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Optimization of Long Biphase Sequences using Progressive Search Algorithm for Radar Communications

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ABSTRACT: Modern high-resolution radar systems are using pulse compression technique. This Technique is used for achieving high range resolution corresponding to a short pulse-width and detection capability of high energy long pulse-width. This process produces the width of the compressed pulse equal to 1/B, where B is the bandwidth of the transmitted pulse. Therefore, to achieve wide bandwidth the transmitted pulse is modulated either in phase or frequency-modulation. Phase coding can be either bi-phase or poly phase. The ultimate goal of modulation is to increase the bandwidth of the transmitted pulse. Ease of implementation always attract the radar signal designers to investigate the larger length bi-phase codes having good autocorrelation property. The major challenge is to synthesize the long binary sequences. This paper proposes Progressive Search Algorithm (PSA) for the optimization of long bi-phase sequences that can be used in high resolution radar systems. Its optimization capability in optimization of binary sequences is also compared with popularly used Particle swarm optimization (PSO) algorithm.

Keywords: Pulse compression, Biphase codes, autocorrelation, matched filter.

I. INTRODUCTION

Sequences with good aperiodic autocorrelation are useful in communication engineering for channel estimation, radar, sonar and spread spectrum communication. The large lengths binary sequences have practical applications in modern pulse compression radar systems. By using pulse compression, range resolution of a short pulse and detection performance of long pulse is achieved simultaneously. Long duration transmitted pulse consists more energy which is required for improving detection capability and resolution in range is achieved by correlating reflected echo pulse with reference in matched filter which is generally used in radar receivers. To achieve wide bandwidth, transmitted pulse is modulated. In binary coding only two phases either 0° or 180° are employed and this makes implementation of binary or bi-phase codes simple [1]. To achieve high range resolution, the length of the sequences must be large because the compression ratio is proportional to the sequence length. Another requirement is to avoid the masking of small targets, sidelobes at the output of matched filter must be low. In this context, Barker codes exhibit best low sidelobe peaks and these are known only up to length of 13. So, the highest compression ratio that can be achieved through Barker codes is 13. For achieving high pulse compression ratio there is a demand for generation of long length codes exists. Demand to optimize the long length codes, having not only good pulse compression ratio but also low sidelobe levels at the output of the matched filter is increasing for accurate traceability of nearby targets in Radar communications. For achieving higher compression ratio that gives high range resolution, demands search of long binary sequences. The criteria for the design is low peak sidelobes (PSL) at the output of matched filter. Various techniques are discussed for achieving low PSL or low integrated sidelobes (ISL) in [2-6]. In this context, there are many ways to design the biphase sequences, but the widely used method is optimization technique. PSO [7-11] is used by many researchers for the optimization of radar sequences [12-14]. The PSO technique is quite promising to find the near optimum solution for smaller population size sets. The proposed progressive search algorithm is a recent development [8] and capable of optimizing longer length binary sequences with faster convergence property. Therefore, PSA is used here for obtaining long binary sequences up to length N = 1300. Its conversion efficiency and optimization capability compared to PSO is presented. Working of PSA Algorithm is explained in section-III. Section IV, presents the results and discussions of Optimized sequences. Conclusion of the paper is discussed in section – V.

II. PROPERTIES OF APERIODIC SEQUENCES

In communication engineering, applications of low PSL codes are channel estimation, radar, sonar and spread spectrum communication. Pulse compression radar is one application that employs low a periodic autocorrelation sidelobe peak sequences. Let us consider S be a sequence having length 'N', where S is represented as:

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

There aperiodic autocorrelation can be given as

$$R_k = \sum_{i=1}^{N-k} s_i^* \, s_{i+k} \; ; \quad \text{where } k = 0, 1, 2, \ldots\ldots (N-1) \quad (2)$$

The above Eqn. (2) is aperiodic autocorrelation which is output of the matched filter of sequences$_i$. in the process of optimization, the main focus is to minimize the peak sidelobes generally occurred in aperiodic autocorrelation. Low peak sidelobes are advantageous in the detection of weak target present near the strong target. Two major criteria in the process of design are low peak sidelobes and time elapsed for Optimization.

