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Author:
Qaisar, Sana; Dempster, Andrew

Publication details:
Proceedings of IGNSS2007

Event details:
IGNSS2007
Sydney, Australia

Publication Date:
2007

DOI:
https://doi.org/10.26190/unsworks/703

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Receiving the L2C Signal with "Namuru" GPS L1 Receiver

Sana Ullah Qaisar
School of Surveying & Spatial Information Systems
University of New South Wales, Sydney 2052, Australia
Tel: +61 (2) 93854208, Fax: +61 (2) 93137493
s.qaisar@student.unsw.edu.au

Andrew G Dempster
School of Surveying & Spatial Information Systems
University of New South Wales, Sydney 2052, Australia
Tel: +61 (2) 93856890, Fax: +61 (2) 93137493
a.dempster@unsw.edu.au

ABSTRACT

L2C is the first modernised GPS signal for civilians, broadcast by the new generation of satellites, designated Block IIR-M. Currently three of these satellites (PRN-17, PRN-31 and PRN-12) have been declared operational by the Air Force Space Command at Schriever Air Force Base, Colorado. The structure of the L2C signal is designed such that it achieves a number of advantages over the GPS L1 signal alone. This includes weak signal acquisition, ionospheric error elimination when both L1 and L2C are used, quicker operations and improved tracking performance. It was suggested that it would be interesting as well as challenging to acquire and track the L2C signal with a standard GPS L1 receiver. "Namuru" is an FPGA-based GPS L1 receiver, developed at School of Surveying & Spatial Information Systems, UNSW. In this work, the RF front end of "Namuru" has been modified by hardware augmentation, to process real L2C signals from Block IIR-M satellites. The modified RF front end provides real time samples of the L2C signal. These samples are recorded in a memory module on "Namuru" board and further processed in Matlab environment to perform the acquisition of L2C signal. The new structure of the L2C signal requires novel approaches for its acquisition. The L2C signal consists of two codes, L2C CM and L2C CL. The L2C CM-code is modulo-2 added to data and the resultant sequence is time-multiplexed with the L2C CL-code on a chip by chip basis. In this work, the replica code used for acquisition primarily contains CM chips while CL chips being replaced by zeros. This replica code is referred to as return to zero (RZ) CM code and can be used for signal search across any 20 milliseconds segment of an L2C signal record. The L2C signal is successfully acquired from all the three operational satellites and "Namuru" is now equipped with L2C acquisition capability.

KEYWORDS: L2C, up converter, replica code, acquisition, multiplexing.

1. INTRODUCTION

On March 28, 2007, "Lockheed Martin delivered the eighth and final satellite in the modernized Global Positioning System Block IIR (GPS IIR-M) production to the U.S. Air Force" (RF Design, 2007). Currently three of these satellites (PRN-17, PRN-31 and PRN-12) have been declared operational by the Air Force Space Command at Schriever Air Force Base, Colorado. Each of these satellites transmits a second civil signal L2C and two new military signals. The L2C signal has been designed such that it can be acquired in the weak signal environments like inside buildings, tree-lined roads and any other areas where the line-of-sight signal is obstructed. It can also better serve the increasing population of 'dual frequency' civil users, where a GPS receiver can use the two frequencies to eliminate the ionospheric error and more quickly resolve phase ambiguity. It will lead to improved positioning accuracy and quicker operation. A compact message format and a "dataless" channel are other advantages of this new signal. With all these features, L2C is likely to be widely used (Richard *et al.*, 2001).

