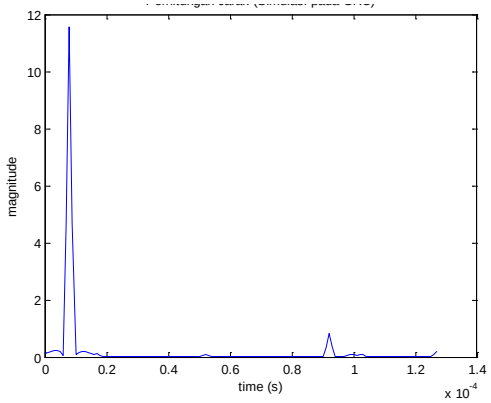
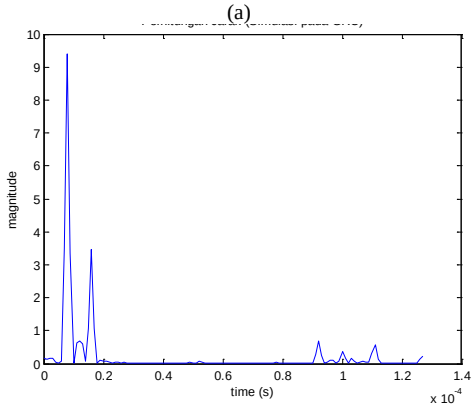


(a)



(b)

Fig. 5 Correlation results in the GRC simulation, (a) one target, (b) two targets.

spaced with only 15 cm spacing. The ideal time delay between transmitted and received signal is 10 µs, according to resolution of sampling rate at 1 Msps.

However, the measured time delay is much greater than the theoretical value. It is probably caused by data exchange process between USRP and a computer that requires time to channel information through Gigabit Ethernet. The time delay affected on the radar target distance calculation result. In this test, *echo*-0 (as shown in Fig. 1) was observed in 30 times observation. The acquired data are shown in Fig. 6.

From the test results, it can be seen that the time delay has random appearance. The delays are almost entirely varying in each trial. Unfortunately, the randomness of time delay seems not to have a specific pattern that can be used for threshold to separate it from transmission delay.

Average time delay between transmitted signal and *echo*-0 is 0.0625 ms, while the standard deviation is 0.053 ms. The large deviation shows the variability of delay is significantly high or data points are spread over a wide range. Therefore, it is impossible to use average value as a correction value in the designed radar system.

C. Random Time Delay Analysis of USRP Implementation

A method that can be used to overcome the random time delay problem in the implementation using USRP and GRC is by taking the direct transmission signal or *echo*-0 as a time reference in distance measurement. To validate the method,

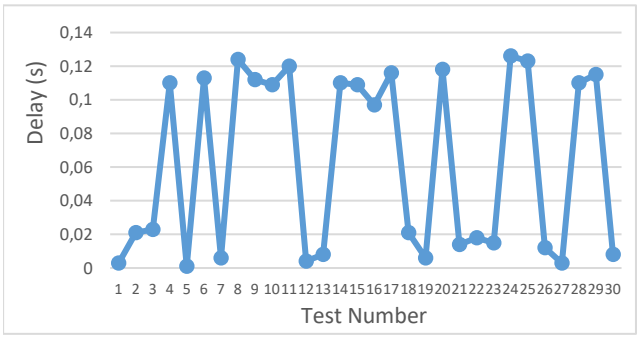


Fig. 6 *Echo*-0 time delay graph.

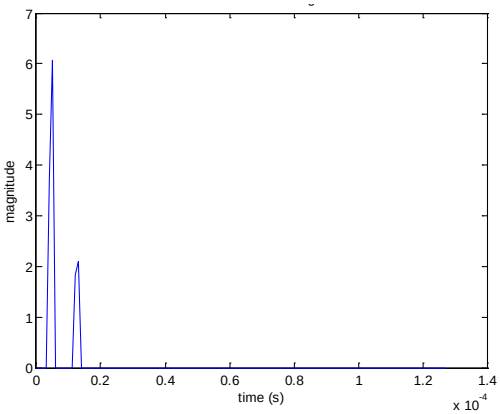


Fig. 7 Results of one target received signal correlation and transmitted signals.

this research developed measurement with USRP for transmitter and receiver. Unfortunately, the designed radar has low range resolution so that it need long target distance to get separated direct transmission from transmitter and reflection echo from target. It should be noticed that USRP has only limited transmitter power so the maximum range is limited to assure the echo is higher than detection threshold. In this situation, the measurement campaign is conducted by some modification on the receiver site. The reflection echo is generated by GRC simulation and added to direct transmission signal from USRP reception.

