SYNTHESIS OF MULTILEVEL AND BINARY SEQUENCES WITH GOOD CORRELATION PROPERTIES

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LIST OF ABBREVIATIONS

3G	Third Generation
4G	Fourth Generation
AM	Amplitude Modulation
ACF	Autocorrelation Function
BPSK	Binary Phase-Shift Keying
CDMA	Code Multiple Access
CW	Continuous Wave
DSP	Digital Signal Processing
EM	Electromagnetic Waves
ER	Energy Ratio
FIR	Finite impulse response
FDMA	Frequency Division Multiple Access
FM	Frequency Modulation
ISL	Integrated Sidelobe Level
LTI	Linear time-invariant
M.F Radar	Medium Frequency Radar
MFR	Matched Filter Receiver
MFR	Matched Filter Receiver
OFDMA	Orthogonal Frequency Division Multiple Access
PM	Phase Modulation
PSL	Peak of Sidelobe Levels
RADAR	Radio Detection And Ranging
SLE	Sidelobe Energy
SNR	Signal to Noise Ratio

Sintesis Urutan Pembilang Aras Dan Urutan Pembilang Perduaan Dengan Sifat Korelasi Yang Baik

ABSTRAK

Dalam sistem radar, cuping sisi yang rendah dicapai dengan mengunakan amplitud dan fasa termodulat terutamanya dalam sistem yang memerlukan julat dinamik yang besar. Tambahan pula prestasi terbaik dari penolakan 'selerakan-diri' diperolehi tanpa menjejaskan keupayaan bagi mengasingkan sasaran terdekat (tiada pelebaran lobus utama). Sebagai tambahan, pengekodan dan penyahkodan dalam amplitud dan fasa termodulat dibenarkan bagi menangani 'selerakan-diri' atau pengendalian dalam persekitaran sasaran yang padat. Masalah yang telah diberi keutamaan dalam merekabentuk radar adalah memilih penghantar gelombang yang sesuai. Ini kerana gelombang yang mengawal resolusi, prestasi 'selerakan' dan juga penanggungan kos dari sistem. Suatu kajian teori di mana menyediakan asas untuk kemajuan teknikal dan setakat ini tidak dapat diselesaikan dari aspek rekabentuk isyarat. Secara praktikal, pengetahuan tentang sifat-sifat denyutan nadi menunjukkan isyarat yang sesuai bagi pemprosesan digital semakin dititikberatkan. Terdapat dua sifat yang ditekankan di dalam urutan tersebut. Pertamanya ialah nisbah tenaga (ER) yang ditakrifkan sebagai nisbah jumlah urutan tenaga kepada nadi tenaga terbesar. Antara sifat lainnya pula adalah jumlah tenaga cuping sisi (SLE) yang mana ia adalah urutan tenaga di dalam cuping sisi fungsi autokorelasi. Penyelidikan yang dijalankan terhadap kajian ini sangat menitikberatkan sintesis bentuk gelombang pembilang aras dan pembilang penduaan bagi urutan panjang mana yang dikehendaki untuk mempunyai peningkatan tenaga nisbah dan penurunan cuping sisi di dalam setiap fungsi autokorelasinya (ACF). Dalam merekabentuk urutan pembilang aras, teknik lelaran adalah dicadangkan. Teknik ini ditugaskan sebagai sifat penapis songsang yang optimum dan ia terbukti berkesan bagi penjanaan urutan panjang pembilang aras yang dikehendaki. Kaedah pengetipan di dalam kajian ini adalah sebagai penukar urutan pembilang aras ke urutan pembilang penduaan dalam panjang urutan yang sama di mana ia masih lagi mengekalkan penurunan cuping sisi di dalam fungsi autokorelasinya. Ini menunjukan bahawa kaedah lelaran berasaskan penapisan songsang dan kaedah pengetipan merupakan kaedah yang berkesan bagi penghasilan urutan pembilang aras yang mempunyai peningkatan nisbah tenaga dan penurunan cuping sisi di dalam setiap fungsi autokorelasinya. Urutan itu kemudian boleh digunakan dengan berkesan untuk meningkatkan julat dan Doppler resolusi radar.

