IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 6, Issue 9, September 2018

Generation and Digital Correlation of Barker Code for Radars and Communication Systems

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Abstract: The recent advances in semiconductor technology allow the realization of low cost hardware architecture for implementing the correlation codes, Barker and Taylor codes, with different lengths. There are many types of modulations used for pulse compression, but two that have seen wide applications are the Linear Frequency Modulation (LFM) and the phase-coded pulse. In this paper, we investigated the second one by the design of Barker code generator circuit using two different configurations. This is very important for modern radar transmitters and communication systems. Such codes enable the design of pulse compression circuit in sophisticated receivers to make use of their benefits in improving the resolution in angles and range as well as enhancement of signal to noise ratio(S / N) . In addition, we addressed the design of 7-bit digital correlator to focus on its correlation property. It is interesting to go beyond the theoretical study and analysis by applying the package of simulation to shed the light on all the details in time domain. Specifically, the binary phase variations (0, π) between the modulating signal ,correlation codes, and the carrier signal. Taylor code ,double Barker code of length: 26, has good autocorrelation properties and we have found it with low cross- correlation. Therefore it is suitable in multi-user environment and to encode the carrier signal of long duration for transmitted pulses. Its combination with Barker code of length:13 leads to form different operating modes which is applied to fire control and early warning radars. Also it keeps constant side lobe level with low value which alleviates the effect of undesired received signals.

Keywords: Barker Code Generator; Taylor Code; Auto Correlation Function; Digital Correlator; Phase coding; Pulse Compression

I. INTRODUCTION

Pulse compression allows a radar to utilize a long pulse to achieve large radiated energy, but simultaneously to obtain the range resolution of a short pulse. Two analog compression techniques are analyzed in [1-3]. The first one is known as correlation processing which is dominantly used for narrow band and some medium band radar operations. The second one is called stretch processing and is normally used to extremely wide band radar operations. The presence of a Barker sequence can be optimally detected using correlation [1,3], which is the process of multiplying bit by bit the received sequence to the reference Barker code sequence at a given alignment and summing the result of the multiplications (multiply and accumulate). With a Barker sequence, you will get maximum correlation when the received sequence and reference sequence are aligned, and near 0 for all other shifts. Depending on the noise resistance desired, longer codes can be chosen, and/or code sequences can be repeated as for Taylor codes. As in our case of study, the Barker code 1010110011111 and the Taylor code can be represented as a binary sequence of length 26 bits 11001100111100001111111111. As an easy way to explain the correlation, multiply, we replace all the 0's in the sequence with -1, and all 1's in the sequence with +1. An example that illustrates the use of autocorrelator to identify a hidden periodicity in an observed physical signal is analyzed in [4]. In pulse compression technique, the transmitted signals frequency or phase modulated and the received signal is processed using a specific filter called "matched filter". A matched filter is a linear network that maximizes the output peak-signal to noise ratio of a radar receiver which in turn maximizes the detect ability of a target [3]. There are several methods of pulse compression that have been used in the past. The most popular of them is frequency codes: (LFM-Costas) [1,3,6] and the phase codes (Binary phase code or Barker code and Polyphase codes: Frank, P1, P2, P3, P4 [5]). Golay complementary sequences are pairs of binary codes belonging to a bigger family of signals called complementary pairs, which consists of two codes of the same length ***n***, whose auto-correlation functions have side-lobes equal in magnitude but opposite in sign. Summing them up results in a composite autocorrelation function with a peak of ***2n*** and zero side-lobe [7].

This paper is organized as follows: the incoming sections deal with the Barker code generator of length 13-bit in section II. The analysis and simulation of digital correlator using Matlab and Multisim-14 in section-III. Simulation results in section IV. and concluding remarks in section V.

