

# Design of Biphase Sequences using Psafor Radar Applications



E.V.Suryanarayana, P.Siddhaiah

**Abstract:** Pulse compression is widely used method to get high range resolution in radar applications. This can be achieved when transmitted pulse is modulated either using phase coding or frequency coding. In phase coding technique, it can be bi-phase or poly phase. Bi-phase coding is preferred method due to its simplicity in generation and needs less signal processing techniques. This paper we propose a new algorithm called Progressive Search Algorithm (PSA) for the optimization of bi-phase sequences for radar applications. It is devised that the new algorithm is capable of optimizing the sequences with low autocorrelation sidelobes. The convergence rate of PSA is very fast compared to the other existing algorithms such as PSO and SGO. The development procedure and its efficiency with respect to the PSO and SGO is also presented in this work.

**Key Words:** Pulse compression, Biphase codes, autocorrelation, matched filter.

## I. INTRODUCTION:

Pulse compression is a technique used by radar engineers, which allows use of long duration modulated pulse to achieve simultaneously high energy for detection of target at desired range and resolution corresponding to a short pulse. For the modulation of transmitted pulses, Phase coded sequences are widely used in modern radar systems. In binary sequences only two phases are employed, hence these are called binary, or biphase sequences. The sequences which are designed or optimized by this algorithm are mainly used for high resolution radar applications. Biphase codes are preferred because of its simplicity in implementation and Barker codes are well known codes that achieve the best possible ratio between the main lobe and side lobe peaks. Unfortunately, Barker codes are not conceivable above length  $N=13$ . To achieve high pulse compression ratio length 13 is not enough. Hence, there is a need to optimize the large length sequences, which have good pulse compression ratio and low sidelobe at the output of the matched filter. To get large pulse compression ratios, there is a continuous search for longer and longer signals whose aperiodic autocorrelation function exhibits low peak side lobes or low integrated side lobes [1]. To achieve low peak sidelobes (PSL) various techniques are explained in [2-

6]. In this context many researches used the optimization algorithms PSO [7-9] for the optimization of radar sequences [10-12]. Additionally, another algorithm which is known as Social Group Optimization (SGO) which was suggested by Satapathy and Naik [13], is a soft computing procedure works on the principle of transfer practice in human behaviour toward solving a complex problem. In section II some basic properties of biphase sequences are discussed, Progressive Search Algorithm (PSA) is explained in section-III. Optimized sequences and related graphs are given in section-IV, whereas discussions and conclusions are given in section -V.

## II. PROPERTIES OF APERIODIC SEQUENCES:

The real time applications such as channel estimation, radar and spread spectrum communication employ sequences with low aperiodic autocorrelation side lobe peaks. Let  $S$  be the sequence of length 'N', where  $S$  can be represented as:

$$S = [s_1, s_2, s_3, \dots, s_N] \quad s_i = \pm 1 \dots (1)$$

There aperiodic autocorrelation

$$R_k = \sum_{i=1}^{N-k} x_i^* x_{i+k};$$

$$k = 0, 1, 2, \dots, (N - 1) \quad (2)$$

Equation (2) represents the auto correlated output of the matched filter to  $x_i$ . The major efforts are to be made to minimize the Peak Side lobe (PSL) at the output of the matched filter so that the even weak target present near the strong target can be detected easily. This paper is mainly focused on the design of binary sequences, considering the PSL as performance index.

## III. PROGRESSIVE SEARCH ALGORITHM (PSA)

Progressive search algorithm (PSA) is a heuristic search algorithm for obtaining the best sequence of the desired length suitable for radar applications. Random search is the key process done progressively to obtain better and better sequence at each iteration. Overall this algorithm can be explained using the following three process:

- a) Sequence generation
- b) Performance evaluation
- c) sequence selection

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\* Correspondence Author

E.V.Suryanarayana\*, Research Scholar Acharya Nagarjuna University.

P.Siddhaiah, Professor & Head of the Department of ECE Acharya Nagarjuna University.

