Evaluation of Radar Performance with Different Waveform Libraries

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***Abstract*– In Radar, the functions such as target detection, and the measurement of different parameters largely depends on transmitted waveform. The selection of waveforms indicates the performance of Radio Detection and Ranging (RADAR) system. These waveforms help to discriminate between two targets, which are closely spaced in range or traveling near to each other by the same speed. In Radar, the range is associated with delay and speed by associated with the doppler shift. In this paper, Fractional Fourier Transform (FRFT) and Frank code/Barker code is used to generate rotatable waveforms. The performance parameters such as delay resolution, doppler resolution, delay side lobe and doppler side lobe are compared using an ambiguity function.**

Keywords— Fractional Fourier Transform (FRFT), Ambiguity Function (AF), Waveform (WF), side lobe level (SLL).

I. INTRODUCTION

Radar operation is based on transmission and reception of signals for two tasks detecting target and determining range and speed of the target. Many advanced technologies have been invented in field of radar. The environment in which radar operates today is very hostile due to various interferences noises and clutters.

The Radar waveform is responsible for the many things such as accuracy, resolution, and ambiguity of determining the range and radial velocity (range rate) of the target. Range is associated with the delay of the signal received. Range rate is associated with the doppler shift of the received signal.

The performance of radar is specified in terms of delay resolution, Doppler resolution and delay side lobe level and Doppler side lobe level. [1]

These parameters are modified by the use of compression of radar pulses using different codes such as Frank code and Barker code. Modern radar systems use waveform libraries to sense the environment. So the transmitted waveforms are chosen for improvement. [2]

There are several methods such as Mutual Information Method, Orthogonal Frequency Division Multiplexing Method (OFDM), and Fractional Fourier Transform method are used to generate waveform libraries for radar [3-5]. Recently FRFT method has attracted the attention of researchers. This paper discusses the use of FRFT for generation of waveform libraries.

This paper is organized as follows. Section II describes briefly use of FRFT to generate waveform library. Section III defines the ambiguity function for analysing the generated waveform performance. Section IV discusses the performance in terms of various performance parameters

II GENERATION OF WAVEFORMS

A.FRFT and Equations

The idea of FRFT was suggested by Namias [6].In this concept, θ is used to compute FRFT in the plane specified by time and frequency. This θ is called an axis rotation angle. For the ordinary Fourier transform,θ is the fractional power.

For the generation of waveform library using FRFT, the number of chips (called as Ω) is used in a code sequence. One of the necessary component for calculation is the number of samples per chip(r) of a sequence. Thus by using Ω and r, the total length of a digital signal can be calculated as: N=Ω * r. If there are N samples of the original waveform (e.g. the traditional Barker 13 code), then c = [c_1, c_2, c_N] is the vector of N samples. The resulting waveform W[n], can be defined as

$$W[n] = \sum_{k=1}^{N} ck\delta[n-k] \quad (1)$$

In equation (1), δ called as the Impulse function. Thus by using FRFT to (1) and using the properties, a fractional waveform Wα can be given as:

$$W\alpha\,[u] = \sum_{k=1}^{N} ckFRFT\alpha\delta[n-k] \quad (2)$$

Then Wα[u] is given as follows

$$W_\alpha[u] = \sqrt{\frac{1-jcot\theta}{2\pi}} \sum_{k=1}^{N} c_k e^{\frac{j(k^2+u^2)}{2}cot\theta - jukcsc\theta} \quad (3)$$

Where FRFTα [.] represents the Fractional Fourier Transform of the αth order [1]. Different fractional-order x corresponds to different angle as α = x * π /2, and different waveform consist of different angles α.

Therefore a fractional waveform library called as rotating waveform library can be defined as:

W = [Wα1 [u], [Wα2 [u], [Wα L[u]]

Where x ε [0, 1] and L represents the total number of waveforms in the library. L depends on different parameters such as original waveform used, applications of waveform, waveform reuse.

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Equation (2) described as the u^{th} element of Wα[u] as the sum of N chirped functions of the original waveform sequence. The modulation rate of the waveforms depends on rotation angle and sample indicator k. The chirped components number depends on N, and the code cardinality multiplied by the chip sampling rate r gives the value of N. Thus by changing r, different waveforms can be obtained from a given canonical waveform. Detail analysis of generation can be found in [7].

