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RADAR WAVEFORMS WITH VARIABLE PULSE DURATION UTILISING PARTIAL COMPLEMENTARITY OF BARKER'S SEQUENCE SET

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Abstract: *The maximum radar range is determined by total radiated energy, which demands that larger pulse duration be applied. However, longer pulse duration increases the blind zone of the radar. This paper proposes a spread spectrum radar/sonar based on a waveform with variable pulse duration as a possible solution for overcoming the blind zone problem. This kind of radar signal is justified from the point of range/time sensitivity control. Lower reflected power is required for shorter ranges for the same reflective target surface. Search for an adequate group of sequences has begun with the binary Barker sequences. If all Barker sequences for the lengths from 3 to 13 were used as a sequence set, the absolute value of maximum side lobes would equal 1, just as in the case of a single Barker sequence. This property could also be preserved during the cumulative integration, by arranging the sequences according to the sidelobe sign, taking into account that they are not added, but cancelled instead. This may be considered as a new method for maximum sidelobe suppression, since the result of -32,6 dB is much better than in any other sidelobe reduction procedure for a single Barker sequence*

1. INTRODUCTION

Modern radar and sonar device designers are facing simultaneous and yet contradictory demands: maximum range, maximum range resolution, minimum transmitter power.

These demands can be simultaneously satisfied if a pulse modulation were utilized that yields a large time bandwidth product [1,2]. This procedure is named spectrum spreading in communications and pulse compression in the radar/sonar technique.

The maximum radar range is determined by total radiated energy, which demands that larger pulse duration be applied. However, larger pulse duration increases the blind zone (eclipsed zone) of the radar, whether the pulse compression is applied or not [3,4].

The paper proposes a spread spectrum radar/sonar with variable pulse duration, as a possible solution for overcoming the eclipsing problem when a long pulse is applied.

The basic demand can be formulated as follows: form a radar signal that (in a given time interval) enables each range between minimum blind zone and maximum unambiguous range to be "seen" at least once. The minimum blind zone determines the minimum transmitting pulse duration, while the maximum unambiguous range is determined by the pulse repetition interval T_R.

The analysis and the possibility of reducing the eclipsing zone in radars with linear frequency (chirp) signal modulation are given in papers [5,6]. The waveform proposal given here is aiming primarily at reducing the eclipse effect in radars with inter pulse phase modulation.

2. VARIABLE DURATION PULSE TRAIN

The common form of a radar signal with variable pulse duration is given in Fig.1. In the analytical form, the following expression defines the general signal form $\mu(t)$

$$\mu(t)=\frac{1}{\sqrt{LT_l}}\sum_{l=1}^{L}\sum_{n=1}^{N_k}\mu_{T_i}^{q_{l,n}}(t-lT_R-nT_{pi}) \tag{1}$$

where

- L - number of pulses in a train
- T_l - width of the lth pulse
- N_k - number of subpulses in the lth pulse
- q_{line} - code symbol of the nth sub pulse in the lth pulse
- T_R - pulse repetition interval (PRI)
- T_{pi} - subpulse width and
- $\mu_{T_i}^{q_{l,n}}(t)$ - normalized transmission signal of duration T

Not desisting from the general claims, we presume that T_1 is the shortest pulse and that the last pulse in the train is the longest: $T_{max}=T_l$. Further, we presume that each pulse length increment does not have to be constant.

Generally speaking, pulse duration variation can follow some other pattern, e.g.: from longer to shorter pulse duration, or the pseudo-random schedule.

Such configuration of a radar signal provides a sufficient radar range (due to the existence of long pulses), while the short pulses achieve target visibility at short ranges. Were there only long pulses in a train, the targets at short ranges would be eclipsed.

This kind of radar signals is justified from the point of range/time sensitivity control. Lower reflected power is required for shorter ranges for the same reflective target surface. That is why the classical radars require the automatic gain control in function of the distance/time axis.

3. VARIABLE DURATION PULSE TRAIN RECEIVER

The receiver scheme of such a signal is given in Fig.2 (MF stands for the matched filter). This kind of detection can be considered a usual procedure for integrating a train of L radar pulses. The only difference in this case would be the existence of variable pulse duration.

