# Barker Code Radar Simulation for Target Range Detection using Software Defined Radio

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***Abstract*— This paper present simulation of radar using Barker code signal to provide pulse compression. Barker code is the most well-known phase coding for pulse compression techniques. Pulse compression techniques has been known can provide solution for range resolution and detection range problem. Radar using Barker code simulated using software-defined radio, GNU Radio. Using GNU Radio give flexibility in operation, lower costs, faster in the realization of the design and easier to use. Radar signal processing for received signal performed on MATLAB. Radar used to detect range of the target which simulated by delaying the signal. This radar using Barker code length of 13. PRI $1.3 \times 10^{-2}$ using for this radar, which give maximum unambiguous range 1950 km. Barker code signal of transmitter delayed 3000, 5000 and 10000 samples for simulation of target. Radar can detect the target as seen from the results of the signal processing done on matlab.**

***Keywords—pulse compression; barker code; gnu radio***

## I. INTRODUCTION

Radar applications in human life is quite fundamental. Radar which initially appeared for the war, now has been widely used for civilian purposes. For example, for the purposes of weather forecasting and aircraft navigation. Radar is an electromagnetic system for the detection and location of objects. It operates by transmitting a particular type of waveform, a pulse-modulated sine wave for example, and detects the nature of the echo signal [1].

Barker code was first presented by R. H. Barker in 1953 for synchronization purposes in telecommunications. Beside widely used in radar technology, Barker code is also used in others telecommunications field. Barker code is used to Enhanced Signal-to-Noise Ratio of SAW Tags [2] and in wireless LAN IEEE 802.11 applications [3]. Barker code used in Radar application because Barker code can provide pulse compression function which can provide optimalization in both main parameter of radar, range resolution and detection range.

On the pulse compression radar, long pulse duration improves SNR and power levels emitted signal is not too high. While the output of the signal processing, the signal response is shorter so as to provide a good range resolution. By using the method of pulse compression, the two important parameters of the radar maximum detection range and range resolution can be optimized without sacrificing one of them. Where the maximum detection range of a radar is determined by the amount of energy emitted. The amount of energy rose by widening pulse. While the resolution of the distance up to shrink the width of the pulse using matching filter.

Radar with pulse compression method using Barker code signal can be implemented using software defined radio (SDR), SDR provides an advantage flexibility in operation, lower costs, faster in the realization of the design and easier to use. SDR can be combined with other software such as MATLAB to perform signal processing.

Implementations of radar using SDR has been done by many researcher, for example, implementation of FMCW radar for weather surveylance [4] and for passive radar implementation [5]. Implementation radar using SDR for pulse compression radar simulation using Barker code is still have not found in literature. In this paper, radar simulation using Barker code using the SDR is presented, and the signal processing is done with MATLAB software.

## II. BARKER CODE RADAR

### A. Barker Code

The most famous phase coding in pulse compression radar is Barker code. In the barker code, pulse divided into N sub-pulses. If the pulse width is $T_p$, then the width of subpulse $\tau_0 = \frac{T_p}{N}$. Then, every sub-pulses conducted a phase shift at $0^\circ$ or $180^\circ$. Phase $0^\circ$ (amplitude 1 Volt) can be characterized by a "1" or "+" and phase $180^\circ$ (amplitude -1 Volt) with "0" or "-". Selecton of phase $0^\circ$ and $180^\circ$ because both of this phase easily generated at the transmitter and the signal processor. Example of Barker code is shown in Fig. 1 [6].

This work is partially supported by the Ministry of Research and Technology, the Republic of Indonesia, under the Grant of Incentive Research Program 2013.

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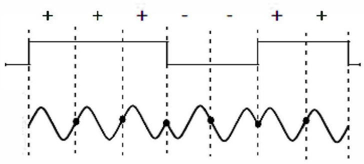



a.

Fig. 1. Binary phase coding with length 7

Code signal phase equation:

$$x(t) = e^{jw_0 t} \sum_{n=1}^{N} P_n(t) e^{j\theta_n} \quad (1)$$

Barker code of length N is denoted by $B_N$. There are only 7 Barker code. List of Barker codes are shown in Table I.