The waveforms generated from the above method are compared with the standard traditional signal and then parameter ratio is find out [1] [2]. The parameter quantitative parameter (parameter ratio) may be outlined by

$$\text{Parameter ratio}=\frac{\text{parameters of waveform in waveform library}}{parameter\ of\ original\ waveform} \quad (4)$$

B Ambiguity Function

To demonstrate the effectiveness of generated waveforms ambiguity analysis is done.

Ambiguity function represents the time response matched to a given finite energy signal when signal is received with a delay τ and a doppler shift f_d relative to nominal values expected by the filter.

For Radar wave shape W (t), AF of wave shape in libraries is outlined as

$$AF(\tau, f_d) = \int_{-\infty}^{\infty} W_\alpha(t)W(t-\tau)e^{-j2\pi f_d t} \quad (5)$$

W (t) represents pulses transmitted and received. The AF shows the range resolution, the range SLL, the doppler resolution, the doppler SLL, the spacing of the doppler ambiguities. [8][9]

AF is a kind of math tool to study and evaluate the waveform performance effectively as it provides the detailed information about the waveform.

III RESULTS AND ANALYSIS

The performance parameters of waveforms are shown in the following table I

TABLE I PERFORMANCE PARAMETERS

Performance Parameters	***Equations***
Delay Resolution	$A_\tau = \frac{\int_{-\infty}^{\infty} \lvert\chi(\tau,0)\rvert^2 d\tau}{\lvert\chi(0,0)\rvert^2}$
Doppler Resolution	$A_\tau = \frac{\int_{-\infty}^{\infty} \lvert\chi(0,fd)\rvert dfd}{\chi(0,0)}$
Delay Side lobe	level of first side lobe is $\lvert \chi(\tau,0) \rvert$
Doppler Side lobe	level of first side lobe is $\lvert \chi(0,f_d) \rvert$

Each performance parameter is analysed on an individual basis for these Barker code and Frank code. The waveform performance in the rotating waveform libraries is analysed based on these parameters.

A. Delay Resolution

Delay resolution is the capability to determine the two or additional targets at totally different ranges. To attain high range resolution without high peak power, pulse compression is required. The Barker code is chosen for performance analysis, as it ends up in equal side-lobes. It has six equal time side-lobes with peak side lobe level (PSLL) of 22.3 dB. Figure 1 indicates the simulation results of Delay resolution using barker code.The number of samples per chip are considered as 100,200 and 300. This figure 1 shows the variation of Parameter ratio versus Fractional order .The parameter ratio is calculated using Equation 4.

This Figure 3 plot is plotted by comparing original signal with signal where delay τ=0 and doppler shift f_d=0.

The fractional order is changed from 0 to 0.9 and Parameter ratio is plotted in between 0.2 to 0.55 for more accurate plots. As the Fractional order changes from 0 to 0.9, the rotational angle changes from 0.9, 1.8, 2.7, 3.6, 4.5, and 5.4 and so on. Then by using equation 3 and Table I the analysis is done in Matlab and the results are obtained.

This simulation is performed using Matlab and Communication toolbox.

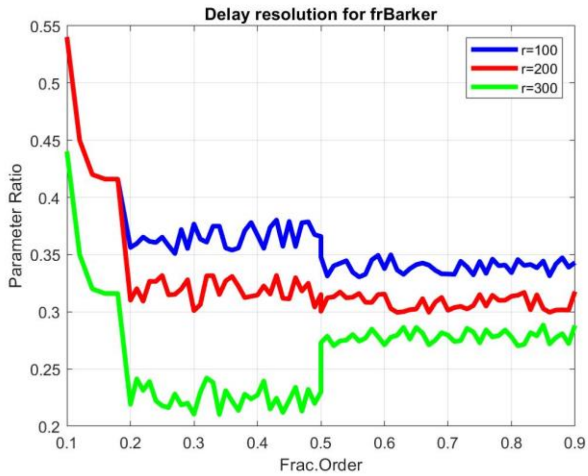

Fig 1 Delay Resolution for Barker 13 code for sampling rate as 100,200 and 300.