III. PROGRESSIVE SEARCH ALGORITHM (PSA)

Progressive search algorithm (PSA) is also a new heuristic search algorithm for obtaining the desired sequences of the required length suitable for radar communications. This Algorithm is based on Random search and the process is carried out progressively to obtain better sequence after each iteration. PSA algorithm consists of the following three process:

– Random Sequence generation

– Performance of the sequence generated.

– Sequence selection meeting the criteria.

In Random Code Generation, binary sequence of required length(say M) is generated, using Matlab. A random binary number generator is used for generation, of sequence consisting of 0 and 1 bits in the sequence. After generation of required sequence, all 0 bits are replaced with -1 bits. So sequence will consists of 1 and -1 bits. Possible sequences will be very large 2^{N-1} during random sequence generation, The algorithm has to stop as per termination criterion of PSA. To stop the algorithm either of the following two criteria have been considered.

– The number of iterations.

– Processing time elapsed.

The Sequence of PSA optimization Algorithm is shown in the Fig. 1. It shows step-by-step progression of algorithm. It is observed that this algorithm optimizes even very long binary sequences in very less time.

Following are the steps in PSA.

(i). Set the desired length of the code (M).

(ii) Initialization of binary bits (0, 1) of length M.

(iii) In the Code generated replacement of all 0 bits with (-1) bits.

(iv) Finding out the Autocorrelation of code consisting of (+1) and (-1) bits.

(v) Evaluation of Peak side lobe value.

(vi) If Peak side lobe value obtained is as per desired value, then STOP Iterations.

Else

Go to Step (ii)

END.

Flow chart of PSA is as shown below in Fig. 1.

