Exploiting the Spectrum Envelope for GPS L2C Signal Acquisition

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BIOGRAPHY

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INTRODUCTION

On March 17 2008, the sixth GPS Block IIR-M satellite was successfully launched from Cape Canaveral. Each of these Block IIR-M satellites include a modernized antenna panel that provides two new military signals and the second GPS civil signal L2C. Where the new L2C signal can offer the advantages of indoor positioning, ionospheric error elimination and a compact navigation message, its long and complex code structure demands novel acquisition approaches.

The L2C signal is composed of two codes, namely L2 CM and L2 CL. The L2 CM-code is 20 milliseconds long and contains 10230 chips while the L2 CL-code has a period of 1.5 seconds containing 767250 chips. L2 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 MHz) carrier. L2 CM code, being shorter, is typically acquired first and then it can be handed over to L2 CL code.

Frequency domain search is a preferred method for rapid acquisition of GNSS signals. An FFT algorithm is generally used to perform this search. Processing resources required in this search are determined by the size of the FFT. In an FFT algorithm, in order to exploit the circular convolution, at least one code period should be processed. Therefore in the case of the L2C signal, at least 20 milliseconds (L2 CM code period) of data should be processed. This however requires very large FFTs, making the frequency domain acquisition highly resource-demanding.

We propose pre-correlation filtering of the L2C signal to significantly reduce the FFT size required for frequency domain acquisiton, at the cost of acceptable correlation loss. The main lobe of the L2C spectrum has a single sided bandwidth of 1.023 MHz containing 90 percent of the total signal power. This main lobe is selected by the RF front-end filter. In the proposed acquisition method, the incoming L2C code is passed through an anti-aliasing low pass filter. This filter removes the tails of the main lobe of the spectrum. The selection of filter cut-off is a trade-off between the desired improvement in the FFT processing and the resulting correlation loss. This filtering removes some signal power and relaxes the minimum sampling frequency requirement, leading to a reduced number of samples in the CM-code period. Eventually, the frequency domain acquisition is performed with much shorter FFTs than required for the original sampling frequency. As a case study, we selected an 819.2 KHz filter cutoff that requires a minimum sampling frequency of 1.6384 MHz. This sampling frequency generates 32768 samples in 20 milliseconds of L2C data which exactly fits into a 32K FFT. On the other hand, the local replica code is directly sampled at the new sampling frequency and sits in a 32K FFT. The two spectra are processed and the desired result is returned to the time domain. Resampling of the received L2C code can cause a sampling jitter with reference to the local-sampled-code. An analysis of pre-correlation filtering and resampling of the L2C code for acquisition is presented and it is established that that the proposed L2C acquisition approach makes frequency domain searches more feasible to implement.

Section I describes the structure of the L2C signal and the choices of local replica codes. Section II described the proposed filtering and its effects on the correlation result. Section III presents the resampling analysis of the L2C code, used in the proposed approach. Details of the selected case study are given in section IV, including the acquisition result of the proposed technique for both simulated and real L2C signals. Finally, section V concludes the paper.

I. THE L2C CODE STRUCTURE

The L2C signal is composed of two codes, L2 CM and L2 CL. The L2 CM-code is 20 milliseconds long and has 10230 chips while the L2 CL-code is 1.5 seconds long and has 767250 chips. The CM-code is modulo-2 added to data (i.e. it modulates the data) and the resultant sequence of chips is time-multiplexed with the CL-code on a chip-by-chip basis. This multiplexed sequence modulates the L2 (1227.6 M Hz.) carrier [1][6].

With the L2C signal structure, three basic options can be used as local replica code. As shown in Figure 2, the three options differ on choice of alternate chips.

