International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 6 Issue 04, April-2017

Movement Detection Using a Modified FMCW Waveform and GNU Radio

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***Abstract*— In this paper results of previous researches and modifications to the Frequency Modulated Continuous Wave (FMCW) are applied on GNU Radio. GNU Radio is an open source software for Software Defined Radio (SDR). The standard FMCW has frequency changing linearly with time. The frequency changes take the form of a triangle. Here, the triangular waveform is modified to obtain two triangles instead of one where the second triangle has a different form. The system is implemented using GNU Radio. We obtained a good estimation of the distance and the speed of different targets. Moreover, the Doppler frequency is estimated with a high precision.**

Keywords—FMCW; Detection; Estimation; GnuRadio; Radar

I. INTRODUCTION

The RADAR (RAdio Detection And Ranging) is based on the propagation of Radio Frequency (RF) electromagnetic waves. In the late of the 19th century, the experiments of Heinrich Heirtz showed that the electromagnetic waves are reflected by metallic objects. The Radar principle was found in 1911 by the American Hugo Gernsback. In 1934, the Frenchman Pierre David successfully did the first experiments to detect the presence of aircraft. The first range calculations were applied on Icebergs with waves of 16 cm wavelength. Then the radar had an important usage in military applications.

The radar uses the reflection properties of an electromagnetic wave on a target. The simplest and the first used waveform consists on a series of pulses [1]. By measuring the delay τ between emission and reception, it is possible to calculate the distance d between the radar and the target by the following equation:

$$d = c\tau / 2 \qquad (1)$$

where c is the speed of the light ($3x10^8$ m/s).

A pulse must have a short duration, A pulse width of 1 nm is needed to detect objects facing the radar with distance less than 1m. Moreover, another problem of Pulse Radar is that we cannot detect nor calculate the speed of moving targets. This problem was solved by the Pulse-Doppler radar [2] where the pulses are modulated on a sine wave. But this system need huge power to work as expected.

A monochromatic radar uses the Doppler effect and gives no information on the distance of the target [3]. A monochromatic continuous wave radar system consists of an RF transmitter and a receiver that mixes the transmitted and the received signals to obtain the beat frequency. The beat frequency f_b is defined as the difference between the frequencies of the received (f_r) and the transmitted signals (f_t): $f_b = f_r – f_t$. It is proportional to the relative speed (v) of the target:

$$f_b = \frac{2f_0 v}{c} \qquad (2)$$

where f_0 is the frequency of the oscillator.

The problem of the monochromatic radar is that it does not provide any information about the distance.

FSK (Frequency Shift Keying) radar [4] transmits a frequency modulated waveform. This modulation uses at least two slightly different frequencies, i.e. f_0 and $f_1 = f_0 + \Delta f$ which are transmitted periodically every T seconds. The spectral analysis of the received information makes it possible to extract the distance and speed. The received signals have equal amplitudes (proportional to the amplitude of the transmitted signal), the same frequency (equal to the Doppler frequency of the target) and a differential phase shift proportional to the distance to be measured.

The speed is calculated by performing a time-discrete Fourier transform of the received signals. The targets are then detected by a previously defined amplitude threshold. Given the small variation Δf of the frequency of a target between two repetition periods, a target will give the same Doppler frequency in the two adjacent intervals associated with f_0 and f_1. But the received signals have a phase difference $\Delta\varphi = |\varphi_0 - \varphi_1|$. From this phase difference, calculated by mixing the transmitted and received signals, the distance d of the target is obtained using the equation:

$$d = \frac{c\,\Delta\varphi}{4\pi\Delta f} \qquad (3)$$

This waveform is simple to produce but it can't detect unmoving targets.

After looking to the different waveform techniques, the FMCW is the best choice to detect a moving or unmoving targets.

II. FMCW THEORY

In the case of the FMCW radar [5], the transmitted frequency varies continuously as a function of time, typically in a linear manner (figure 1). To detect a target placed at a distance d, we mix the transmitted and the received signals to produce a beat frequency f_b. In the absence of Doppler (fixed target) this frequency is only related to the distance of the target.