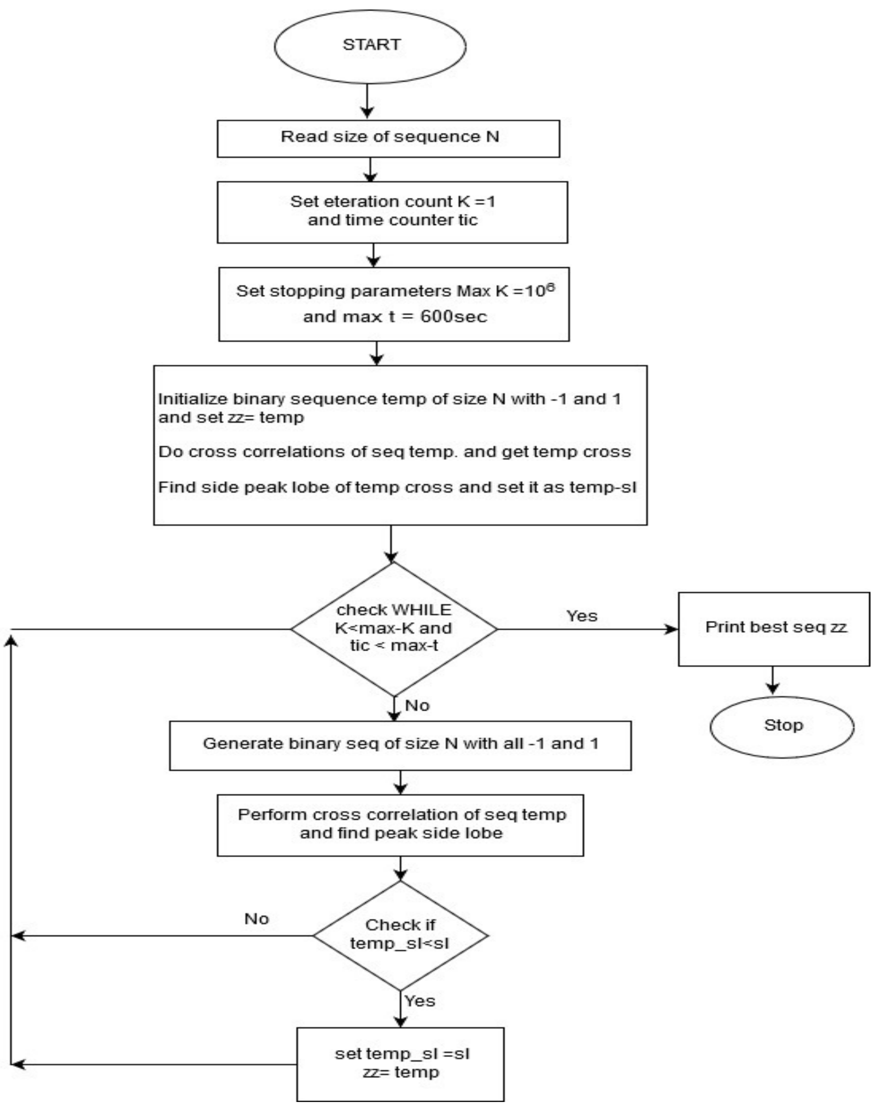

Fig. 1. Flow Chart of Progressive Search Algorithm: (PSA).

IV. RESULTS AND DISCUSSIONS

As discussed earlier, the best-known binary codes are Barker codes. The maximum compression ratio that can be achieved through Barker codes is 13, which is not sufficient for many applications. To achieve high compression ratio so that the high range resolution can be achieved, there is a demand to investigate long binary sequences with good autocorrelation property. This paper uses PSA to optimize long binary sequences up to length 1300. From Figs. 2-7 shows that the optimized sequences have good autocorrelation property. Long length biphase sequences are optimized by using PSA optimization Algorithm and Particle Swarm Optimization (PSO) algorithm, which can be used for radar applications. Results obtained using PSA and PSO Algorithms are compared. It is proved that Progressive Search Algorithm is very efficient compared to the PSO for pulse compression of Radar signals. Time for optimization and discrimination factor obtained for various codes using PSA in comparison with PSO are shown at Table 1.

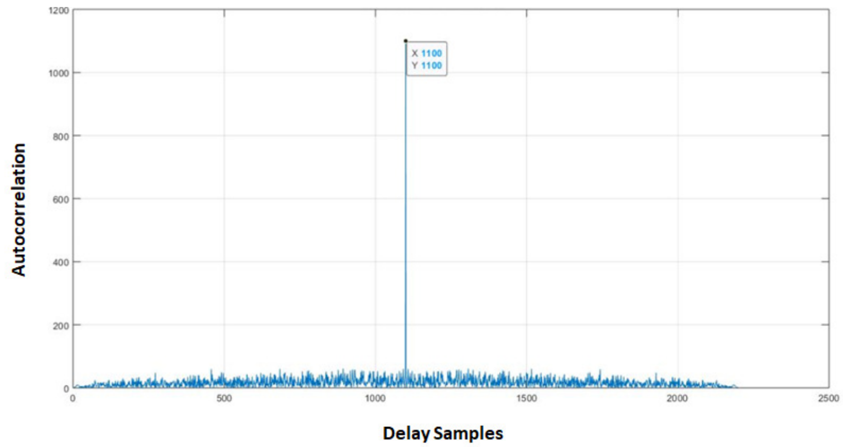

Fig. 2. Matched filter response for Sequence length N= 1100 using PSA.

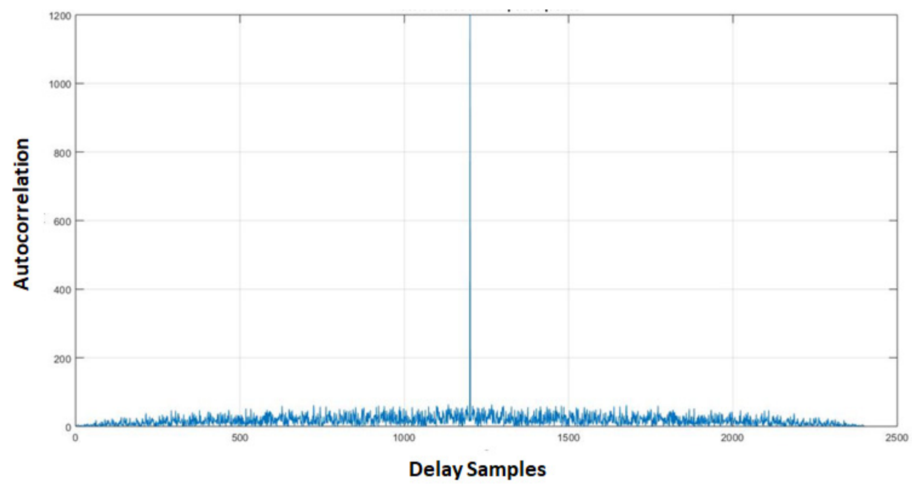

Fig. 3. Matched filter response for Sequence length N= 1200 using PSA.