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II. GENERATION OF BARKER CODE

The design steps of the Barker code generator can be disseminated as following: a) As the 5V power is switched on (start-up time), the capacitor shorts to ground to set or reset the D-FF through the Preset and Clear terminals respectively. Therefore, each bit of the intended **code is** stored into the corresponding bit memory cell (D-FF) according to the states 1 &2 in table-1. These states are considered asynchronous mode of operation, i.e. logic zero at either the preset or clear inputs sets or resets the outputs regardless of the levels of the other inputs. b) In the steady state, the capacitor charges to the value of 5V, the preset and clear inputs become high, logic 1. Then, the data of D outputs are transferred between them at the positive-going edge of the incoming clock pulse. This mode of operation is called synchronous mode and is demonstrated in states 4 &5 of table-1. c) The feedback connection between the output of last memory cell and input one to rotate the generated code for obtaining periodic structure. In addition to this proposed design for code generation, we have discussed another structure for the design of 7 bit code generator (-+--+++) using linear feedback shift register LFSR [18].

Table:1 Truth table of SN7474.

Inputs					Outputs	
State	$\overline{Preset}$	$\overline{Clear}$	CLK	D	Q	$\overline{Q}$
1	**L**	**H**	**X**	**X**	**H**	**L**
2	**H**	**L**	**X**	**X**	**L**	**H**
3	**L**	**L**	**X**	**X**	**H^+**	**H^+**
4	**H**	**H**	↑	**H**	**H**	**L**
5	**H**	**H**	↑	**L**	**L**	**H**
6	**H**	**H**	**L**	**X**	Q_o	$\overline{Q}_0$

III. DIGITAL CORRELATION

Correlation is useful in real-world scenarios [1-4,8-10]. There are, in fact, many practical applications for correlation. Here we focus on two of them:

a) **Radar engineering:** Correlation can help determine the presence of a target and its range from the radar unit. When a target is present, the signal sent by the radar is scattered by it and bounced back to the transmitter antenna after being highly attenuated and corrupted by noise. If there is no target, then the signal received will be just noise. Now, if we correlate the arriving signal with the signal sent, and if we obtain a peak at a certain point, then we can conclude that a target is present. Moreover, by knowing the time-delay (indicated by the time-instant at which the correlated signal exhibits a peak) between the sent and received signals, we can even determine the distance between the target and the radar. .

b) **Interpreting digital communications through noise:** As demonstrated above, correlation can aid in digital communications by retrieving the bits when a received signal is corrupted heavily by noise. Here, the receiver correlates the received signal with two standard signals which indicate the level of '0' and '1', respectively. Now, if the signal highly correlates with the standard signal which indicates the level of '1' more than with the one which represents '0', then it means that the received bit is '1' (or vice versa).

The matched filter receiver [4,11,12,17] or digital correlator circuit is shown in Fig. 5. It consists of six stages of unit delay (D-FF), seven gain multipliers representing the stored sequence (+++--+-) of the filter coefficients and summing amplifier. The output stands for the autocorrelated signal ,compressed pulse, obtained from the convolution between the input (-+--+++) and stored sequences is investigated in Fig. 7. Such pulse improves the resolution in range between the detected targets [11, 13-15]. The autocorrelation process of discrete time signal $x(n)$ can be computed as following:

$$R_{xx}[m] = \sum_{n=-\infty}^{n=\infty} x(n)x(n-m)$$

The seven bit Barker code generator is depicted in Fig.4. Barker codes can be combined to generate much longer codes [1]. In this case, a B_m code can be used within a B_n code (m within n) to generate a code of length mn. The compression ratio for the combined B_{mn} code is equal to mn. These Combined Barker codes are very useful as relatively long binary signals with good correlation properties. Although a larger compression gain is achieved, the peak side lobes are not proportionally decreased. For the testing purpose of simulation, we illustrate two types of digital pulse compression techniques based on phase coding a) Binary phase (0, π) code or Barker code and b) Compound Barker codes B_{45} and B_{54} with their bit sequences shown in the following tables.

