Optimization of Biphase Codes for Pulse Compression Radars

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Abstract: Radar designers utilize long pulse with a specific goal to acquire high energy for detection of the targets at long ranges and resolution of short Pulse by modulation of the long Pulse is known as Pulse compression. Through frequency or phase coding of the large bandwidth of signal can be achieved. In this technique, the performance of radar for a given application demands good autocorrelation property – to maintain low sidelobe levels at the matched filter output. One of the essential kinds of coding is the biphase code. Because these codes are easy to implement. The condition for the goodness of the transmitted codes depends upon the peak sidelobe level at the output of the matched filter. In this project, we tend to describe the optimization of biphase codes of larger length so that a high compression ratio can be achieved. Though the barker codes are the well-known biphase codes these are available only for lengths upto13. It means with the help of barker code one can achieve the compression ratio only up to 13. Therefore, there is a need of searching higher length codes. In this work particle swarm optimization algorithm is used for the optimization of biphase codes up to 105. The results obtained are encouraging. For the code lengths, 60 to 64 the PSL = 4 and as length increases the results acquired are better. Further, the sidelobes are suppressed by designing a mismatched filter. It is shown that the sidelobes are appreciably at the cost of some signal-to-noise ratio.

Keywords: Particle Swarm Optimization (PSO) Algorithm, Biphase Codes, Autocorrelation.

1. INTRODUCTION

Sequences with peaky autocorrelation are widely used for RADAR applications. Achieving such sequences is a combination of non-comparable issues. So designing a signal having the above properties is a challenging problem. Many algorithms which are known as global optimization algorithms such as simulated annealing, tunneling algorithm, genetic algorithm, and particle swarm optimization algorithm, etc., only PSO was described in the literature. This project mainly focused on the designing of an optimum set of Biphase codes, which are optimized by using the Particle Swarm Optimization Algorithm.

Binary sequences having good autocorrelation that is low sidelobe levels are very useful in various applications such as in radar,[1] communication systems, and theoretical physics, etc.

The basic aim of using such sequences in radar systems is to achieve high range resolution. In fact, the resolution is stated as the ability of the radar to distinct two nearly spaced targets. When radar transmits such sequences, on receive, the output of the matched filter gives the compressed output that decides the resolution of the radar. The cost that we have to pay is sidelobes at the output of the matched filter. These sidelobes may mask the detection of weak target-present near the strong target. Therefore, the arrangement of the sequences is to be chosen in such a way that the peak sidelobes levels at the output of the matched filter must be minimum. Sets of codes that achieve the minimum peak sidelobes are of immense importance in radar applications. This project is an attempt to optimize the sequences having good autocorrelation properties using an optimization technique.

2. LITERATURE SURVEY

Biphase codes of lengthier series having low PSL and high Merit Factor (MF) are vital study area in the field of radar signal processing. The effectiveness of code design using PSO converges to autocorrelation shows the importance of the project. To attain decent range resolution we include PSO optimization that gives a decent autocorrelation of biphase codes in pulse compression radars.

Electronic counter measure (ECM) is the main threat in modern days. Anti-radiation missiles (ARM) are mostly endangering most of the military radars. Therefore, the Biphase coded signal having code agility can accomplish a low probability of intercept (LPI).

3. METHODOLOGY

In this project optimizes biphase code for pulse compression radar having low peak sidelobes (PSL). The toughness of the genetic algorithm degrades when code length increases. So, it is an attempt, to adopt the PSO algorithm for the generation of sequences of higher lengths. The PSO algorithm is founded based on biologically inspired and driven by social comparison. However, it is related to the Evolutionary Computation (EC) techniques, still, there are major modifications with genetic algorithms.

The PSO algorithm gives potential solutions to develop an approach to discovering an appropriate solution for a given problem. Being an optimization technique, the objective is to discover the global optimum solution of a real-valued function described in an above search space. In 1995 James Kennedy [9] and Russel Ebhart introduced the concept of Particle Swarm Optimization (PSO). However, it is inspired by the observed behavior of creatures in their natural habitations such as bird clustering or fish schooling. It means ultimately its origin is nature itself. The origins in natural processes, which lead the swarms, categorize the algorithm as Swarm Cleverness and Artificial Life.

