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Sidelobes Reduction Technique for Biphase Barker Codes

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Abstract: *In radar and sonar communications, Barker codes are extensively used for pulse compression. High range resolution radar requires high pulse compression ratio to detect and resolve the desired target in dense clutter environment. This paper proposes a radar signal design technique in which biphase Barker codes are modulated with Discrete Frequency Coding (DFC). The proposed technique improves pulse compression ratio and also reduces the pulse compression sidelobes. The Modified Genetic Algorithm (MGA) is used for optimizing discrete frequency coded Barker codes. DFC coded Barker signals exhibit good pulse compression ratio and minimum peak sidelobe level. Complex signal structure of DFC modulated signal is very difficult to analyze by enemy Electronic Support Measures (ESM).*

Keywords: *Autocorrelation, Barker codes, Discrete Frequency Code, High resolution, Modified Genetic Algorithm.*

I. INTRODUCTION

Pulse compression technique is used by radar designers to achieve detection of target at long range that depends upon long duration transmitted pulse and resolution in range corresponding to short pulse simultaneously. The central issue of radar signal design is to control the self-generated sidelobes at the matched filter output. The sequences with low autocorrelation sidelobes are very useful in radar, sonar, ultrasound imaging, spread spectrum communications, channel estimation etc. The sequences which generate well controlled peak sidelobes of ±1, are known as Barker codes. Two important parameters of radar signal design are autocorrelation peak sidelobe and pulse compression ratio [1-5]. In radar receiver, the matched filter output is cross correlation between the replica of transmitted signal and reflected signal from the target. If radar uses pseudo noise like signals or complex signals that improve anti-jamming capability of the radar system and it is difficult to jam or intercept by enemy ESM. Additionally, if radar is changing or varying the transmitted code pulse to pulse, it makes analysis of intercepted signal difficult and can not achieve matched processing [2, 4, 6].

In this paper, we deal with the minimization of peak sidelobe and increase the pulse compression ratio by using both phase and frequency coding simultaneously. The proposed sequences have higher pulse compression ratio that improves resolution capability. These sequences are achieved by using frequency coding on biphase Barker codes.

II. BINARY BARKER SEQUENCES

In order to synthesize a biphase Barker code S(n) of length N with good autocorrelation property is represented as shown below

$$S(n) = [s_1, s_2, s_3 \ldots\ldots s_N] \qquad \ldots\ldots (1)$$

For binary sequence, $s_n = \pm 1$, where n is defined as n = 1, 2, 3 ... N.

The sequences which generates small peak sidelobes of ± 1, are known as Barker Sequences

III. DISCRETE FREQUENCY CODED BARKER SEQUENCES

Discrete Frequency Coded signals have high pulse compression ratio. To design the DFC modulated signals, Barker sequences of length N is considered. Where the sequence consists N contiguous sub-pulses and time duration of each sub-pulse is 't_b'. Distinct frequency coding is used to modulate each sub-pulse. The coded waveform can be represented as:

$$X(t) = \sum_{n=1}^{N} s(t)\, e^{j2\pi f_n t} \qquad \ldots \quad (2)$$

Where f_n represents the distinct coded frequency of n^{th} sub-pulse. The coded frequencies $\{f_1, f_2, f_3, \ldots f_N\}$ of a DFC Barker sequence is a permutation of frequencies $\{0, \Delta f, 2\Delta f, \ldots (N-1)\Delta f\}$. where Δf is chosen to satisfy the condition that $\Delta f = 1/t_b$. For convenience, coded frequency sequence $\{n_1\Delta f, n_2\Delta f, n_3\Delta f, \ldots n_N\Delta f\}$ is generally represented as sequence of coefficients $\{n_1, n_2, n_3, \ldots n_N\}$, which is simply given as {0,1, 2, …, N-1} [7-9]. The final DFC Barker sequence can be represented by Eq. (3).

$$X(n) = [x_1, x_2, x_3 \ldots\ldots x_N] \qquad \ldots\ldots \quad (3)$$

Eq. (4) gives the autocorrelation function (ACF) of sequence X(n).