"Namuru" is an open-source, FPGA-based GPS L1 receiver developed at School of Surveying and Spatial Information Systems UNSW, in collaboration with NICTA (Mumford *et al.* 2006)(Parkinson *et al.*, 2005). In this work, RF front end of "Namuru" is modified to process real L2C signals. An L2 up converter is developed and added to the RF front end of "Namuru". The L2 up-converter translates the spectrum of L2C signal from L2 to the L1 carrier. The modified RF front end provides real time samples of the L2C signal. These samples are recorded in a memory module on the "Namuru" board and further processed in Matlab environment to perform the acquisition of the L2C signal. The structure of the L2C signal requires novel approaches for its acquisition and tracking. The L2C signal consists of two codes, L2 CM and L2 CL. L2 CM-code is 20 milliseconds long and has 10230 chips while L2 CL-code is 1.5 seconds long and has 767250 chips. L2C CM-code is modulo-2 added to data (i.e. it modulates the data) and the resultant sequence of chips is time-multiplexed with L2 CL-code on a chip by chip basis. This multiplexed sequence modulates the L2 (1227.6 M Hz.) carrier. In order to acquire the L2C signal, first a replica of the L2C code has to be locally generated. With the L2C signal structure, a number of replica codes can be used for acquisition (Tran, 2004). A key parameter in selection of the replica code is the 'signal search time' (i.e. the time required to acquire the signal). The replica code used in this work only contains CM chips while CL chips are replaced by zeros. Called the return-to-zero (RZ) CM-code, this code permits signal search across any 20 millisecond segment of the L2C signal record. The L2C signal is successfully acquired from all the three operational satellites (Qaisar *et al.*, 2007) and "Namuru" is now equipped with the L2C acquisition capability. This paper presents an introduction to the "Namuru" receiver, followed by details of the hardware modifications made to the RF front end of "Namuru", in section 2. In section 3, the L2C signal structure is explained, the choice of local replica code and acquisition methodology are then discussed. Results of acquisition experiments are discussed in section 4 and finally concluding remarks are given.

2. RF FRONT END MODIFICATION

2.1 "Namuru" GPS L1 Receiver

"Namuru" is an open-source, FPGA-based GPS L1 receiver developed at School of Surveying and Spatial Information Systems UNSW, in collaboration with NICTA (Mumford *et a*l, 2006). "Namuru" uses a standard Zarlink front end GP2015 (Zarlink Semiconductors, 2005). The GP2015 has a 2 MHz. filter centered at L1 (1575.42 MHz.) frequency. The L2C signal on

the other hand is centered at the L2 (1227.6 MHz.) carrier. Hence in order for "Namuru" to process the L2C signal, the signal spectrum should be translated from L2 to the L1 carrier. Figure 1 shows the required spectrum translation.

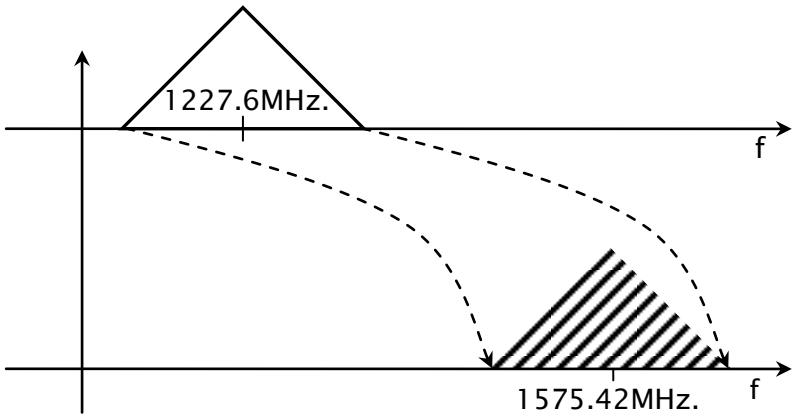


Figure 1. The L2C signal spectrum translation from L2 to L1 carrier

2.2 The L2 Up-Converter

The spectrum translation or up-conversion from L2 to L1 is accomplished by an L2 up-converter, developed using the basic design by Ledvina *et al.* (2005). Figure 2 and Figure 3 show the block diagram and hardware implementation of the L2 up converter, respectively.