Table 2: Combined Barker code B_{45}

N=5 Barker code (frame)	+	+	+	-	+
N=4 Barker code	++-+				
4x5 Barker code B_{45}	++-+	++-+	++-+	--+-	++-+

Table 3: Combined Barker code B_{54}

N=4 Barker code (frame)	+	+	-	+
N=5 Barker code	+++-+			
5x4 Barker code B_{54}	+++-+	+++-+	---+-	+++-+

IV. SIMULATION RESULTS

The software simulation packages applied to emphasize our analysis are Multisim-14 and Matlab-2015. The general block diagram for the pulse compression technique applied to modern pulse radars is shown in Fig. 1 to clarify that the frequency and phase modulation processes are highly required for the transmitters being used. The results of autocorrelation functions of the combined Barker codes B_{45} and B_{54} are illustrated in Fig.2. The compression ratio is equal to 20. Unfortunately, the side lobes of combined Barker code are no longer equal to unity. The maximum side lobe level values become 4 and 5 for these codes. This is in opposite to that of Barker code of length 13 and Taylor with length 26 which have the peaks of the main lobes (13, 26) and the side lobe levels of (1, 2) respectively as shown in Fig. 3. Therefore the matched filter receiver should be followed by a side lobe reduction filter (linear transversal filter) to have zero side lobe level in case of B_{45} and B_{54} codes. We apply the phase coding process in our work using Taylor code to cope with applying such filter. Two Barker codes of lengths 7, 13 bits are represented in Figures 4 and 6 by

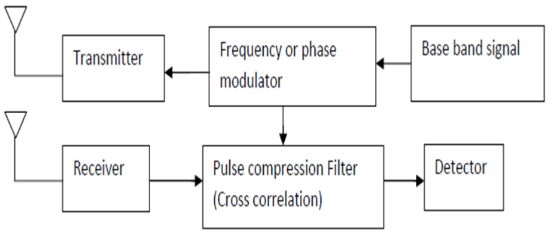
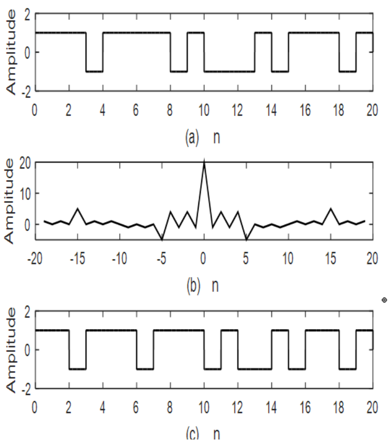
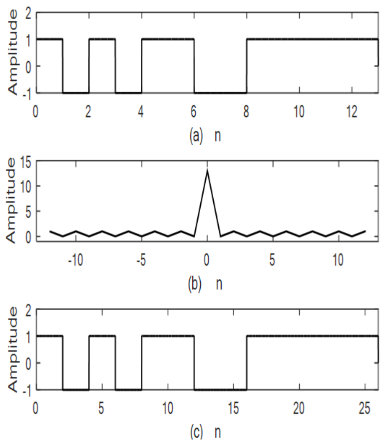


Fig. 1 General block diagram of pulse compression.





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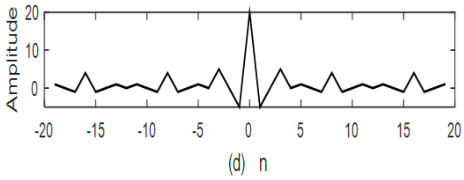


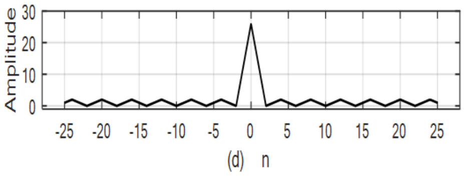


Fig. 2: depicts the combined Barker codes and their autocorrelation functions as following:
(a) Combined Barker code B_{54} of length 20 bits
(b) Autocorrelation function of code in part (a).
(c) Combined Barker code B_{45} of length 20 bits.
(d) Autocorrelation function of code in part (c).

