Linear Frequency Modulation - Continuous Wave (LFM - CW) Radar Implementation using GNU Radio and USRP

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***Abstract* — In this paper, the results of previous research on the beat frequency filter for the LFM-CW Radar is applied for the realization of GNU software into radio and applied on the USRP. The beat frequency components for distances of 10 km, 50 km and 70 km respectively were found around the frequencies of 66 kHz, 330 kHz, and 460 kHz. By using MATLAB simulation, the computed results are 66.67 kHz, 333.33 kHz, and 466.67 kHz. As it occurs in the observation of the targets, frequency components obtained from the frequency spectrum can be divided into two parts, namely, the negative frequency components and the positive frequency components, where one component of this frequency is a reflection of the other frequency components. Therefore, the negative frequency components can be ignored. By observing at the positive frequency components, our experiment shows that the frequency spectrum shape of the output of the WX GUI FFT block is already similar with the simulation results by using the MATLAB®.**

Keywords— LFM-CW Radar, USRP, GNU software, frequency spectrum, and beat frequency.

I. INTRODUCTION

Universal Software Radio Peripheral (USRP) is one software defined radio (SDR) products. USRP is produced and distributed by Ettus Research, LLC, and National Instruments. This USRP is widely used for research including at the university, and also by hobbyist. The USRP can be connected to the computer via high-speed USB or Gigabit Ethernet lines. The USRP is accessible by open-source software. All products USRP can be controlled by using the driver UHD, which is also open source. UHD (USRP Hardware Driver) is a driver for the USRP product. This driver can be run on the operating system Linux, Mac OS, and Windows. UHD can be used with GNU Radio, where there will be a block UHD in the GNU Radio. By using USRP and GNU radio technology, the performance of the radar for the signal processing can be maximized.

Radar can detect targets at a far distance in any directions. The information retrieved can be the target position, speed, direction, and shape (radar cross section). Radar technology is applied for civilian and military purposes including traffic monitoring, air/land/sea surveillance, weather forecast, vehicle speed detection (Doppler Radar), navigation and etc. Due to the advancement in computing and devices technologies, radio communications system can be applied by using Software Define Radio (SDR). This SDR has a simpler architecture than conventional radio systems because most of the modulation process is performed by software. GNU Radio is software that can be used to design this software-defined radio.

II. BASIC THEORY

A. FM-CW Radar

One type of radar that can be implemented using SDR is Frequency Modulated Continuous Wave (FM-CW) radar [7]. FM-CW radars generally use modulation Linear FM and emit waves in the entire span of periodic; this is different from the pulse radar that sends short pulses in a periodic time span. FM-CW radar does not require a large transmits power to obtain sufficient SNR (signal to noise ratio) value for target detection process, such as occurs in the pulse radar [8]. Considering the hardware side, FM-CW radars, which can be constructed by using solid state amplifiers, are smaller and cheaper than pulse radars using magnetron as the amplifier. Doppler CW (continuous wave), FM-CW (Frequency Modulated Continuous Wave) and FH (frequency hopping) can be applied to a radar system to measure the distance and speed of a moving target for a certain period [9]. The ability of CW radar to detect targets depends on the beat signal SNR and radar resolution, which is the ability to separate adjacent targets within range or Doppler direction [9]. The main drawback of the CW radar is that this radar system can only provide resolution in one direction, either range or Doppler. In [9], FM-CW radar is able to provide resolution 2-D, which is resulted from FM-CW radar measurements and range Doppler 2-D Fourier transform processing. One of the signals processing technique that is widely used in the FM-CW radar

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system is to derive beat frequencies and utilizing the Fast Fourier Transform (FFT) to obtain distance information of the target [7].

A. LFM-CW

Research presented and discussed in this Paper is for continuous wave (CW) radar. Excess CW radar most important is the ability to detect the speed of a target, because the target movement will result in changes in the signal frequency, which is called Doppler frequency. In contrary to its advantages, CW radar has a weakness where it cannot detect the distance of the target, unlike the pulse radar. In order for CW radar to be able to measure distance, a little modification is required, i.e., by modulating the transmitted signal using FM modulation, where the frequency changes with time. There are several types of FM modulation that can be used. However, in this paper, a linear modulation is used, where frequency changes linearly over time. Thus, this system is referred to as linear frequency modulation continuous wave (LFM-CW) radar. Frequency change for the transmitted and received signals are shown in Figure 1.