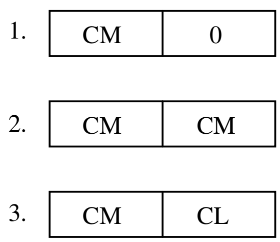

Figure 2. Choices of local replica code for observing the L2C signal (only two chips are shown)

The first option replaces CL chips in the L2C code with zeros and consequently the local code alternates between the CM chips and zeros (also known as return-to-zero CM code). In the second option a CM chip is extended to the duration of two chips to make it a non-return-to-zero CM code. The third option however retains original CL chips in place, as in the L2C code sequence [2] [3]. The RZ CM code is preferred for acquiring the L2C signal as it allows signal searches across 20 milliseconds and it removes half (3 dB) of the cross-correlation noise between CM and CL chips [4]. For all experiments conducted in this work, the RZ CM code is used for observing the L2C signal. Direct use of L2 CL-code for acquisition, on the other hand requires 1.5 seconds for each code phase search and is therefore not recommended.

i. FFT Size for L2C Signal Search

FFT algorithm is generally used for frequency domain acquisition of GPS signals [7]. L2C signal acquisition requires a search of at least 20 milliseconds, which is the CM-code length. The number of samples contained in 20 milliseconds of L2C data is given by:

$$N = \frac{f_s \times 20}{1000} \tag{1}$$

Where 'f_s' is the sampling frequency. The number of samples 'N' can thus be reduced by reducing the f_s. While the minimum f_s of 2.046 MHz has been discussed in [8], we propose to reduce the f_s below "Nyquist" criterion in order to minimize the size of FFT for frequency domain acquisition of L2C signal. This however causes aliasing and consequently significant correlation loss. An anti-aliasing filter is therefore added in the correlation process.

ii. The Proposed Acquisition Approach

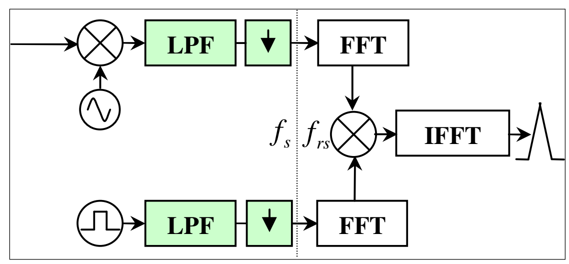

Figure 3. A block diagram illustrating the proposed acquisition approach

As shown in Figure 3, in the proposed acquisition method, the incoming signal (after mixing with the local carrier) is passed through a low-pass anti-aliasing filter. This filtering removes certain signal power, causing a correlation loss. It is then resampled at a new reduced sampling frequency 'f_{rs}', determined by the anti-aliasing filter cut-off frequency. Similarly, the local replica code is first sampled at the original frequency f_s, passed through the same low pass anti-aliasing filter and then resampled at the new sampling frequency f_{rs}. The resampling of incoming signal can cause a sampling jitter with reference to the original sampling frequency, leading to additional correlation loss. The incoming and local signal spectra are then processed by much shorter FFTs and the desired result is returned to the time domain. The correlation loss due to filtering and sampling jitter is discussed in detail in the following sections.

II. PRE-CORRELATION FILTERING

The L2C code has a line spectrum with 50 Hertz line-spacing and the envelope of the spectrum follows a '*sinc*' function. As shown in Figure (4), the main lobe of the spectrum occupies a single sided bandwidth of 1.023 MHz and contains 90 percent of the signal power. This main lobe is typically filtered by the RF front-end of the receiver. By 'pre-correlation filtering', we refer to further filtering of the main lobe (i.e. below 1.023 MHz). Since the spectrum envelope follows a '*sinc*' function, the tail of main lobe contains minimal power and its filtering therefore causes a minimal loss of signal power.