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## Design of Biphase Sequences using Psafor Radar Applications

In sequence generation, a binary sequence of the desired length (say  $N$ ) is generated randomly. In this sequence, only two values either  $-1$  or  $1$  are used as the binary bits. In MATLAB, this task is done by using a random binary number generator where  $0$  and  $1$  are considered as the binary bits of the sequence. After that, all zeros are replaced with  $-1$  and thus the sequence of desired bits ( $-1$  and  $1$ ) is obtained. During the process, such sequence is generated randomly at each iteration. Also, this sequence is expected to be different at each iteration because each time the random generator generates a different set of sequence. In this algorithm, this sequence is termed as temp. In performance evaluation, the cross-correlation of the generated sequence is obtained. In this total number of data points are  $2^{N-1}$ . This sequence is termed as temp-cross. The obtained cross-correlated sequence is always symmetrical about the middle-most data point which is the  $N$ -th data point. Also, the value of this peak is the same as the original sequence length that is  $N$ . The maximum value of the cross-correlated sequence from  $1$  to  $N-1$  and  $N+1$  to  $2N$  are known as side peak lobe. In the cross-correlated sequence, there is two side peak of equal value on both sides of the main peak lobe. Here, the value of side peak lobe is calculated. In this algorithm, it is termed as temp\_sl.

In sequence selection, the evaluated sequence is selected if it qualifies the desired criteria of radar application. In means that the side peak of the cross-correlated sequence should be the least of the sequence to be selected. The above two operations are performed progressively till we get the sequence of desired merits. During the process, the obtained better sequence with Peak side lobe is stored and search of the next better sequence is continued. As the number of the possible sequences are very large  $2^{N-1}$ , the algorithm needs to stop at some stopping criterion. In this algorithm, two stopping criterion have been used which are the number of iterations and CPU time elapsed. The overall, PSA approach is shown in the flowchart and the step-by-step algorithm. It is observed this algorithm is suitable for the binary sequence of data which always gives peak lobe value equal to the size of the sequence. The PSA gives the least values of the side peak lobes of the cross-correlated sequence of any size. The flow chart of PSA is given in figure 1.

In brief, we can represent the new algorithm in following steps.

Step I. Set the length of sequence that is equal to  $N$ .

Step II. Initialize binary bits (0,1) of Size  $N$ .

Step III. Convert all zeros of the sequence with  $-1$ .

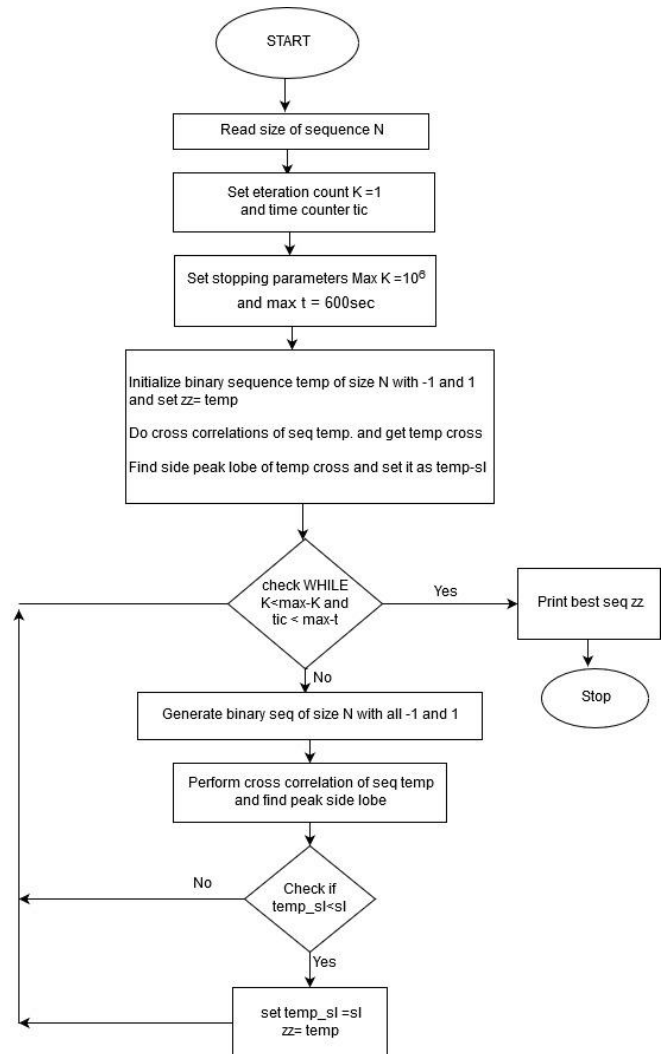
Step IV. Perform the autocorrelation of the sequence consisting  $-1$  and  $1$ .