PSO Algorithm

Generally, the function that is needed to be minimized is f: $R^n \rightarrow R$. To this, function a candidate solution that is in terms of the vector is given as the input argument and the produced real number is taken as the output that indicates the candidate solution's objective function value [4]. The $\nabla.f$ is unknown. The intention is to determine a solution such that f (**a**) $\leq f$ (**b**) for all **b** in the search space, which is **a** denoted by global minimum. By considering $\boldsymbol{h} = -\boldsymbol{f}$ a maximum value can attain.

Here S denotes the number of particles in the swarm, which held the position $\mathbf{x}_i \in \mathbb{R}^n$ in the search space and velocity $\mathbf{v}_i \in \mathbb{R}^n$. If $\mathbf{p}_i$ is considered a well-recognized position of particle $\boldsymbol{i}$ and **g** be the better-recognized position of the entire swarm.

The algorithm is given by:

Each particle ***i*** =1,2,3…, S does:

By initialization of particle's position with the evenly distributed random vector is given by $\mathbf{x}_i \sim U(\mathbf{b}_{lo}, \mathbf{b}_{up})$, $\mathbf{b}_{lo}$, and $\mathbf{b}_{up}$ are the lower and upper limits of the search space.

Particle's good recognized position is initialized [5] by its primary position: $\mathbf{p}_i \leftarrow \mathbf{x}_i$

Swarm's good recognized position is updated if $(f(\mathbf{p}_i) < f(\mathbf{g}))$:$\mathbf{g} \leftarrow \mathbf{x}_i$

Particle's velocity is primed: $\mathbf{v}_i \sim U(-|\mathbf{b}_{up}-\mathbf{b}_{lo}|, |\mathbf{b}_{up}-\mathbf{b}_{lo}|)$

Till the termination condition is met (e.g. execute s number of iterations otherwise the solution with satisfactory above function value is established), recurrence:

1. Every particle i = 1,2,3 ..., S do:
2. Each dimension d = 1,2,3 ..., n do:
3. Random numbers are picked: r_p, $r_g \sim U(0,1)$
4. Particle's velocity to be updated: $\mathbf{v}_{i,d} \leftarrow \omega\, \mathbf{v}_{i,d} + \varphi_p r_p\, (\mathbf{p}_{i,d}-\mathbf{x}_{i,d}) + \varphi_g r_g\, (\mathbf{g}_d-\mathbf{x}_{i,d})$
5. Particle's position is to be updated: $\mathbf{x}_i \leftarrow \mathbf{x}_i + \mathbf{v}_i$

If $(f(\mathbf{x}_i) < f(\mathbf{p}_i))$ do:

Particle's good recognized position is updated: $\mathbf{p}_i \leftarrow \mathbf{x}_i$

If $(f(\mathbf{p}_i) < f(\mathbf{g}))$ swarm's good recognized position is updated: $\mathbf{g} \leftarrow \mathbf{p}_i$

6. The best solution found in **g**.

The practitioner controls the behavior and efficiency of the PSO method selecting the factorsω, φ_p, and φ_g.