Synthesis Of Multilevel And Binary Sequences With Good Correlation Properties

ABSTRACT

In radar systems the very low side lobes that can be achieved with amplitude and phase modulated pulse trains especially particularly in systems requiring a large dynamic range. Moreover, the excellent self-clutter rejection performance is obtained without sacrificing the ability for the separation of close targets (no main lobe widening). The additional expense of encoding and decoding in amplitude and phase may be justified for radars that must cope with land clutter or operating in a dense-target environment. To choose a suitable transmit waveform is an important problem in radar design. This is so because, the waveform controls resolution, clutter performance and also bears heavily on the system cost. Theoretical studies which provide the basis for technical advances have not so far solved the general signal design problem. The knowledge about the properties of the pulse trains shows that, a class of signals particularly well suited to digital processing of increasing practical importance. Two properties of such sequences are of interest. One is the energy ratio (ER) defined as the ratio of the total energy of the sequence to the energy of the largest pulse. The other property is the total side lobe energy (SLE) which is the energy in the side lobes of the autocorrelation function of the sequency. The work presented in this research is mainly concerned with the synthesis of multilevel and binary waveform of any desired length that has high energy ratio and low side lobe in their autocorrelation function (ACF). For the design of multilevel sequences in iterative technique is proposed, this techniques employed the properties of optimum inverse filtering and shown to be effective for the generation of multilevel sequences in any desired lengths. The method of clipping proposed in this research converts a multilevel sequence to binary sequence in same lengths while it is still retaining at low side lobe in autocorrelation function. It is shown that the iterative method based on inverse filtering and the method of clipping provide effective techniques for the generation of multilevel sequences that have high energy ratio and low side lobe energy in their autocorrelation function. Such sequences can then be effectively used to improve the range and Doppler resolution of radars.

CHAPTER 1

INTRODUCTION

1.1 Background of the Project

Radar is a method for remote sensing using radio waves. Its basic purpose is to detect the presence of a target of interest and to provide information concerning the target's location, motion, size and other parameters . The problem of target detection is solved with a typical radar system (Figure 1.1) by transmitting a radio signal and detecting the waveform reflected by the target in the presence of unavoidable system noise and reflections from undesired scatterers (clutter). If a return signal of adequate strength is received, it is further analyzed to determine the target's range, velocity shape, size and so on. This process is known as parameter estimation. The range of the target is determined by measuring the delay of the return signal. Similarly, the velocity of the target can be estimated, neglecting higher order effects, by measuring the shift in carrier frequency (Doppler shift) of the received waveform (Satyabrata Sen., 2013). Furthermore, the transmitted signal can be carefully chosen and generated to optimize its capability for extracting the required information (Andrzel Dyka & Henry Ugoski, 1988).

Target detection and parameter estimation are difficult practical problems, particularly for small targets at great distances. In principle however, both problems are simple when only a single target is present. Target resolution which may be defined as the capability of a radar system to recognize particular target in the presence of others is one of the most important and demanding task (Griffes, 2000).

For high performance radar systems, these tasks can become increasingly complex. This explains the continuing effort being directed towards improving the resolution capabilities of modern radars. Some improvements are still being made in the components which affect radar performance; for example, receivers with low noise figures, transmitters with higher output power and antennas with more gain. Further improvement can be obtained by means of elaborate signal processing schemes. In recent years a considerable amount of work has been done in digital processing for radar.

The technical problems imposed by modern radar systems are those of processing (real time) a large number of data and the requirement of complex signal processing operations. These problems can only be solved by the use of digital methods but in some cases, modern optical processing schemes can offer an alternative (Yangbo Chen, 2000).

The suitable transmit waveform controls resolution and clutter performance and also bears heavily on the system cost. As compactness, cheapness and computational speed of digital microcircuits continue to increase their use, signal processing applications becomes more practical. In particular, the advent of solid-state antenna arrays has its impact on radar system designers in two principal ways. First of all, peak power limitations of solid state array elements have necessitated the use of waveforms with long durations in order to achieve the required signal energy over a desired range. The required stability and reproducibility of such signals can only be satisfied reliably by digital signal generation and processing. Secondly, the ability to switch the beam of solid-state array at high speeds gives the radar a multi-function capability, thus requiring the flexibility to enable a variety of waveforms to be employed (Sarkar, I., Fam, A.T, 2008; Munoz-Ferreras, J. M. & Perez-Mrtinez, F., 2010). These requirements have made digital signal processing with its inherent adaptability an attractive alternative to analogue processing (Solomon W. Golomb & Moe Z. Win, 1965 and 1998).