Step V. Find Peak side lobe.

Step VI. If criterion of peak side lobe is satisfied stop else go to Step II.

END.

Search Algorithm: (PSA)



**Figure 1 : (Flow Chart of Progressive)**

### III. RESULTS AND DISCUSSIONS:

In pulse compression radar systems, the energy of long pulse and resolution related to the short pulse is achieved at the cost of sidelobes at the output of matched filter. Large sidelobes may mask the echoes of the small target which is present near the strong target and small target goes undetected due to the high sidelobes of the strong target. Hence, there is a demand to optimize the phases of the sequences in such a way that the peak sidelobes must be low. In this work we have optimized the biphase codes by using optimization technique for good autocorrelation property. And it is observed that PSA is most suitable compared to the other algorithms such as PSO and SGO. Auto correlation of input sequence of length 13 has resulted in Maximum peak side lobe of 1, which is better than the result obtained as per previous results [2]. Auto correlation of input sequence of length 28 has resulted in Maximum peak side lobe of 2, which is same as the result obtained as per previous results [2]. Relative performance ( Sequence length Vs Maximum peak side lobe) of PSA compared with PSO & SGO is indicated at Figure 3. Time for processing using PSA in comparison with PSO & SGO is indicated at Figure 4.

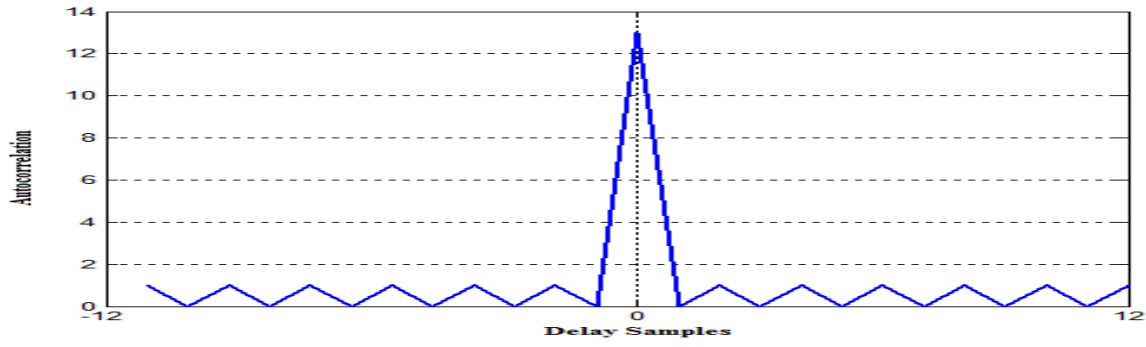


Fig 2. Auto correlation of Sequence length N= 13 using PSA  
 $N = [-1 \ 1 \ -1 \ 1 \ -1 \ -1 \ 1 \ 1 \ -1 \ -1 \ -1 \ -1 \ -1]$