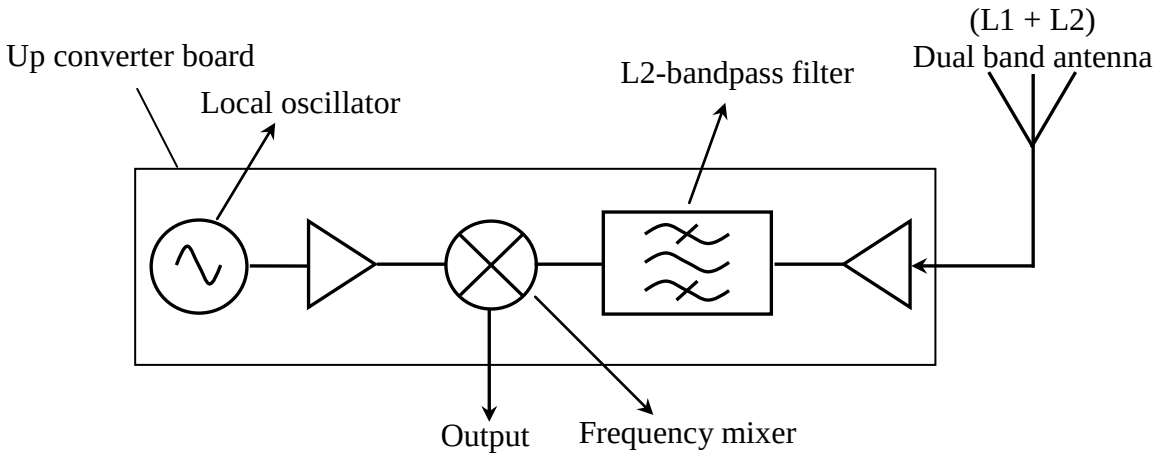


Figure 2. Block diagram of the L2 up converter

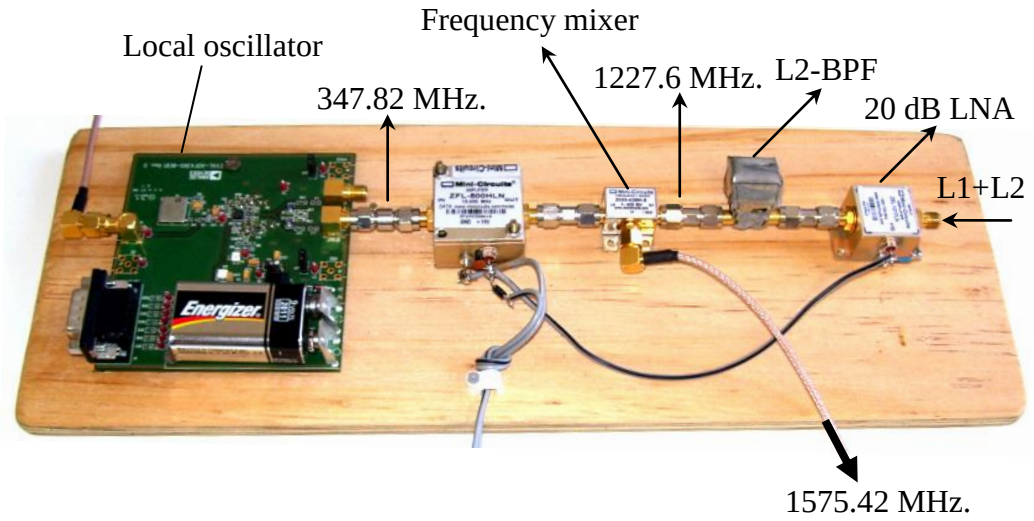


Figure 3. The L2C up converter hardware

As shown in Figures 2 and 3, the RF signal from a Leica AT 504 dual band antenna is fed into the L2 up-converter. The first component (from the right) on the L2 up-converter board is a 20 dB LNA that compensates for the insertion losses in the subsequent components (L2 bandpass filter and frequency mixer). The job of the L2 filter is to pass a 20 MHz. wide signal centred at L2 (1227.6 MHz.) carrier and hence the L1 band is rejected here. On the left side of the L2 up converter board, a local oscillator generates the mixing signal. The frequency of the mixing signal is the difference of L1 and L2 carriers, that is 347.82 MHz. Another 19 dB amplifier is placed after the oscillator to give the appropriate power level to mixing signal (Ledvina et *al.*, 2005). The two signals at 347.82 MHz. and 1227.6 MHz. are mixed together in the frequency mixer. The output of the frequency mixer is the L2C signal spectrum, centred at L1 carrier. Table 1 gives details of all components used in the L2 up converter.

No.	Component	Manufacturer	Model	Reference
1	20 dB LNA	Mini Circuits	ZEL 1217 LN	(Mini-Circuits)
2	19 dB Amplifier	Mini Circuits	ZFL 500 HLN	(Mini-Circuits)
3	L2 GPS BPF	CTS	CER0004A	(CTS-Electronics)
4	Mixer	Mini Circuits	ZX05-42MH	(Mini Circuits)
5	Oscillator	Analog Devices	ADF-4360-8	(Analog Devices)

Table 1. Details of L2 up converter components

3. L2C SIGNAL ACQUISITION

3.1 Structure of the L2C Signal

The L2C signal consists of two separate codes, L2C CM (civil moderate) and L2C CL (civil long). The L2C CM-code has a period of 20 milliseconds and contains 10230 chips while L2C CL-code is 1.5 seconds long and contains 767250 chips. Each of the two codes is running at 511.5 Kcps (kilo chips per second). The L2C CM-code is modulo2 added to data (i.e. L2C CM-code is used to modulate the data) and the resultant sequence of chips is combined with

L2C CL-code using chip by chip multiplexing (i.e. alternating between "L2C CM ⊕ data" and "L2C CL chips")(IS-GPS-200D, 2006). This multiplexed sequence is used to modulate the L2 carrier. Figure 4 shows the structure of the L2C signal.

