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Matlab and GNU Radio-Based SFCW Radar for Range Detection

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***Abstract*—Stepped Frequency Continues Wave (SFCW) has been proposed to gain higher range resolution. It makes bandwidth wider without makes a pulse width shorter. The bandwidth equals to step frequency and number of pulses generated. The simulation has been performed in Matlab and GNU Radio to measure range detection and its spectrum. It shows the range resolution of 0.11m in frequency of 1.5GHz with step frequency of 10MHz and has a wide bandwidth. Another measurement has been performed with different frequency in human voice spectrum region. The measurement used speakers as transmitter and microphone as receiver. It is hard to tell the performance of range resolution because its echoed signal, however it shows the capability for range detection with an error is 5.35%.**

Keywords— GNU Radio; high range resolution; Matlab; SFCW; voice spectrum.

I. INTRODUCTION

Stepped Frequency Continuous Wave (SFCW) has been used vary due to its capability to serve high range resolution without wider pulse width. Range resolution is the performance of radar system to differ two or more different target in a certain range. If the range between the targets is shorter than the range resolution, the radar will detect the targets as one target. Range resolution is inverse equal to bandwidth or equal to pulse width. To get better range resolution, shorter pulse width is needed. But it also will make bandwidth wider and so decrease the power transmitted which means decrease the maximum range of detection.

Due to its capability to gain high range resolution, SFCW has been used such as Ground Penetrating Radar (GPR) [1], Through Wall Radar (TWR) [2], Medical Imaging [3] and other. SFCW usually used for static target because it needs more time for signal processing equal to pulse width times number of pulses. The time processing depends on one period of signal from first or lowest frequency to last or highest frequency called T_{dwell} and the number of desired burst.

An advanced method has been proposed for moving target such as for Inverse Synthetic Aperture Radar (ISAR) and in-door fall detection based on CW Doppler Radar [4]. Other advantages of SFCW radar are the possibility to compensate the imperfections of RF electronics, antenna, and feed system through post processing of the collected data, wider dynamic range, higher mean power, the possibility of shaping the power spectral density [5].

This paper discusses an algorithm of designed SFCW radar using Matlab and GNU Radio. It also discusses an SFCW range detection using audio frequency. In section II, the architecture of SFCW radar was designed is introduced. While the result of simulation and experimental is discussed in section III. The section IV will be the conclusion of the research.

II. ARCHITECTURE OF SFCW RADAR

SFCW radar used pulses in frequency domain as signal generated. Each pulse of N has different frequency of Δf as step frequency from the lowest to the highest as showed in Fig. 1. For each frequency can be written as equation (1) [6],

$$f_n = f_0 + n.\Delta f \quad (1)$$

where f_0 is a starting frequency, f_n is frequency of n^{th} pulse for n = 0,1,2,3,…,N. Each pulse has pulse width of n. The pulse width is not defined the range resolution because the signal generates in frequency domain. Moreover the bandwidth is not inverse equal to pulse width as pulse radar, but it's equal to number of pulses times frequency step size. A range resolution ΔR can be written as (2) along with an unambiguous range, R_u, in (3) [7].

$$\Delta R = \frac{c}{2n\Delta f} \quad (2)$$

$$R_u = \frac{c}{2\Delta f} \quad (3)$$

with n is a number of pulse designed an c is speed of light in vacuum ≈ $3x10^8$ m/s. The higher frequency step size the lower range resolution and also the lower unambiguous range. SFCW is good to use as low range detection such as GPR, TWR, or mine detector. However it's not limit a long range application as well such as ISAR.

Despite its wideband architecture, SFCW has narrow instantaneous bandwidth and makes a hardware computation less complex. The requirement of receiver bandwidth is smaller and makes noise bandwidth lower. Fig. 1 is generated signal for SFCW radar with input from SFCW had a frequency different (Δf) and the total frequency is f_N. Difference in the basic principles of radar pulses with

SFCW is the inputs signal. Pulse radar had one pulse but SFCW radar had input signal with a frequency different.