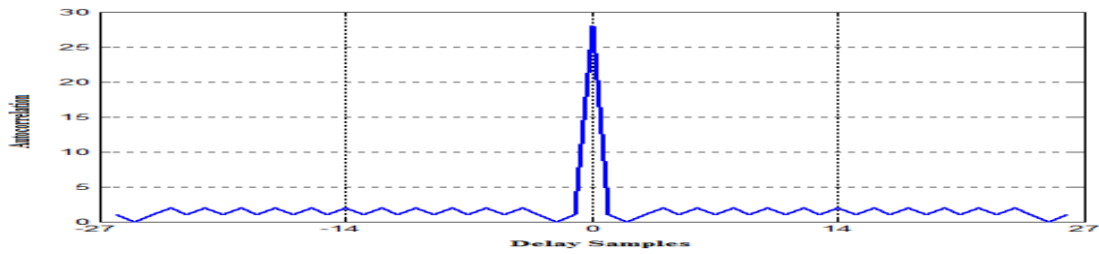


Fig 3. Auto correlation of Sequence length N= 28 using PSA

$N = [-1 \ -1 \ -1 \ 1 \ 1 \ -1 \ -1 \ -1 \ 1 \ 1 \ 1 \ 1 \ 1 \ 1 \ -1 \ -1 \ -1 \ -1 \ 1 \ 1 \ -1 \ 1 \ 1 \ -1]$

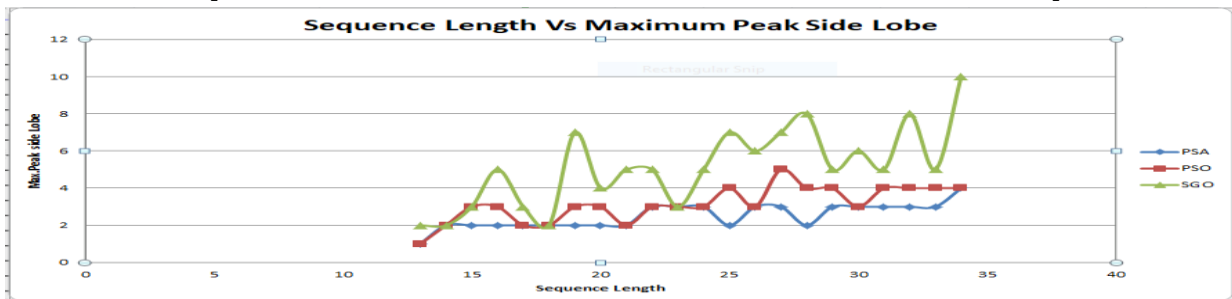


Fig 4. Sequence length Vs. Maximum peak side lobe using PSA N= 13 onwards

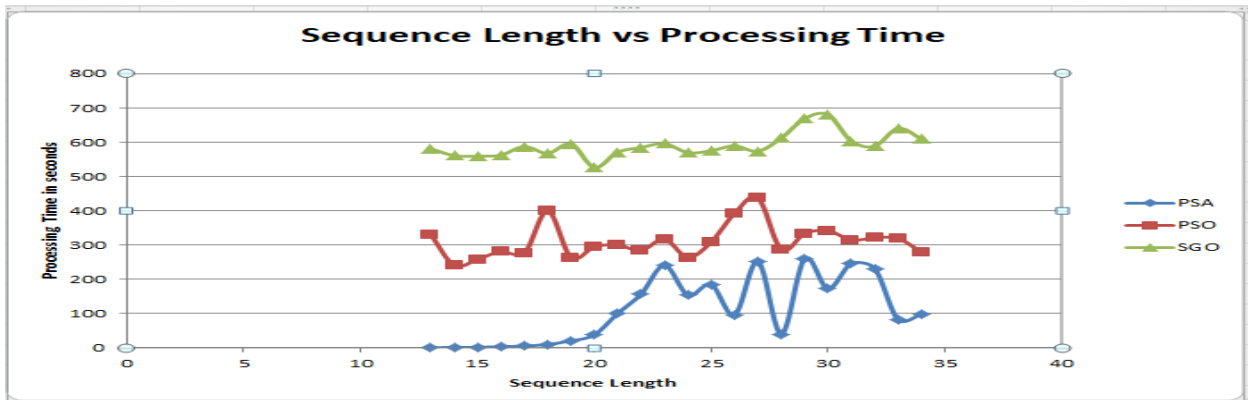


Fig 5. Sequence length Vs. Time for Processing using PSA, N= 13 onwards

Table 1

COMPARISON OF RESULTS OF PROGRESSIVE SEARCH ALGORITHM (PSA) with PSO & SGO

Sequence length	Minimum Peak side lobe For PSA	Minimum Peak side lobe as per previous literature[2]	Time for processing (seconds) FOR PSA	Minimum Peak side lobe for PSO	Time for processing (seconds) for PSO	Minimum Peak side lobe for SGO	Time for processing (seconds) for SGO
6	2	2	0.093	2	209.46	2	515.4522
8	2	2	0.1169	2	213.436	2	593.6331
