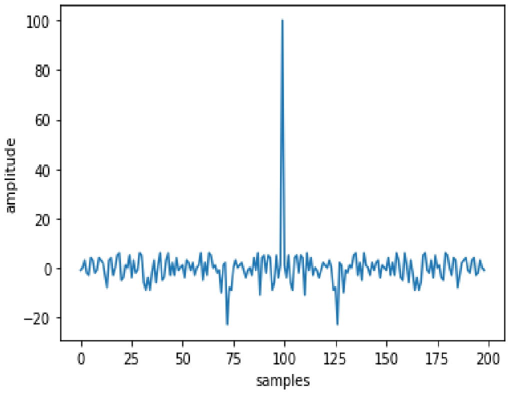

Figure 2: Autocorrelation of a 100-bit code(PSL = 6)

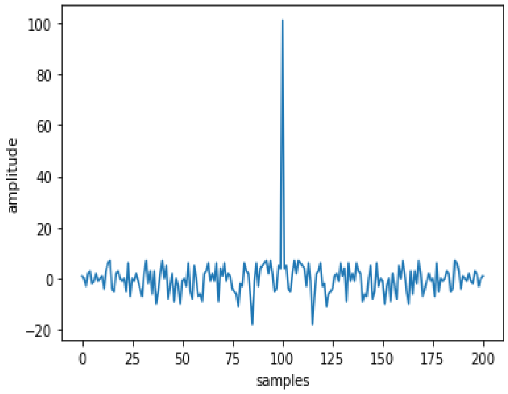

Figure 3: Autocorrelation of a 101-bit code(PSL = 7)

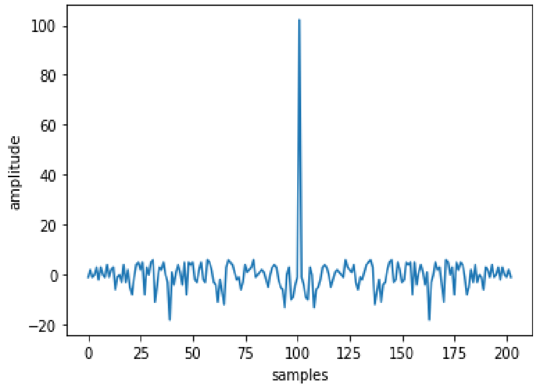

Figure 4: Autocorrelation of a 102-bit code(PSL = 6)

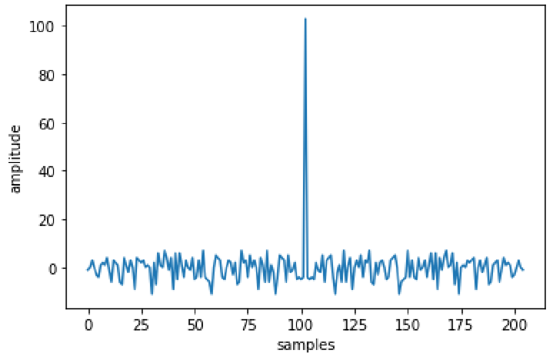

Figure 5: Autocorrelation of a 103-bit code(PSL = 7)

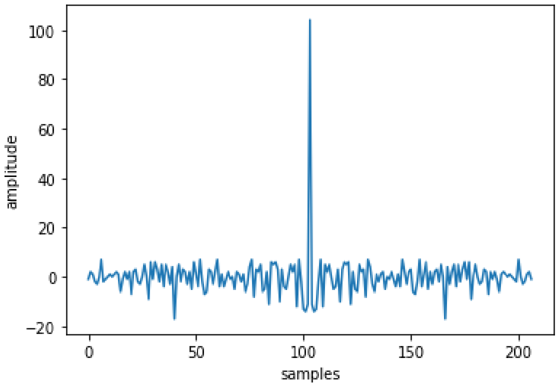

Figure 6: Autocorrelation of 104-bit code(PSL = 7)

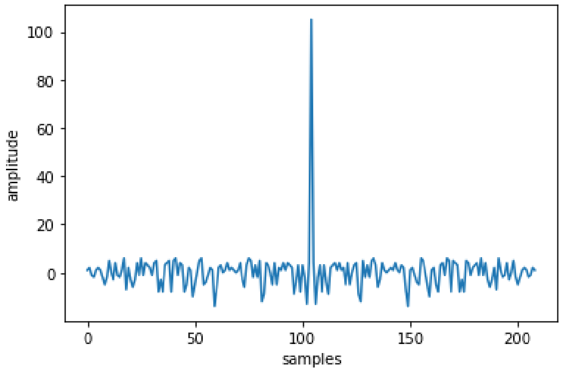

Figure 7: Autocorrelation of a 105-bit code(PSL = 6)

Table: 2

Length of the sequence	ISL	Sequences
100	2396	0101110010101010010001000001101110111011101000111000011000011001000001011011000000011010110101100001
101	2516	00101100000010100101000011000010101100110100111011111000000010110011111000110111000100110101110000101
102	2206	110111001111011100011000000100101010111101000101110100110111110000111101111110000110110111101100 0110110
103	2854	0110100100111110111010011100100111001101110010101011110001111111101110101000111001101000010110110001010
104	2800	00000010100100011101010000101010001101101101001000010001001000111100010110111101010000011101100111000011
105	3016	101010011111110000011101001110100001001000110000100010101100010110010100100001000100100111110111000101001

