Genetic Algorithm for Synthesis of Binary Signals with Optimal Autocorrelation

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Introduction

The binary phase manipulated (PM) signals, whose auto-correlation functions (ACFs) have small side-lobes, are named optimal, as they have a critical role for many types of radio communication systems (RCSs). More specifically, the contrast between the main lobe and the side lobes of ACF defines the resolution of echo-signals in radars, as well as the positive effect of exploitation of separate processing and coherent accumulation of radio signals, that passed different ways from the transmitter to the receiver in RCSs.

Introduction

Due to their positive features, the optimal binary PM signals are extensively researched during the past seventy years. The obtained experience shows that the problem for their synthesis is extremely hard both from theoretical and computational points of view.

With regard to this situation, in the paper we present a genetic algorithm for synthesis of binary PM signals with length N=256 and demonstrate its practical effectiveness.

Criterions for Estimation of Signal Auto-Correlation Properties

The classic mathematical model of the PM signals is:

$$U(t) = \sum_{i=0}^{N-1} U_{mi} e^{j(2\pi f_0 + \psi_i)} \{\sigma(i\tau_{ch}) - \sigma[(i+1)\tau_{ch}]\} \qquad (1)$$

Here the length N presents the quantity of consecutive chips (elementary phase pulses), forming the PM signal, and U_{mi}, ψ_i are the amplitude and the initial phase of the i-th chip respectively. The carrier frequency f_0 and the duration τ_{ch} are constant quantities for all the chips.

Criterions for Estimation of Signal Auto-Correlation Properties

$\sigma(t_0)$ is the so named unit step function, defined by the conditions:

$$\sigma(t_0) = \begin{cases} 0, & t < t_0, \\ 1, & t_0 \leq t. \end{cases} \tag{2}$$

Due to the constant character both of the carrier frequency f_0 and the duration τ_{ch} of all chips, the correlation properties of PM signals can be explored by the means of the following sequence of complex numbers:

$$\{s(i)\}_{i=0}^{N-1} = \{s(0), s(1), \dots, s(N-1)\}. \tag{3}$$

Criterions for Estimation of Signal Auto-Correlation Properties

In (3) the sample

$$s(i) = U_{mi} e^{j\psi_i},\ j = \sqrt{-1},\ i = 0, 1, \dots, N-1 \qquad (4)$$

is the complex envelope of the i-th chip. It contains simultaneously all information for the amplitude U_{mi} and initial phase ψ_i of the i-th chip.

Today the uniform PM signals are most widely exploited, as they provide maximal energetic effectiveness of RCSs transmitters and can be easily processed by digital electronic devices.

Criterions for Estimation of Signal Auto-Correlation Properties

The uniform PM signals satisfy the following conditions:

$$U_{mi} = U_{m0} = const,$$

$$\psi_i \in \{\left(\frac{2\pi}{p}\right) l, l = 0, 1, \dots, p-1\}, i = 0, 1, \dots, N-1 \qquad (5)$$

In the sequel of this paper the attention will be focused on the binary PM signals (or simply binary signals) due to their implementation's simplicity and cost-effectiveness. At present, these factors are very important for smart cars' radars and many types of sensor networks.

Criterions for Estimation of Signal Auto-Correlation Properties

The ratio of the maximal level (magnitude) ($M(S)$) of the side lobes to the main lobe ($R(0)$) of the ACF (named peak side lobe ratio - PSLR), which is:

$$\eta_{PSLR} = \frac{M(S)}{R(0)},$$

$$M(s) = \max_{r} |R(r)|, -(N-1) \leq r \leq N-1, r \neq 0. \quad (8)$$

Here r is the time-shift between the detected and the etalon signals in the receiver.

Criterions for Estimation of Signal Auto-Correlation Properties

In this paper as criterion for optimality of the synthesized binary signals the PSL is adopted. This approach is reasonable as according to (7) the main lobe of ACF of the binary signal (3) is $R(0) = N$. Consequently, η_{PSLR} differs from $M(S)$ only by the constant $1/N$.

Due to their positive features, listed above, the binary signals have been intensively explored during the past seventy years. The obtained experience shows, that the problem for synthesis of optimal PM signals seems to be extremely hard.

Genetic Algorithm for Synthesis of Binary Signals with Optimal Autocorrelation

For the purposes of our study we developed and exploited a computer program, based on a genetic algorithm (GA). This approach can be substantiated by the fact that in the biologic evolution the following mechanisms: input of mistake(s) (mutation(s)), combining of different solutions from a set (crossbreeding), choice of the best solutions (selection), exchange of some solutions by others, assessing the resistance of the obtained good solutions in the optimization process, are successfully used.