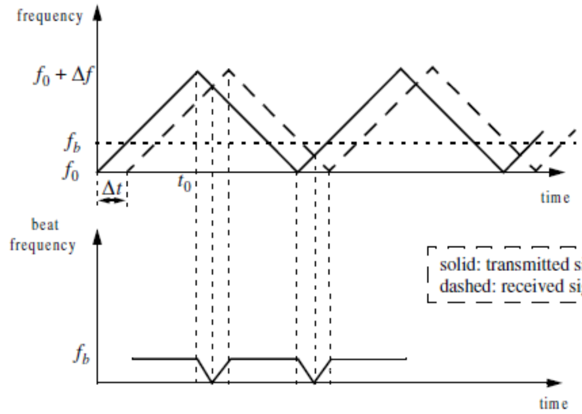

Fig.1. Signal shapes of LFM-CW radar [1].

The radar signals have a saw tooth shape, where the frequency changes against time and then repeats with a frequency *fm*. This frequency is also called frequency sweep. Because of the triangular shape, LFM-CW radar has a limited bandwidth, i.e., *Δf*. When a radar signal arrives on a target with a certain distance, the received radar signal will have a delay of *Δt* relative to the transmitted signal. This same delay also occurs as the signal frequency changes, as shown in Fig. 1. If the difference between the change in the frequency of the transmitted and received signal, beat frequency (*fb*) will be obtained. This beat frequency is proportional to the distance delay and send a signal reflecting targets, meaning that the farther the target, the greater the delay, and the greater the beat frequency. The relationship between the delay and the target range is expressed by Equation (1).

$$R = \frac{c \times \Delta t}{2} \quad (1)$$

Furthermore, the relationship between the beat frequency and target distance is shown by Equation (2).

$$R = \frac{c f_b}{4 f_m \Delta f} \quad (2)$$

A target at a distance of (R) will reflect back the signal with delay of:

$$= \frac{2R}{c} \quad (3)$$

The form of produced LFM-CW radar signal is illustrated in Figure 2.

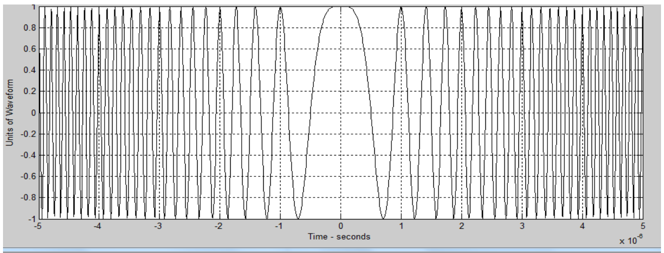

Fig.2. Example of Output Signal Modulation LFM one period in time domain [1]

From Fig. 1, signal waves in one period will be generated with frequencies that go up for the half of period and go down for the next half of period. This is in accordance with the frequency change as shown graph in Fig. 2.

Radar, in general, has a limited detection range in the so-called non ambiguous or unambiguous distance range. If a target is located further away from the unambiguous range, then the target cannot be detected. This will be shown in the simulation with MATLAB®. The formula to determine the unambiguous radar range LFM-CW is shown in Equation (4).

$$R_u = \frac{c}{4 f_m} \quad (4)$$

Another limitation is the resolution of the distance. Resolution for the radar range is the ability to distinguish the two targets that are close together. The smaller the distance resolution, the radar is able to detect two targets within closer. Equation (5) shows the formula to calculate the distance resolution.

$$\Delta R = \frac{c}{2\Delta f} \quad (5)$$

III. LFM-CW Radar experiment using Software Defined Radio (SDR)

Software Defined Radio (SDR) *GNU Radio* is a free software that can be used by anyone to create and design software-based radio systems. Open-source software is

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distributed under the GNU general public license. Eric Blossom and John Gilmore pioneering GNU Radio began in 2001, and now has been widely used by universities and industry to research wireless communication that can be implemented for real-time radio [4, 7, 8]. GNU Radio is composed of blocks of signal processing, which is coded by using C ++ programming language, and all these blocks can be connected. Users can easily create software radio to create a graph, which is by connecting the blocks that have been available in the software. GNU Radio software can be run with various Linux OS-based computers. An example of GNU Radio and USRP test kit is depicted in Figure 3.