In general, the autocorrelation function (output of the matched filter) of $B_N$ Barker code will be as wide as $2N\tau_0$. The width of the mainlobe $2\tau_0$, peak value N. There are (N-1)/2 sidelobes on each side of the mainlobe [6].

TABLE I. BARKER CODE

| Code Symbol | Code Length | Code Elements | Side Lobe Reduction (dB) |
|---|---|---|---|
| $B_2$ | 2 | + -<br>+ + | 6.0 |
| $B_3$ | 3 | + + - | 9.5 |
| $B_4$ | 4 | + + - +<br>+ + + - | 12.0 |
| $B_5$ | 5 | + + + - + | 14.0 |
| $B_7$ | 7 | + + + - - + - | 16.9 |
| $B_{11}$ | 11 | + + + - - - + - - + - | 20.8 |
| $B_{13}$ | 13 | + + + + + - - + + -<br>+ - + | 22.3 |

Maximum sidelobe reduction of Barker code of length 13 Barker code is -22.3 dB, is not enough for applications in Radar. Barker code can be combined to generate a longer code. Barker code can be combined to generate a longer code. $B_M$ combined with $B_N$ become $B_{MN}$ [6] as shown in Fig. 2 .

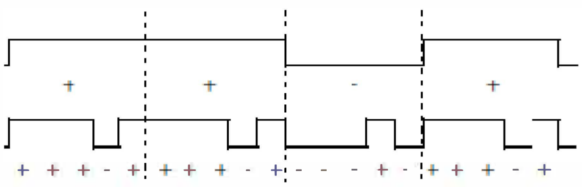



Fig. 2. Combination Barker code 5 dna 4, $B_{54}$

*B. Software-Defined Radio*

GNU Radio is a free software development toolkit that provides the signal processing runtime and processing blocks to implement software radios using readily-available, low-cost external RF hardware and commodity processors. It is widely used in hobbyist, academic and commercial environments to support wireless communications research as well as to implement real-world radio systems [7]. GNU Radio is licensed under the GNU General Public License (GPL) version 3. All of the code is copyright of the Free Software Foundation [7].

GNU Radio applications are primarily written using the Python programming language, while the supplied, performance-critical signal processing path is implemented in C++ using processor floating point extensions where available. Thus, the developer is able to implement real-time, high-throughput radio systems in a simple-to-use, rapid-application-development environment [7]. GNU Radio Companion is a GUI for GNU Radio that allows the user to design the system using schematic blocks.

## III. METHOD AND DESIGN

Models of architectural simulation radar Barker code is shown in Fig. 3. Simulation of radar Barker code is done on GNU Radio. Signal of transmit and receive saved and then the signal processing is done in MATLAB.

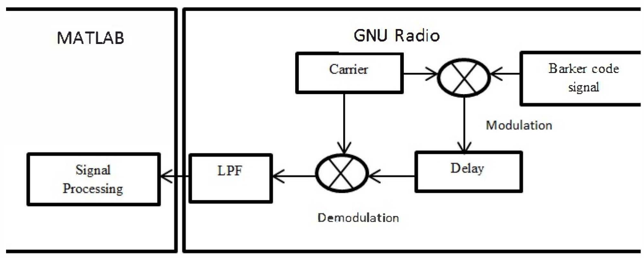



Fig. 3. The architecture of Barker code radar system based on SDR

The specification of the radar is to be simulated as shown in Table II.

