International Journal of Research and Innovation in Applied Science (IJRIAS) |Volume VII, Issue III, March 2022|ISSN 2454-6194

Developing step frequency train waveform for improved range resolution of Target in radar system

UGWU K. I. C, Eke J., Abonyi D. O

Enugu State University Of Science and Technology (Esut), Enugu

***Abstract*: This paper presents the developed step frequency model for high range resolution of target in radar system. The idea behind this research is to improve the detection capability of radar systems through improved step frequency model. This was achieved by transmitting a long linear frequency modulated (LFM) signals in a step-wise pattern, in which the centre frequency of the narrow bandwidth pulses of the transmitted signals are changed step by step and, are synthesized at the receiver to give a time profile characteristics of the target in view. The work was implemented using Matlab and the result of the simulation was carefully analyzed using the Ambiguity function for waveform analysis. It was observed that this waveform model really improved the range or detection index by 98% accuracy.**

***Keywords*: Range, stepped frequency, transmitted signal, Ambiguity function, detection, reflected signal, waveform**

I. INTRODUCTION

Based on several literatures by different authors on radar study and investigation, the waveform design and analysis [1] forms the important part of the radar design. When the radar transmits an electromagnetic signal to a target, the signal interacts with the target and then returns to the radar. The change in the properties of the returned signal reflects on the characteristics of the target. When the target is moving, the carrier frequency of the returned signal will be shifted due to Doppler Effect. The Doppler frequency shift can be used to determine the radial velocity of the moving target. If the target or any structure on the target is vibrating or rotating in addition to target translation, it will induce frequency modulation on the returned signal that generates sidebands about the target's Doppler frequency [2]. However, a long pulse degrades range resolution. Hence, frequency or phase modulation of the signal is used to achieve a high range resolution when a long pulse is required. The capabilities of short-pulse and high range resolution radar are significant [3].

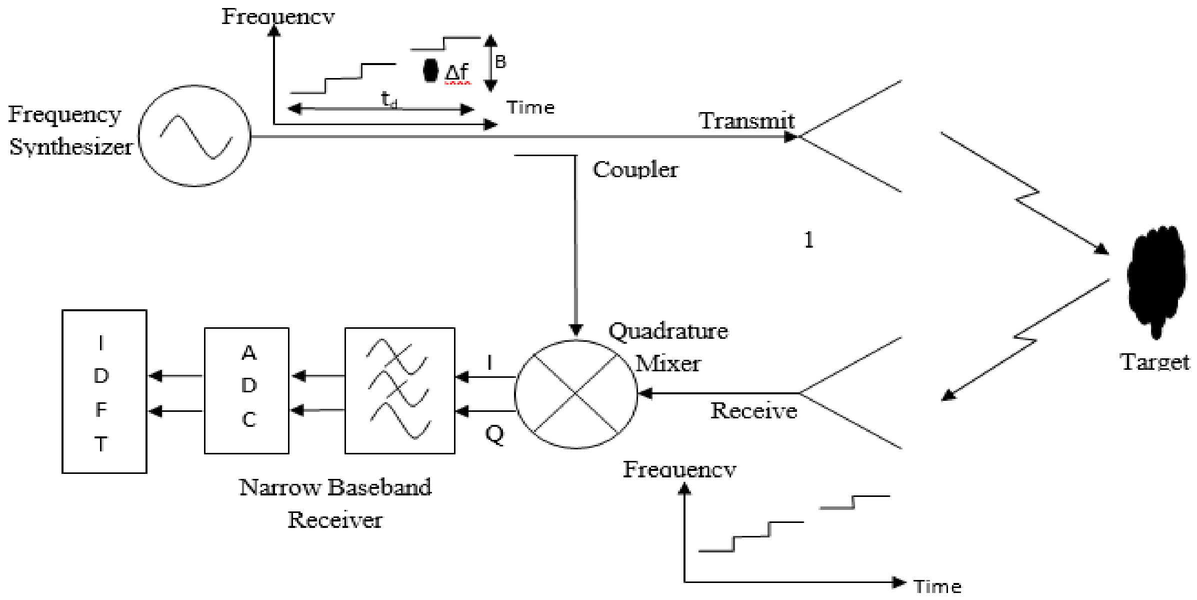
Stepped-frequency radars have linear frequency transmission, down-conversion in the receiver, and the Inverse discrete Fourier transform(IDFT) being the digital match filter is performed on the data sample. The stepped-frequency radar measures the travel time of the reflected signals by measuring the phase difference between the receiver and reference paths at each frequency. In-phase and quadrature samples must be taken at each frequency step to measure the phase. Match filtering or Inverse Discrete Fourier Transform (IDFT) which is the digital equivalent of match filter is performed on the frequency samples to proper arrange the time profile characteristic of the target. The Ambiguity function analysis [4] is performed to analyze the signal.