Fig. 3. USRP N210.

Fig. 4. Configuration USRP + GNU Radio with antenna.

Before conducting the test by using USRP, a simulation is used to view the output signal on the GNU Radio software. As has been mentioned previously, GNU Radio consists of various blocks which can be connected into one system intact. In this experiment, the blocks can be seen in Fig. 5.

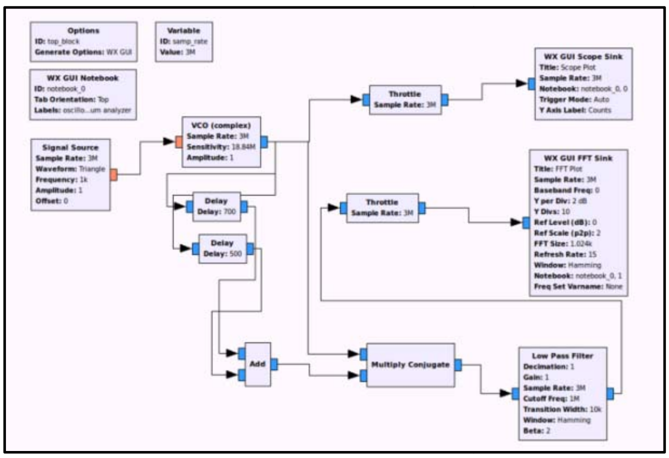

Fig.5. Block Diagram FM-CW GNU Radio.

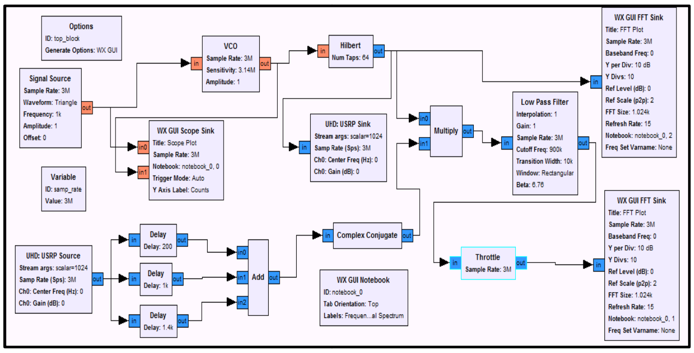

Fig.6. Block Diagram LFM-CW GNU Radio.

TABLE I. SPECIFICATIONS OF GNU RADIO BLOCK

Block Name	Parameters	Parameter Value
Variable	samp_rate	3 × 106
Signal Source	Waveform	Triangle
	Frequency	1000
	Amplitude	1
VCO	Sensitivity	3.14 × 106
	Amplitude	1
Hilbert	-	-
Delay	Delay 1	200
	Delay 2	1000
	Delay 3	1400
Add	-	-
Complex Conjugate	-	-
Multiply	-	-
Low Pass Filter	Gain	1
	Cutoff Freq	900 × 103
	Window	Rectangular
WX GUI Scope Sink	-	-
WX GUI FFT Sink	FFT Size	1024
WX GUI Notebook	-	-
UHD: USRP Sink	-	-
UHD: USRP Source	-	-

A VCO output is inserted into the Hilbert block. This block has a function to convert the signal into a complex-type estate by shifting the phase of the input signal by 90 degrees and multiplying it by an imaginary number and add it to the real signal value as mentioned previously. This is can be done due to the use of USRP. Additional blocks are required into the interface between GNU Radio with computers connected to the USRP, which is called UHD block: USRP Sink. The block requires the input of complex type. Once connected to the USRP, then the signal emitted by an antenna is connected to the USRP. Results of the beam spectrum can be viewed by using a spectrum analyzer. Hilbert block output is also incorporated into the block WX FFT GUI Sink. This block is

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monitored on the signal frequency spectrum. After that, the spectrum that is shown in spectrum analyzer is compared with the spectrum shown in WX GUI FFT Sink. This comparison can be seen in following Figure 7.