An early suggestion for using discrete sequence waveforms in radar appeared in a paper by Siebert (1956) treating the general problems of radar. Siebert noted that certain binary sequence waveforms offered a substantial improvement in range and velocity resolution. However, it was shown that in order to obtain these improvements, it would be necessary to employ long periodic binary sequences known as pseudo-random sequences (Barker, R.H., 1953). Later, Lerner (1958) suggested that the periodic sequence could be modified to form an aperiodic signal and yet retain the nearly optimum resolution property of the waveform. The use of aperiodic signals allows the construction of passive matched filter receivers (Ainiwan Abudoukeremu, Shinya Matsufuji, Takahiro Matsumoto., 2013; Angeletti, P., Petrolati, D., Giovanni Toso., 2012). At about this time the signal design problem was approached in a slightly different way. Assuming a matched filter receiver of the range resolution capability (in the absence of doppler shift) was found to be directly related to the autocorrelation function of the transmitted waveform (Mir, H. S. & Carlson, B. D., 2012). Therefore, the approach consisted of attempting to design aperiodic binary sequences having optimum autocorrelation properties (Boehmer, A.M., 1967; Varakin, L. YE., 1969). These sequences were called 'Optimum finite code groups' or Barker sequences.

Since these early evaluations a number of authors have made valuable contributions in the field of waveform design, (Turyn, R. & Storer, 1958 and 1961; Turyn, R., 1963 and 1968; Hollis, E., 1967; Hiemiller, R. C., 1961; Frank, R. L., 1963; Frank, R.

L. & Zadoff, S. A., 1962). An interesting analytical method for generating binary codes was reported by Boehmer (1967), using a number theory. Another quite different approach to the problem is discussed in a paper by Vakman et al. (1970) and Varakin (1969). The authors suggested a synthesis procedure on the basis of spectral theory and the method of stationary phase.

Heimiller (1961), Frank, (1962 and 1963) and Zadoff, (1962) have shown that there are other suitable codes if the restriction of 0°-180° phase shifting is removed (Cook, C. E. & Bernfeld, M. 1967). In the case of Frank codes (1962 and 1963), higher order poly-phase sequence words can be generated by coding each sub-phase into one of multi-phases. Huffman (1962) considered the problem of designing amplitude and phase modulated pulse trains. He has shown that finite length signals with nearly ideal autocorrelation function can be generated. This property however, was achieved at the expense of amplitude modulation which resulted in increased system complexity and lower energy utilization at the transmitter. Nevertheless, the additional expense of encoding and decoding of amplitude and or phase modulated waveforms may be justified for radars that must cope with land clutter or operate in a dense-target environment. However, the use of amplitude modulated pulse trains is precluded in the higher powerful applications due to the inevitable loss in energy ratio.

In spite of the considerable effort that has been devoted to the problem of designing waveforms with high range resolution there seems to be lack of signal design methods and theories. All present methods tend to contain an element of trial and error, thus rely on the skill and ingenuity of the designer. In short, the study of the properties of pulse trains does not appear to have progressed much beyond an understanding of the types described above. The currently accepted belief that there is no ideal waveform is not surprising considering the various different tasks a modern radar systems have to perform. On the other hand, the inability to find an ideal waveform is not an excuse to fail in the search for finding the locally optimum waveforms for specific radar applications and environments.

The effort in this thesis is directed towards the improvement of a factor which constitutes a fundamental limitation of radar performance; namely the transmitted waveform. Although the ways in which the transmitted signal affects the system performance are well understood, (Price, R. & Hofstetter, E.M., 1965) there seems to be no obvious solution to the problem of designing energy efficient pulse trains for high resolution radars. Therefore, the work presented in this thesis is concerned primarily with the study and development of design methods for improving the range resolution capability of pulse trains. The pulse sequences discussed later, besides representing an interesting mathematical area, there are also parts regarding the practical significance in related fields such as digital communication and navigation.