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If we denote by $f_t(t)=f_0 + \alpha t$ the transmitted frequency. At the receiver, we obtain the frequency $f_r = f_0 + \alpha\,(t\text{-}2d/c)$. A mixer is used to provide the beat frequency:

$$f_b = f_r - f_t = -\frac{2\alpha d}{c} \qquad (4)$$

Where α is the slope of the frequency.

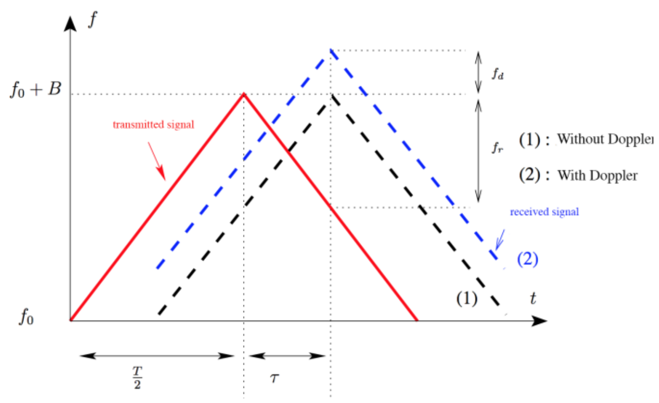

Fig. 1. FMCW waveform

But we have two ramps (up and down). So, for a non-moving target, we obtain two beat frequencies:

$$f_b^{down} = -f_b^{up} = \frac{2\alpha d}{c} \qquad (5)$$

If the target is moving the beat frequencies are:

$$f_b^{up} = f_d - \frac{2\alpha d}{c} \qquad (6)$$

and,

$$f_b^{down} = f_d + \frac{2\alpha d}{c} \qquad (7)$$

Using equations (6) and (7) and because the slope α is equal to the bandwidth B divided by the time of the slope (T/2), by a simple calculation, we can obtain the distance and the Doppler frequency of the targets using:

$$d = \frac{cT}{8B}\left(f_b^{down} - f_b^{up}\right) \qquad (8)$$

and,

$$f_d = \frac{1}{2}\left(f_b^{down} + f_b^{up}\right) \qquad (9)$$

Using equations (2) and (9) we can obtain the speed:

$$v = \frac{c}{4f_0}\left(f_b^{down} + f_b^{up}\right) \qquad (10)$$

As the distance is inversely proportional to the Bandwidth, we should use a large bandwidth to detect near objects. Concerning the speed, we need to use an oscillator with a large frequency.

III. THE MODIFIED FMCW

When we have multiple targets, it is hard to associate the $f^{\,up}$ and $f^{\,down}$ for each target when using the FMCW waveform.

Miyahra introduced in [6] a new waveform with two (or more) successive ramps with slightly different slopes. In this waveform, the order in which the beat frequencies are observed on the first ramp is identical to the order observed on the second ramp. Thus, the association between the beat frequencies on the ramps is easy, and the problem of FMCW is solved. The simplified association between the beat frequencies, is a great advantage of this waveform.

By combining the idea of ramps of near slopes and that of ramps of opposite slopes, a new waveform, called double FMCW, composed of two successive triangles with slightly different slopes between the first and Second triangle was proposed. The order of the beat frequencies of the targets is thus preserved between the two rising ramps, as well as between the two descending ramps. The association of beat frequencies remains simple and the variance of the estimate of the speed remains low, by considering, in a second step, the ramps of opposite slopes.

The structure of this waveform is summarized in Figure 2. It can be characterized by four parameters:

- The carrier frequency (f_0)
- The bandwidth (B)
- Total duration (T)
- The duration of the first triangle (θ)

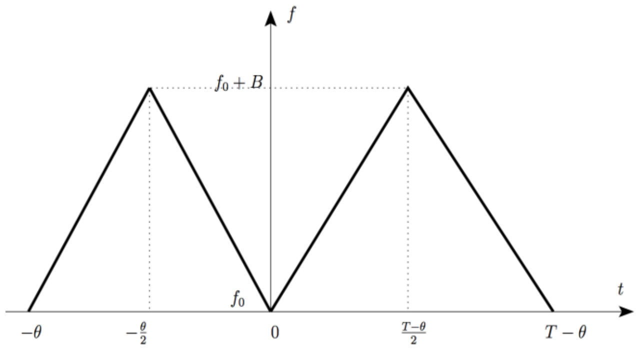

Fig. 2. The modified FMCW waveform

By some calculations like the equations (4-10) we can obtain two estimates of the distance and the Doppler frequency:

$$d_1 = \frac{c\theta}{8B}\left(f_b^{down1} - f_b^{up1}\right) \qquad (11)$$

$$f_{d1} = \frac{1}{2}\left(f_b^{down1} + f_b^{up1}\right) \qquad (12)$$

And on the second one:

$$d_2 = \frac{c(T-\theta)}{8B}\left(f_b^{down2} - f_b^{up2}\right) \qquad (13)$$

$$f_{d2} = \frac{1}{2}\left(f_b^{down2} + f_b^{up2}\right) \qquad (14)$$

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A final estimate is done by taking the averages of the equations (11-14) to obtain:

$$d = \frac{c}{16B}\left[\theta\left(f_b^{down1} - f_b^{up1}\right) + (T-\theta)\left(f_b^{down2} - f_b^{up2}\right)\right] \quad (15)$$

$$f_d = \frac{1}{4}\left(f_b^{down1} + f_b^{up1} + f_b^{down2} + f_b^{up2}\right) \quad (16)$$

IV. GNU RADIO IMPLEMENTATION

The FMCW was implemented using GNU Radio in many publications [7-11].

Here, the first change is the use of a file source instead of signal source. The values of the modified triangles (Figure 3) are calculated using Matlab, then were written in a binary file. In the "file source block" the repeat option is set.

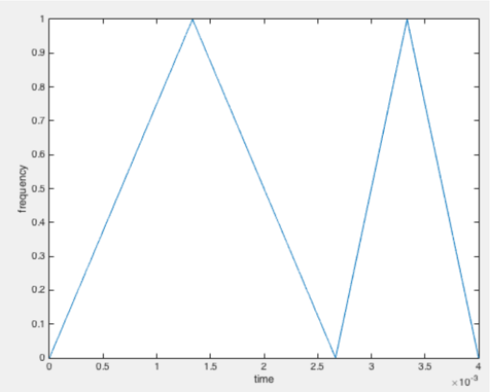

Fig. 3. Beat frequencies when we have a moving target.

In the simulation, we have chosen the following parameters:

Bandwidth (B)	15MHz
Carrier frequency	500MHz
Period of the two triangles	4ms
Time of the first triangle	2.6666ms

In the first simulation, we supposed that we have 1 fixed target. We supposed that the delay of the echo is 100µs (distance of 15 Km). The Fourier transform of the complex mixed signal is illustrated in Figure 4.

We see that we have 4 beating frequencies:

$$f^{up2} = -2.248MHz$$
$$f^{up1} = -1.124MHz$$
$$f^{down1} = 1.124MHz$$
$$f^{down2} = 2.248MHz$$

We see that, in the absence of Doppler, the equation (5) is verified.

By applying the equation (15) we obtain d = 14.985 Km. So, the distance is correctly estimated. And using the equation (16) the Doppler frequency f_d is equal to zero.

In the second scenario (figure 7), we suppose we have a target at the same distance of the first scenario. But in addition, we have a Doppler shift of 94.2 KHz. After the mixer, we obtain the spectrum of figure 5.

The obtained beat frequencies are:

$$f^{up2} = -2.155MHz$$
$$f^{up1} = -1.030MHz$$
$$f^{down1} = 1.218MHz$$
$$f^{down2} = 2.343MHz$$

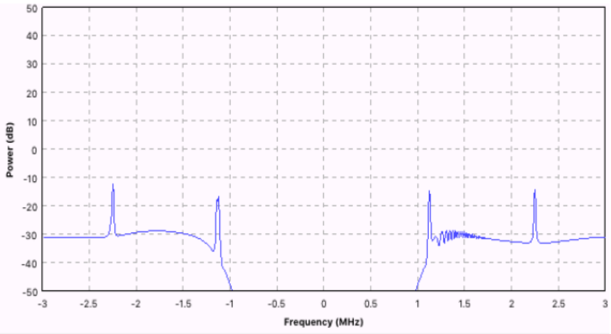

Fig. 4. Beat frequencies when we have a fixed target.