TABLE II. DELAY RESOLUTION USING BARKER 13 CODE

Sample rate	***r =100***	***r =200***	***r =300***
Parameter ratio	0.35 to 0.355	0.3 to 0.325	0.21 to 0.24

The results for the above analysis (for x=0.2 to 0.5) in figure 1 can be shown by following Table II.

From Table II, it is clear that as the sampling rate increases from r=100 to r=300, the parameter ratio decreases drastically. That is delay resolution performance is of better-quality with increasing the rate.

Now instead of using Barker code, if Frank code is used for the analysis of delay Resolution, the parameter ratio is changed drastically. The following figure 2 shows the

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analysis of Delay Resolution using Frank16 code for sampling rates 100,200 and 300.

If the observations(x=0.2 to 0.5) are analysed, then the findings can be explained by Table III.
For sample rate r=300, for fractional order of 0.2< x < 0.5$, the parameter ratio is much healthier as compared to r=100 and r=200.i.e.sampling rate r affects the delay resolution.

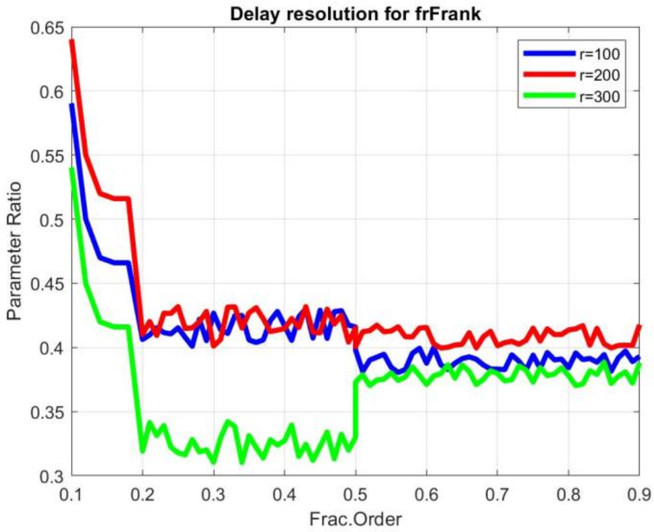

Fig 2 Delay Resolution for Frank16 code for sampling rate as 100,200 and 300.

TABLE III. DELAY RESOLUTION USING FRANK16 CODE

Sample rate	***r =100***	***r =200***	***r =300***
Parameter ratio	0.4 to 0.425	0.4 to 0.425	0.31 to 0.335

B. Doppler Resolution

Doppler Resolution is analysed for different sampling rates for both Barker code and Frank code.

Figure 3 shows Doppler Resolution for Barker code. In the interval 0.3< x<0.6, the doppler resolution upgraded slightly with increasing the order x.

Figure 4 shows the Doppler Resolution performance for frank 16 code for r=100, r=200 and r=300. The waveforms generated by changing the fractional-order x are compared with canonical signal(x= 0), and the parameter ratio is found out.

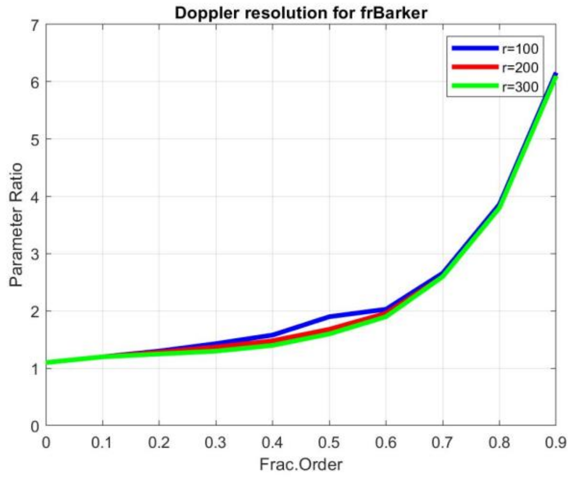

Fig 3 Doppler Resolution for Barker 13 code for sampling rate as 100,200 and 300.