9	2	2	0.1336	2	191.0316	3	715.4332
10	2	2	0.1298	2	221.5835	2	822.3303
12	2	2	0.4282	2	211.210	2	746.9465
13	1	2	0.6357	1	329.95	2	581.1053
14	2	2	1.06449	2	240.715	2	561.076
15	2	2	1.66498	3	258.077	3	559.5576
16	2	2	3.13068	3	281.13	5	562.6214
17	2	2	5.4746	2	275.792	3	587.5761
18	2	2	10.0160	2	399.908	2	567.5891
19	2	2	20.3141	3	263.424	7	595.1211
20	2	2	37.9000	3	294.774	4	526.3182
21	2	2	100.1291	2	300.132	5	571.1918
22	3	3	156.8274	3	283.945	5	584.6315
23	3	3	240.7427	3	317.391	3	596.0675
24	3	3	154.0611	3	263.847	5	569.8120
25	2	2	184.5973	4	309.003	7	575.3651
26	3	3	95.2833	3	392.563	6	589.7658
27	3	3	252.2615	5	437.819	7	573.7819
28	2	2	39.7108	4	286.663	8	612.3684
29	3	3	260.5336	4	333.686	5	669.3952
30	3	3	172.5507	3	341.815	6	680.4279
31	3	3	246.4853	4	314.687	5	603.3915
32	3	3	231.4966	4	321.332	8	588.7955
33	3	3	81.527	4	319.302	5	640.7141
34	4	3	97.8101	4	278.915	10	609.56837

