Non-Linear Frequency Modulated Nested Barker Codes with improved Range Resolution

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ABSTRACT
Range resolution is an important factor for target detection in radar. Pulse compression techniques are used to achieve high range resolution. Pulse compression techniques such as nested barker codes which are also known as bi-phase codes are used for phase modulation. In this paper Linear frequency modulation(LFM) andNon linear frequency modulation (NLFM) codes are used to modulate the nested barker codes for reducing the side lobes which finally results in producing good range resolution. Using LFM in nested barker codes will decrease the main lobe width but results in producing the grating lobes in the delay axis of autocorrelation function. This paper proposes nested barker codes with NLFM which allows toreduce the grating lobes along with the side lobes for achieving high range resolution. Furthervarious lengths of Non-Linear frequency modulated nested barker codes PSLR and ISLR values are tabulated with the help of Ambiguity functions.
KEYWORDS: Nested Barker codes, Pulse compression, Peak side lobe ratio, Range resolution, Auto correlation function, Grating lobes, Side lobes and Non-linear frequency modulation.

I. INTRODUCTION

In the radar signal processing, waveform design plays major role. The target range and Doppler resolution depends on the radar waveform. In the waveform design, pulse compression techniques are being implemented for better resolution and accuracy measurements of range and velocity of targets[1-2].

Modern radar systems uses pulse compression technique to get high energy of long pulse with high resolution of short pulses. Pulse compression is achieved by either phase modulation or frequency modulation. The frequency modulation can be performed in two types, if the frequency varies linearly with respect to frequency is called linear frequency modulation and if the frequency varies non linearly it is called non linear frequency modulation.In case of phase coded pulse compression, entire long pulse is divided into sub pulses. In general, at receiver the echo signal is processed through a matched filter to improve signal to noise ratio and the output is aperiodic autocorrelation function of received signal. Depending upon the side lobe levels and main lobe width the range resolution can be determined. When the grating lobes appeared in auto correlation function it may mask the weaker targets. When the side lobes, grating lobes levels are suppressed [3] weaker target echoes can be easily identified from the stronger echoes. By changing the amplitude and phase of multi-level bi-phase pulse compression codes, side lobes are lowered but it has energy loss. Barker codes are used in phase modulation for pulse compression and these codes are limited lengths. Nested Barker codes[4] are constructed by two barker codes using product of two Kronecker functions to increase the length of the code.
Thus Range resolution can be improved by reducing the grating lobes, main lobe width and side lobe levels. When the length of barker codes is increased the range resolution can be improved. Suppressing the grating lobes is also one of the main criteria for increasing the range resolution hencean NLFM is introduced in the nested barker codes. When nested barker codes are modulated by non-linear frequency modulated codes, the level of the side lobes is decreased and peak side lobe ratio is improved without the loss of signal to noise ratio.

II. BARKER CODES

In pulse compression, barker codes are used for phase modulation. Barker codes are also known as Bi-phase codes. The autocorrelation function of barker code of length N with sequence $x_1,x_2,x_3 .... x_N$ is given by

$$R(k) = \sum_{n=1}^{N} X_n X_{n+1} (1)$$

Where k= - (N-1)……+ (N-1)

The maximum length of the barker codes is 13 and these are the perfect codes. The ratio of main lobe to the side lobe level in the autocorrelation will give the length of the barker code. All the side lobes present in its autocorrelation are '1' and '-1'.

INTEGRATED SIDE LOBE RATIO

Integrated side lobe ratio is defined as the ratio of energy in the side lobes to the energy in the main lobe of autocorrelation function and it's mathematical representation is given as

$$ISLR(dB) = 10\log_{10} \frac{\sum_{k=1}^{N-1} |R(k)|^2}{|R(0)|^2} (2)$$

where R(0) is the main lobe level and R(k) is the maximum side lobe level among all sidelobes.

PEAK SIDE LOBE RATIO

Peak side lobe ratio[5] is defined as the ratio of absolute maximum among the side lobes to the main peak level in the autocorrelation function and its mathematical representation is given as

$$PSLR(dB) = 20\log_{10} \frac{max_{1<k<N}|R(k)|}{|R(0)|} (3)$$

Whenever the received signal is matched with the transmitted waveform, then the matched filter output becomes maximum. This is the cross correlation between the received signal and the transmitted signal. Mathematically it is represented as

$$Output=\int_{-\infty}^{\infty} s(t)s_r^*(t-\tau)dt \qquad (4)$$

Where $s_r(t)$ is the received signal, s(t)is the transmittedsignal, the asterix denotes complex conjugation, and -r is the time delay.The transmitted signal can be expressed as