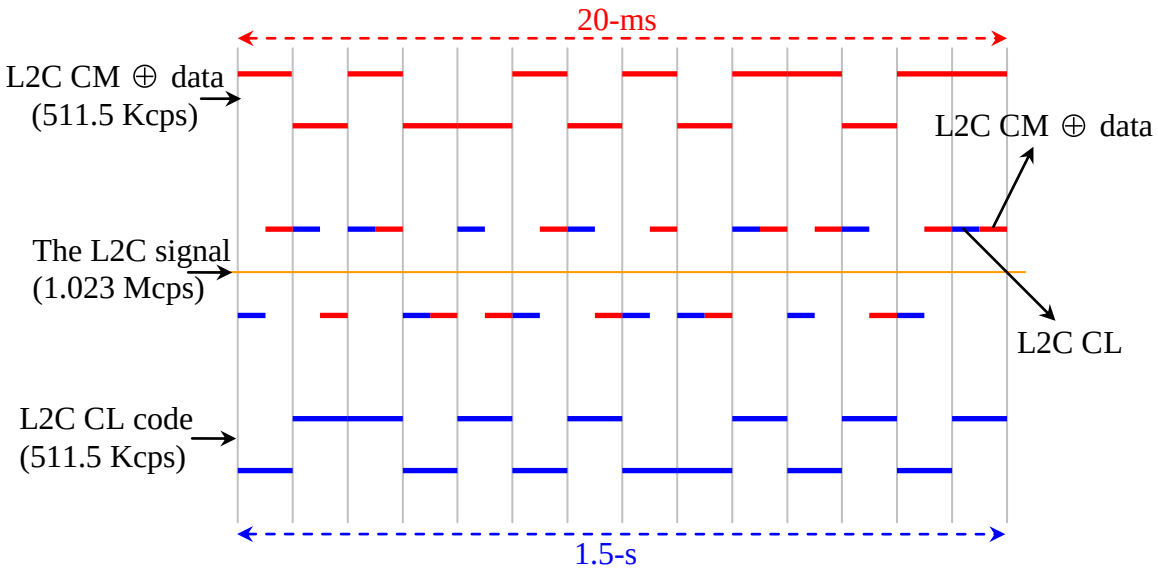


Figure 4. The L2C signal structure

3.2 The Local Replica Code

In order to acquire a signal, first a replica of the desired code is locally generated. With the L2C signal structure a number of replica codes can be used (Tran, 2004) (Dempster, 2006). The choice of replica code is primarily based on the time required to acquire a signal. As shown in Figure 4, the received L2C signal is alternating between "L2C CM ⊕ data" and "L2C CL chips". In the acquisition process, it is required to identify the desired code boundaries in a signal by searching each code delay. It is therefore more time consuming to identify the L2C CL-code boundary than that of the L2C CM-code. For this reason, typically, L2C CM-code, being shorter than L2C CL-code, is used for initial acquisition (Dempster 2006). There are a number of approaches to acquire L2C CM-code (Tran, 2004). In this work a time multiplexed sequence of CM and zeros sampled at 1.023 MHz. is used. In other words, the CL chips in the L2C code are replaced by zeros. This replica code is known as return-to-zero (RZ) CM code. Figure 5 show the RZ CM replica code structure. In this code, 1s and -1s are representing CM chips while 0 has replaced CL chips. This is primarily to remove the noise that will occur between the incoming and replica CL codes, if zeros do not replace CL chips in the replica code.