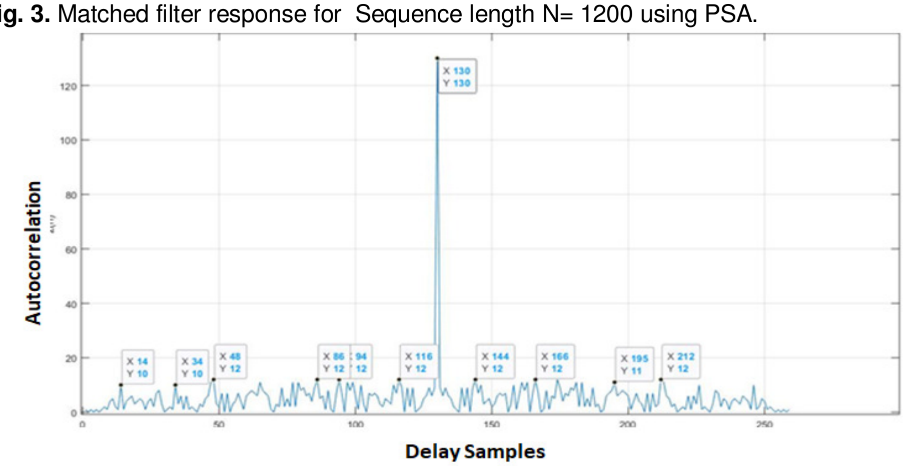

Fig. 4. Matched filter response for Sequence length N= 1300 using PSA.

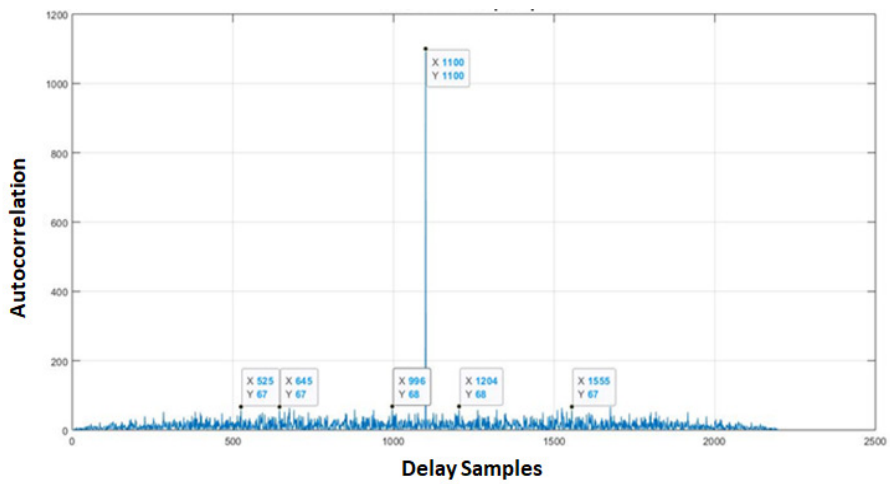

Fig. 5. Matched filter response for Sequence length N= 1100 using PSO.