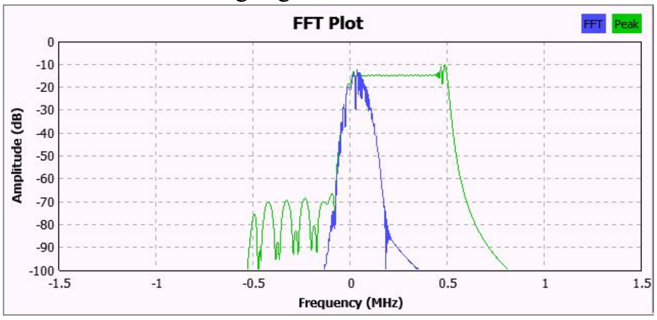

Fig.7. The frequency spectrum of LFM-CW radar signals on GNU Radio.

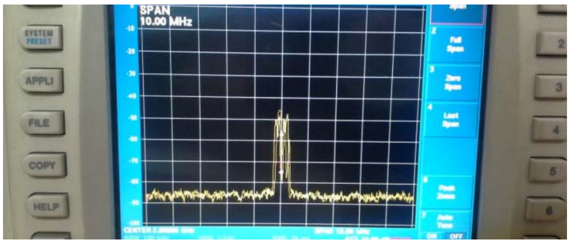

Figure 8. Frequency spectrum of LFM-CW radar signal on Spectrum Analyzer.

According to the theory discussed in [1, 2], because of the bandwidth as mentioned in the specifications is 500 kHz, the frequency spectrum should have LFM-CW radar signals with a similar range. In the spectrum analyzer, the changing peak indicated is in the center frequency of 500 kHz. In the FFT GUI WX Sink, the same value is also encountered. Blue chart shows the actual shape of the frequency spectrum of LFM-CW radar signals, while the green is the magnitude of the peak value of the frequency spectrum. It can be observed that the frequency spectrum of LFM-CW radar signal has a peak average within frequency of 0-500 kHz. The second observation of the frequency spectrum, it is encountered that the phenomenon of frequency changes over time. This is because the frequency of the radar LFM-CW is indeed changing; up and down according to output signals form block Signal Source. Thus, both of the observation frequency spectra show that the system meets the specifications.

Using the same scheme, the output signal blocks corresponding to Hilbert delay give the desired target range. In the GNU Radio, delay blocks have parameters of number of samples. To get the number of samples, after entering the target range to Equation (1), the result is multiplied by the sampling frequency. For example, if the desired target ranges of 10 km, the number of samples to Delay block is 200. The next process is to conjugate signal output of Delay block using the Conjugate Complex block. Then, the output signal of this block is multiplied by the transmission signal, which is output from the block using a Multiply Hilbert block . After the mixing process, the next step is filtering. By using the same filter specifications using MATLAB® simulation, signal and filtering the results observed by the use of the frequency spectrum FFT block WX GUI Sink. For a target distance of 10 km, the frequency spectrum shown in Figure 9.

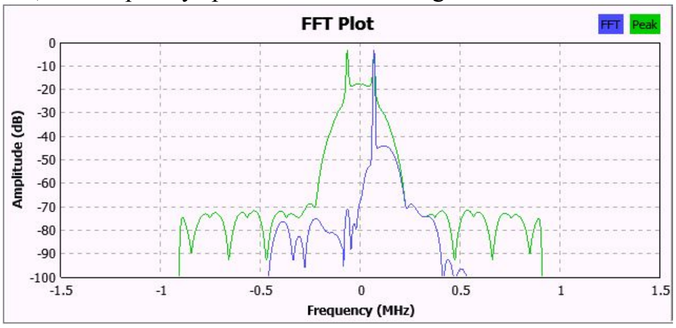

Fig. 9. Beat frequency spectrum of the signal to the target distance of 10 km.

Fig. 9 shows the frequency spectrum of the beat signal. There are two plots on the graph, the blue color plot shows the actual frequency spectrum, and green plot shows the peak of the frequency spectrum for all observation time. To facilitate the observation of the beat frequency, then the green plot should be observed because its value is not changeable (fix). The beat frequency component obtained from the target within 10 km is approximately 66 kHz. This is similar with the theoretical calculations that give a value of 66.67 kHz. The difference in the form of graphs in FFT GUI WX Sink with FFT on MATLAB® simulation is the negative frequency components on FFT GUI WX Sink. However, it can be seen from the graph output of FFT GUI WX Sink; negative frequency component is a reflection of the positive frequency components, so that the negative frequency components can be ignored.