In this test, the first echo signal *echo*-1 was formed from direct transmission signal with addition 8 µs delay, which represented a target distance of 1,200 m. Correlation results from radar received and transmitted signals are shown in Fig. 7.

Initially the target range is calculated without echo 0 as time reference. As shown by the correlation in Fig. 6, the time delay of the *echo*-0 is 5 µs, while *echo*-1 is 13 µs. The measured distance for target 1 is 1,950 m. The results are certainly not in accurate to simulated target distance.

Secondly, the range is calculated by considering the direct transmission signal as time reference. The *echo*-0 is detected and shifted to zero time reference as shown in Fig. 8. The *echo 0* is recognized as the first echo appeared in received signal, fortunately the direct transmission is from short range and come earlier than other echo signals.

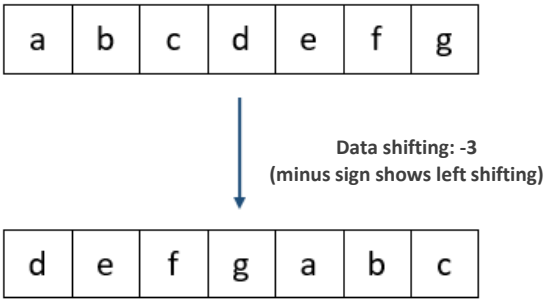


Fig. 8 Data shifting process.

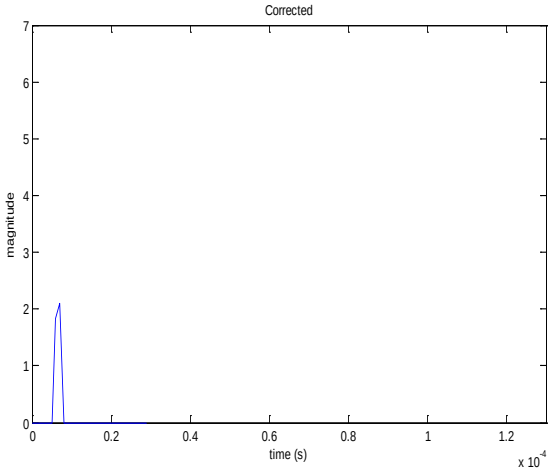


Fig. 9 Corrected echo signal for single target implementation.

After shifting process, the target distance is calculated. From the process, the measured distance was 1,200 m. Fig. 9 shows a correction results graph in the implementation of the one target distance detection using USRP.

The distance measurement test from USRP receiving signal and simulated target echo were conducted for 30 times. From 30 time tests, the success rate of correctly measured distance was 100%. This shows that the method of making *echo*-0 as a reference is successfully mitigate the random delay problem.

The second validation is by assuming two targets produce echo in the radar receiver, so received signal is the sum of three signals, i.e. *echo*-0 which is a direct received signal from radar transmitter; *echo*-1 is an *echo*-0 signal that has been delayed by $\Delta t1$; and *echo*-2 which is an *echo*-0 that has been delayed by $\Delta t2$. Each time delay represents r_1 and r_2 distances, respectively.

Simulated received signal for two targets at GRC is shown in Fig. 10. Delay time of $\Delta t1$ and $\Delta t2$ set in *echo*-1 and *echo*-2 are 8 µs and 16 µs, respectively, representing target range of 1,200 m and 2,400 m from radar.

In the measurement campaign, the time difference between transmitted signal and *echo*-0 is 1.26 ms, with *echo*-1 is 6 µs, and with *echo*-2 is 14 µs. Time delay experienced by *echo*-0 is seemed greater than *echo*-1 and *echo*-2. This is actually caused by the high processing delay that close to the pulse repetition period, so the echo signals are arrived in the processing windows of the next pulse. Correlation results in two-target implementation are shown in Fig. 11.