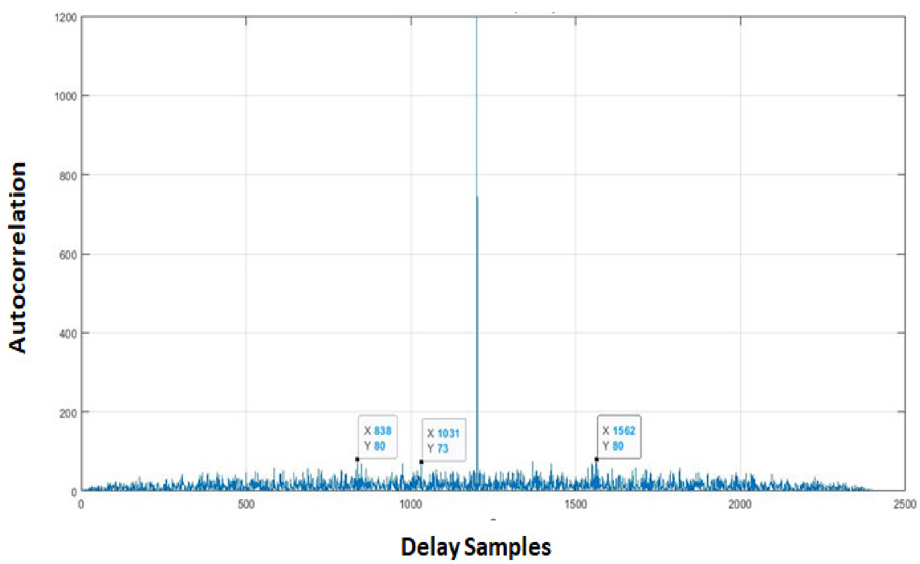

Fig. 6. Matched filter response for Sequence length N = 1200 using PSO.

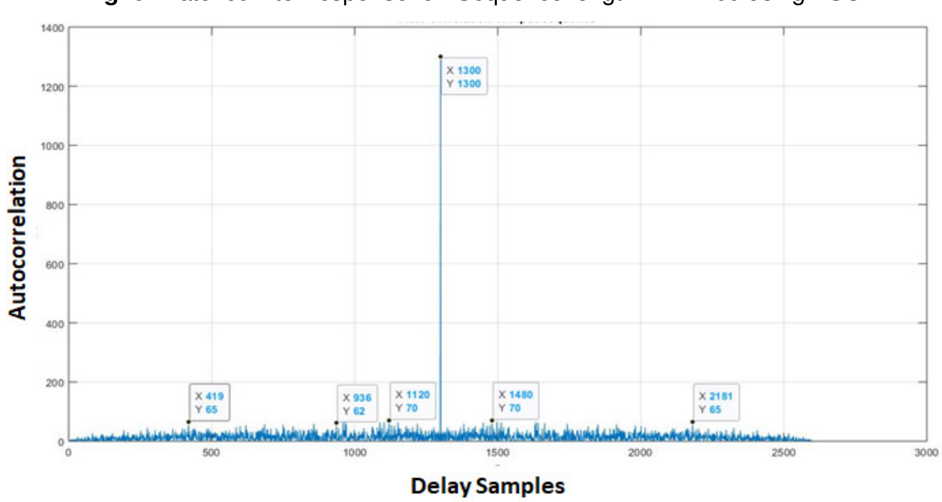

Fig. 7. Matched filter response for Sequence length N= 1300 using PSO.