The detection process for more than one target is actually equal to the detection of a target, only in this time, there are three delays used as a marker as there are three objects which reflect signals having different distances. For more details, the used block diagram is shown in Figure 10.

The signals output of this block is applied to a block of Complex Conjugate to conjugate signal. After that, the signal is multiplied by the conjugate results from transmission signals output of Hilbert blocks, where blocks are multiplied to get beat signals. Furthermore, the filtering is performed to eliminate the high frequency components on the beat signal by using the Low Pass Filter block. These results in filtered signals and then inserted into the WX Sink FFT GUI block to produce the frequency spectrum.

For experiment, three objects at a distance of respectively 10 km, 50 km and 70 km can be set up. To get the value of the block Delay parameter for each object, distances of three objects are inserted into Equation (2) for each delay in the time dimension, and then multiplies the values of this delay with the sampling frequency. For the third object is selected, it will be obtained the value of each parameter of Delay blocks

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are 200, 1000, and 1400. The frequency spectrum of these three objects is depicted in Figure 10.

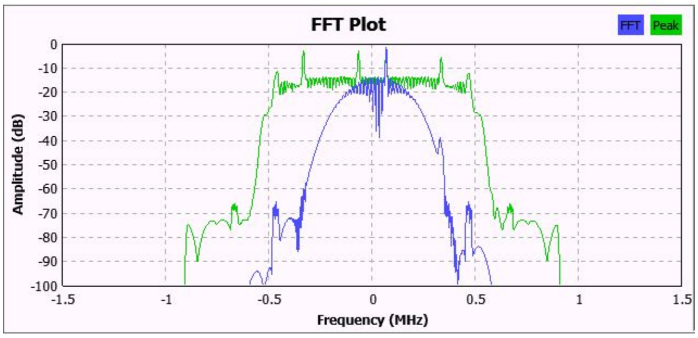

Fig. 10. The frequency spectrum of beat signal for targets range of 10 km, 50 km, and 70 km

The blue plot is the form of the beat frequency spectrum , which is the actual signal at a certain time and the green plot is the highest magnitude frequency spectrum of the beat signal at all the observation time. For the ease of observation, it was observed only green plot for a constant value.

Beat frequency components to a distance of 10 km, 50 km and 70 km respectively are found around the frequency of 66 kHz, 330 kHz, and 460 kHz. The third (simulated) value is approaching the value of the calculation result that is 66.67 kHz, 333.33 kHz, and 466.67 kHz. As it is in the observation of the targets, the frequency spectrum obtained can be divided into two, namely the negative frequency components and the positive frequency components, where one component of this frequency is a reflection of the other frequency components. Therefore, the negative frequency components can be ignored and attention is on the positive frequency components only. The shape of the frequency spectrum of the output blocks WX GUI FFT is similar with that of the simulation results using MATLAB®.

Other phenomenon that can be observed is the decrease of the magnitude of the beat frequency component if the distance is farther. This is due to lack of ideal filters in use. Filters are designed to have steep low pass band, so the magnitude at high frequency before the cut-off will be slightly attenuated. Nevertheless, this does not influence the detection of the target range for the near unambiguous range. It can be seen in Figure 10, if the threshold detector device has a value of about -12 dB, then the target that is located at a distance of 70 km is still able to be detected.

IV. Conclusion

The process of target detection using LFM-CW radar consists of signal generation, and then processing the reflected signal from the target by means of conjugate of the reflected signal, multiplying the transmission signal, and filtering with a low pass filter. Then, the frequency spectrum can be seen to determine the generated beat frequencies.

LFM-CW radar signals are generated using GNU Radio and USRP already meets the specifications. Radar is implemented in GNU Radio is also capable of detecting one or three targets at varying distances well. The difference in the frequency spectrum belongs to the chart of GNU Radio. Based on the GNU Radio frequency spectrum, the used frequency components are only the positive frequency components, while the negative frequency components are ignored.

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