The integration on a long pulse train when mobile targets of high velocity are concerned may be inappropriate, in which case the receiver architecture should be used according to Fig.3. This detection procedure may represent a kind of cumulative integration of pulses in a train.

The first pulse echo from the targets in the vicinity is not detained while other pulses are searching more distant targets. However, the detection of the farthest targets is realized through entire train integration.

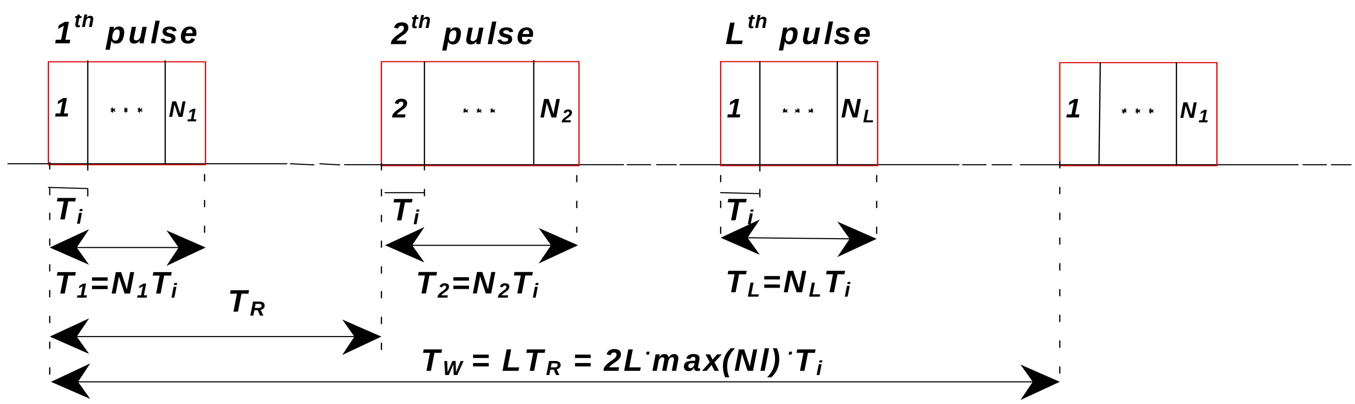

Figure 1. *Train of the variable length coded radar pulses.*

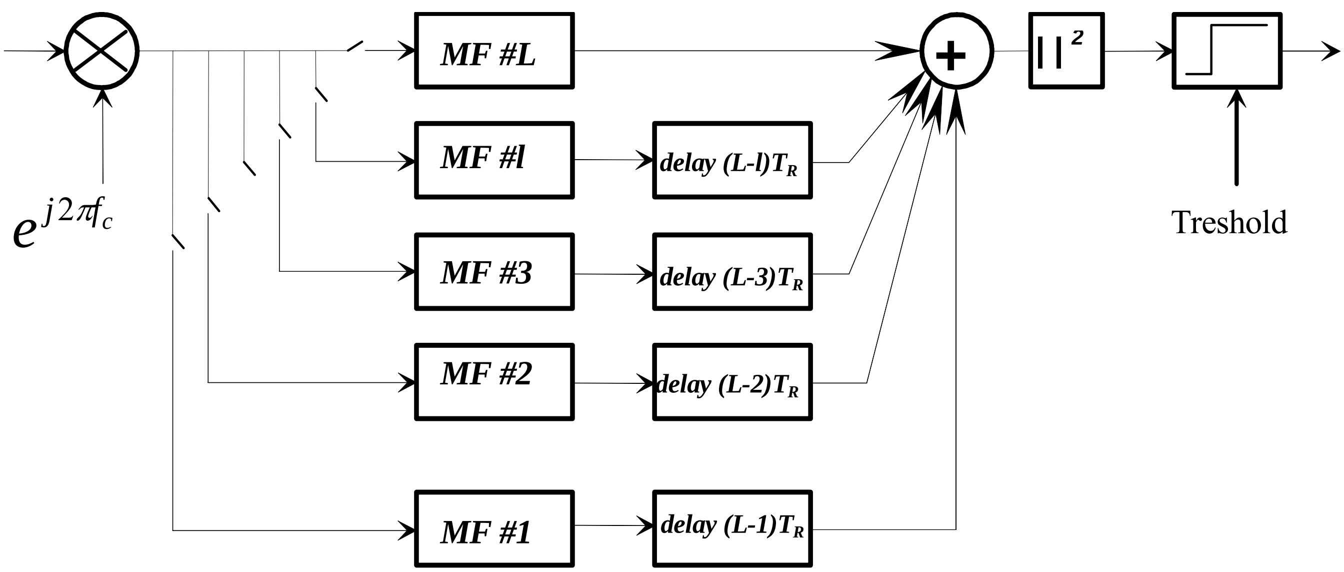

Figure 2. *Receiver with integration on the package of the pulses.*

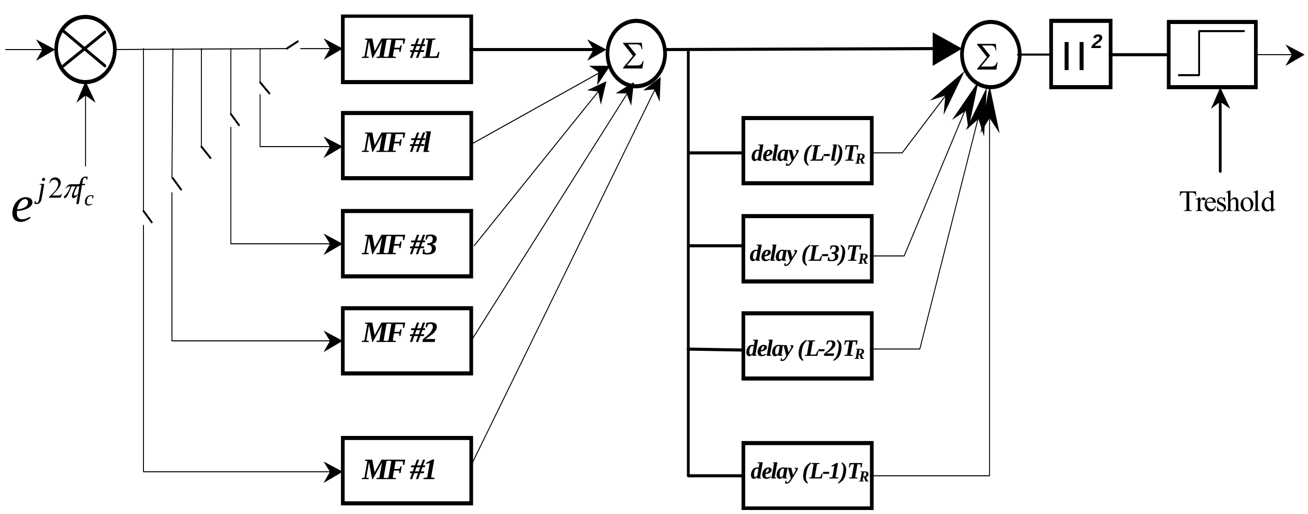

Figure 3. *Receiver with cumulative integration on the package of the pulses*