TABLE II. BARKER CODE RADAR SPESIFICATION

| Parameter | Value |
|---|---|
| Barker code length | 13 |
| Repeat | 1000 |
| Baseband frequency | 1 kHz |
| Sampling Rate | 1 MHz |
| Carrier frequency | 100 kHz |
| Delay | 3000, 5000, 10000 samples |

Simulated Barker code radar on the GNU Radio Companion is done by making the scheme of the blocks that have been provided on the software GNU Radio Companion. Scheme of the blocks is as shown in Fig. 4 below :

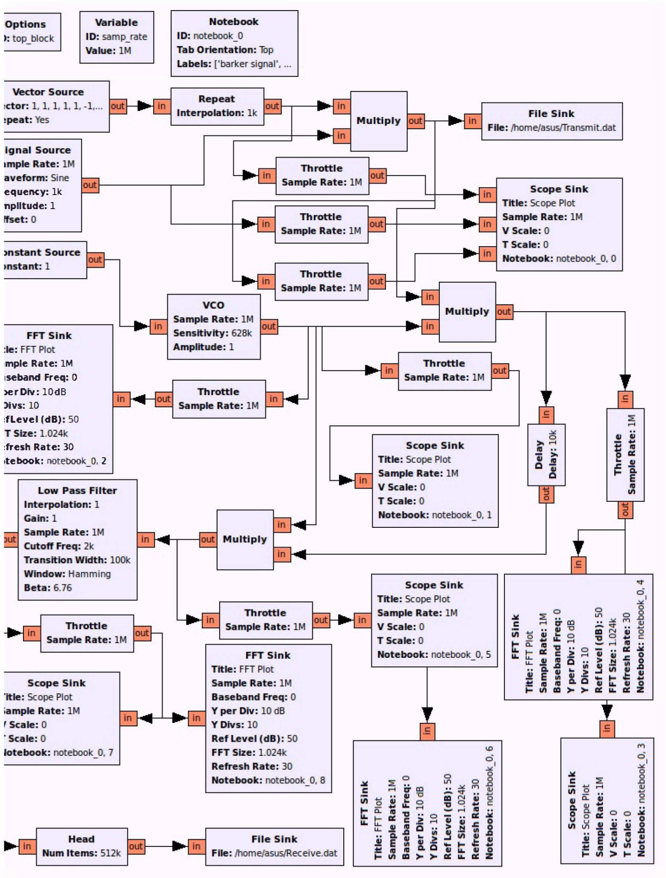



Fig. 4. Block Scheme for Barker code radar simulation on GNU Radio Companion

Values of parameters are adjusted in order to obtain the corresponding simulation results. The parameters of the blocks are given in Table III.

TABLE III. PARAMATER OF BLOCK ON GNU RADIO COMPANION

| Block | Parameter |
|---|---|
| Vector Source | Output Type : Float<br>Vector : 1, 1, 1, 1, 1, -1, -1, 1, 1, -1, 1, -1, 1<br>Repeat : Yes<br>Vec Length : 1 |
| Repeat | Type : Float<br>Interpolation : 1000<br>Vector Lenth : 1 |
| Signal Source | Output Type : Float<br>Sample Rate : 1 MHz<br>Waveform : Sine<br>Frequency : 1 kHz<br>Amplitude : 1<br>Offset : 0 |
| Constant Source | Output Type : Float<br>Constant : 1 |
| VCO | Sample Rate : 1 MHz<br>Sensitivity : 628000<br>Amplitude : 1 |
| Multiply | IO Type : Float<br>Number Inputs : 2<br>Vec Length : 1 |
| Delay | Type : Float<br>Delay : 3000<br>Vector : 1 |
| Low Pass Filter | FIR Type : Float -> (Interpolating)<br>Interpolation : 1<br>Gain : 1<br>Sampling Rate : 1 MHz<br>Cutoff Frequency : 2 kHz<br>Transition Width : 100 kHz<br>Window : Hamming<br>Beta : 6.76 |
| Throttle | Type : Float<br>Sample Rate : 1 MHz<br>Vector Length : 1 |
| Scope Sink | Type : Float<br>Sample Rate : 1 MHz<br>V Scale : 0<br>T Scale : 0<br>AC Couple : Off<br>XY Mode : Off<br>Num Inputs : 2 |
| FFT Sink | Type : Float<br>Sample Rate : 1 MHz<br>Basebabd Frquency : 0<br>Y per Div : 20 dB<br>Y Divs : 10<br>Ref Level (dB) : 50<br>FFT Size : 1024<br>Refresh Rate : 30<br>Peak Hold : Off<br>Average : Off |
| Head | Type : Float<br>Num items : 8000*64<br>Vec length : 1 |