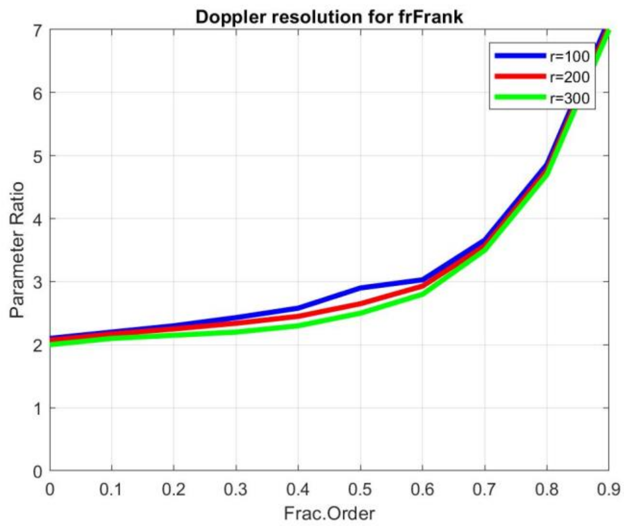

Fig 4 Doppler Resolution for Frank 16 code for sampling rate as 100,200 and 300.

C. Delay Side lobe

The analysis of delay Side lobe for sampling rates of 100,200 and 300 is as per shown in Figure 5

The performance of delay side lobe is lower as compared to original waveform. It is observed that parameter ratio range is increasing as the sampling rates are increased as shown in Table IV.

TABLE IV. DELAY SIDE LOBE PERFORMANCE USING BARKER 13 CODE

Number of samples per chip	***r =100***	***r =200***	***r =300***
Parameter Ratio	0.75 to 1.69	0.8 to 1.75	1.1 to 2

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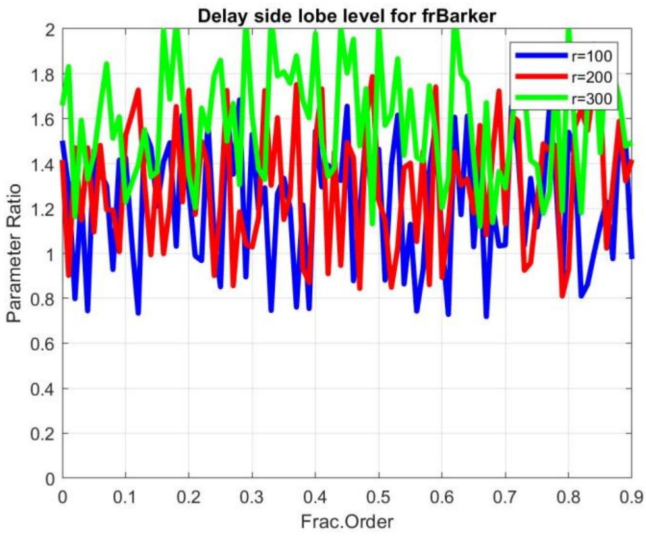

Fig 5 Delay Side lobe for Barker 13 code for sampling rate as 100,200 and 300.

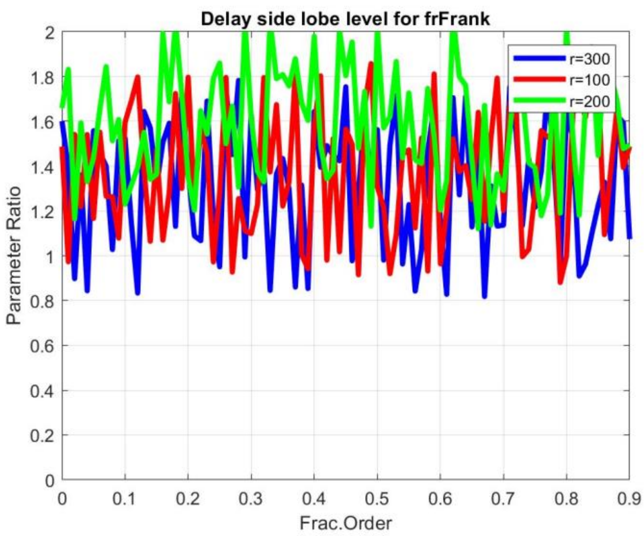

Fig 6 Delay Side lobe for Frank 16 code for sampling rate as 100,200 and 300.