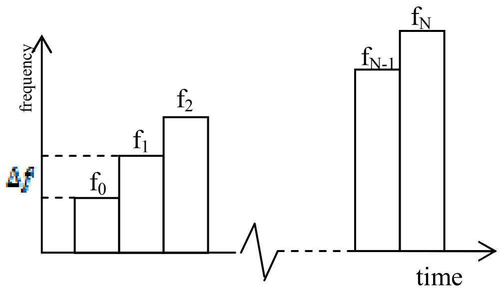


Fig. 1. Generated signal of SFCW radar

The block diagram of SFCW showed in fig. 2. The generated step frequency signal is transmitted. The signal will be reflected by the target and will be received to receiver. Similar to CW radar, SFCW is bistatic Radar for transmitter and receiver. But different from other CW radar, SFCW has the capability to detect the range of target.

The received signal is a complex signal and will be guided to the IQ Demodulator along with the replica of transmitted signal. Every n^{th} pulse reflected from the target will be mixed by same n^{th} pulse of transmitted signal in IQ Demodulator and produced Inphase and Quadrature part.

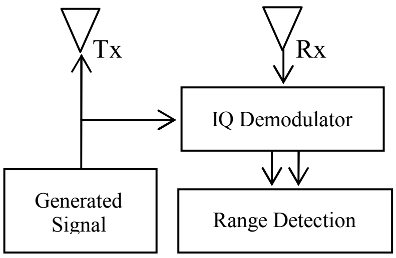


Fig. 2. Block diagram of SFCW radar system

The system will store every Inphase and Quadrature part from each frequency until all bursts desired is stored [6]. The IFFT is done for each n^{th} frequency to determine range of the target.

III. Simulation and Experimental Result

The simulation of SFCW used a Matlab Software [8]-[9]. A Flowchart of the program is shown in Fig. 3. The designed parameter is shown in table I. The number of pulse, N, in this simulation is 128. The more pulses is better but it will also make the computation longer.

TABLE I. PARAMETER SPECIFICATION SFCW RADAR IN MATLAB USING SPEED OF LIGHT

Parameter	Value
Start Frequency (f_0)	150MHz
Step Frequency (Δf)	10MHz
Velocity of signal (v)	$3x10^8$ m/s
Number of pulses (N)	128

From the specification, as a theory stated in section II, we can get the bandwidth of 1.25GHz, an unambiguous range of 15m and range resolution of 0.125m.

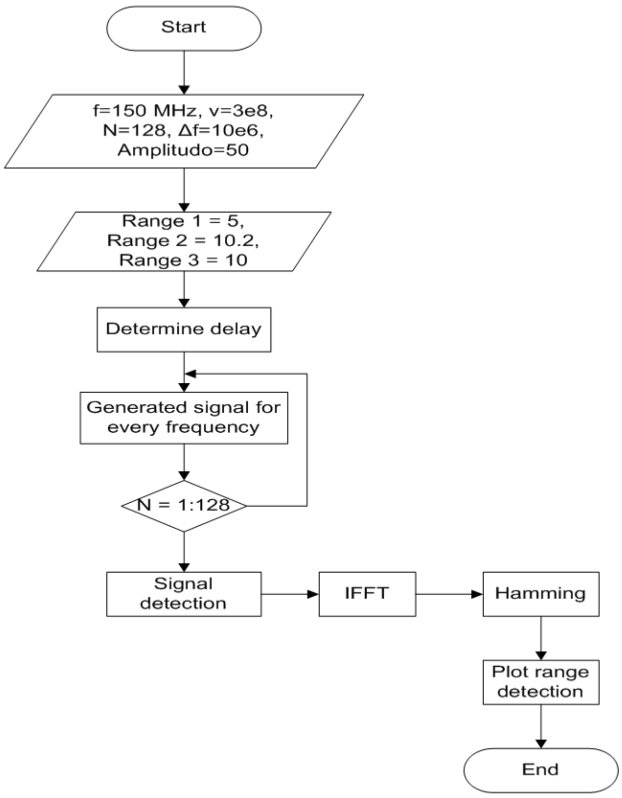


Fig. 3. Flowchart of SFCW radar simulation in Matlab

The first simulation used 3 targets with each position of 5m, 10m, and 10.2m consecutively. From the first simulation, the 3 targets could be detected separately. Fig. 4 can be seen within the second target and the third target very near. It is due to the range of the second target was 10m and the range of the third target was 10.2m. Based on the theory, a range resolution was 0.125m so that the third target can be seen in the red circle.