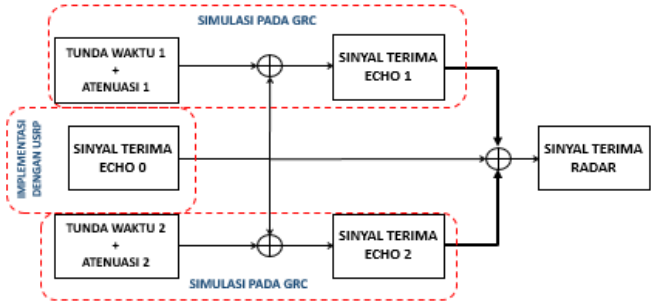


Fig. 10 Received signal forming of two targets at GRC.

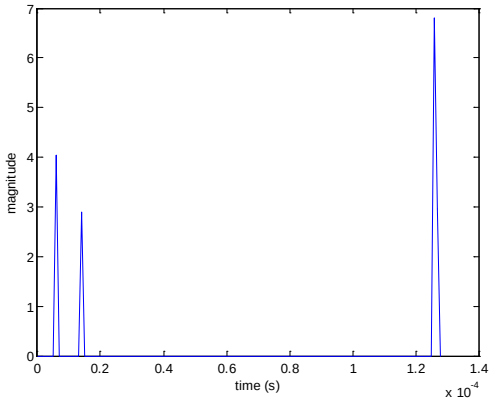


Fig. 11 Correlation results on two-target implementation.

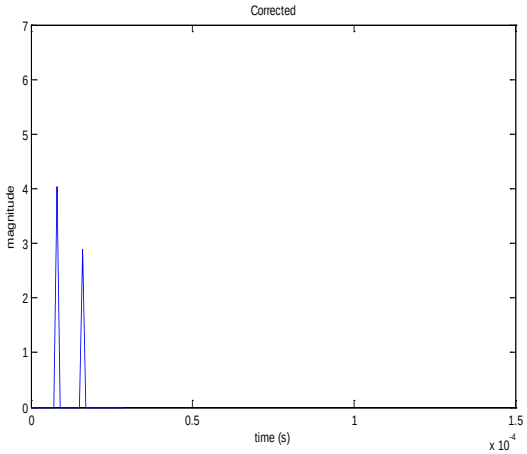


Fig. 12 Correction results for the two targets implementation.

When the range calculation was conducted without time reference correction, it obtains target 1 was detected at the distance of 900 m and target 2 was at a distance of 2,100m which disagree to the distance of simulated targets. The reference correction was made by shifting the peak position from *echo*-0 to position $t = 0$ and be utilized as a reference to calculate the *echo*-1 and *echo*- 2. The corrected results are shown in Fig. 12.

After correction, the calculation results are 1,200 m and 2,400 m. From the results of 30 times repeated test, the first target is detected with 100% correct results, while second target detection suffers 6.7% error or two of 30 tests are detected in wrong distance. However, these results are still

acceptable because it gives 93% correct distance of second target.

The distance calculation error in the second target was 150 m from the exact distance. The measured distance was 2.550 m, while the distance should be 2,400 m. Radar resolution was 150 m equivalent to a sampling period in signal processing. This error is probably caused by the shift of echo signals due to noise or lag of clock synchronization between USRP in transmitter and receiver.

VI. CONCLUSION

The paper describes the implementation of USRP that is programmed by using GRC for to test it functionality as pulse radar and measure the processing delay time for pulse radar. The measurement campaign shows the appearance of random time delay. The average time delay is 0.0625 ms with a standard deviation value of 0.053 ms. The higher variability of random delay caused difficulty on ranging process of pulsed radar with USRP. A solution to mitigate this delay problem is also implemented by transmitting Barker Code with 128 bits in length. The delay between the transmitted and received signals can be evaluated from the correlation process between the radar transmitted signal and received signal. Then problems with random time delay in this system implementation can be overcome by using direct reception from the transmitting antenna to the receiving antenna as a reference. The result shows the target is successfully detected but the second target suffers from 6.7% measurement error after the correction of time reference.

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