**Table 2. Sequence Details obtained using PSA**

Length of sequence (N)	Peak Side Lobe	Sequence Details
6	2	-1 1 1 1 1 -1
8	2	-1 1 1 -1 1 -1 -1 -1
9	2	-1 1 -1 -1 -1 -1 1 1 -1
10	2	-1 1 1 -1 1 1 1 -1 -1 -1
12	2	-1 1 1 -1 -1 -1 -1 -1 1 -1 1 -1
13	1	-1 1 -1 1 -1 -1 1 1 -1 -1 -1 -1 -1
14	2	-1 1 -1 1 1 1 1 1 1 -1 -1 1 1 -1
15	2	-1 1 1 1 -1 -1 -1 -1 -1 -1 1 -1 -1 1 -1
16	2	-1 1 1 1 -1 -1 -1 -1 -1 -1 1 -1 -1 1 -1 1
17	2	-1 -1 -1 1 1 1 1 1 1 -1 1 -1 1 1 -1 -1 1
18	2	-1 1 -1 1 1 -1 1 -1 -1 -1 -1 -1 1 1 -1 -1 1 1
19	2	-1 1 -1 1 1 -1 1 1 -1 1 1 1 -1 1 1 1 -1 -1 -1
20	2	-1 1 1 -1 1 -1 1 -1 1 1 -1 -1 1 1 1 1 1 1 1 -1
21	2	-1 1 -1 1 -1 1 1 1 1 -1 1 1 1 1 -1 -1 1 -1 -1 1 1
22	3	-1 -1 1 -1 1 -1 1 -1 -1 -1 -1 -1 -1 1 1 -1 -1 1 1 1 1 -1
23	3	-1 -1 1 1 -1 1 -1 -1 -1 1 -1 1 -1 -1 -1 -1 1 -1 -1 1 1 -1
24	3	-1 1 1 -1 -1 -1 1 1 -1 1 -1 -1 1 1 1 1 1 -1 1 -1 -1 -1 1 -1
25	2	-1 -1 1 1 1 -1 -1 -1 -1 -1 -1 -1 1 -1 1 -1 1 1 -1 1 1 -1 -1 1 -1
26	3	-1 1 1 1 1 -1 -1 -1 1 1 -1 1 1 -1 1 1 -1 1 -1 1 -1 -1 -1 1 -1 -1
27	3	-1 -1 -1 -1 1 -1 -1 -1 1 1 1 1 1 -1 -1 1 -1 -1 1 1 -1 1 -1 -1 1 1
28	2	-1 -1 -1 1 1 -1 -1 -1 1 1 1 1 1 1 -1 1 -1 1 -1 1 1 -1 1 1 -1
29	3	-1 1 -1 -1 1 -1 1 1 1 1 1 1 -1 1 -1 1 1 1 -1 1 -1 -1 1 1 -1 1 1
30	3	-1 1 1 -1 1 1 -1 -1 1 -1 1 -1 1 -1 -1 -1 -1 -1 1 1 1 -1 -1 1 1 1 -1 -1
31	3	-1 -1 -1 1 1 1 1 1 1 -1 1 1 1 1 -1 1 -1 1 1 -1 1 1 -1 -1 1 1 -1 -1
32	3	-1 1 1 -1 -1 -1 1 -1 1 -1 -1 1 -1 -1 -1 1 -1 -1 1 -1 -1 -1 1 1 1 1 1 -1
33	3	-1 1 -1 1 1 1 1 1 -1 1 -1 -1 1 1 1 -1 1 1 1 -1 1 1 -1 1 1 1 -1 1 1

**V. CONCLUSION:**

The objective is to mainly demonstrate the potential of the Progressive Search Algorithm in the optimization of binary sequences for radar applications. The main focus of the work is to minimize the sidelobes at the output of the matched filter. The optimized sequences can be widely used in pulse compression radars for improving the resolution and detection performance of radar systems. In this paper we have optimized the sequences up to length 33, and the results obtained by using PSA are in agreement with the

results presented in [14]. The major advantage of this algorithm is the low processing time and efficient in optimizing the binary sequences. The efficiency of the PSA is compared with Particle Swarm Optimization and Social Group Optimization algorithms. The results obtained are as per the requirement in very less time which are evident from Table1&Table2. Comparison of PSAwith PSO & SGO are shown in the figures 4 and 5.



# Design of Biphas Sequences using Psafor Radar Applications

Results were processed using Intel® core™i5-7200U CPU@2.50GHz-2.70 processor.

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## AUTHORS PROFILE



**E.V.Suryanarayana** completed his M.E Degree from Osmania University, Hyderabad, India. He worked in various Industries for 38 years in control Systems group and superannuated as Addnl. GM ( Engg. Services) in 2018 from Mishra Dhatau Nigam Limited, ( Ministry of Defense), Hyderabad. Presently he is pursuing his Ph.D in Acharya Nagarjuna University,

Guntur, India.

SGO2 70L 25000ITR 4000P C=0.5 3R PSL 10



**Dr. P.Siddaiah** obtained his M.Tech Degree from SV University Tirupati. He did his Ph.D from JNTU Hyderabad. He is chief of Investigator for several outstanding Projects sponsored by Defense Organizations, AICTE,UGC& ISRO. He is currently working as Professor & Principal College of Engineering, Acharya Nagarjuna University, Guntur, India. Several Research Scholars completed their Ph.d under his guidance. He published several papers in National & International Journals & Conferences. He is a life member of FIETE,IE &MISTE.