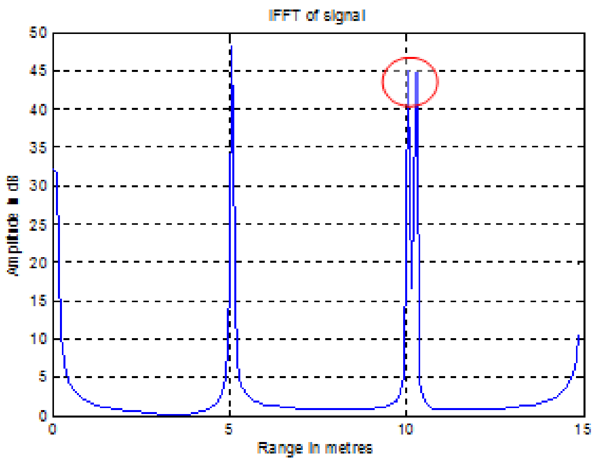


Fig. 4. The first simulation result

The second simulation used 3 targets of 5m, 10m, and 10.1m consecutively at Fig. 5. The second simulation, only two targets were shown. It's because the second and third target differ only 0.1m, shorter then range resolution of 0.125m. The designed SFCW Radar could not differ of two targets within 0.125m.

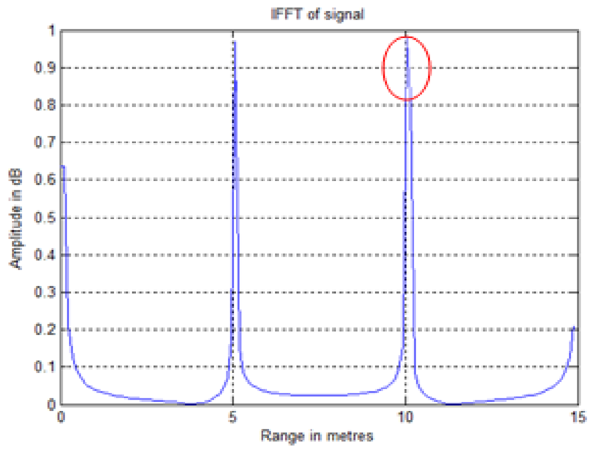


Fig. 5. The second simulation result

The next simulation on Matlab used an audio frequency rather than radio frequency. The designed parameter is shown in Table II.

TABLE II. PARAMETER SPECIFICATION SFCW RADAR IN MATLAB USING AUDIO FILE

Parameter	Value
Start Frequency (f_0)	5kHz
Step Frequency (Δf)	0.2kHz
Velocity of signal (v)	300m/s
Number of pulses (N)	8

Every parameters need to be lowered because it would be hard to implement using the audio frequency. The frequency was chosen 5kHz and bandwidth of 1.6kHz as a range of audio frequency. The velocity of signal is a speed of sound in the air. The number of pulse was lowered to 8 to shorten the time of simulation. The pulse width should be made longer so the speaker and the microphone can read the signal. The transmitter and receiver antenna were replaced by speaker and microphone. The experiment was done two times, for 2 ranges: 0m and 5.8m. It is a limit range that could be made in the simulation. The result is shown in Figs. 6 and 7 for range of 0m and 5.8m, respectively.