II. METHODOLOGY

The stepped-frequency radar transmits a waveform comprising of single frequency tones or pulses stepped in frequency intervals of Δf Hertz across a bandwidth *B.* Each frequency step is received from the reflected signal of a target, and down-converted to In- phase and Quadrature (I and Q) narrow baseband signals using a quadrature mixer (Fig. 1). Each I and Q signal is sampled with high precision, low frequency (audio) digitizers before the next frequency step is transmitted. Once the radar has completed the steps across the bandwidth, an Inverse Discrete Fourier Transform (IDFT) is applied to the digitized I and Q frequency domain arrays to produce a synthetic sine *(Bt)* envelope response. The effective pulse repetition frequency of the synthesized envelope responses is determined by the frequency step interval Δf. The IDFT is the digital equivalent to the analog matched filter of the SAW compressor (chirp) and delay equalizer (discrete-frequency radar) which compresses all the frequency steps to produce the synthesized time profile of the targets.

III. DESIGN IMPLEMENTATION

The block diagram of the stepped frequency design is illustrated in the figure 1 below



The stepped-frequency radar can transmit each frequency step as a pulse which enables the receiver to be switched off for a short blanking period and avoid signals from close, unwanted targets *(e.g.* the antenna leakage signal). This type of waveform is called interrupted continuous wave ICW, and is frequently used in stepped-frequency of the synthetic impulse and Aperture radar (SIAR) systems.

The stepped-frequency profile processing of stepped frequency radar consists of the following processes.

1) Transmitting a series of stepped frequency pulses with stepwise time-varying carrier frequency. We denote Δf as the step frequency width at each pulse.
2) Synthesizing these bandwidths of received pulses in the frequency domain for attaining effective broad bandwidth.
3) Carrying out IDFT for the synthesized bandwidth.

Figure.2, 3 and 4 shows the stepped-frequency profile processing with frequency step number *N*. Then each pulse is transmitted at different carrier frequency, stepped up by spacing Δf from the first frequency f_0 as shown in Fig2. The transmitted signal is reflected by the stationary target located in range *R*,

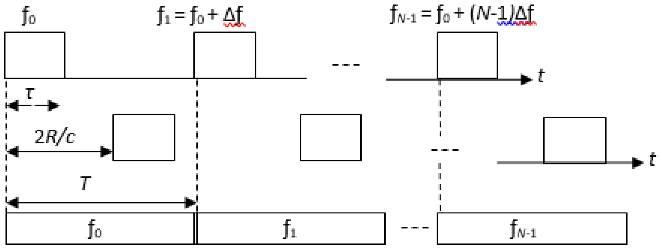


Fig.2: Received pulses in the frequency domain

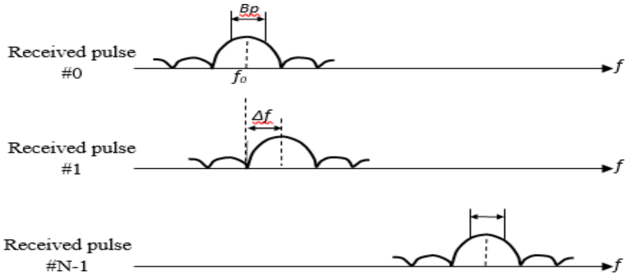


Fig.3: Received pulses in the frequency domain

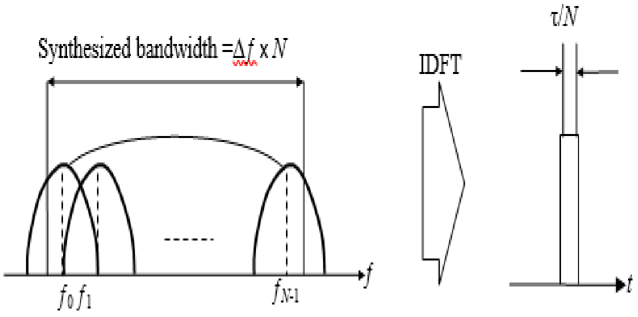


Fig. 4: Synthesized bandwidth and resulted range resolution.