Fig. 3: depicts the Barker and Taylor codes and their autocorrelation functions as following:
(a) Barker code of length 13 bits
(b) Autocorrelation function of code in part (a).
(c) Taylor code of length 26 bits.
(d) Autocorrelation function of Taylor code in part (c).

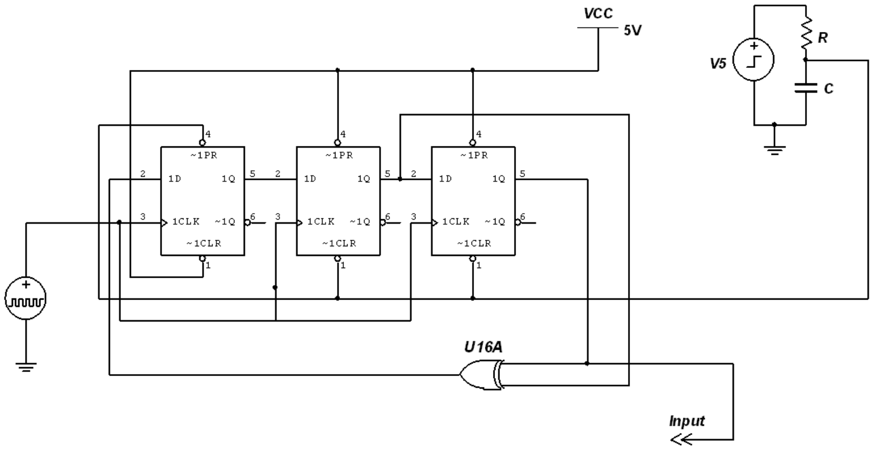


Fig.4 7 bit Barker code generator circuit using linear feedback shift register with 3 stages.