$$S(t)=u(t)e^{j2\pi f_0 t} (5)$$

Where u(t)is the complex modulation and f_o is the carrier frequency. The received signal is assumed to be the same as the transmitted signal except for the time delay τ_o and a Doppler frequency shift and it is given as

$$Sr(t)= u(t-\tau o)e^{(j2\pi(f+v)(t-\tau o))} (6)$$

The output can be determined by substituting equations(5)and(6) into(4). It is customary to set τ =0 (that is, to "center" the filter response at the target delay) and to set f_0=0 (that isto removetheeffectofcarrierandconsider the situation atthebaseband).Assigningthesymbolχ torepresentthematchedfilteroutput,

$$\chi(\tau,v)=\int_{-\infty}^{\infty} u(t)u^*(t-\tau)e^{j2\pi vt}dt (7)$$

The equation(8) is the matched filter response, χ (τ, v), is obtained by correlating a signal with its Doppler-shifted and time shifted version, that is χ(τ, v) is the two dimensional correlation function in delay and Doppler. The magnitude |χ (τ, v)| is called the ambiguity function that is given as

$$|\chi(\tau,v)|= \int_{-\infty}^{\infty} u(t)u^*(t-\tau)e^{j2\pi vt}dt \ (8)$$

Discrimination Factor and PSLR (dB) for all Barker codes are shown in table 1. It shows, maximum length of the barker code is 13 and corresponding PSLR is -22.3 dB. The minimum PSLR required for good range resolution is -30 dB.

Table 1: Different Lengths of Barker Codes with PSLR and Discrimination

Code length	Codes	Discrimination factor	PSLR(dB)
2	1 -1, 1 1	2	-6.0
3	1 1 -1	3	-9.5
4	1 1 -1 1, 1 1 1 -1	4	-12.0
5	1 1 1 -1 1	5	-14.0
7	1 1 1 -1 -1 1 -1	7	-16.9
11	1 1 1 -1 -1 -1 1 -1 -1 1 -1	11	-20.8
13	1 1 1 1 1 -1 -1 1 1 -1 1 -1 1	13	-22.3

III. NESTED BARKER CODES

The known Barker Codes are only suitable for relatively short transmission pulses, as they are limited to a length of 13 code elements. The Nested Barker code can be implemented by nesting of two barker codes.It gives an improvement in Peak side Lobe Ratio(PSLR) compared to the Barker codes.Nested Barker codes can be obtained by using the Kronecker product of two barker codes.If an N-bit Barker code is denoted by BN and anotherBM,then an MN bit code can be constructed as BN⊗BM. The Kronecker product is simply the BM code repeated N times, with each repetition multiplied by the corresponding element of the BN code. For example, a 33 bit code can be constructed as the product B3⊗B11.These codes have a peak sidelobes greater than 1.The nested codes of length 33, 77 and 169 are shown below.

Nested Barker code 33(3⊗11)=

1	1	1	-1	-1	-1	1	-1	-1	1	-1
1	1	1	-1	-1	-1	1	-1	-1	1	-1
-1	-1	-1	1	1	1	-1	1	1	-1	1

Nested Barker code 77(7⊗11)=

1	1	1	-1	-1	-1	1	-1	-1	1	-1
1	1	1	-1	-1	-1	1	-1	-1	1	-1
1	1	1	-1	-1	-1	1	-1	-1	1	-1
-1	-1	-1	1	1	1	-1	1	1	-1	1
-1	-1	-1	1	1	1	-1	1	1	-1	1
1	1	1	-1	-1	-1	1	-1	-1	1	-1
-1	-1	-1	1	1	1	-1	1	1	-1	1

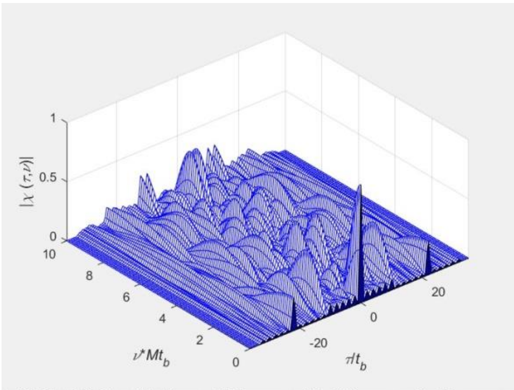
Nested Barker code 169(13⊗13)=

1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
-1	-1	-1	-1	-1	1	1	-1	-1	1	-1	1	-1
-1	-1	-1	-1	-1	1	1	-1	-1	1	-1	1	-1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
-1	-1	-1	-1	-1	1	1	-1	-1	1	-1	1	-1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1
-1	-1	-1	-1	-1	1	1	-1	-1	1	-1	1	-1
1	1	1	1	1	-1	-1	1	1	-1	1	-1	1