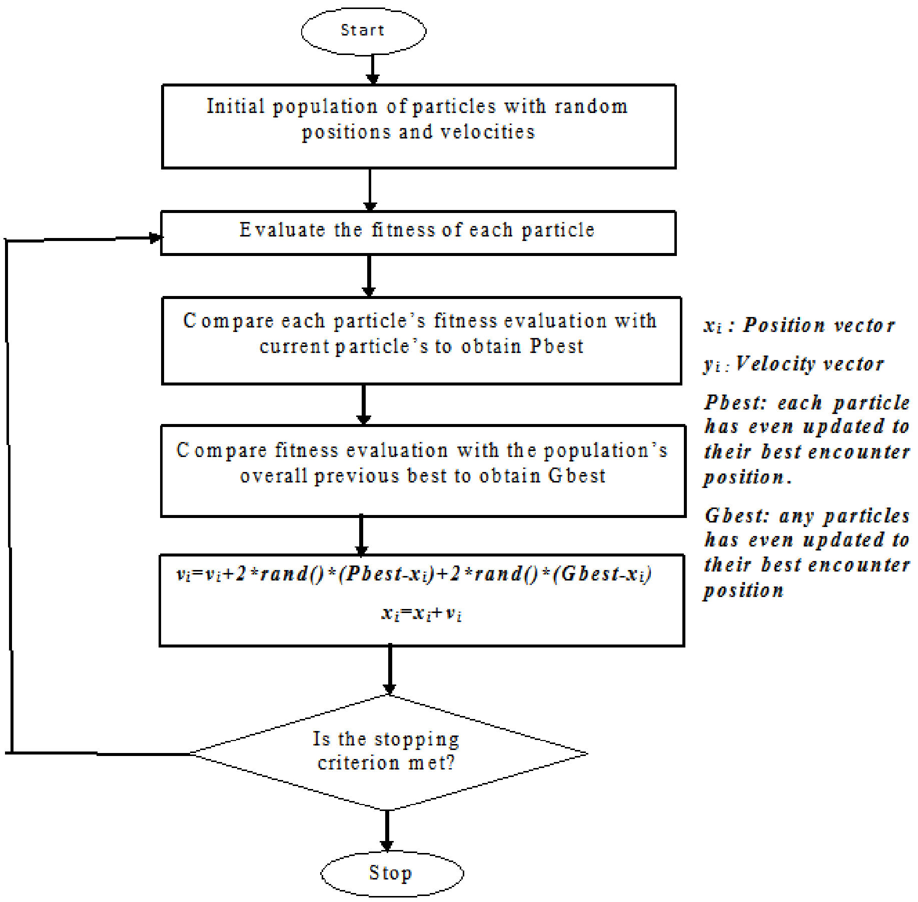

Figure 1: Working of PSO Algorithm

Nested Barker Codes

For radar application, a lengthier sequence is preferred in order to attain a high pulse compression ratio. The longer code is obtained by combining two barker codes by Kronecker product [2]. It can also be called a compound barker code. For example a 35-bit compound biphase code is obtained by nesting 5-bit with 7-bit codes and the obtained 35 bit code is [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 1 1 -1 -1 1 -1]. The peak sidelobes are not relatively diminished inspite of the greater compression ratio.

The only bi-phase code, which is having littlest sidelobe, is Barker code. The only odd length code 13 is the longest one which is a big disadvantage. The 13 length Barker code that attains mainlobe to sidelobe ratio of 22.8 dB that is smaller than 30dB practical value. In order to improve the ratio mismatched filter is proposed. The Nested code has a high PSR compared to barker codes. A nested binary code acquired by utilizing Kronecker product and its matched filter response are better. In the event that an N-bit Barker code is meant by BN, and another BM, then an MN bit code can be developed as BN⊗BM. The Kronecker item is basically the BM code rehashed N times, with every redundancy increased by the relating component of the BN code. For instance, a 65-bit code can be built as the item B13⊗B5. These codes have a peak sidelobe more prominent than 1.

Auto Correlation Property of Biphase Codes

To obtain good autocorrelation property for the biphase codes is optimized with the PSO algorithm. As per the PSO strategy initially, the best position and global best are assigned and modifies the velocity equation. The particle's motion is according to the velocity and the best sequence is extracted finally. The following equation determines the equations under the PSO algorithm:

$$x_{i,d}(it+1) = x_{i,d}(it)+\upsilon_{i,d}(it+1) \quad (1)$$

$$\upsilon_{i,d}(it+1) = \upsilon_{i,d}(it) + C_1*Rnd(0,1) * [pb_{i,d}(it) - x_{i,d}(it)] +C_2* Rnd(0,1) * [(gb_{i,d}(it) - x_{i,d}(it)] \quad (2)$$