## IV. SIMULATON RESULT

### A. *Simulation Result on GNU Radio*

Barker code signal generated by the Vector Source, Repeat, Signal Source and Multiply blocks as shown in the Fig. 4. Vector Repeat Souce and generate a signal box with a length of 13, according to the used Barker code length. Source Signal produces a sinusoidal signal which is then multiplied by the signal box on the Multiply block that generate Barker code signal with a length of 13, as shown in Fig. 5.

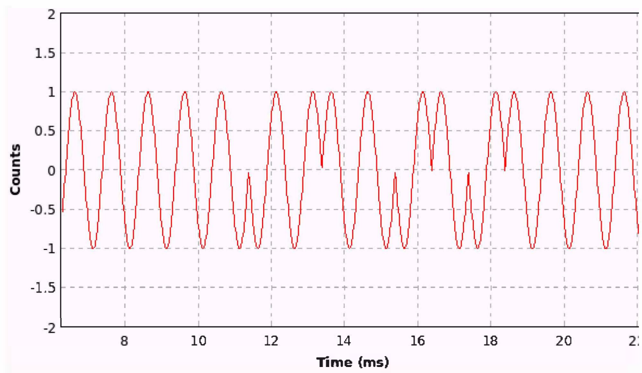
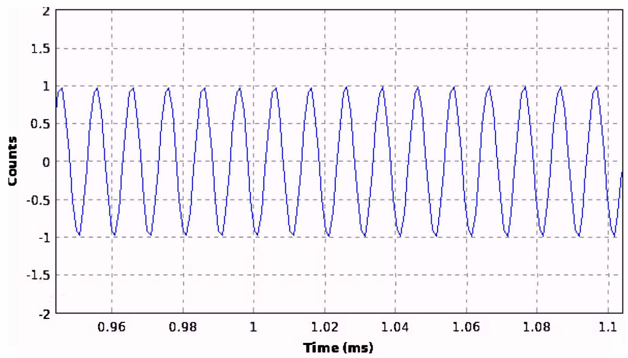
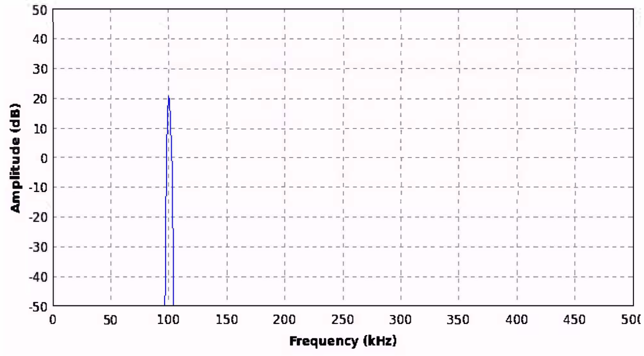



Fig. 5. Barker code signal

Carrier signal 100 kHz generated by the VCO and Constant Source blocks. Carrier signal is then modulated with the Barker code signal on Multiply block. FFT signal carrier and the carrier signal shown in Fig. 6. Signal modulation results are shown in Fig. 7.



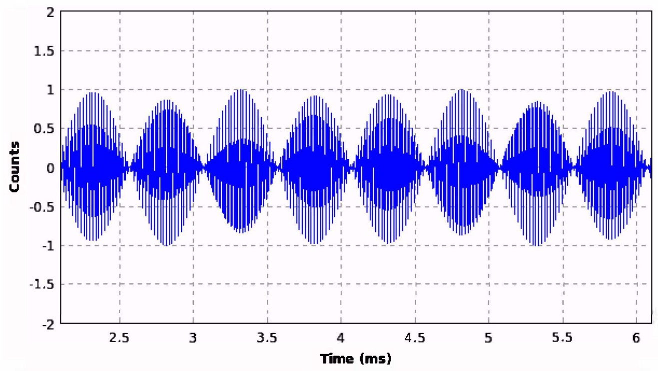

(a)