$$A(k) = \begin{cases} \sum_{n=0}^{N-k-1} x_n x^*_{n+k} \,; & 0 \le k \le N-1 \\ \sum_{n=0}^{N+k-1} x_n \, x^*_{n-k} \,; & -N+1 \le k \le 0 \end{cases} \quad \text{.... (4)}$$

If ACF of any binary sequence whose side lobes are bounded by the Eq. (5), such sequence is known as Barker sequence [6].

$$|A(k)| \le 1, \quad 1 \le |k| \le N-1 \qquad \ldots \quad (5)$$

To provide more practical solution for constructing DFC Barker sequences, which satisfy the autocorrelation properties in Eq. (5) is to find the optimum solution numerically. To get the optimum solution, the cost function given in Eq. (6) must be minimized. Optimization technique is used here to minimize the cost function.

$$E = \sum_{k=1}^{N-1} |A(k)|^2 \qquad \ldots.. \quad (6)$$

Eq. (6) gives the cost function that is autocorrelation sidelobe energy of the proposed signal. The minimization of cost function produces DFC Barker sequences with minimum peak sidelobes. The algorithm used here for minimizing cost function is Modified Genetic Algorithm.

IV. MODIFIED GENETIC ALGORITHM

Eexhaustive search is widely used method to design the signals with desired autocorrelation properties. [7-12]. Modified Genetic Algorithm, which combines the properties of Genetic Algorithm (GA) and Hamming Scan Algorithm (HSA), is used for designing DFC Barker sequences. MGA integrates the advantageous attributes of two algorithms that is GA algorithm's global minimum convergence property and Hamming scan algorithm's quick and effective convergence rate [3]. MGA is greatly enhancing GA's performance and also overcomes HSA's lack of robustness. MGA is employed in this work as computational algorithm for optimizing DFC Barker sequences. Parameters such as crossover, mutation and selection of the fittest are the main operators used in algorithm.

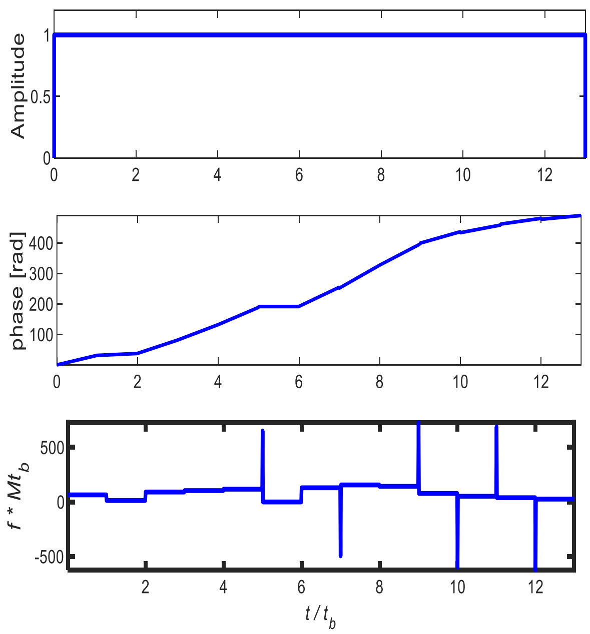
V. AMBIGUITY FUNCTION

Ambiguity function $|\chi(\tau,\nu)|$ is a two dimensional autocorrelation response of a matched filter in time and frequency. When transmitted signal is reflected back and received with delay in time 'τ' and shift in Doppler 'ν', the output to which the filer is matched is known as ambiguity function (AF). It is defined as [2]

$$|\chi(\tau, \upsilon)| = \int x(t) x^*(t+\tau) e^{j2\pi\upsilon t} dt \qquad \ldots \quad (7)$$