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In our GA the length of the explored binary signals was doubled and was divided into “dominant” and “recessive” parts respectively

$$\{s(i)\}_{i=0}^{2N-1} = \{s_d(0), s_d(1), \dots, s_d(N-1)\} \cup$$
$$\cup \{s_r(0), s_r(1), \dots, s_r(N-1)\} \qquad (21)$$

This modification of the conventional evolutionary algorithms can be substantiated by the fact that this “contradistinction” of the signal’s parts provokes an inner concurrence, which enhances the computational effectiveness.

Genetic Algorithm for Synthesis of Binary Signals with Optimal Autocorrelation

Our GA consists of the following steps.

Step 1) Input the basic parameters and initial pool's generation;

Step 2) Creating a "parents"" pool $\left\{\{s_k(i)\}_{i=0}^{511}\right\}_{k=0}^{199}$ i.e. 200 binary signals with length $2N = 512$;

Step 3) Dividing signals in the parents' pool into "dominant" and "recessive" parts according to (21);

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Step 4) Forming “normal length” ($N = 256$) signals, which i-th sample can be the i -th sample of its “dominant” or “recessive” parts by probabilities $p_d = \frac{5}{6}, p_r = \frac{1}{6}$ respectively;

Step 5) Evaluating the ACFs of “normal length” ($N = 256$) signals;

Step 6) Crossbreeding, mutation and replacing signals in the parents’ pool with signals with smaller PSL.

Genetic Algorithm for Synthesis of Binary Signals with Optimal Autocorrelation

The algorithm was realized as a C++ computer program and in it the accelerated libraries of Intel Compiler for evaluating of ACFs were implemented.

The program was started to work on a separate work-station without usage of parallelization, except this, implemented in Intel Integrated Performance Primitives (IPP). After approximately 160 hours the program has found several binary signals with length $N = 256$ and $PSL = 11$. Some of the found signals are presented in Table 1.

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Table 1. Binary Signals with PSL=11, Found by the Program, Using Genetic Algorithm.

No	Binary signal in hexadecimal code
S_1	F19CCB67644AAB3FAC44BC02A8B7E62F7F4ED5F6179F428DA5D9B4983DC73C2C
S_2	DB7F5D7DAFA9CC94C3C1F03AB5DAC549D494C97B92E69AB031BFE463820DFB0E
S_3	DF17DD5DEF05BC94C7C1F2BAB55AC689D484C97A92E6998035B7EF71830F3B0E
S_4	5584317483B6447494D2489D21283AA85F9E731FB468301B77B3018B1A83C470
S_5	76A7529DDA52C74C0B701205E338C776FAE041ECF6D71F81B76D7D114D9A9BAF
S_6	9BEBAAF9FB36F8EC1E4BC4513AB13F9E40B9A5291427FB1B082E30BD69D5A08C

Genetic Algorithm for Synthesis of Binary Signals with Optimal Autocorrelation

Often in the practice of sensor networks it is necessary to exploit families of signals, providing ability many radars to work simultaneously without electromagnetic interference. this requirement can be defined as follows. Let $\left\{\{s_k(i)\}_{i=0}^{N-1}\right\}_{k=0}^{N_F-1}$ be a family of N_F binary signals with lengths N. Then this family possesses optimal correlation properties if and only if

$$M(S_k) \leq M_{ACF} \cup M(S_k S_l) \leq M_{CCF},$$

$$k, l = 0, 1, \dots, N_F - 1,\ i \neq l. \qquad (22)$$

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In (22) $M(S_k)$ is the PSL of i-th signal's ACF, $M(S_k S_l)$ is the PSL of i-th and k-th signals' cross-correlation function (CCF) and M_{ACF}, M_{CCF} are the admissible values for ACFs' and CCFs' PSLs. The following algorithm for synthesis of binary signal's families with optimal correlation properties can be used.

Step 1) Input the initial set, containing all known binary signals, satisfying the condition $M(S_k) \leq M_{ACF}$;

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Step 2) Enlarging the initial set by all negative, reflective and alternate derivatives of the binary signals in the initial set;

Step 3) Evaluating CCFs of all pairs of binary signals in the enlarged initial set;

Step 4) Estimating and arranging the PSLs of all CCFs from Step 3;

Step 5) Discarding from enlarged initial set all binary signals, which produce CCFs with PSLs, exceeding M_{CCF}.

Conclusion

In the paper a genetic algorithm for finding of binary signals, whose PACFs have small side lobes, is substantiated and is realized as a C++ computer program. By it several binary signals, which outperform the present known optimal binary signals with length $N = 256$, have been found. Besides, in the paper an algorithm for synthesis of binary signal's families with optimal correlation properties is suggested. The algorithms, could be used in the development of small radar networks for surveillance and traffic control in the smart cities.

Thanks for Your Attention!

Questions?