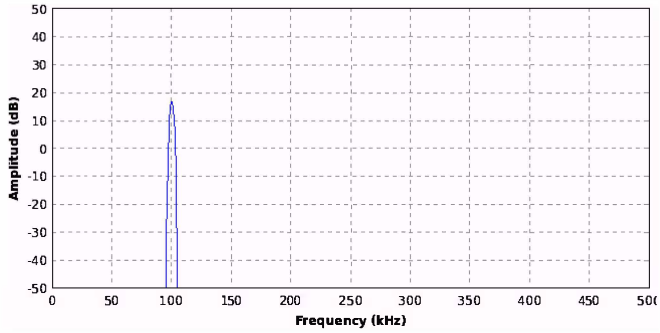

(b)

Fig. 6. Carrier signal(a) FFT of carrier signal (b)

Scope sink use to show carrier signal that have period 0.1 ms. FFT sink use to shoe the frequency at 100 kHz. This carrier signal will modulated with barker code signal on Multiply block. Modulated signal as shown in Fig. 7 (a).




(a)

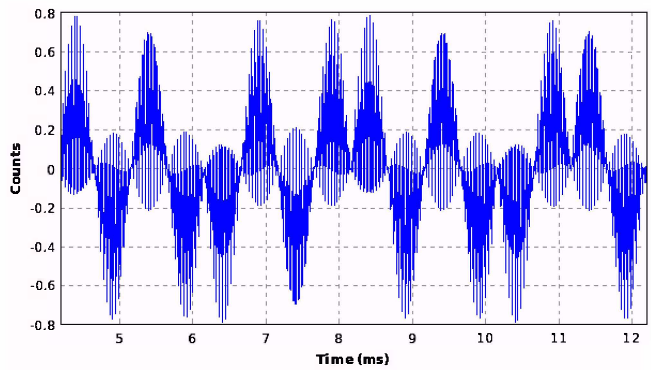



(b)

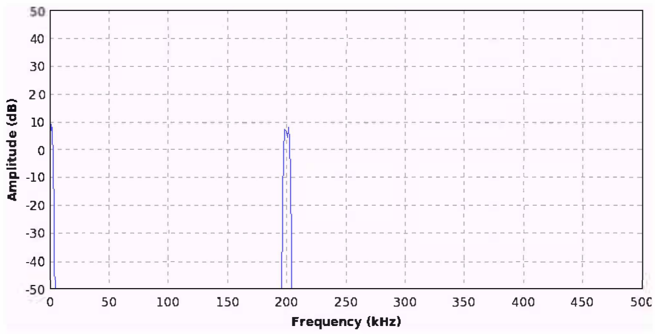
Fig. 7. Modulated signal (a) FFT of modulated signal (b)

Scope sink show that modulation type is amplitude modulation. Modulated signal between carrier signal 100 kHz and baseband frequency 1 kHz is in 99-101 kHz range.

Modulated signal then delayed alternately 3000, 5000 and 10000 samples on Delay block. Signal has delayed then demodulated by multiplying it by the same signal with the carrier signal (1 kHz). Signal of demodulation results are shown in Fig. 8.




(a)

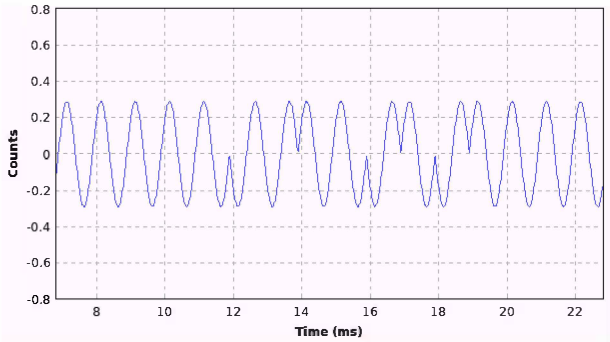



(b)