Figure 6 indicates the how parameter ratio changes by changing fractional order and sampling rates for Frank 16 code. The parameter ratio for the delay side lobe changes as the sampling rate is changed from 100 to 200 or to 300.This variations are shown through Table V.

TABLE V. DELAY SIDE LOBE PERFORAMANCE USING FRANK16 CODE

Number of samples per chip	*r =100*	*r =200*	*r =300*
Parameter Ratio	0.9 to 1.85	1.2 to 2	0.8 to 1.8

D. Doppler Side lobe

After analyzing doppler Side lobe for 100, 200 and 300 sampling rates, the results for Barker code are obtained as shown in Figure 7.

For all the sampling rates, the values are almost same, that is the parameter ratio is same, even if the sampling rates are changed.

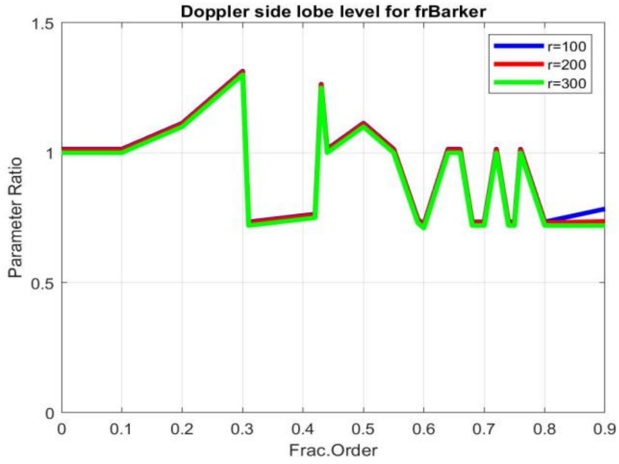

Fig.7 Doppler Side lobe for Barker 13 code for sampling rate as 100,200 and 300.

Figure 8 indicates doppler side lobe for same sampling rate using Frank code. It is verified that after changing the sampling rates, there is no change in parameter ratio of doppler side lobe level.

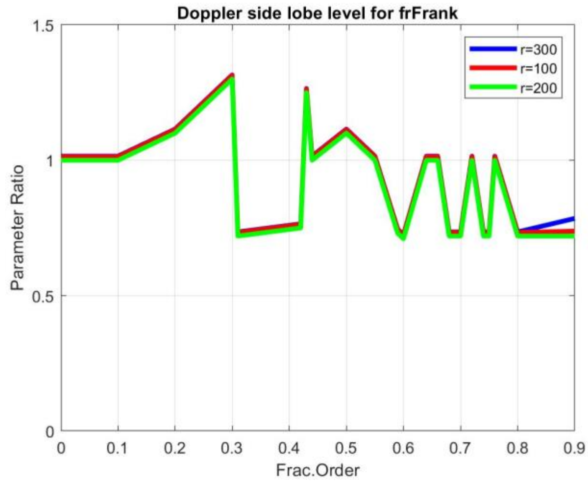

Fig.8 Doppler Side lobe level using Frank 16 code for sampling rate as 100,200 and 300.

IV CONCLUSION

In this project, rotatable waveforms are generated for different fractional order and thus for different angles. Their performance is analysed with the help of ambiguity function Barker code and Frank code.In each simulation, the parameter ratio is find out by comparing it with traditional signal.

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For sample rate r=300, for fractional order of 0.2 to 0.5, the delay resolution performance is improved with Barker 13 code.

For sample rate r=300, for fractional order of 0.2 to 0.5, the parameter ratio is much better as compared to r=100 and r=200 for delay resolution for frank16 code.

For r=300 for fractional order of 0.2 to 0.6 doppler resolution is highly improved as compared to r=100 and 200 with Barker 13 code.

For fractional order of 0.1 to 0.6, doppler resolution is

slightly improved with increasing order with increasing order of sampling rate with frank16 code.

If the delay side lobes are compared with the original waveform, then the performance is lower with Barker code.

After changing sampling rate also, doppler side lobe level remains same for Barker code as well as Frank code.

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