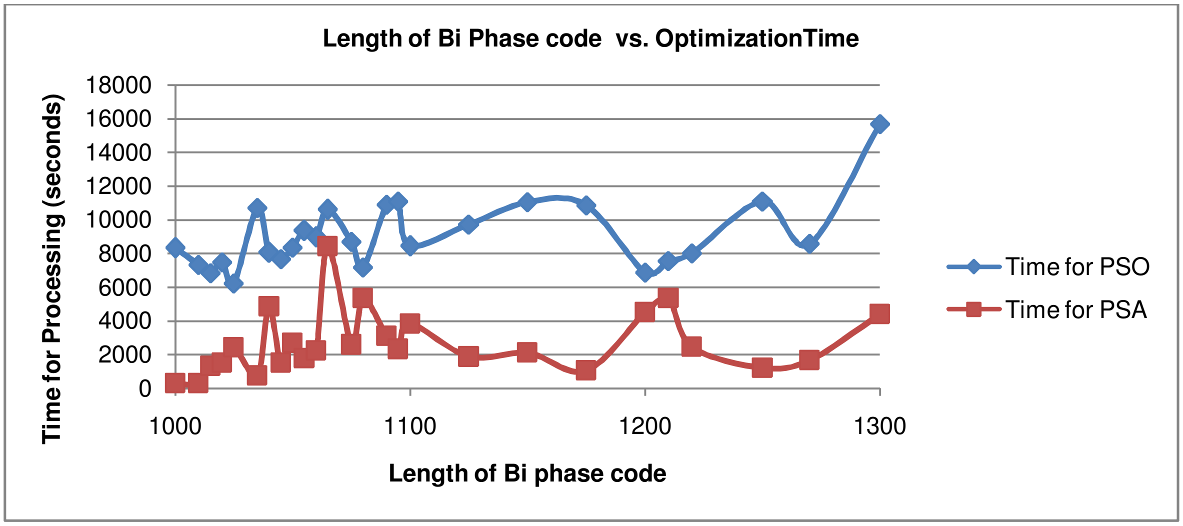

Fig. 8. Length of Bi Phase code vs. Optimization Time.

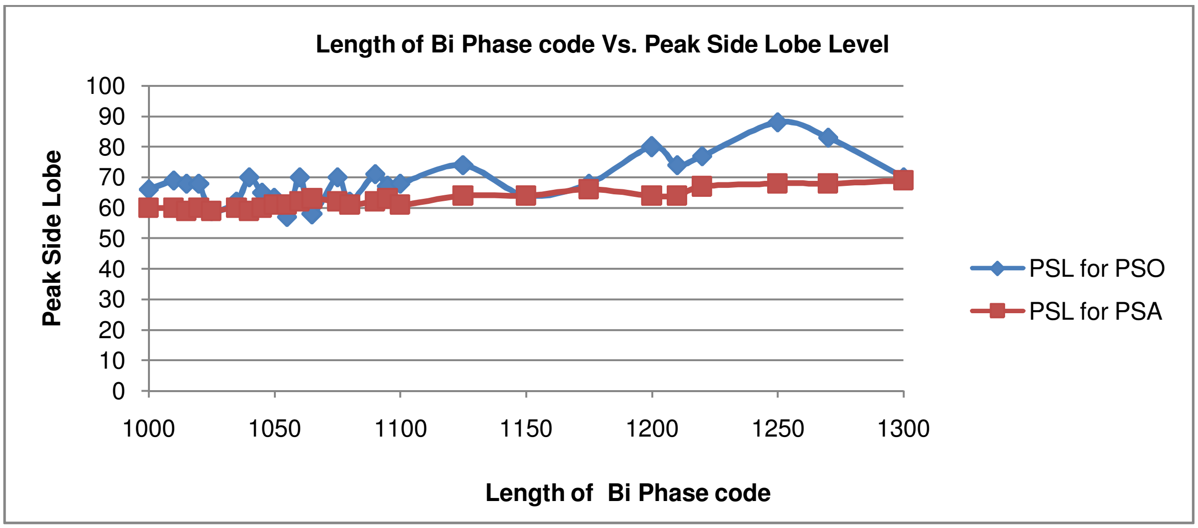

Fig. 9. Length of Bi phase code vs. Peak Side Lobe Level.