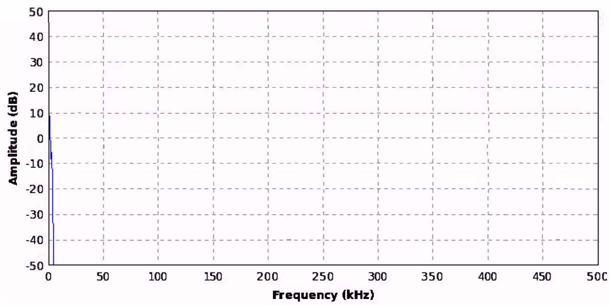
Fig. 8. Demodulated signal (a) FFT Demodulated signal (b)

Scope sink show that after demodulated, signal have two frequency, at range 1 kHz and 199-201 kHz. Because baseband frequency have low frequency, Low Pass Filter (LPF) used to block high frequency.

Demodulated signal results then inserted into the Low Pass Filter (LPF), the output of the LPF is stored in the File Sink and saved as Receive.dat file. Head use to limit the size of file. Output signal of LPF is shown in Fig. 9.




(a)




(b)

Fig. 9. Output signal of LPF (a) FFT of LPF output (b)

Scope show that after inserted in LPF, high frequency blocked and only low frequency passed. Output signal similar to barker code signal. Barker code signal (Fig. 5) and LPF output signal (Fig. 9 (a)) are stored in file sink for later signal processing performed on MATLAB software.

*B. Simulation Result on Matlab*

Send and receive signals that have been stored in a file in GNU Radio Companion and then processed in MATLAB. Basically signal processing in MATLAB done by is matched filtering between the received signal with transmit signal that has been complex conjugated using FFT as shown in Fig. 10 [1] .

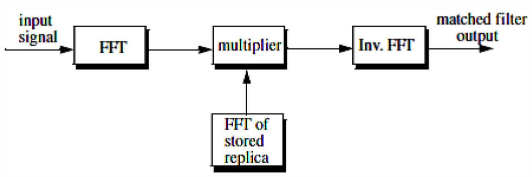
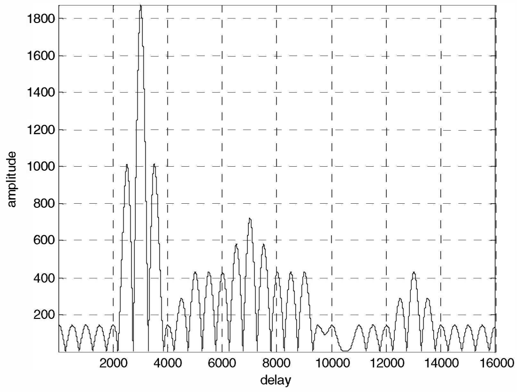
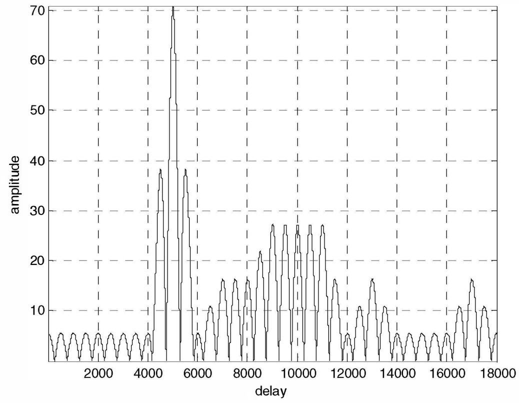



Fig. 10. Computing mached filter using FFT

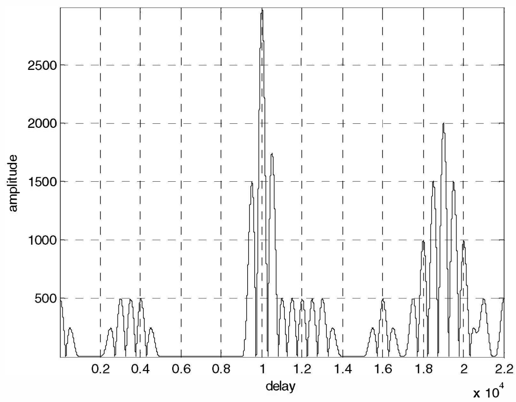
After signal processing on MATLAB, the result is shown in Fig. 11. Simulated result shown delayed signal 3000, 5000 and 10000 samples.