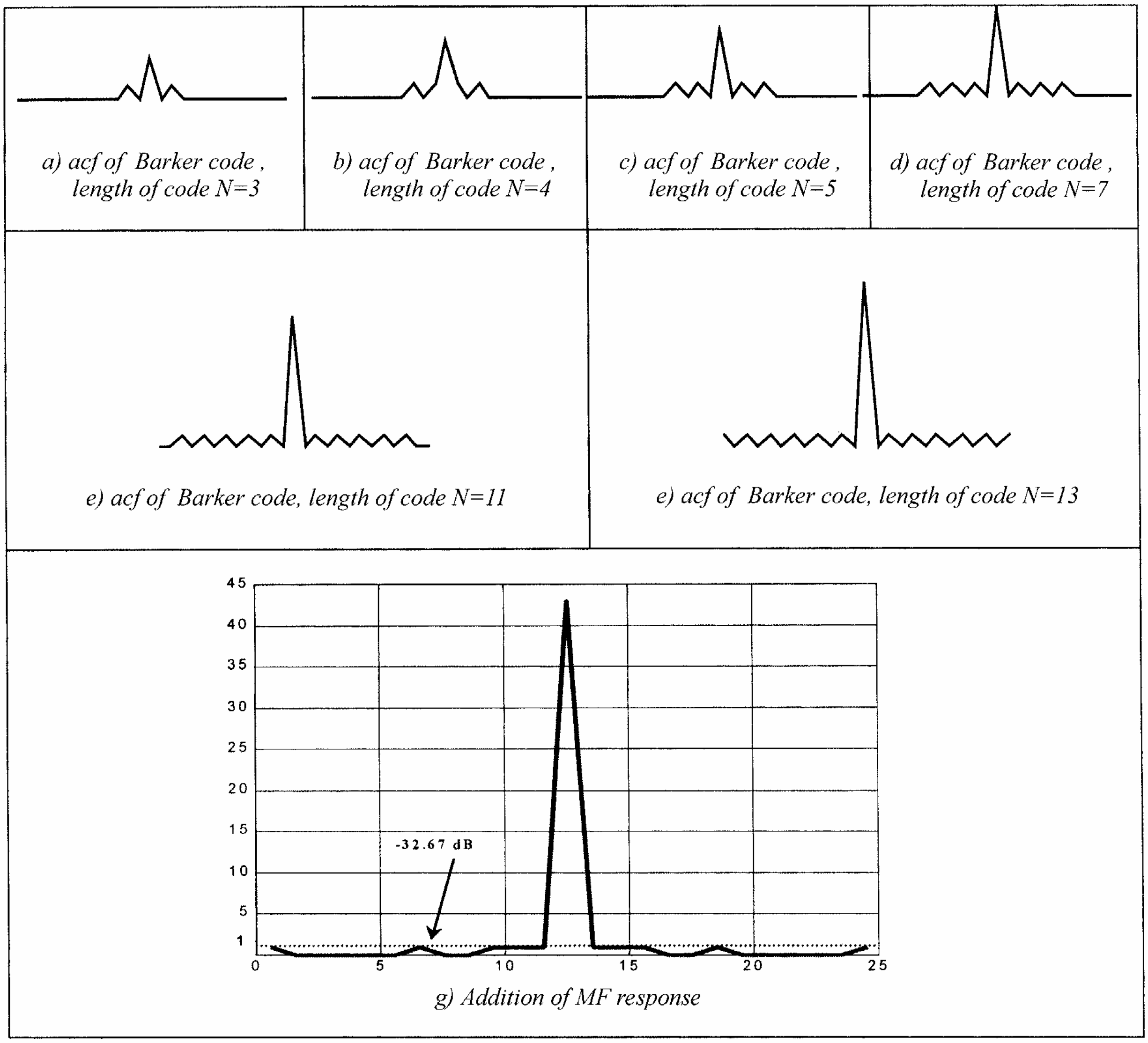

Figure 4. *Autocorrelation function (acf) of Barker code: a, b, c, d, e, f and addition of the MF response g.*

4. PULSE TRAIN MODULATION TECHNIQUE SELECTION

Pulse train modulation sequence selection has a number of specific properties resulting from the nature of variable length pulse processing. General principles (along with several examples) will be discussed here.

Were our choice to fall upon the continuous modulation, the linear frequency modulation (linear chirp) would have the preference. The chirp advantages in this case originate from the fact that every chirp time segment is also a chirp. This simplifies the generation and the reception of signals for the proposed variable duration pulse train.

In a search for a phase modulation sequence there are two possible directions:

The first one is determined by similarity criterion of the needed sequence with the chirp signal. A set of variable length sequences is needed such that the shorter sequences are contained within the longer ones. Such a criterion leads to utilization of chirp-like sequences such as Frank sequences, P sequences, etc.

The second direction is determined by the similarity criterion of the needed sequence with the complementary sequences. It is known that the sum of autocorrelation functions (joint autocorrelation function) of the group of complementary sequences produces a single pulse without sidelobes.

Therefore, a set of complementary sequences of various durations is required. At the same time, it is necessary that the autocorrelation function of a single sequence is acceptable because of the cumulative summing receiver configuration, as shown in Fig.3.