Using equation (15) we obtain the same distance d=14.985 Km. And using equation (16), the estimated Doppler frequency f_d=94KHz.

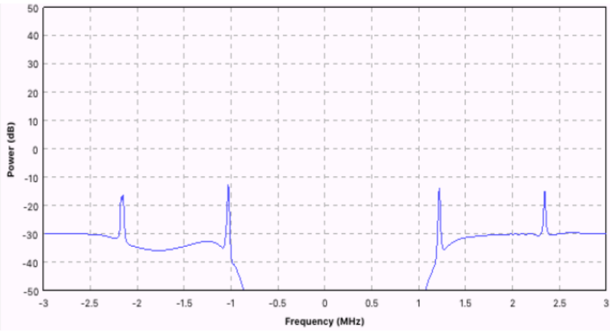

Fig. 5. Beat frequencies when we have a moving target.

In a third scenario, we supposed that we have two moving targets. The system is illustrated in figure 8. The beat frequencies obtained after the mixer are shown in Figure 5. We see that we have 8 beat frequencies. We can allocate to each target its beat frequencies by searching the matching four peaks in frequencies.

The first target, simulated as in the second scenario provides the same beating frequencies obtained before.

The second target is simulated with a delay 400 (corresponds to 66.66667 µs or 10Km) and a Doppler frequency equal to 150 KHz.

The beat frequencies are always in the same order: f^{up2}, f^{up1}, f^{down1} then f^{down2}

So, the beat frequencies of the second target are:

$$f^{up2} = -1350KHz$$
$$f^{up1} = -600KHz$$
$$f^{down1} = 899.4KHz$$
$$f^{down2} = 1649KHz$$

Again, using equations (15) and (16) we obtain an estimated distance equal to 9.99Km and an estimated Doppler frequency equal to 149.6KHz.

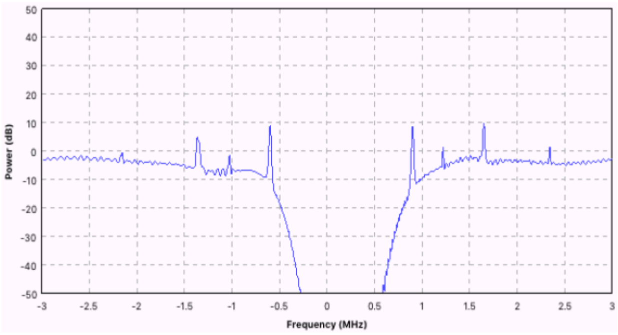

Fig. 6. Beat frequencies when we have two moving targets.

V. CONCLUSION

A modification on the FMCW was implemented using GNU Radio to detect stationary and moving targets. We showed that the obtained results are correct and corresponds to the theoretical values. Using a modified FMCW waveform, the targets can be detected and their distance and velocity can be estimated in a simple way. If we have different targets, the beat frequencies are ordered, and by matching its amplitudes we can associate to each target the corresponding beat frequencies. The system will be modified in the future to implement a real-time Radar using USRPs and Log-periodic directive antennas.

REFERENCES

[1] M. G. M. Hussain and M. J. Yedlin. Active-array beamforming for ultra-wideband impulse radar. In Radar Conference, 2000. The Record of the IEEE 2000 International, pages 267–272, 2000

[2] M.I Skolnik. Introduction to radar systems. TMc Graw-Hill, book Company Inc, 1962.J. Clerk Maxwell, A Treatise on Electricity and Magnetism, 3rd ed., vol. 2. Oxford: Clarendon, 1892, pp.68-73.

[3] M. Petit Didier G. Sol, P. Larzabal and H. Clergeot. A new approach for wind profiling with doppler radar. In International journal of Radio sciences, vo- lume 32, pages 1391–1408, July-August 1997.

[4] Kemkemians J. P. Artis. The radar in the automotive domain. In Annales des télécommunications, volume 60, pages 4326–356, March/April 2005.

[5] G. Piel. Contribution à la Mise en oeuvre d'une Platforme De Simulation D'un Système Radar : Application A Un Radar Automobile D'aide à La Conduite. PhD thesis, Telecom Bretagne, 2007.