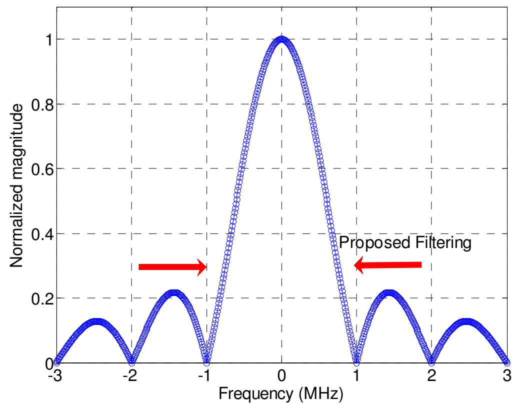

Figure 4. Envelope of the L2C code spectrum, showing the proposed filtering of the main lobe

i. Power Spectral Density

At baseband, the spectral density of L2C signal can be approximated as follows [5]:

$$S(\omega) = \frac{A^2 T_c}{2} \frac{\sin^2(\omega Tc/2)}{(\omega Tc/2)^2} \qquad (2)$$

Where 'A' is the signal amplitude and 'T_c' is the PRN code chip width. The signal power in the single sided bandwidth 'B' can be obtained as:

$$P = \frac{1}{\pi} \int_0^{2\pi B} S(\omega) d\omega \qquad (3)$$

For the un-filtered spectrum, $B = \infty$ and the signal power is computed as $A^2/2$. The power in main lobe of the spectrum can be computed by evaluating equation (3) for $B = 1/T_c = 1.023 \times 10^6$ and it can be calculated to be $0.9(A^2/2)$, i.e. 90 percent of the total signal power meaning a signal power loss of 0.45 dB. We evaluated equation (3) as a function of single sided bandwidth and the relative (to 1.023 MHz single sided bandwidth) power loss was recorded (see Figure 5).

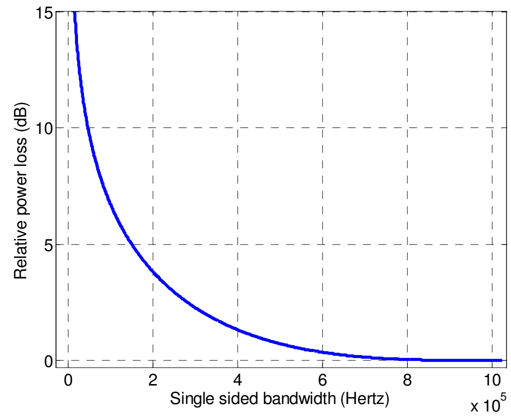

Figure 5. Relative power loss in L2C signal as a function of single sided spectrum bandwidth

It can be observed from Figure 5 that the relative power loss becomes negligible as the single-sided bandwidth approaches the end of main lobe (zoomed in Figure 6) converges to 0.45 dB. This verifies that the power loss is minimal for removing tails of the spectrum.

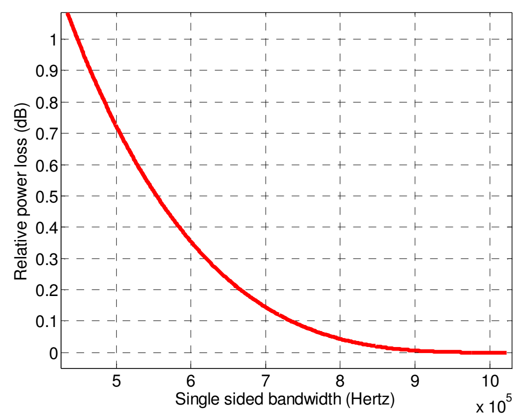

Figure 6. Relative power loss in L2C signal as a function of single sided spectrum bandwidth when approaching the end of the main lobe

ii. The Autocorrelation Triangle

The effect of proposed filtering on the auto-correlation triangle was observed for different cut-off frequencies. Table 1 describes the data set used for this experiment.

Signal	Incoming PRN	Local PRN	Fs (MHz)	T (ms)
L2C	28 (CM-CL)	28(CM-0)	5.115	20

Table 1. Parameters used for observing the effect of main lobe filtering on the autocorrelation triangle

Auto-correlation was performed for L2C code of PRN-28 for different cut-off frequencies and the auto-correlation triangles were compared.

