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ScienceDirect

Procedia Engineering 201 (2017) 398–407

Procedia Engineering

www.elsevier.com/locate/procedia

3rd International Conference "Information Technology and Nanotechnology", ITNT-2017, 25-27 April 2017, Samara, Russia

Signals for Synthetic Aperture Radar

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Abstract

The paper presents a brief overview of different types of signals for synthetic aperture radar (SAR). The best chosen signal should provide a minimum peak sidelobes (PSL) level in the range-azimuth plane. This paper gives numerical method for unimodular sequences design with low PSL level of AACF. The results of numerical optimization for constructing of unimodular sequences of lengths $N=128$, $N=256$ and N=512 with $PSL\approx 1$ are shown. It is shown that the synthesized in this paper unimodular signal with good aperiodic autocorrelation properties has a lowest average PSL in the range-azimuth plane.

Peer-review under responsibility of the scientific committee of the 3rd International Conference "Information Technology and Nanotechnology".

Keywords: aperiodic autocorrelatio; unimodular sequences; minimum peak sidelobe sequences

1. Introduction

The principle of SAR relies on the coherent addition of recorded echos at successive positions during the movement of the radar. It turns out, that the azimuth resolution of a synthetic aperture radar depends on the distance during which a point in the imaged area is visible to the radar. Increasing the synthetic aperture length gives a better azimuth resolution, and moreover resolution is independent of the range. The range resolution is depend on PSL level of aperiodic autocorrelation function (AACF). So the problem of minimizing PSL in the range-azimuth plane is very important to SAR. In this paper such problem will be solved by choosing as type of radar signal as method of PSL level suppressing due to coherent accumulation.

The required dynamic range of detected signal is offered by using pulse compression coding with a large base

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1877-7058
Peer-review under responsibility of the scientific committee of the 3rd International Conference "Information Technology and Nanotechnology".
10.1016/j.proeng.2017.09.660

$$B = \Delta F_u \cdot T_u , \quad (1)$$

where ΔF_u и T_u -spectral width and time duration of the signal u.

The length of the compressed pulse will be equal to

$$\tau_{compr} = \frac{1}{\Delta F_u} \quad (2)$$

after processing of the signal in a matched filter

The signal-to-noise ratio (SNR) of compression filter is determined by the expression:

$$\frac{q^2}{p^2} = B , \quad (3)$$

where p^2 - input SNR, q^2 - output SNR.

It is also necessary to provide the minimum PSL level of a compressed pulse signal, which further should became equal to zero under perfect compression by azimuth.

Unimodular sequences have a peak-factor equal to 1. Due to this property they are preferred to use in radar applications. One of a problem of sequence design is to determine long unimodular sequences for which the absolute values of the aperiodic autocorrelations are collectively small as possible. The last sidelobe of AACF is always equal to unit. So the optimal aperiodic sequence has minimum $PSL = 1$. Barker [1] firstly constructed binary sequences with the lengths $N = 2,3,4,5,7,11,13$ for which all non-trivial aperiodic autocorrelations are at most 1 in magnitude. Turin [2] showed that no Barker sequence of length greater than 13 exists for even lengths. Also in [3] it was shown that if a Barker sequence of length $N > 13$ exist, then either $N = 3\,979\,201\,339\,721\,749\,133\,016\,171\,583\,224\,100$, or $N > 4 \cdot 10^{23}$.

But it is possible to find binary sequences with minimum peak sidelobe (MPS) level for some lengths using global exhaustive search method. Lidner [4] did an exhaustive search for binary MPS sequences up to $N = 40$. Cohen et al. [5] continued up to $N = 48$. Coxson and Ruso [6] performed exhaustive search for $N = 64$. Erders-Ball et al. [7] found MPS sequences up to $N = 61$. In series of papers [8-13] we did an exhaustive search of binary MPS sequences up to length $N = 85$.

Alternatively it is possible to find binary sequences with low peak sidelobe level for greater lengths using local search methods. Kerdock et al. [14] found binary sequences for lengths $N = 51,69,88$ with $PSL = 3,4,5$ respectively. Nunn and Coxson [15] found the best known binary sequences with $PSL = 4$ up to $N = 82$ and with $PSL = 5$ for $N = [83,105]$.

Ein-Dor et al. [16] showed that minimum PSL of binary sequence A of length N should be equal to $MPS \approx 0.432\sqrt{N}$. Sverdlik [17] published analytical constructions of binary sequences with low PSL for unlimited lengths. Mow et al. [18] published binary sequences with low PSL up to $N = 300$ founded using genetic search algorithm. Also they published binary sequences for some lengths between $N = 303$ and $N = 1000$, as well as between $N = 1019$ and $N = 4096$. Coxson et al. [19] found binary sequences using adiabatic quantum computer for the lengths $N = 128$, $N = 256$ and $N = 426$.

Another way to reduce PSL of sequence is to use a non-binary unimodular sequence. Let us determine an unimodular sequence as

$$U = \{u_0, u_1, ..., u_{N-1}\} \quad (4)$$

where a code element $u_n = \exp\left(\sqrt{-1} \cdot \varphi_n\right)$, a phase φ_n is any value from $\varphi_n = [0, 2\pi]$, instead of binary sequence

$$A = \{a_0, a_1, ..., a_{N-1}\} \quad (5)$$

where a code element $a_n = \{1 \; or \; -1\}$.

De Long [20] and Welti [21] used respectively ternary and quaternary sequences to construct sequences with lowest PSL. Golomb and Scholtz [22] called such sequences with non-binary alphabet as generalised Barker sequences if they have PSL equal or less than 1.

Friese and Zottmann [23] found generalized Barker sequences up to $N = 31$. Later Friese [24] continued generalized Barker sequences up to $N = 36$. Brenner [25] found generalized Barker sequences up to $N = 45$. Borwein and Ferguson [26] performed search up to $N = 63$. Nunn [27] found generalized Barker sequences for the