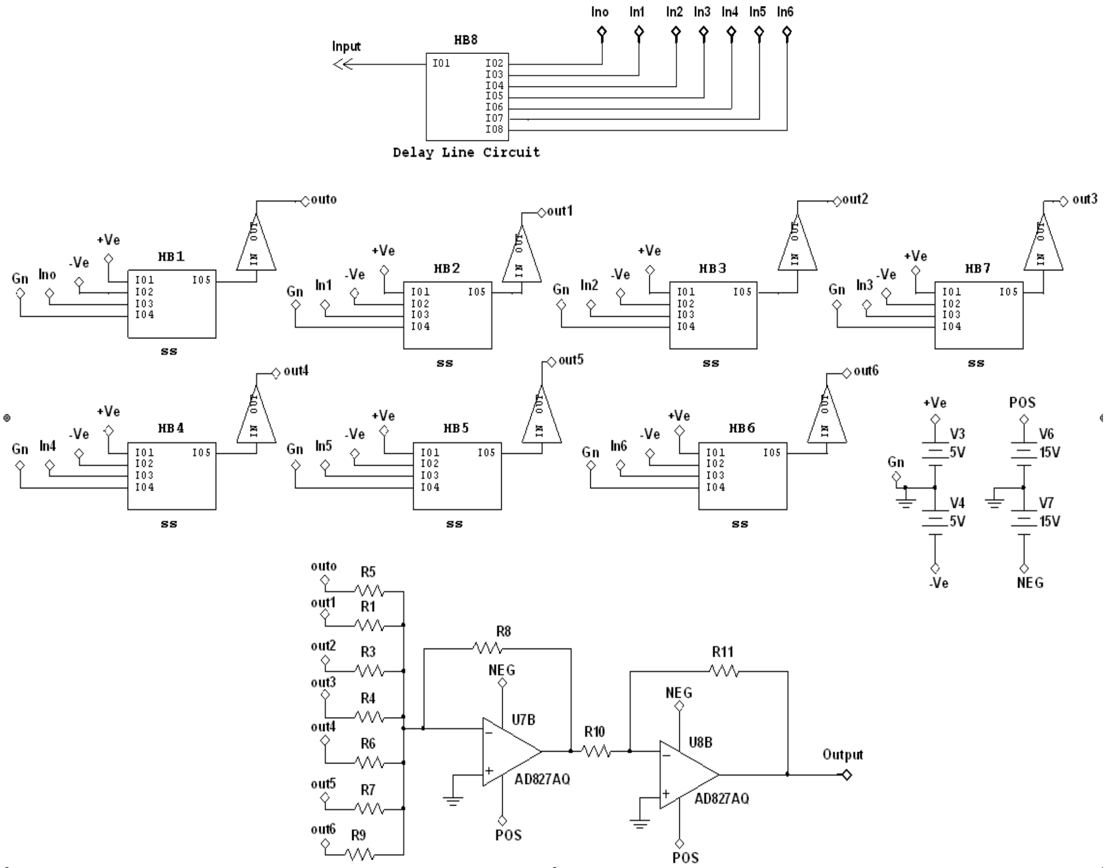


Fig. 5 Digital correlator circuit of 7-bit Barker code

ISSN (Online) 2321-2004
ISSN (Print) 2321- 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 6, Issue 9, September 2018

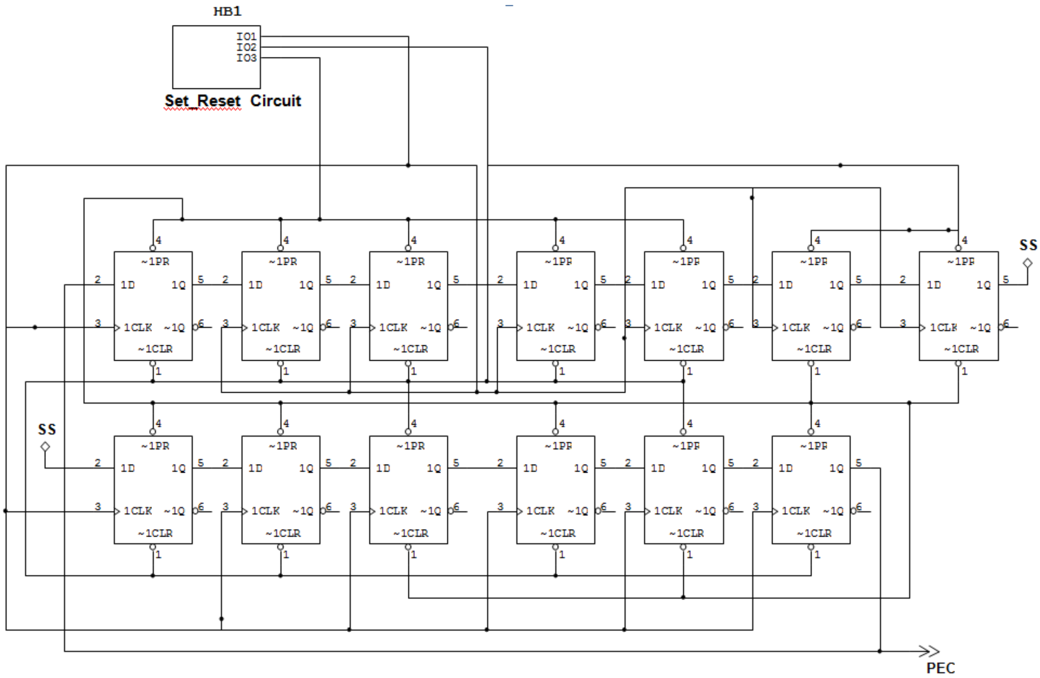
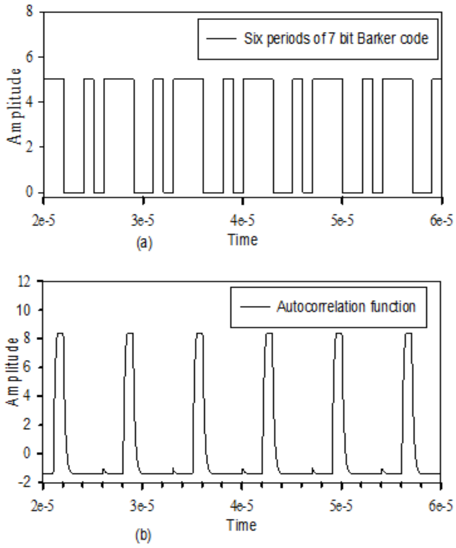