[6] S. Miyahara. New algorithm for multiple object detection in the fmcw radar. In SAE Technical Paper Series, 2004.

[7] Saputera, Yussi Perdana, et al. "Linear frequency modulated continuous wave radar using GNU radio and USRP." *Wireless and Telematics (ICWT), 2015 1st International Conference on*. IEEE, 2015.

[8] Sundaresan, S., et al. "Real time implementation of FMCW radar for target detection using GNU radio and USRP." *Communications and Signal Processing (ICCSP), 2015 International Conference on*. IEEE, 2015.

[9] Prabaswara, Aditya, Achmad Munir, and Andriyan Bayu Suksmono. "GNU Radio based software-defined FMCW radar for weather surveillance application." *Telecommunication Systems, Services, and Applications (TSSA), 2011 6th International Conference on*. IEEE, 2011.

[10] Amin, Ershad Junus, Andriyan Bayu Suksmono, and Achmad Munir. "Accuracy analysis of FM chirp in GNU radio-based FMCW radar for multiple target detection." Computer, Control, Informatics and Its Applications (IC3INA), 2014 International Conference on. IEEE, 2014.

[11] Aulia, Siska, Andriyan Bayu Suksmono, and Achmad Munir. "Stationary and moving targets detection on FMCW radar using GNU radio-based software defined radio." Intelligent Signal Processing and Communication Systems (ISPACS), 2015 International Symposium on. IEEE, 2015.