Table 1: Parameters for simulation

Parameter	Value
Number of Pulses, No P	20
Signal bandwidth	10 MHz
Pulse width	10 µs
Signal to Noise Ratio, SNR	10 dB
Sampling frequency	120 MHz
Normalized Doppler shift of the target	0.1

Pulse radar system was simulated for this project. Also, only a single target was considered here.

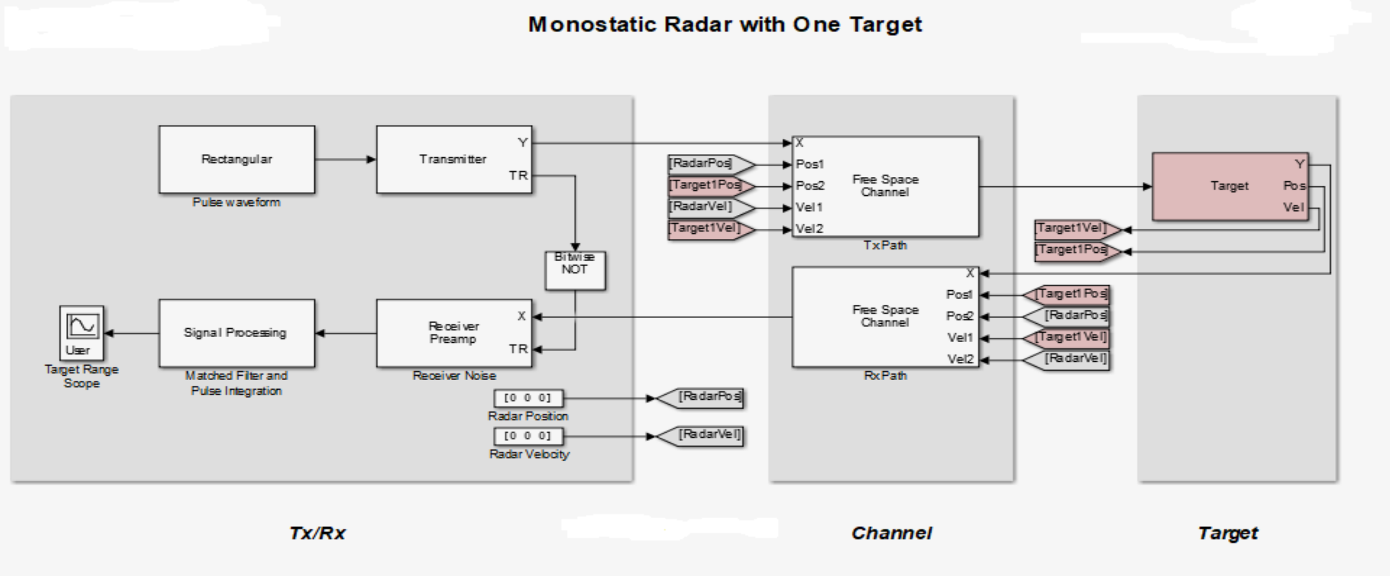


Fig.5 Matlab Model for Target detection

The model consists of a transceiver, a channel, and a target. The blocks that correspond to each section of the model are:

Transceiver

- Rectangular - Creates rectangular pulses.
- Transmitter - Amplifies the pulses and sends a Transmit/Receive status to the Receiver Preamp block to indicate if it is transmitting.
- Receiver Preamp - Receives the pulses from free space when the transmitter is off. This block also adds noise to the signal.
- Constant - Used to set the position and velocity of the radar. Their values are received by the free space blocks.
- Signal Processing - Subsystem performs match filtering and pulse integration.
- Vector Scope - Displays the integrated pulse as a function of the range.