VI. RESULTS AND DISCUSSIONS

In this paper, optimization technique is used to synthesize optimum DFC Barker signals. Algorithm used for optimization is MGA. Optimized DFC Barker sequences can be used in radar to detect the target embedded in high dense clutter background. The optimization cost function depends on Eq. (6). Fig. 1 shows the signal structure of synthesized DFC Barker sequence of length N = 13. Fig.2 displays the comparison of autocorrelation function of Barker sequence and DFC Barker sequence of length 11. Fig. 2 shows that DFC Barker code not only have lower peak sidelobe but also have higher pulse compression ratio. Similarly, Fig. 3 represents the comparison of autocorrelation function of Barker sequence and DFC Barker sequence of length N = 13 and shows that DFC Barker code have lower sidelobes. Figs. 4 and 5 show the AF of Barker code and DFC Barker code respectively for the length of sequence N = 11. From these two figures, higher compression ratio and sidelobe suppression capability of DFC Barker sequence compared to Barker sequence can be ascertained. Similar analysis is shown in Figs. 6 and 7 for sequence lengths of N=13. The resolution capability of Barker sequence of length N=11 is shown in Figs. 8 and 9 using ambiguity functions. Figs. 10 and 11 are showing the ambiguity functions of DFC Barker code of length N=11. It is evident that two targets located in same distance can be clearly resolved when DFC Barker sequence is used (refer Fig. 10). It can be concluded that range resolution of DFC Barker code is much better than the Barker code alone. From the result analysis it can be shown that DFC coded binary Barker signals has better correlation property and compression ratio than Barker codes. High speed DSP processors and FPGA are available in the market that makes processing and synthesizing of DFC Barker codes easy. The proposed codes are most appropriate for pulse compression radars, LPI radar waveform agility and netted-radar systems.



Fig(1) DFC Barker signal structure

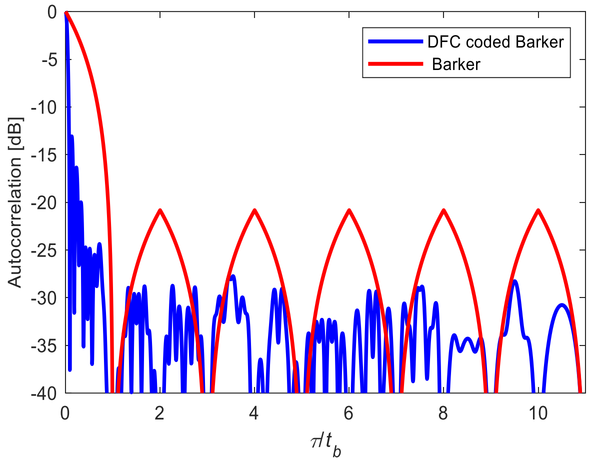


Fig. 2. Comparison of ACF of Barker code and DFC Barker code of length, N=11.

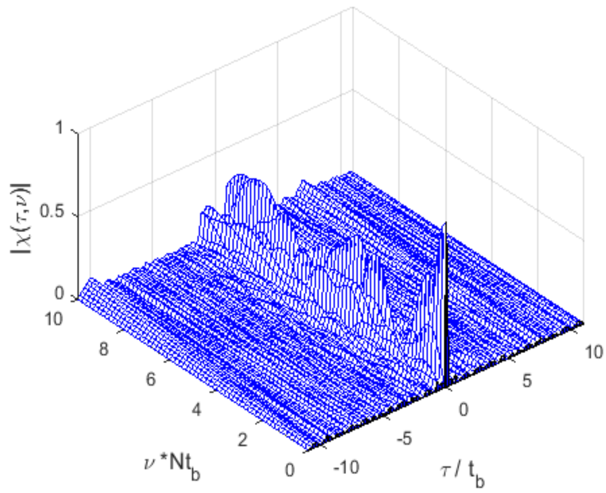


Fig. 5. AF of DFC Barker sequence of length, N=11.

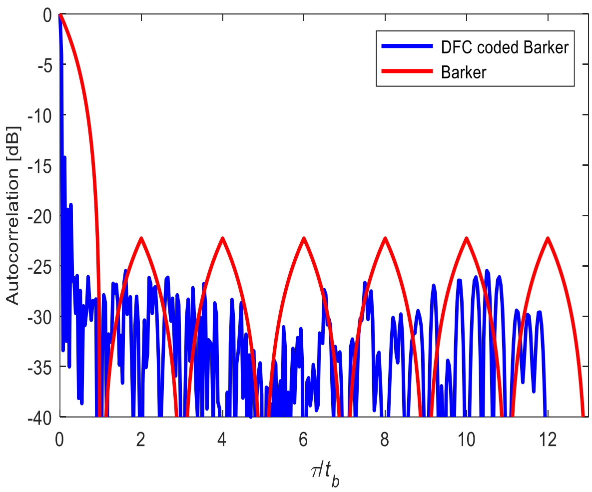


Fig. 3. Comparison of ACF of Barker code and DFC Barker code of length, N=13.