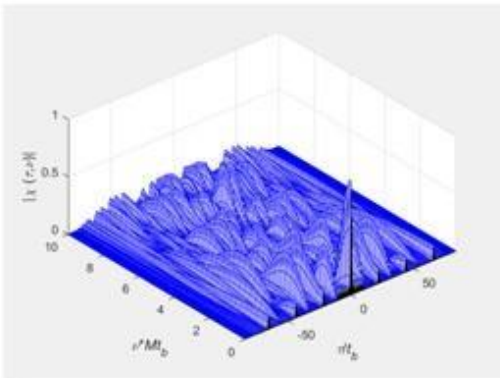
AUTOCORRELATION OF NESTED BARKER CODES

The pulse compression results in the appearance of range sidelobes on either side of the main lobe, the level of which lies in the range between ‘13/169’ and ‘0’ and the maximum main lobe level is 169 for nested Barker code of length 169 (13 $\otimes$13).In 33 length code, every 11thsidelobe height in ACF is 11 andmainlobe height is 33. PSLR is -11dB.For 77 length code every 11thsidelobe height in ACF is 11 and mainlobe height is 77. PSLR value achieved for 77 length code is -17.3dB. In 169 length code every 13thsidelobe height is 13 and PSLR is -20.3dB.

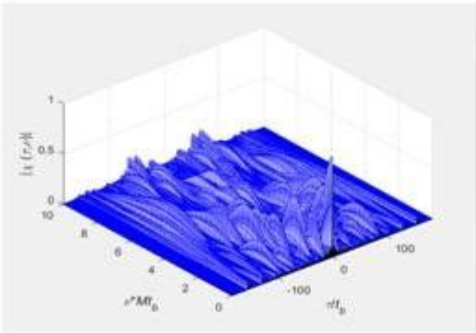
The Nested Barker sequences are perfect only in the time domain i.e. for Zero Doppler shift. In presenceof Doppler shift, the output of the matched filter reduces rapidly, so the ambiguity function does not approach the ideal thumbtack, which is essential for good range and Doppler resolution. If the length of barker code is increased using modulation techniques PSLR and ISLR values are also improved. The PSLR and ISLR values for different lengths of nested Barker codes are tabulated in table 2 and corresponding Ambiguity plots are shown in Figure 1 (a-c).



(a)



(b)



(c)

Fig.1.Ambiguity plots for Nested Barker code of length (a) 3⊗11, (b) 7⊗11, (c) 13⊗13

IV. NESTED BARKER CODES MODULATED BY LFM

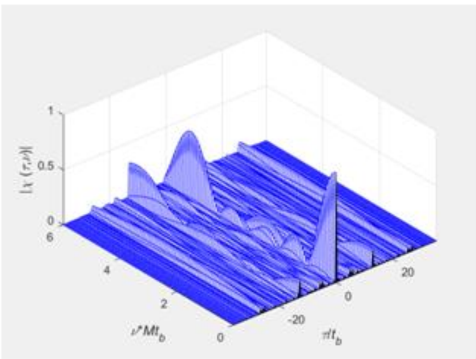
Linear frequency modulation[6-7] improves the range and doppler resolution in radar. In LFM, the frequency of the carrier varies linearly with time over a specific period.LFM is mostly used in pulsed and CW radars.Here A is amplitude and it is a constant.it also spreads the energy widely in frequency domain and it is represented as