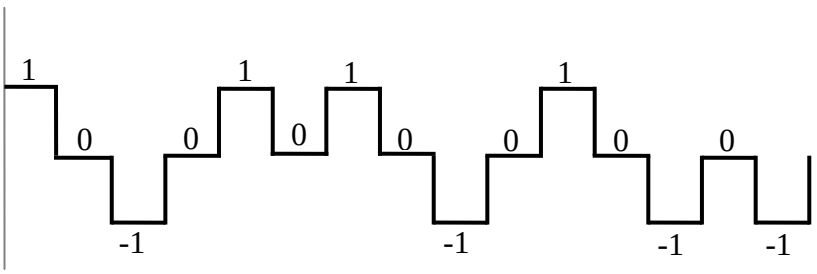


Figure 5. The L2C RZ CM replica code

The RZ CM code also results in a narrower autocorrelation function, which reduces the effects of multipath.

3.3 The Signal Acquisition Setup

As shown in Figure 6, the RF signal from the Leica AT 504 dual band (containing both L1 and L2 bands) antenna is fed to the L2 up converter. As explained in section 2.2, the up converter rejects the L1 band and translates the remaining L2 band to 1575.42 MHz. (L1 carrier). This signal is provided to RF front end (GP2015) of "Namuru" for processing. The samples of L2C signal are collected and stored in a memory module on the Namuru board. These samples (or signal records) are then transferred to a computer for post processing, required for signal acquisition.

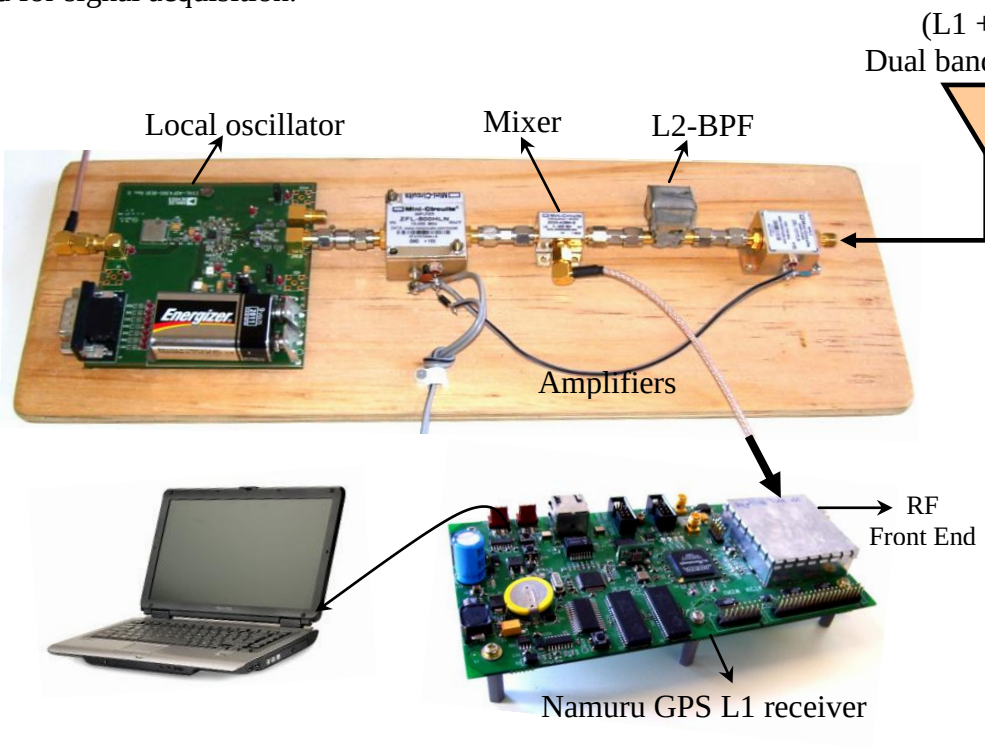


Figure 6. Hardware setup used for the L2C acquisition

3.3 The Signal Acquisition Strategy

In the process of acquisition, the received satellite signal is searched for the correct code phase and Doppler. The search is performed by observing the signal for a certain duration known as the "integration interval". A longer integration interval accumulates more signal power but consumes more time for search in both code phase and Doppler dimensions. The acquisition approach used in this work in only meant to be able to acquire the signal and is not to optimize the efficiency of L2C signal acquisition. To acquire the L2C signal, initially one millisecond of integration interval is used. That is 1 millisecond of replica code is used to search across twenty consecutive (1 millisecond long) segments of received satellite data. Each code phase is trialled across +/- 10 KHz. Doppler. The Doppler bin size is set to 1/2T, where "T"is the integration interval. So for T = 1-ms, the Doppler bin size is 500 Hz. This search is performed using the FFT approach (Tsui, 2000). Results of this search provide the correct phase and Doppler estimate of the desired code.