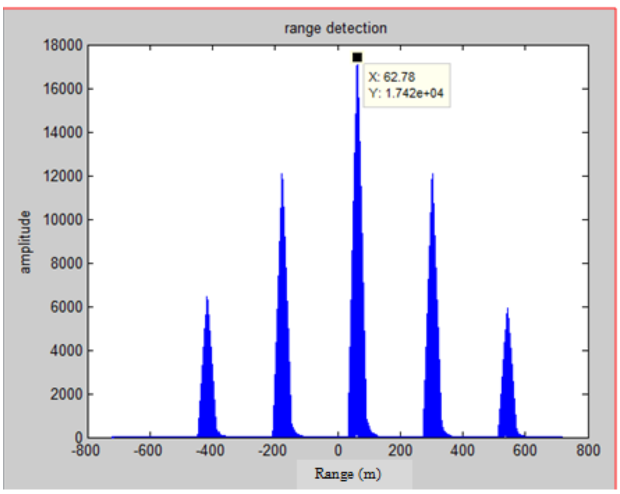


Fig. 6. Range detection for audio frequency with range of 0 m

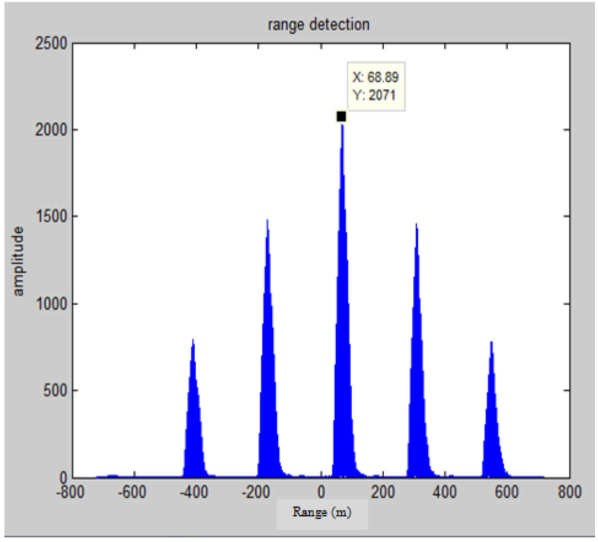


Fig. 7. Range detection for audio frequency with range of 5.88m

The result for 0m is showed that there is an undesired delay of the system and from computer to the speaker and from the microphone to computer. Fig. 6 shows the undesired delay was equal to 62.78m. Then, the real value of range detection in Fig. 7 is 6.11m, hence the error is 5.35%.

In simulation using GNU Radio, the signal generated with vector source and modulated with VCO. The full block diagram is showed in Fig. 8. With the result of simulation is showed in Fig. 9. The source vector block was filled with the number of pulses that wanted raised. Based on the desired spesification, the number of pulses were 32. So the resulting signal was a sifnal SFCW where there were 32 steps frequency, this signal would be repeated. Step frequency signal that had been raised then repeated used the block repeat. From the new repeat block was inserted into the block so that the VCO signal frequency step can be seen in the form of a sinusoidal sgnal. In Fig. 9, was the output of GNU Radio on the FFT output.

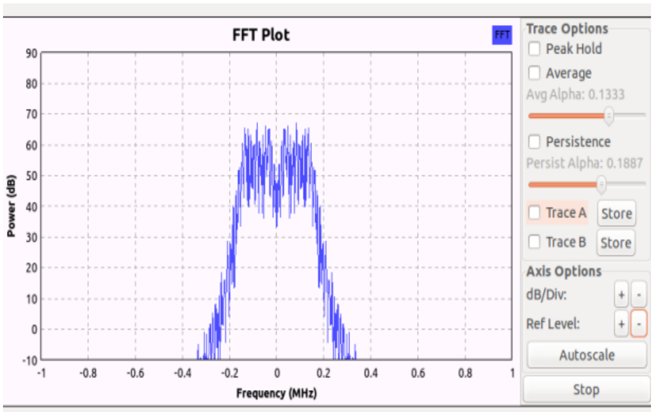


Fig. 9. The spectrum in receiver of GNU Radio

Spectrum analyzer was set on frequency division of 200kHz/div and the power receive was -86,7dBm. The experiment used an USRP with centre frequency of 1GHz is showed in Fig 10(a). The simulation shows the bandwidth of the signal was 2MHz with center frequency was 1GHz, meanwhile the experiment with USRP shows the bandwidth of 600kHz.