Signal Processing Subsystem

- Matched Filter - Performs match filtering to improve SNR.
- TVG - Time varying gain to compensate for range loss.
- Pulse Integrator - Integrates several pulses non-coherently.

Channel

- Free space - Applies propagation delays, losses and Doppler shifts to the pulses. One block is used for the transmitted pulses and another one for the reflected pulses. The Free space blocks require the positions and velocities of the radar and the target.

Target

- Target - Subsystem reflects the pulses according to the specified RCS. This subsystem includes a Platform block that models the speed and position of the target which are supplied to the free space blocks. In this simulation the target is stationary and positioned 2000 meters from the radar.

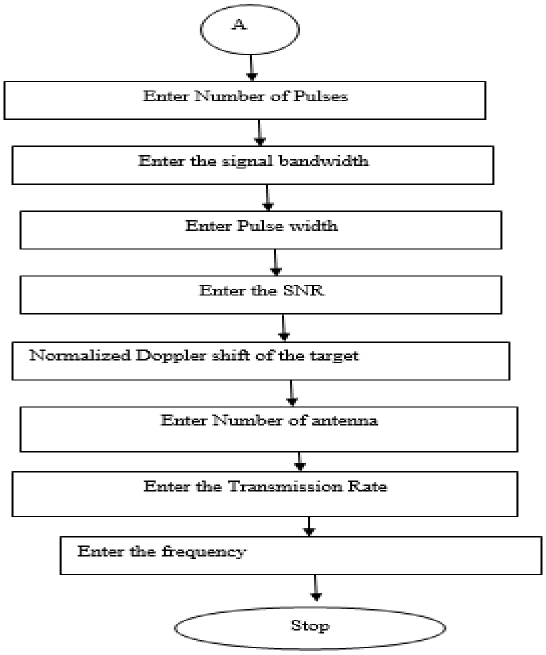


Fig.7 parameter entry flow diagram

IV. RESULT AND DISCUSSION

From the simulation result carried out, 8 receiving antennae element were used at the receiver with several pulses transmitted through the model and result recorded.

Table 2: Transmitted LFM Signal (magnitude) Vs Frequency

Frequency (Hz)	**Magnitude (dB)**
0	0
10	0.9260
20	0.7119
30	0.8152
40	0.7795
50	0.7748
60	0.8068
70	0.7585
80	0.8127
90	0.7626
100	0.7989
110	0.7857
120	0.7668
130	0.8279
140	0.7095
150	0.9222
160	0.0143

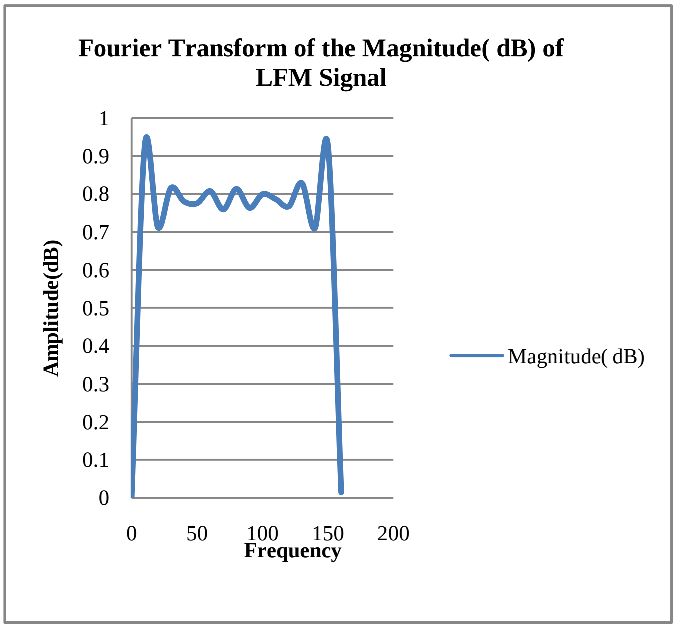


Fig. 8 Transmitted LFM Signal Vs Frequency

Fig 8 shows the linear FM *(LFM)* pulse waveform for frequency-amplitude product.

The transmitted signal has been reflected by the target and reached the receiver. During this travel time of the signal, it experienced several types of noise and interferences. Additive White Gaussian Noise (AWGN) was considered for all types of noise and interferences. There are 8 different receiving elements at the receiver end. The reflected signal was fed through all the receiving elements. The scaled signal vector is fed to a matched filter.