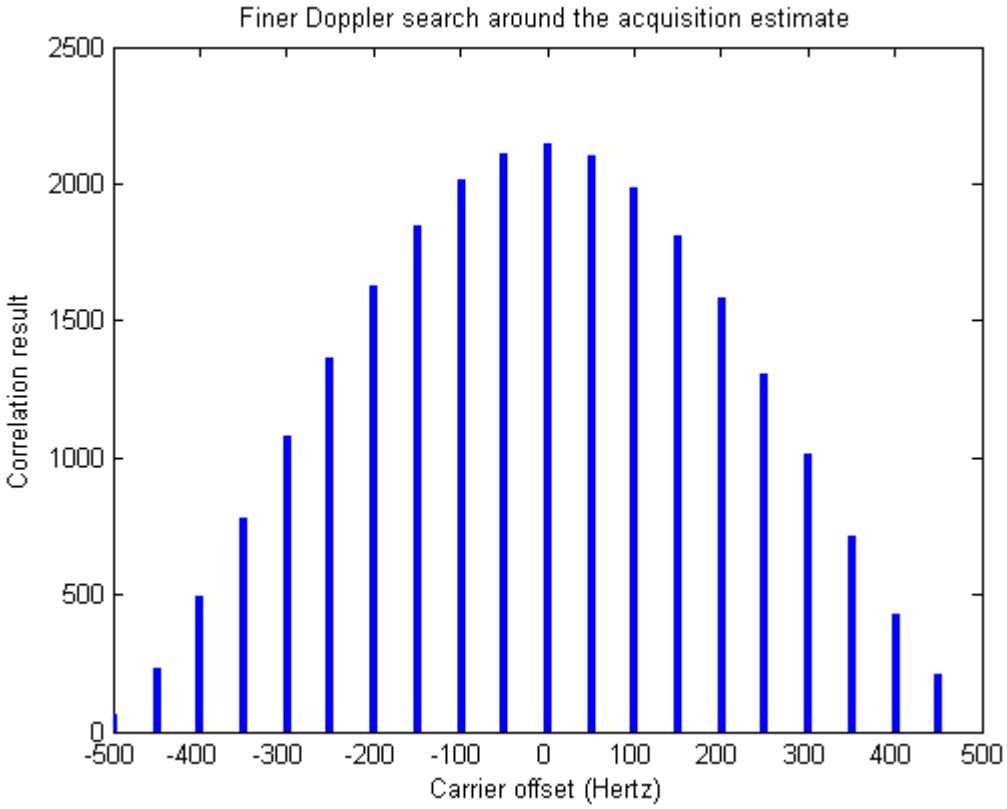


Figure 7. Result of finer carrier search around Doppler estimate

Once the correct code phase is known, then as shown in Figure 7, a finer search can be made around the correct Doppler estimate to know the accurate carrier frequency. The finer Doppler search is required as the correlation tolerance to offset between the incoming and local carrier is reduced for longer integration intervals. With the accurate carrier frequency and known code phase, acquisition is performed with longer integration periods to increase the signal to noise ratio. Therefore the integration interval is gradually increased from 1 millisecond to 20 milliseconds to maximize the signal to noise ratio. For L2C CM-code, the longest integration interval to avoid navigation bit transition is 20 milliseconds.

4. RESULTS OF ACQUISITION

The L2C signals from all the three currently operating satellites (PRN-17, PRN-31 and PRN-12) were successfully acquired by using the modified RF front end of "Namuru". Figure 8 shows the results of acquisition experiments from PRN-31 for different lengths of replica code used for integration. It can be observed that the signal to noise ratio, at the output of correlator, improves in the appropriate proportion with the length of integration period. Here the maximum integration period, to avoid navigation bit transition, is 20 milliseconds. Once the L2C CM-code has been acquired, a quick search across 75 consecutive segments (each of 20 milliseconds) of data can find the beginning of L2 CL-code, as there are exactly 75 periods of CM-code for every period of L2C CL-code. Acquisition is also performed by inserting original CL chips in place of zeros and the results, shown in Figure 9, indicate that the signal to noise ratio for this case is doubled as compared to RZ CM replica code. This verifies the acquisition of the L2 CL code as well.