$$X(t)=A\cos(W_0+kt^2) \quad (9)$$

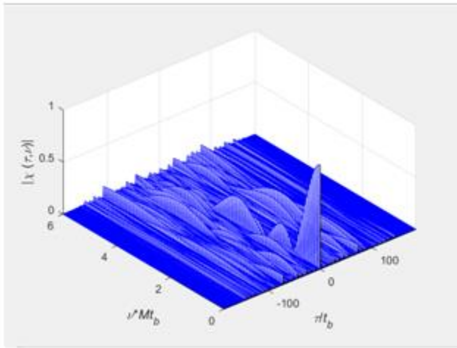
The carrier signal used in LFM is

$$\mathrm{Cos}(2\pi f_c+kt^2)(10)$$

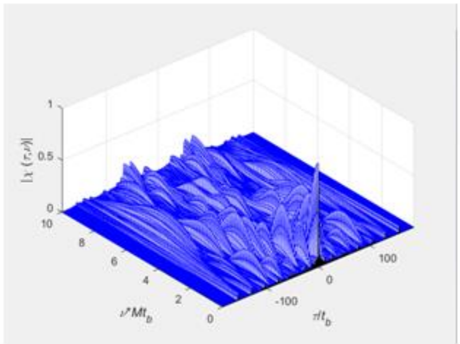
By using the linear frequency modulation(LFM) method in nested barker codes, the bandwidth is increased.When nested barker codes undergoes LFM,the main lobe width has been reduced but consists of grating lobes in the time delay axis.Due to which the smaller target echoes are masked.PSLR and ISLR values of different length LFM nested barker codes are tabulated and their corresponding ambiguity plots are shown below.When compared to nested barker codes,the PSLR and ISLR values of LFM nested barker codes are improved.



(a)



(b)



(c)

Fig.2.Ambiguity plots for Nested Barker code with LFM of length (a) 3⊗11, (b) 7⊗11, (c) 13⊗13

V. NESTED BARKER CODES MODULATED BY NLFM

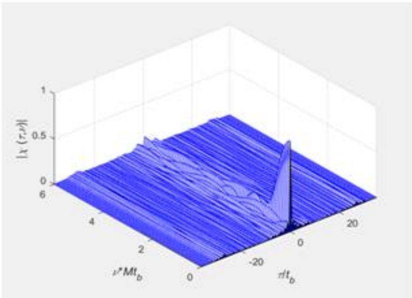
In LFM modulated nested barker codes, grating lobes are present which masks the echoes of weaker targets. So, to reduce those grating lobes introduce NLFM in nested barker codes[8] which helps in improving the range resolution. In Non linear frequency modulation the frequency varies non-linearly with time. Now the nested barker codes are modulated with non linear frequency codes and the NLFM is expressed as

$$X(t)=A\cos(W_0+kt^2+kt) \qquad (11)$$

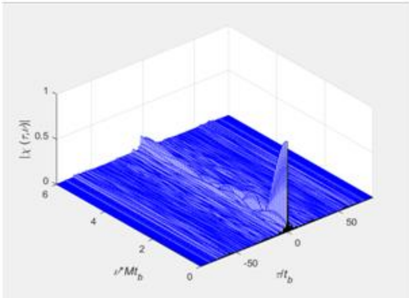
Here A indicates the amplitude which is a constant value and the carrier of NLFM is represented as

$$\mathrm{Cos}(2\pi f_c+kt^2+kt)(12)$$

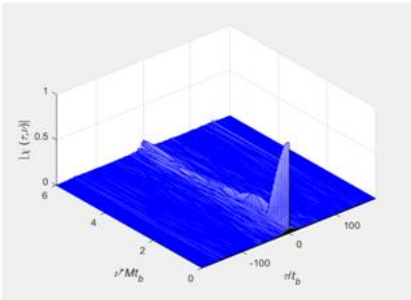
PSLR and ISLR values of different length NLFM nested barker codes are tabulated and their corresponding ambiguity plots are shown below. When compared to LFM modulated nested barker codes, the PSLR and ISLR values of NLFM nested barker codes shows the better results



(a)



(b)



(c)

Fig.3.Ambiguity plots for Nested Barker code with NLFM of length (a) 3⊗11, (b) 7⊗11, (c) 13⊗13

Code length	Nested Barker code		LFM Nested Barker code		NLFM Nested Barker code	
	PSLR(dB)	ISLR(dB)	PSLR(dB)	ISLR(dB)	PSLR(dB)	ISLR(dB)
33 (3 ⊗11)	-10.95	-6.218	-15.46	-10.23	-17.74	-12.17
77 (7 ⊗11)	-17.27	-7.42	-19.37	-10.81	-19.75	-12.68
169(13 ⊗)	-20.35	-8.3	-20.778	-12.34	-24.36	-13.07

Table 2: PSLR and ISLR values for various nested barker codes

VI. CONCLUSION

The improvement in range resolution can be achieved by reducing the main lobe width, grating lobes and the side lobes in the ambiguity function.By using Linear frequency modulation codes in nested barkercodes the main lobe width has been reduced and PSLR,ISLR values are also improved compared to that of nested barker codes. But grating lobes are present in the time delay axis which masks the weaker targets.So, to supress those grating lobes NLFM is introduced in nested barker codes which are not only reduces grating lobes but also improves the PSLR and ISLR values compared to that of the LFM nested barker codes. Hence Nested barker code with NLFM shows better results in terms of reduced side lobes, grating lobes and main lobe width to improve range resolution of the RADAR.

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