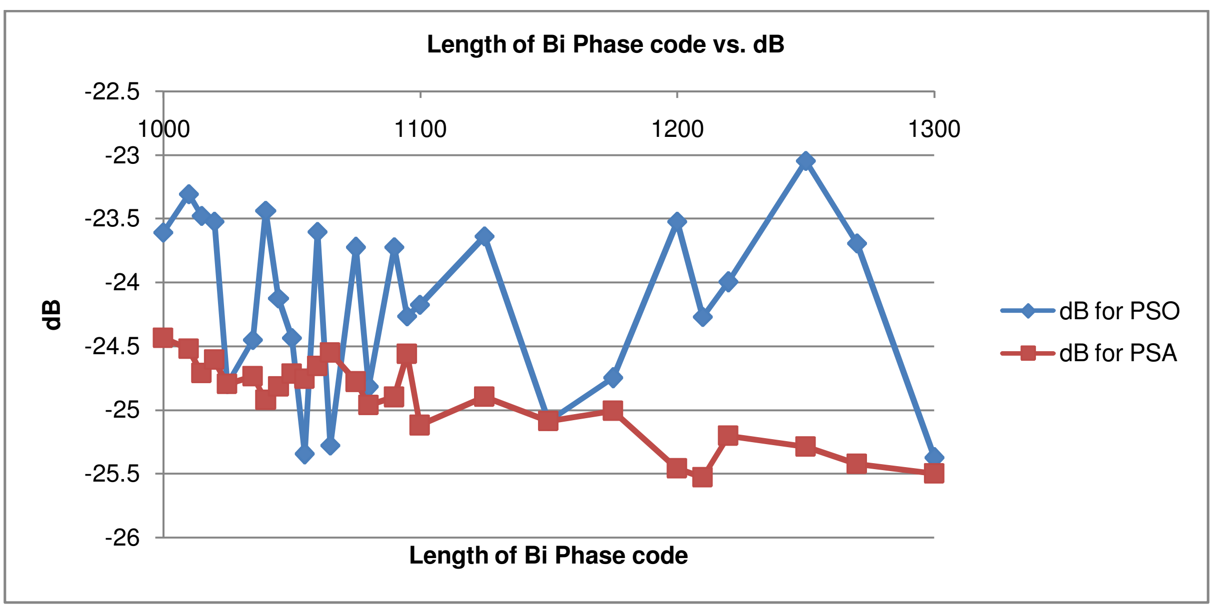

Fig. 10. Length of Bi phase code vs. dB.

Table 1: PSO algorithm MPSL values in comparison with PSA Algorithm MPSL values.

Length	PSL PSO	dB	Optimization Time (Seconds)	PSA PSL	dB	Optimization Time for PSA (seconds)
1000	66	-23.6091	8344.07	60	-24.4369	309.2635
1010	69	-23.3094	7347.46	60	-24.5234	321.9821
1015	68	-23.4791	6835.18	59	-24.7122	1346.9
1020	68	-23.5218	7491.95	60	-24.6089	1531.2
1025	59	-24.7974	6240.40	59	-24.7974	2451.1
1030	63	-24.2699	6545.35	61	-24.5501	2949.1
1035	62	-24.4509	13529.28	60	-24.7357	776.7610
1040	70	-23.4387	8077.822	59	-24.9236	4856.5
1045	65	-24.1240	7687.65	60	-24.8193	1536.7
1050	63	-24.4369	8366.8949	61	-24.7171	2721.6
1055	57	-25.3475	9369.250	61	-24.7584	1783.6
1065	58	-25.2784	10620.74	62	-24.6991	940.126
1060	70	-23.6041	8990.64	62	-24.6582	2257.7
1065	71	-23.5218	10032.01	63	-24.5520	8439.66
1070	72	-23.4410	11046.94	60	-25.0246	2127.8
1075	70	-23.7262	8716.287	62	-24.7803	2614.1
1080	62	-24.8206	7185.08	61	-24.9618	5349.8
1085	68	-24.0584	8268.50	61	-25.0019	3538.8
1090	71	-23.7233	10917.06	62	-24.9006	3126.6
1095	67	-24.2667	11093.35	62	-24.9404	7448.6
1100	68	-24.1776	8455.89	63	-24.5601	2347.8
1125	74	-23.6384	9742.10	64	-24.8994	1890
1150	64	-25.0903	11070	64	-25.0903	3161
1175	68	-24.7505	10872.87	66	-25.0098	1074.9
1200	80	-23.52182	6888.1	64	-25.4600	4535.9
1210	74	-24.2710	7567.01	64	-25.5321	5349.8
1220	77	-23.9973	8028.76	67	-25.2057	2476.6
1230	75	-24.2968	11257.72	67	-25.2766	1590.8
1240	70	-24.9664	11214.44	67	-25.3469	6487.3
1250	88	-23.0485	11109.03	68	-25.2880	1224.7
1270	83	-23.6945	8575.96	68	-25.4258	1682
1290	72	-25.0651	12492.37	70	-25.3098	9102.9
1300	70	-25.3769	15698.55	69	-25.5018	4412.1