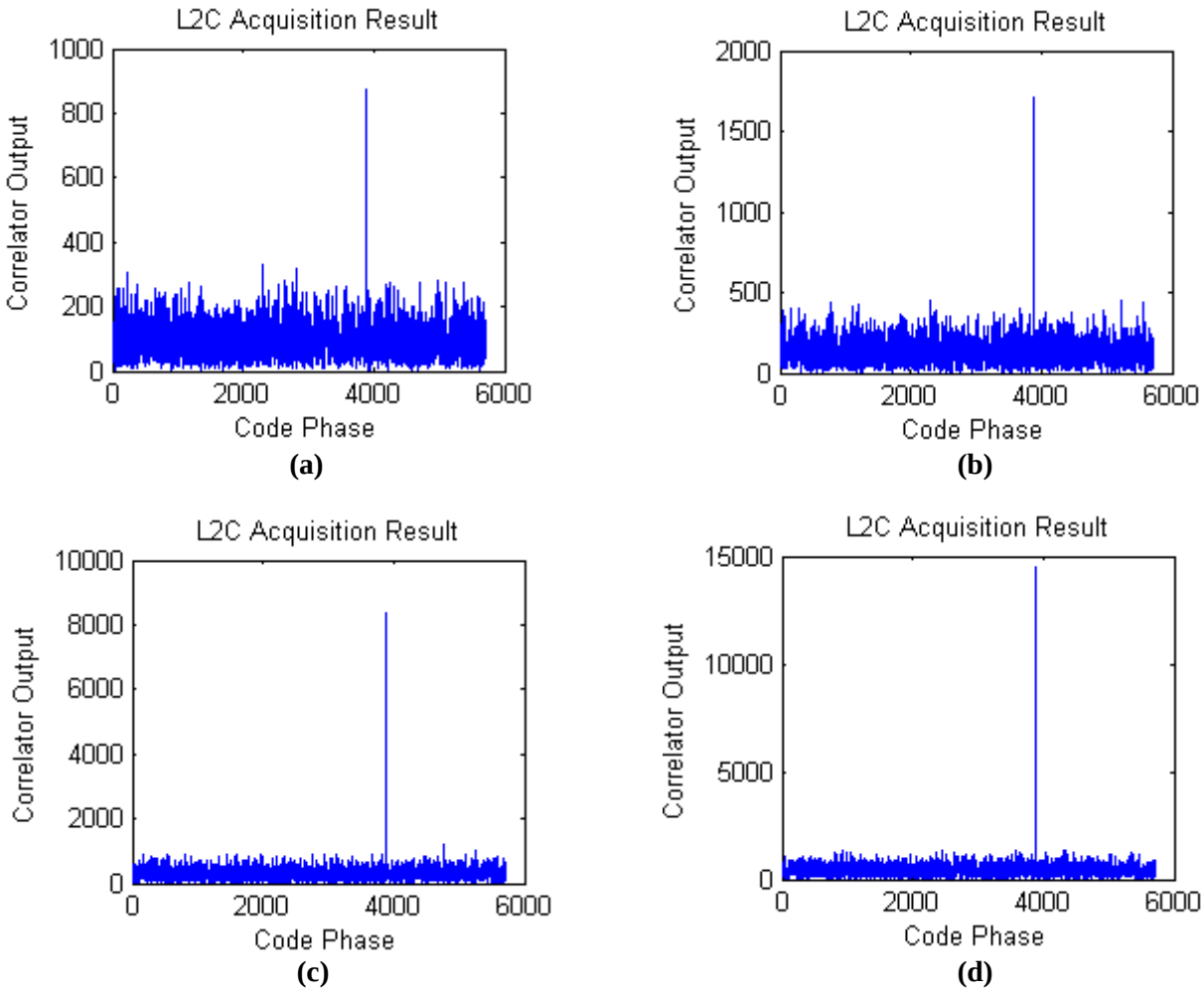


Figure 8. L2C acquisition results from PRN-31 using different lengths of replica RZ CM code for integration. (a) 1-millisecond, (b) 2-milliseconds, (c) 10-milliseconds, (d) 20-milliseconds