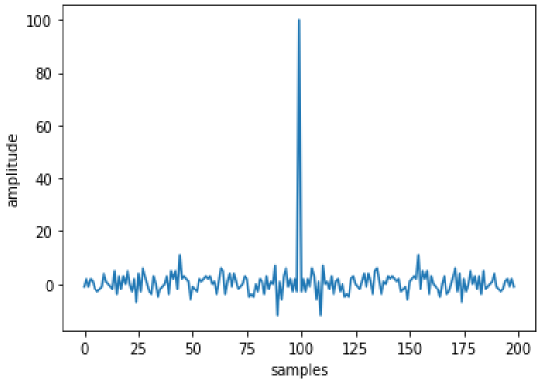

Figure 8: Autocorrelation of a 100-bitcode(ISL = 2396)

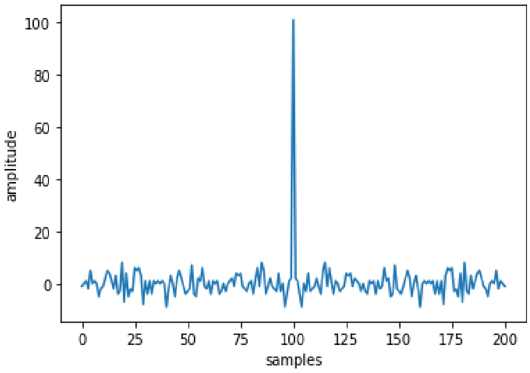

Figure 9: Autocorrelation of a 101-bit code(ISL = 2516)

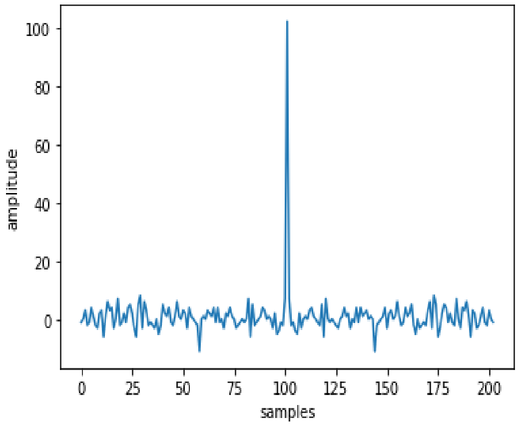

Figure 10: Autocorrelation of a 102-bit code(ISL= 2206)

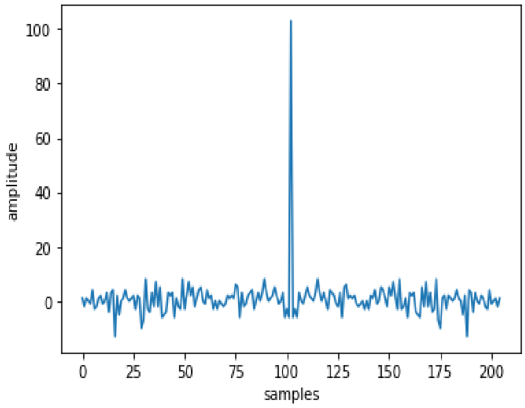

Figure 11: Autocorrelation of a 103-bit code(ISL = 2854)

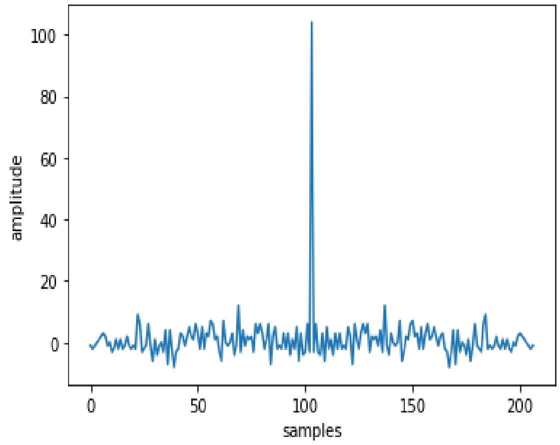

Figure 12: Autocorrelation of a 104-bit code(ISL = 2800)

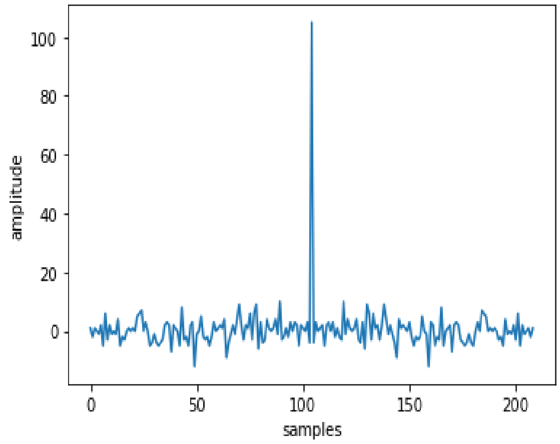

Figure 13: Autocorrelation of a 105-bit code(ISL = 3016)

VI. CONCLUSION

While designing radar transmit sequences, having appropriate autocorrelation properties is critical. The PSL and ISL of the ACF determine the goodness of the sequence. For achieving this, genetic algorithm is used in this paper. Thereby, a list of sequences with lengths varying from 100 to 105 and having minimum PSL and ISL in the autocorrelation function has been obtained. The optimized sequences can be used in radar systems for improving their resolution and detection capabilities. To conserve space 0's are utilized instead of -1's. It is noted that the quality of the solution improves as the number of generations increases. Also, as the length of the sequences increases the search technique takes longer time to find a good solution.

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