1.2 Basic Concept of Radar Waveform

The basic idea behind radar is very simple: a signal is transmitted, it bounces off an object and it is later received by some type of receiver. This is like the type of thing that happens when sound echo's off a wall. However radars do not use sound as a signal. Instead they use certain kinds of electromagnetic waves called radio waves and microwaves. This is where the name RADAR comes from (RAdio Detection And Ranging). Radar measurement of range or distance is made possible because of the properties of radiated electromagnetic energy**.** Radio waves and microwaves are two types of electromagnetic waves (EM). Sound waves and ocean waves require matter to transport energy but EM waves can do so without the presence of matter. Because of this, satellites can use radars to work on projects outside of the Earth's atmosphere and on other planets (John, A. & Katherine, G. J., 2009).

A basic radar system as shown in Figure 1.1 is spilt up into a transmitter, switch, antenna, receiver, matched filter and some sort of output display. Everything starts with the transmitter as it transmits a high power pulse to a switch which then directs the pulse to be transmitted out to an antenna. Just after the antenna is finished transmitting the pulse, the switch switches control to the receiver which allows the antenna to receive echoed signals. Once the signals are received the switch then transfers control back to the transmitter to transmit another signal. The switch may toggle control between the transmitter and the receiver as much as 1000 times per second.

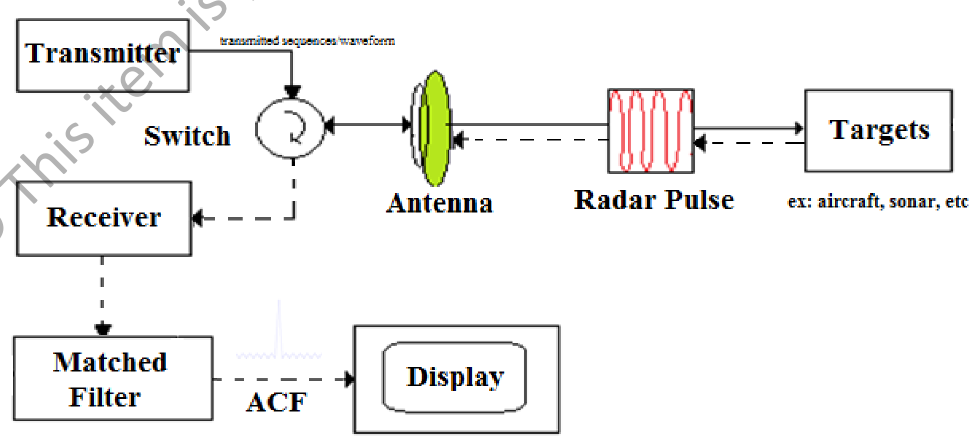

Figure 1.1 Basic Pulse Compression Radar (Catania, G., Wonsuck Kim, et al. 2009)

1.3 Problem Statement

Sequences with favourable correlation properties like low out-of-phase auto-correlation values, low cross-correlation values, low nontrivial partial-period correlation values, large linear span, balance of symbols, large family size, ease of implementation and high energy ratios has increased dramatically in recent years.

The theory of sequences has found major applications in a wide variety of technological situations including secure, reliable and efficient communications, digital ranging and tracking systems, deterministic simulation of random processes and computer sequencing and timing schemes (Zhou, C. T. 2006). In addition, there is intense interest in the applications of Code Division Multiple Access (CDMA) and Orthogonal Frequency Division Multiple Access (OFDMA) signals for mobile and wireless communications (Srikanth, S., et al., 2004). In fact, essentially all the standards for third generation (3G) and fourth generation (4G) cellular telephony are based on CDMA and FDMA (4G - Wikipedia, 2011). It is a challenge to build the project thus, their practical importance of considerable research is being carried out to develop methods for the synthesis and design of these sequences. In spite of considerable effort that has been devoted to the problem of designing sequences with good correlation properties, there seems to be a lack of sequence design methods and theories.

Fundamental studies that provide the basis for technical advances have not, yet, solved the general signal design problem. All available methods tend to have an element of trial and error and also rely on the skill and ingenuity of the designer. Therefore, the signal design problem has in general defied solution by all means other than exhaustion. In particular, no concise set of necessary and sufficient conditions has been formulated