Bi Phase sequence using PSO algorithm

Sequence length	Bi Phase sequence (Hexadecimal code)	Peak side Lobe
1100	50B5349404059B1CB4E6F1AEBEA68ECD38F35E18F2B22228727F800CEB69B4A3CFF9 3771164722FEEBE6D62E2AE936141B9D685B8D81A0043B045F82DEC716676AB62EFC BE28C3246616AC503DF56B8EF4FA7DFED1187C63BBCE729CDA95BF98062E7B41364B 33F730191B16563484EE259F0B80A50436FE597AA1B55EAF657D8A15EFCAB7C77062C	68
1200	D582F540F11BDA55AAFEF84A771BBF59082CACB9D9EE1648DD11D85AC7F6C0D4D49 4CE683B5D5DBBADBDCEF5F2F6B92D6A3A9F9B57DD06955ECF0C3D58A6400A025367 D67839E29FA25419AB48BCD93A1791E22CC98C98CA9003DBFD9A9C745E32437C069C 5E0D3F848F17F6B8FE1B1E087651F3B041333BE6835C1DE6F16FF170ED0E690D963D8 9FB2920D7EC4C66C1A85BD5083599	80
1300	3C35DB9B349EF718A2B33BD02B5A0FB064A53FE6FAA5B885E564ACC8C356417481B6 C2FC6D6C165C202A6624137AD1576240E0D91ED7A26DB0DC56A5A1E3B5593D6E5541 7DB066BB532307ABE3E5ECCA03CEAEF53F69DBF1DA6FA0F11BF71014296D5600FAF 98E71C08EF9F3FBA6197D7CE9823D5DAC39D657730EFDD1EEB01C1C9A7B1990CEDF 9B3EEC600843C1595F3AAB3F671917D8D83E7AEFEC490DB08150B97	70

Bi phase sequence using PSA algorithm.

Sequence length	Bi Phase sequence (Hexadecimal code)	Peak side Lobe
1100	00000ECE3EC1F12FC1D6F18DC2654650D3A678CCB19D95BCFD3A6A56B0F1120BF042A2EF81D8E 449DD9CA7C613FEDFAB712072096D60B24B2280B1B441542E379F9B69970B7823E96D7775675B42 D9F98E18AC7A1BFC41713A803F975F7B503D7F2D14B7A7D5C46E952572EEDC55BC9B91C0FB63C 3E565ECD55843E22FA6A7B60818638EC2ECEC19FEB	63
1200	0000011C92EF4C6090B01FCA759BA9B2F95B45A572B60E0510B4894CA5C21BF9DAEEAD3FC0747 D03E45732B2EB2E38C7352C0F19346A822667C4A93CB7F6486E2B0C70D848CDFFE54FFC512F99A 73F3A053E2C34096FAF1B20AFB56AD59B1766365C2F479D13372256A0181908D9FF4B82B2B4A0B5 C8E4F8AB87ABA2300F9588A2CB59666EAFB43751A1C0E8C8F26B989E28AF656877	64
1300	0000002C49F6C04E01ADB7D6F885F2B31A7A96CD85C2E59A6B0F18B5F6CAACC85B4407402367D7 70E664BA6A1BC6ACFBA999FC55DE984A70878865FE2549D009EA2448CCA3053352AB338C98E566 6CC59906956A5CB9B726F0B6C97E151E72340412D3F460396D69847915E6A2F576BC33474EC78C8 AAEB6899136664D13FB5F06797C15E1725F4E8BF77ADE90EDA44554AFB32B29BF7C6D794C7C106 42D3A693AE798	69

V. CONCLUSION

The main focus of the work is to prove that the advantages of Progressive Search Algorithm in optimization of long Biphase codes for Radar communications. It is aimed to reduce the sidelobe levels to the lowest possible at the output of matched filter. The Bi phase codes obtained can be used for Radar applications, which will improve the resolution between nearby targets and thereby improve the detection capability of Radar. In this work long bi-phase codes up to 1300 are optimized. Results shows that Progressive Search Algorithm is superior than the codes obtained by Particle Swarm Optimization method. The major advantage of this algorithm is lower optimization time and less side lobe levels. Results of Progressive Search algorithm and Particle Swarm Optimization are compared which is evident from Fig. 7-10. Results were processed using Intel® core™ i5-7200U CPU@2.50GHz-2.70processor.

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