Fig.6 Barker code generator with length 13 bit (+-+-++--+++++)



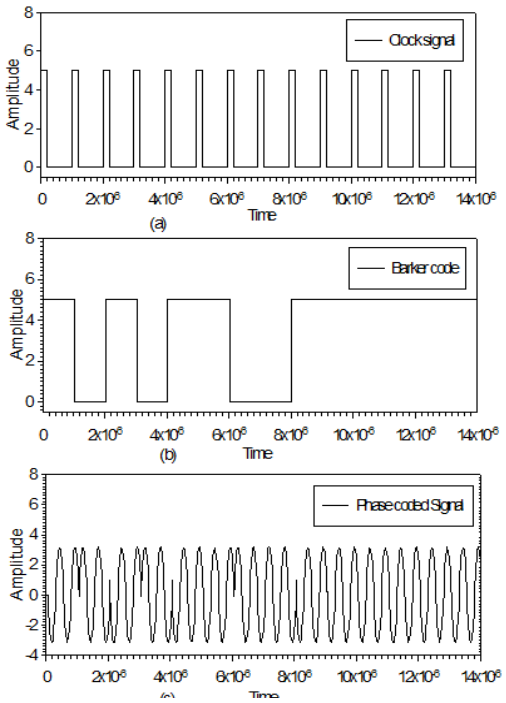


Fig. 7 illustrates

(a) Six periods of 7 bit (+++--+-) Barker code.
(b) Autocorrelation function (output of digital correlator) for the input sequence in part (a).

Fig. 8 illustrates

(a) Clock signal with frequency 1 MHz.
(b) Barker code with length 13 bits.
(c) Phase coded Signal with frequency 2 MHz.

using different structures as explained in section II. Fig. 5 depicts the digital correlator circuit to show how the correlation process can be accomplished and to minimize the effect of the undesired signals received from the side lobes. Six periods of 7 bit Barker code and associated correlation process are elaborated in Fig. 7. Fig. 8 describes the phase encoded signal with frequency of 2MHz, clock signal having frequency 1MHz and the Barker code of length: 13µs.

DOI 10.17148/IJIREEICE.2018.691

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321- 5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 6, Issue 9, September 2018

V. CONCLUDING REMARKS

We present analysis and simulation of Barker code generator of lengths 7 and 13 bits using two different representations. A digital correlator circuit or matched filter receiver of 7 bit Barker code is described. In this simulation, the received signal is compared to matched filter impulse response for correlation. For the targets, to be resolved in range, the basic criterion is that targets must be separated at least in the range equivalent of the width of the processed echo pulse. In addition, it is shown that the application of Taylor code avoids the unwanted signals or False alarm by using a threshold level greater than that of the side lobe level especially we still have a large processing gain. Two additional advantages obtained from the combination of both Taylor code (length: 26) and Barker code (length: 13) can be summarized as follows: a) Ability to control the transmitted power to be radiated in different operating modes. b) Ease of the design and implementation of frequency agility technique with randomly varied carrier frequency from pulse to pulse. Consequently, this exhibits superior performance compared to the conventional fixed carrier frequency against the electromagnetic interference. This confirms that at the present time and in the future the Barker and Taylor codes can be successfully used in modern pulse radars.

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BIOGRAPHY

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