Search for an adequate set of sequences has begun with the binary Barker sequences. Sidelobes of a Barker sequence autocorrelation function the take the values within the {-1,0,1} range. Unfortunately, this outstanding property of the Barker sequences applies only to lengths 2,3,4,5,7,11 and 13.

Should all Barker sequences for the lengths from 3 to 13 be used, a Barker sequence set would be obtained with the absolute maximum sidelobe value equal to 1, just as in case of a single Barker sequence.

This property could also be preserved during the cumulative integration, by arranging the sequences according to the sidelobe sign, taking into account that they are not added, but cancelled instead.

The forms of signals at the outputs of single matched filters (i.e. autocorrelation functions) for the applied Barker sequences group, as well as a summed response of the entire train are given in Fig.4.

Similar results are gained with a polyphase code sequence. A train of five pulses coded by the polyphase P_3 sequence with values 10,15,20,25 and 30 has been simulated. The responses of singular matched filters as well as summary responses are given in Fig.4. an ambiguity function on Fig.5. The characteristic existence of two sidelobes left and right from the main lobe can be observed, while the more detached sidelobes are pushed backwards. This becomes obvious when the summary response of this pulse train (Fig.4g) is compared to that of the fixed duration pulse train (determined by the duration of the longest pulse in the train of alternate duration pulses).

5. CONCLUSION

A concept is proposed for radar/sonar signal synthesis in cases when a substantial range has to be achieved with a limited peak power of the transmitter. Variable pulse length solves the detection problem within the range that would be eclipsed were the pulse of longer duration utilized. It has been also shown that the Barker sequence set is very acceptable in signal design for such a scenario.

Further research in the field will be aimed at the following:

- Synthesis and choosing the sequence set for variable duration pulse train.
- Eclipsed zone analysis.
- Synthesis of the pulse train that would expose a variable pulse duration and variable Pulse Repetition Interval (PRI) with a constant fill rate (i.e. constant energy efficiency).

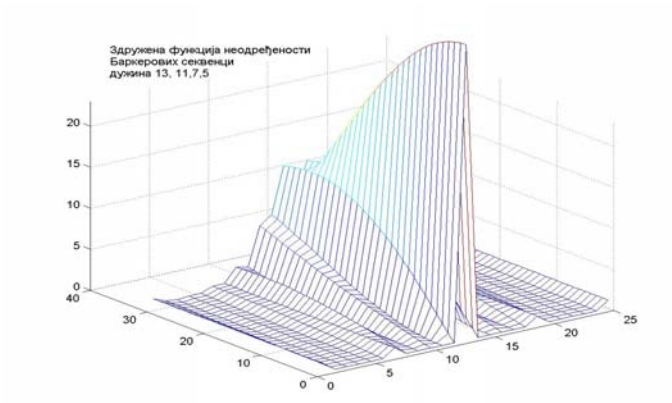

Figure 5. *Ambiguity function of the MF response (4.g)*

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Садржај: Максимални домет радара одређен је укупном израченом енергијом, што изискује коришћење дужег радарског импулса. Међутим, дужи импулс повећава и слепу зону радара. У овом чланку предлаже се радар/сонар заснован на облику сигнала са променљивим трајањем, као могућим решењем за превазилажењем проблема слепе зоне. Овакав облик радарског сигнала је добар и са становишта контроле осетљивости по даљини – потребно је мање рефлектоване енергије на ближим растојањима за циљеве исте рефлексне површине. Потрагу за адекватном групом секвенци почели смо од бинарних Баркерових секвенци. Уколико се све Баркерове секвенце дужина од 3 ди 13 искористе као скуп секвенци, абсолутна вредност максималних бочних снопова биће једнака 1, као и код сваке појединачне Баркерове секвенце. Ово јсвојство биће очувано и код кумулативног интегрисања ако се секвенце поређају према предзнаку бочних лобова, водећи рачуна да се бочни снопови аутокорелационих функција узастопних секвенци поништавају. Ова идеја може се посматрати и као нови метод за потискивање бочних снопова компресионог филтра, будући да је резултат -32,6 dB бољи од било којег поступка потискивања бочних снопова за појединачне Баркерове секвенце.

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