Table 3: Range Doppler Frequency and Delay of the received signal after matched filter

Doppler Frequency (Hz)	**Delay (μs)**
0	-1.5667
0.3333	-1.2185
0.6667	-0.8704
1.0000	-0.5222
1.3333	-0.1741
1.6667	0.1741
2.0000	0.5222
2.3333	0.8704
2.6667	1.2185
3.0000	1.5667

The linear frequency modulated (LFM) signal was used for this work. However, it does present some challenges to the hardware. The hardware has to be able to sweep the entire frequency range in one pulse. Using this waveform also makes it harder to build the receiver because it has to accommodate the entire bandwidth. The root issue here is that both the delay and the Doppler resolution depend on the pulse width in opposite ways. Therefore, one way to solve this issue is to come up with a waveform that decouples this dependency. The range resolution of a linear FM waveform is no longer depending on the pulse width. Instead, the range resolution is determined by the sweep bandwidth.

In linear FM waveform, because the range resolution is now determined by the sweep bandwidth, the system can afford a longer pulse width. Hence, the power requirement is alleviated. Meanwhile, because of the longer pulse width, the Doppler resolution improves. This improvement occurs even though the Doppler resolution of a linear FM waveform is still given by the reciprocal of the pulse width.

To get around these issues, a stepped FM waveform was used instead. In a stepped FM waveform, one uses a pulse train within which each pulse is a single frequency pulse. However, each of these pulses takes a different frequency and together they occupy the entire bandwidth. Hence, there is no more sweep within the pulse, and the receiver only needs to accommodate the bandwidth that is the reciprocal of the pulse width of a single pulse.

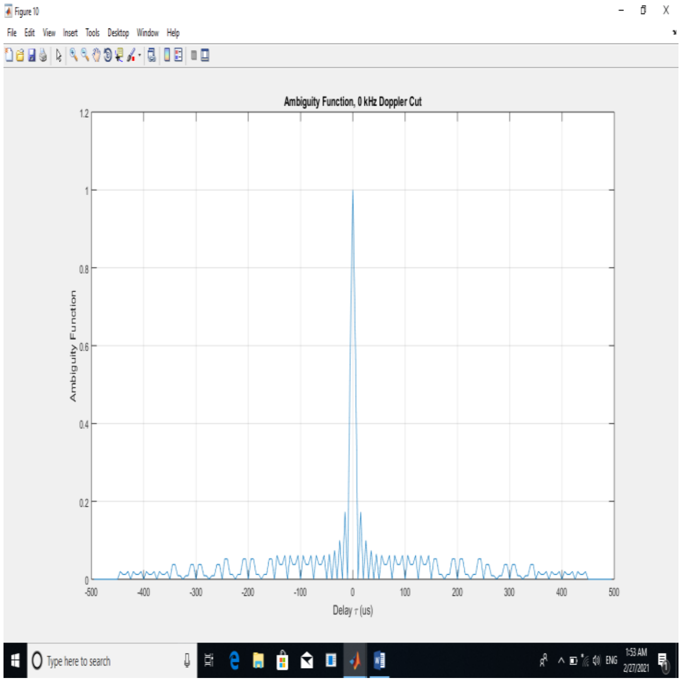


Figure 9: Ambiguity Function versus Delay Using Stepped Frequency

From figure the above; one can make the following observations: the ambiguity function only has one peak and therefore does not cause any ambiguity. However the single peak might not be narrow enough to satisfy the requirements of accuracy and resolution. If the single central peak is made too narrow, it may cause other smaller peaks to occur in regions other than the origin, and therefore cause ambiguities. Therefore having only a single peak in the simulation result shows that stepped FM waveform helps in more accurate target detection.

IV. CONCLUSION

When investigating a waveform's resolution capability, the zero delay cut and the zero Doppler cut of the waveform ambiguity function are often of interest. The zero Doppler cut of the ambiguity function returns the auto-correlation function (ACF) of the rectangular waveform. The zero Doppler cut of the ambiguity function depicts the matched filter response of a target when the target is stationary. Hence, the response matches the requirement in the design specification.

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