Caption:

i particle's index, used as a particle identifier;

d dimension being considered, each particle[6] has a position and a velocity for each dimension;

It iteration number, the algorithm is iterative;

$x_{i,d}$ position of particle i in dimension d;

$\upsilon_{i,d}$ position of particle i in dimension d;

C_1 acceleration constant for the cognitive component;

Rnd stochastic component of the algorithm, a random value between 0 and 1;

$pb_{i,d}$ the location in dimension d with the best fitness of all the visited locations in that dimension of the particle i;

C_2 acceleration constant for the social component;

The paper "The particle swarm optimization algorithm" suggests parameters. Ioan Cristian Trelea does convergence study and parameter choice. And the parameters chosen are C_1 = 1.494, C_2 = 1.494and random value chosen as 0.5.

When the velocity component utilized otherwise atleast multiplied with factor W though it cannot simply modify its velocity concerning the best solution but tends to discover new fangled regions of search space. It enables the discovery of new-fangled spaces according to time "spend counteracting" the former momentum when it first "counteracts" the gained momentum previously. By multiplying, the previous velocity to weight factor the above variation achieved. To acquire a better ratio of performance progress and the successful algorithm's in discovering the desired solution W value chosen between [0.9, 1.2].

Mismatched Filter

Further to reduce the sidelobes of the optimized sequences, a mismatched filter is designed in this section. The reduction or suppression of sidelobe is achieved by sacrificing some amount of signal-to-noise ratio (SNR). Let the biphase sequence is given by

$$A = \{a, a, a_3, \ldots\ldots, a_N\} \qquad (1)$$

The filter elements are

$$H = \{h_1, h_2, h_3 \ldots\ldots h_M\} \qquad (2)$$

Where the elements are real and the relationship is maintained as N $\leq$ M. In addition to this condition, another condition is that if N is odd then M must be odd, and if we consider N even, M also must be even. This specifies that (M- N) is always even, and (M-N)/2 = Z, which is an integer. We are defining that the Z is an all-zero sequence of length n. Now a zero-padded signal sequence can be created whose length is (M = N + 2n). The final sequence is given by

$$S = \{Z \;\; A \;\; Z\} \qquad (3)$$

The above equation gives an explanation for a simple mismatch filter. By using the windowing function even sidelobes can be further suppressed. This is clearly observed from the fig3 the sidelobe suppression increases as the length of '**S**' increases. Length of the sequence results H and **S** are equal and that is equal to M. It is also kept in mind the filter is designed in such a way that the cross-correlation peak appears at zero delay (τ = 0). The cross-correlated output is shown in fig.1 can observe that the sidelobes are suppressed at the cost of SNR loss. Mismatch loss for different filter M is given in Table 1.

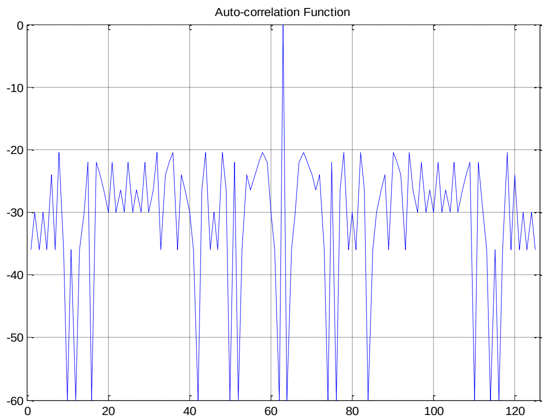

Figure 2 ACF of N=63, PSO (Matched Filter)