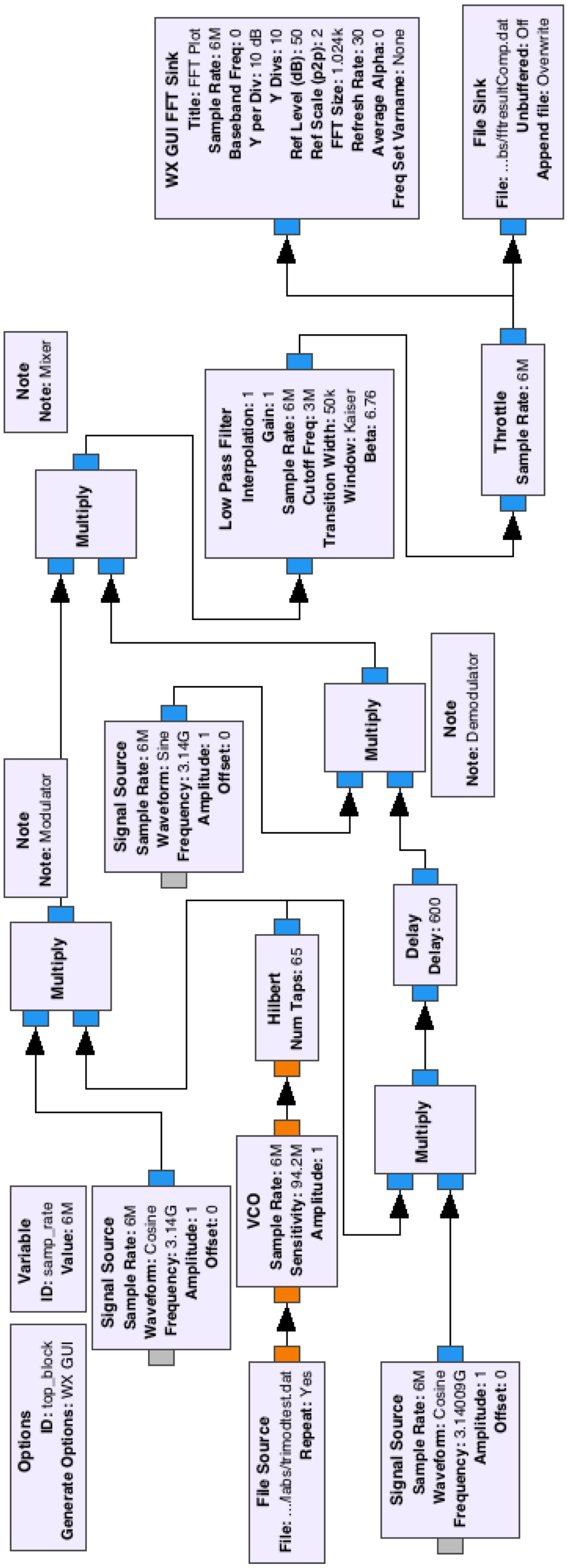

Fig 7. GNU Radio blocks to simulate one moving target

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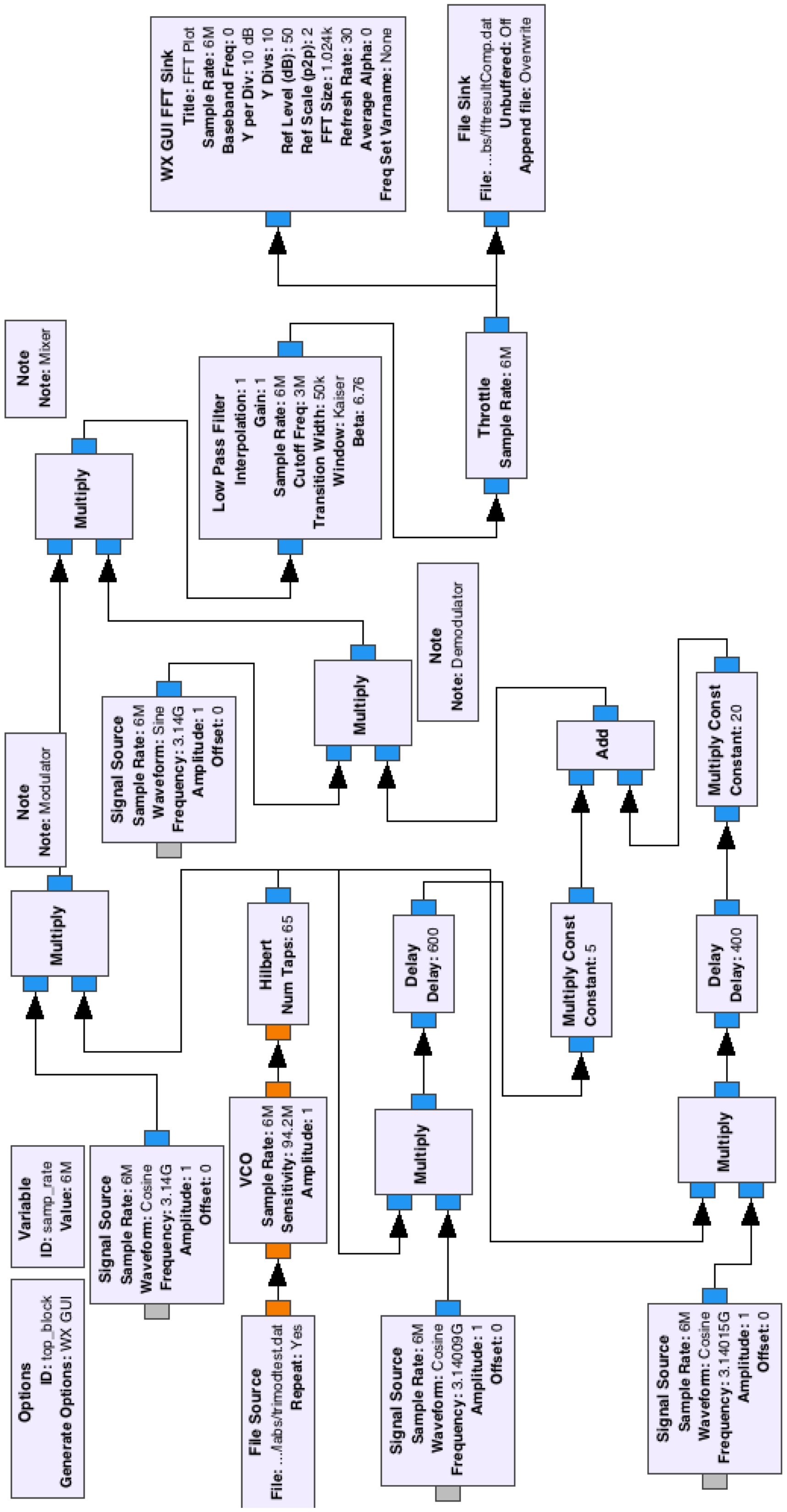

Fig 8. GNU Radio blocks to simulate one moving target