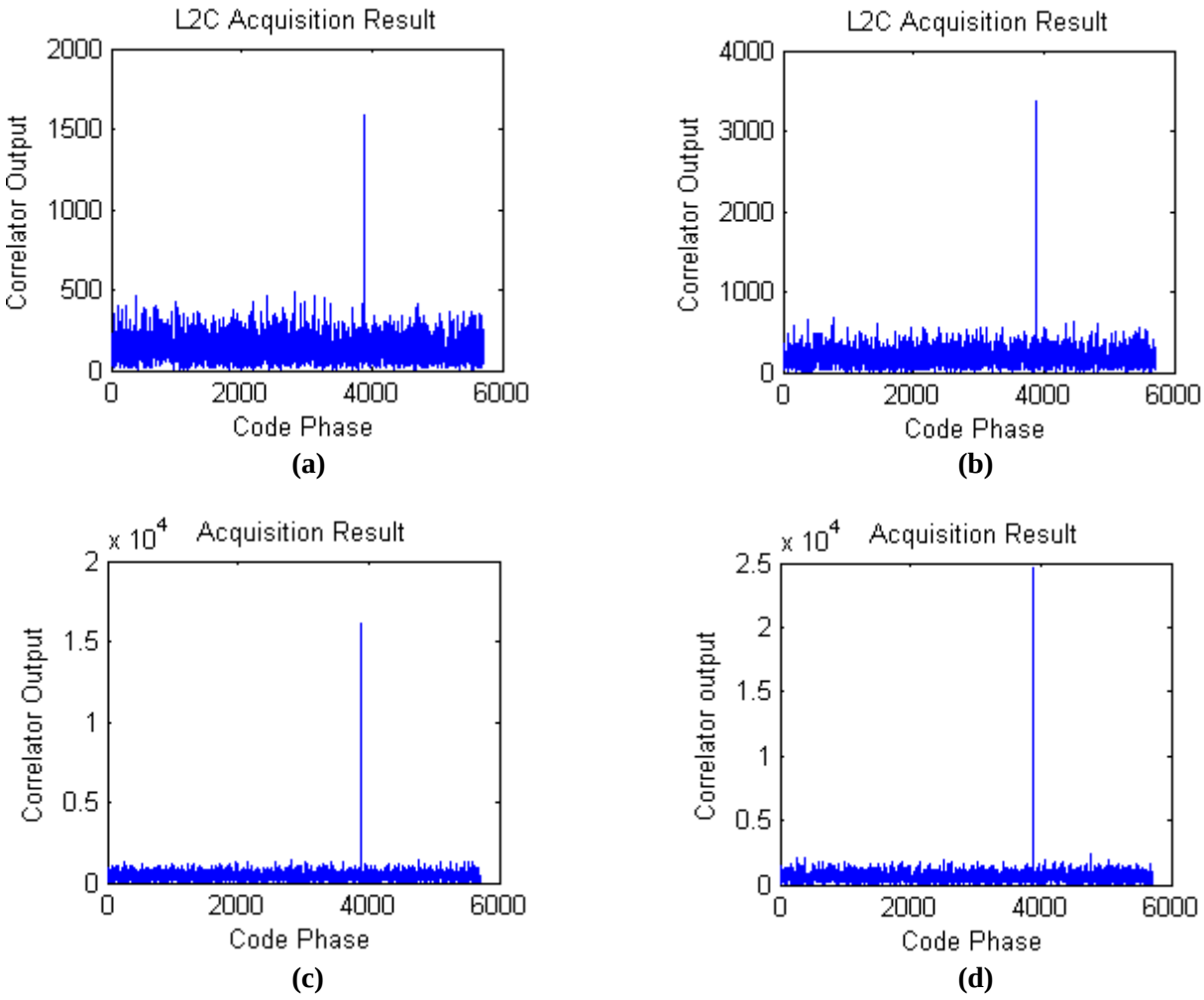


Figure 9. L2C acquisition results from PRN-31 using different lengths of replica CM-with-CL code for integration. (a) 1-millisecond, (b) 2-milliseconds, (c) 10-milliseconds, (d) 20-milliseconds

5. CONCLUSIONS

In this work, the RF front end of a GPS L1 receiver ("Namuru") is modified to process real L2C signals. An L2 up converter (hardware) is developed and added to the RF front end of "Namuru". The modified RF front end provides real time samples of the L2C signal. These samples are recorded and then processed to acquire the L2C signal. The new structure of the L2C requires novel approaches for its acquisition such as the return to zero CM replica code. The L2C signal is successfully acquired with the modified RF front end and results of acquisition are presented. Results of acquisition experiments verify the new capability of "Namuru" to acquire the L2C signal.

ACKNOWLEDGEMENTS

This research work is supported by the Australian Research Council Discovery Project DP0556848.

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