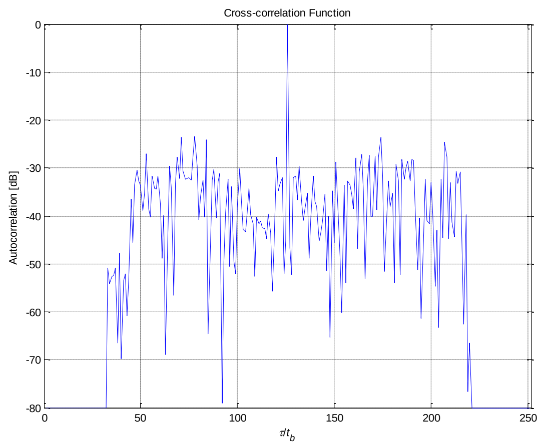

Figure 3 ACF of N=63, PSO (Mismatched Filter length M=126) mismatch loss=1.02db

Table 1: Results obtained for length 63,126,189,252

Filter Length (M)	63	126	189	252
SNR Loss (dB)	0	1.02	1.34	1.83
Sidelobe Suppression (dB)	-20	-24	-30	-35

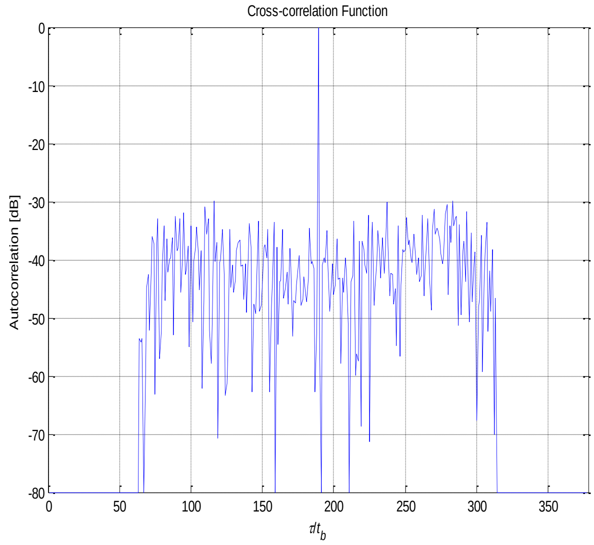

Figure 4 ACF of N=63, PSO (Mismatched Filter length M= 189) mismatch loss = 1.34db

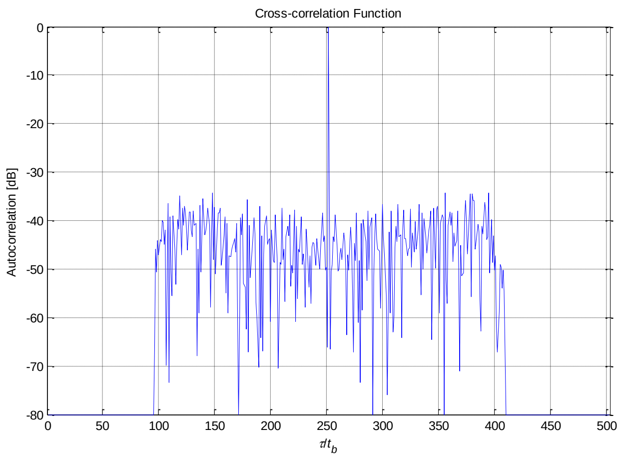

Figure 5 ACF of N=63, PSO (Mismatched Filter length M= 252) mismatch loss = 1.83db

4. RESULTS AND DISCUSSION

Computational difficulty in generating codes and its restriction on code length can be negated by using an optimization algorithm. In this project Particle swarm optimization algorithm [4] is used to generate codes with length up to 105. On observation, we can show how the sidelobe levels are reduced with the best correlation property.

The following project is related to the particle swarm optimization the following are the results observed for different lengths with its phases.

The results are noticed for various lengths such as n=61,62,63,64,65,66,66,67,------101,102,103,104,105.And its PSL value is also observed for certain lengths. For this matlab R2015a is utilized.