(a)




(b)




(c)

Fig. 11. Matched filtering result on MATLAB, delay 3000 samples (a), 5000 samples (b) and 10000 samples (c)

Match filtering result show that signal that delayed can be detected after processed in Matlab. High side lobe that shown in the figure because the Barker code use sinusoidal waveform that have high sidelobe than other waveform for example chirp waveform. High sidelobe at 19000 in Fig. 11 (c) is ignored because this radar system have maximum unambiguos range 13000 in samples.

### C. Analysis of Simulation Result

From radar spesification, maximum unambigous range can be calculated.

$$Ru = \frac{c \ PRI}{2} \quad (2)$$

Maximum Unambiguous Range calculation :
Barker code length 13,
Sampling rate = 1 MHz,
Baseband Frequency = 1 kHz,
Repeat interpolation = 1000

dt= 1/Sampling rate = $1/10^6 = 10^{-6}$ second
PRI = 13 x 1000 x $10^{-6} = 1.3x10^{-2}$ second
Ru (sample) = $1.3x10^{-2}/10^{-6}$ = 13000 samples
Ru = c x PRI/2 = $3x10^8$ x $1.3x10^{-2}/2$ = 1950 km

From calculation we get maximum unambiguos range in samples is 13000 in samples and 1950 in km. Pulse compression function also shown in simulation result, signal after matched filter process is narrower and this is give better range resolution.

Using the formula (3) [1], range of the target can be calculated:

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

For delay 3000 samples, coverted to time $3x10^{-3}$ s, the range is 450 km. For delay 5000 samples, range is 750km and for delay 10000 samples, range is 1500 km.

## V. CONCLUSIONS

From these simulations it can be concluded that Radar Simulation with Barker code code length of 13 with maximum unambiguous range 1950 km using Software defined radio, GNU Radio Companion, and Signal processing using MATLAB can be implemented. This Barker code radar simulation can detect range of the target with different range as simulated with delaying the signal. Future works for this paper is this simulation can implemented with using USRP hardware and antenna. Sidelobe reduction processing can also used in signal processing in Matlab to reduce the high sidelobe

## REFERENCES


[1] Skolnik, Merrill I., Introduction to Radar Systems, 1980 by McGRAW-HILL BOOK COMPANY

[2] Bae, H., Kim, J., Burm, J., "The Enhancement of Signal-to-Noise Ratio of SAW Tags Using 5-bit Barker Code Sequence", Proceedings of the 40th European Microwave Conference, 2010

[3] Konig, S., Schmidt, M., Hoene, C., "Precise Time of Flight measurements in IEEE 802.11 Networks by Cross-Correlating the Sampled Signal with a Continuous Barker Code", Mobile Adhoc and Sensor System (MASS), 2010 IEEE 7th International Conference, 2010

[4] Prabaswara, A., Munir, A., Suksmono, Andriyan B., "GNU Radio Based Software-Defined FMCW Radar for Weather Surveillance Application", The 6th International Conference on Telecommunication Systems, Services, and Applications 2011, 2011

[5] Heunis, S., Paichard, Y., Inggs, M., "Passive Radar using a Software-Defined Radio Platform and Opensource Software Tools", Radar Conference (RADAR), 2011 IEEE, 2011

[6] Mahafza, Bassem R., Radar Systems & Analysis and Design using Matlab, 2000 by Chapman & Hall/CRC

[7] GNU Radio – WikiStart – gnuradio.org http://gnuradio.org/redmine/projects/gnuradio/wiki, accessed on Mei, 30th 2012