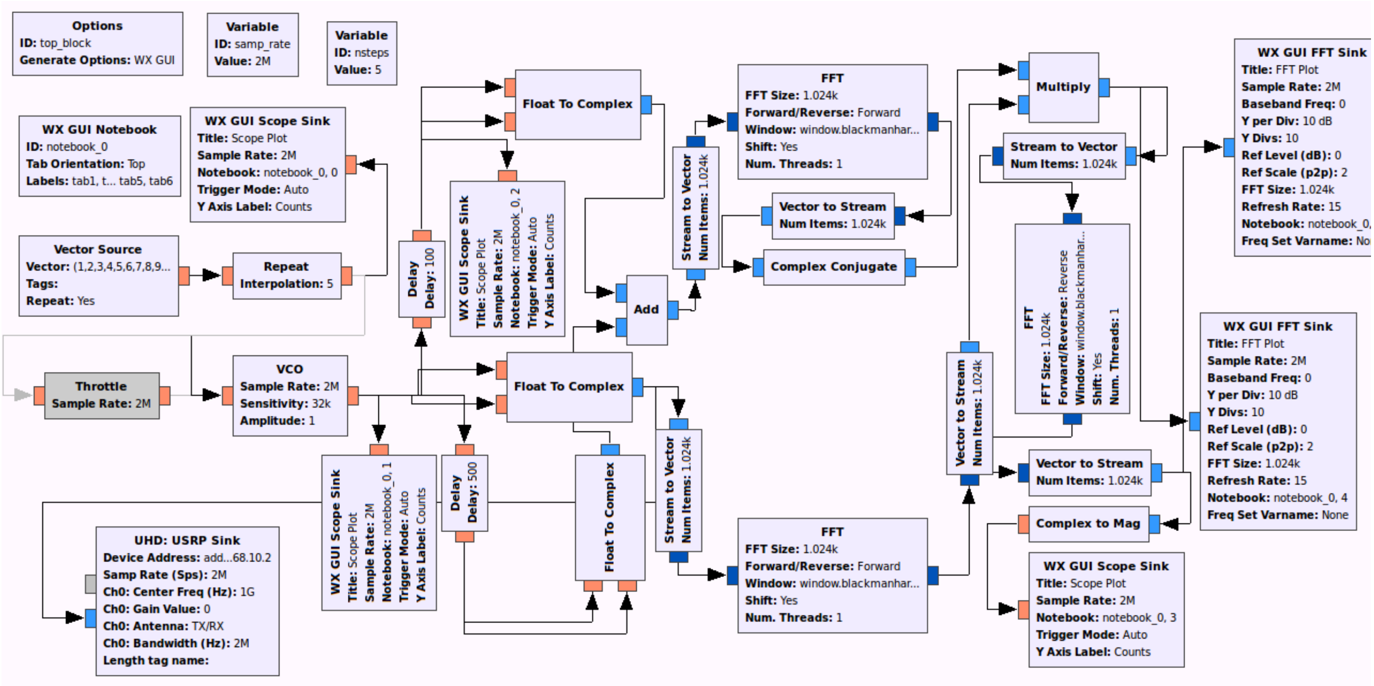
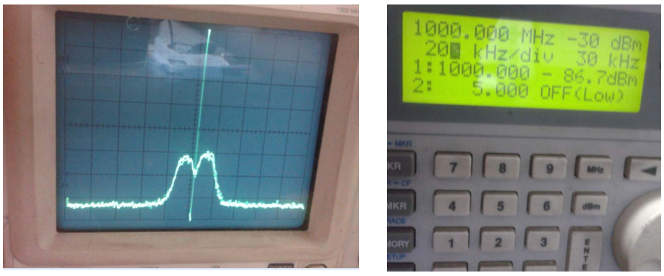


Fig. 8. Block diagram SFCW using GNU radio



(a) (b)

Fig. 10. The spectrum in receiver from spectrum analyzer using USRP, (a) spectrum analyzer display, (b) spectrum analyzer settings

IV. CONCLUSION

The SFCW radar system for range detection has been made and it is shown the advantages of its high range resolution of 0.125m for start frequency of 150MHz and bandwidth of 1.25GHz. Two targets will be detected as one target if their distance is within 0.125m. SFCW for audio spectrum has been applied with lowered specification. It's showed the result to determine the range.

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