For sig-len=31

mainlobe=31

sidelobe=2.0000
df=15.5000
x =[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 -1 1]

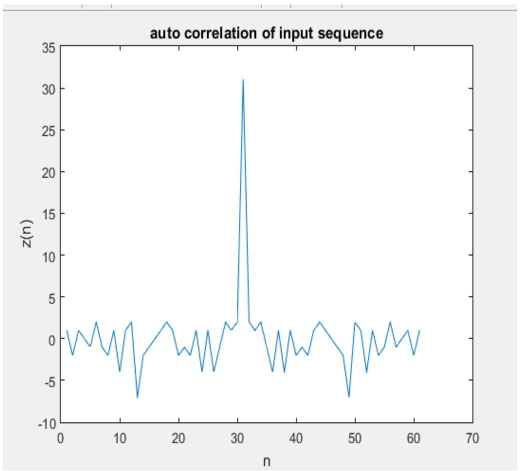

Figure 6 ACF of input length sequence 31

- sig-len=60

mainlobe=60
sidelobe=4.0000
df=15.0000
x =[-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 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 1 1]

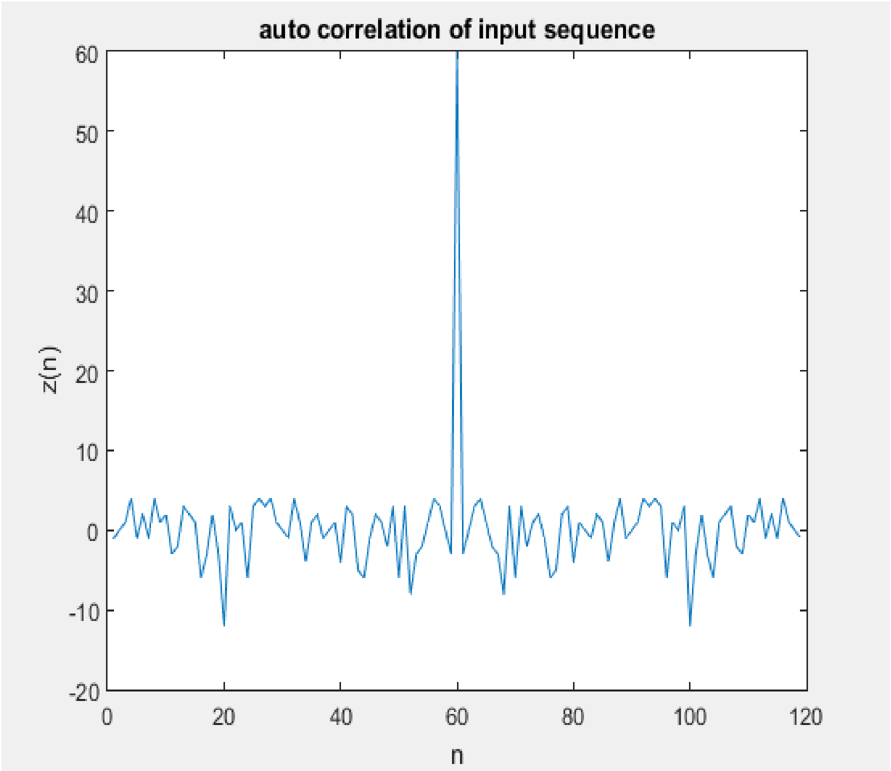

Figure 7 ACF of input length sequence60

The results for a length up to 105 are recorded and the sequence is a combination of 1 and -1 but it is rearranged as 1 and 0 respectively and sequence are represented in hexadecimal.