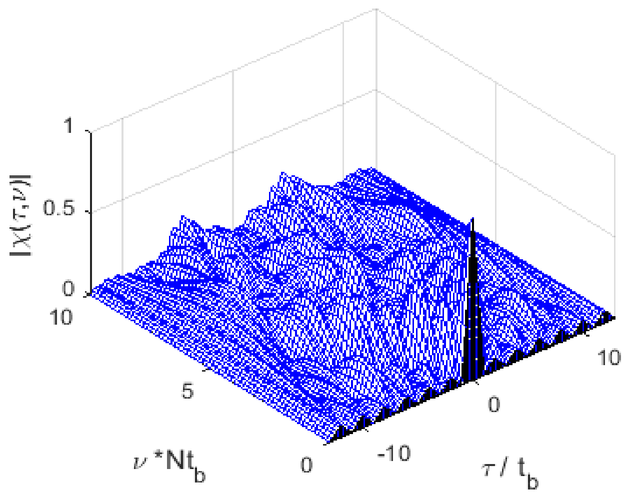


Fig. 6. AF of Barker sequence of length, N=13.

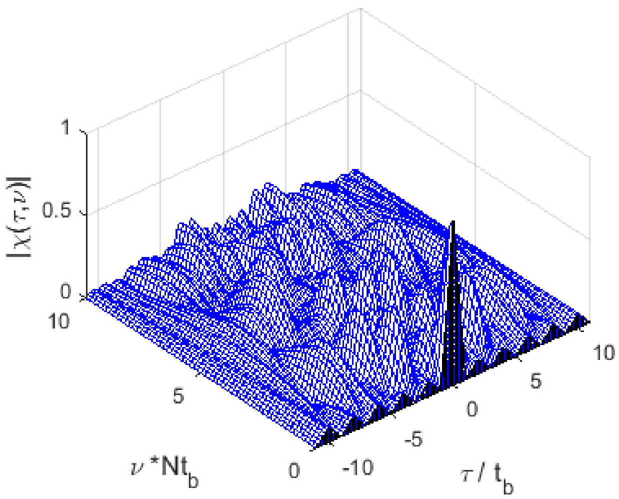


Fig. 4. AF of Barker sequence of length, N=11.

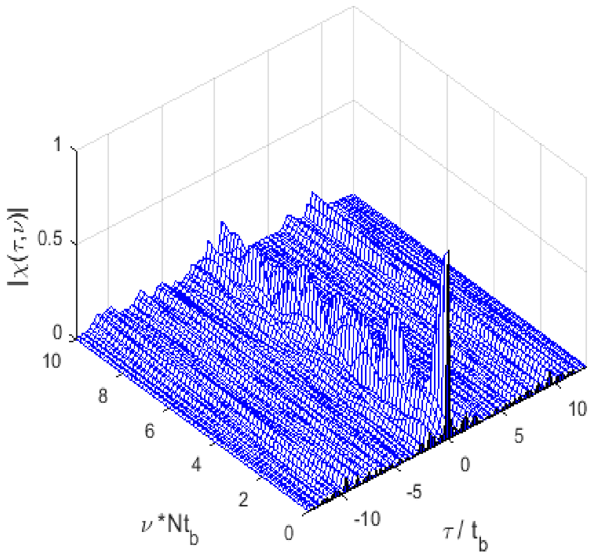


Fig. 7. AF of DFC Barker sequence of length N=13.

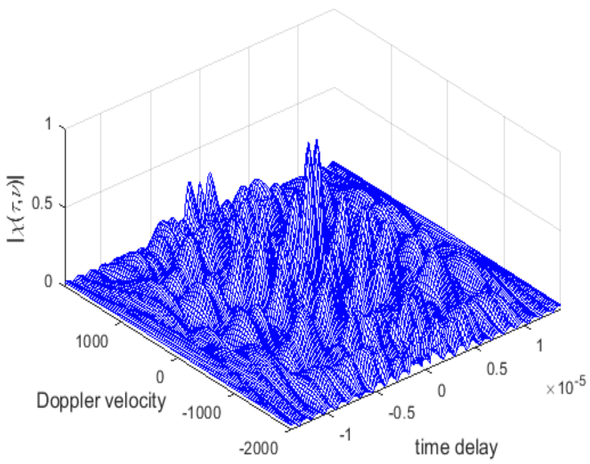


Fig. 8. AF of two targets in close vicinity using Barker sequence of length N=11.

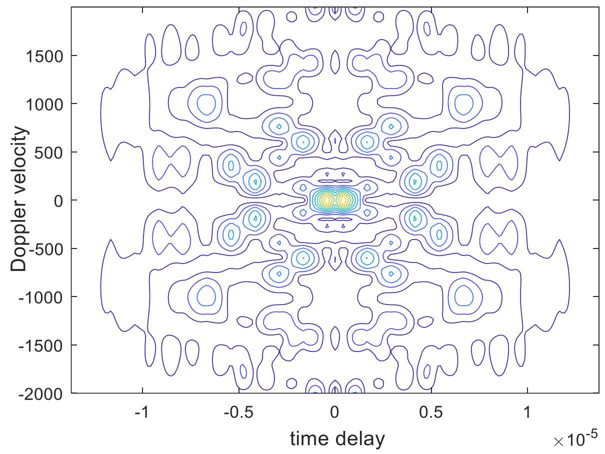


Fig. 9. Two dimensional AF of two targets in close vicinity using Barker sequence of length N=11

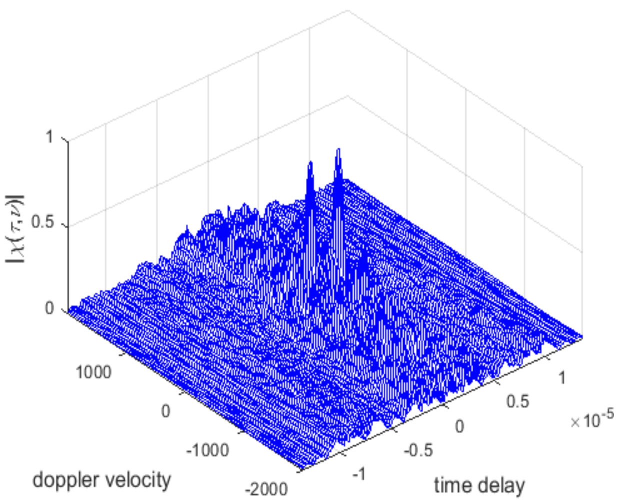


Fig. 10. AF of two targets in close vicinity using DFC Barker sequence of length N=11.

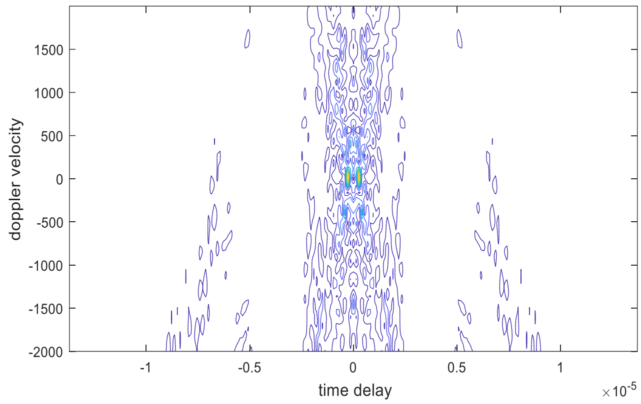


Fig. 11. Two dimensional AF of two targets in close vicinity using DFC Barker sequence of length, N=11

VII. CONCLUSION

DFC Barker sequences are synthesized signals optimized by using an efficient modified genetic algorithm. The Synthesized DFC Barker sequences not only have better compression ratio but also have lower autocorrelation peak sidelobes. The synthesized DFC Barker sequences can be used in radar sonar systems to enhance system detection capability considerably. The proposed signals can also be useful in LPI radar waveform agility, multi radar systems and multiple access communications. .

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