Table 2: Results obtained up to length 105

Length of sequence	**Sidelobe**	**PSL**	**ISL**	**Merit factor**	**Sequence**
61	5	-21.7271	-10.1921	10.4522	E653A2FE4907943
62	5	-21.8684	-10.6104	11.5090	11AE87BB2701699C
63	4	-23.9456	-11.5464	14.2770	6583F32E3BB48422
64	5	-22.1441	-10.8088	12.0471	42173660D574B7B8
65	4	-24.2170	-10.6952	11.7361	27E486B85858E6DA
66	5	-22.4114	-10.8038	12.0331	3112CB76BDB831DC1
67	5	-22.5420	-10.3515	10.8430	354D9F08F8AC25BEB
68	5	-22.6707	-10.2953	10.7037	9B02AE47ABCA19259
69	5	-22.7975	-10.1118	10.2608	C5C9F0B2D9FA439E8
70	5	-22.9225	-10.5271	11.2903	10B9A03D6791966EB5
71	5	-23.0457	-10.6503	11.6152	C29B63D5AA980FBB8
72	5	-23.1672	-10.0400	12.7059	9543D7C80A41B631C9
73	5	-23.2870	-10.7537	11.8951	10357397D3B606E9AD4
74	5	-23.4052	-11.2568	13.3561	A191D7F7A47B85DA6C
75	5	-23.5218	-10.8926	12.2817	4BC6A87CDBD022E309E
76	5	-23.6368	-10.9511	12.4483	11EB5E8B2270C0E414F
77	5	-23.7504	-11.1022	12.8891	193EE09BF0B02953DD4E
78	5	-23.8624	-10.9755	12.5185	3D233FA9B55E606116D7
79	5	-23.9731	-11.2687	13.3927	1F9970BCD12EEC25099E
80	6	-22.4987	-11.1776	13.1148	1E22CC21C906B7D9958E8
81	5	-	-	13.5558	4CAF34C443AFB94B82D0

		24.1903	11.3212		
82	5	-24.2968	-11.4820	14.0669	17274F41DE2CBBDC44825
83	6	-22.8185	-11.2383	13.2992	D3BD3FA09AAED13A321C
84	6	-22.9225	-11.2265	13.2632	11182BDC2C37EDD9D6585
85	6	-23.0253	-10.7493	11.8832	1E92A206D2AB778D277C72
86	6	-23.1269	-11.3180	13.5458	958110AFB84F363D91AA7
87	6	-23.2273	-10.8805	12.2476	11CCC4C951A7A4BFAC550F
88	5	-24.9102	-11.1372	12.9933	88D52B6FD618D17C407926
89	6	-23.4247	-11.5684	14.3496	1E6396E1F64E5D58009AD46
90	5	-25.1054	-11.4656	14.0138	2BCB1CB13FB25C0316C453F
91	6	-23.6178	-11.0785	12.8189	784F595DBB5307BE9822503
92	6	-23.7127	-11.4082	13.8301	557D4B9B4D6A746618606F
93	6	-23.8066	-11.0191	12.6447	1B97E2A24B064C7A866157D0
94	6	-23.8995	-10.9992	12.5869	1A973D38AE024EE594377496
95	6	-23.9914	-11.4521	13.9706	1E66A5CBDECE8A2487F40BB5
96	6	-24.0823	-11.0241	12.6593	E646CE11035D426BE47E52E5
97	6	-24.1724	-10.9045	12.3154	19848D81169E65BE763A8BEE4
98	6	-24.2614	-11.2875	13.4510	17242BDDF383533A17839E8A6
99	6	-24.3496	-11.6261	14.5415	7E1340620D4E1AB69AB9E8947
100	7	-23.0980	-11.3312	13.5870	F2405D453F4CEA7B6654A86C1
101	7	-23.1844	-10.9695	12.5012	124E73CCA2F66AD89028E0CF64
102	7	-23.2700	-11.8854	15.4362	A2E5DCBE6728028DEC0DAC1AF
103	7	-23.3547	-11.5294	14.2212	9A6B395AC5E8BB64484C7847
104	7	-23.4387	-11.0567	12.7547	4D0FA54AFFB90764E628E06BA4
105	7	-23.5218	-11.3069	13.5110	1E9D6C21A2A6F79B159F6393762

5. CONCLUSION

The effort of extracting the best frequency order is increasing with the increase in the length of code. In order to lessen the time we took an approach for optimized search instead of an exhaustive search. The decent autocorrelation property is achieved by a particle swarm optimization algorithm. The main objective of the project is to develop decent codes with better correlation properties. That is why we have chosen autocorrelation property. This can be prolonged to the confrontation between autocorrelation and cross-correlation. Further can be extended for a longer length and better results are achieved by using a mismatched filter. Many other optimization techniques such as GA, Stimulated Annealing can be used.

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