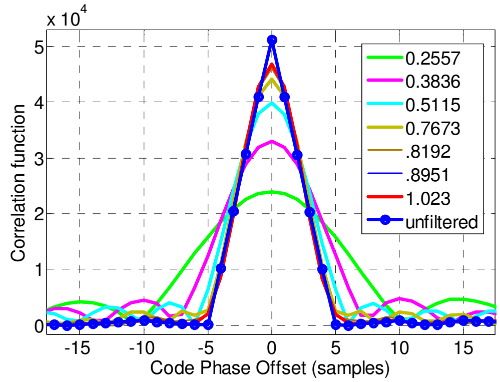

Figure 7. Effect of main lobe filtering on the autocorrelation triangle in L2C signal

It can be observed from Figure 7 that as more and more signal power is filtered out; the auto-correlation function tends to become like a '*sinc*' and the side lobes of auto-correlation function become prominent, causing a further correlation loss while the red line shows the un-filtered case.

iii. The Correlation Loss

Using parameters shown in Table (1), the auto-correlation of L2C code was performed for different cut-off frequencies of anti-aliasing filter and the peak was compared to the un-filtered case peak. Figure 8 shows the result of this test.

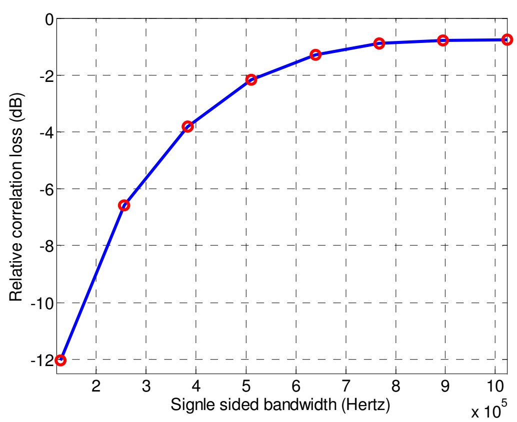

Figure 8. The correlation loss in L2C signal due to pre-correlation filtering of the main lobe

It can be observed from Figure 8 that the correlation loss of the 'correlator' degrades for lower cut-off frequencies and this loss becomes minimal as the cut-off frequency approaches 1.023 MHz. This verifies that the L2C spectrum tail has little contribution to this correlation result.

III. RESAMPLING OF L2C DATA

In the proposed acquisition method, resampling of the L2C data is performed to reduce the number of samples in the CM-code period. This resampling can however cause an additional correlation loss due to sampling jitter. The sampling jitter would occur because of a non-integer ratio between the original sampling frequency and the resampling frequency (f_s / f_{rs}). Code phase offset per samples is given as $\gamma\left(\frac{f_s}{f_{rs}}\right)$, where '$\gamma$' refers to remainder of the f_s / f_{rs} ratio. This remainder would exist if a sample does not exist where the direct resampling should produce it. The correlation loss due to sampling jitter can thus be expressed as:

$$\xi = \frac{T_s}{N}\sum_{n=1}^{N}\gamma\left(\left(\frac{f_s}{f_{rs}}\right)\times n\right) \quad (4)$$

Where T_s is the sampling interval with original sampling frequency f_s, N is number of samples with new sampling frequency f_{rs}, given by:

$$N = \frac{f_{rs}\times 20}{1000} \quad (5)$$

'γ' refers to fractional part of the real number produced by $\left(f_s \times n / f_{rs}\right)$ term in the equation (4). Equation (4) shows that the resampling jitter loss would depend on the size of sampling interval and the ratio of sampling frequency to the resampling frequency. For a given T_s, an optimal f_{rs} can be selected to minimize this loss. Figure 9 shows this loss for $T_s = 5\times 1.023$ MHz as a function of ratio of the sampling frequency to the resampling frequency. The horizontal axis of the figure gives the fractional part of the ratio while the vertical axis gives the corresponding correlation loss.

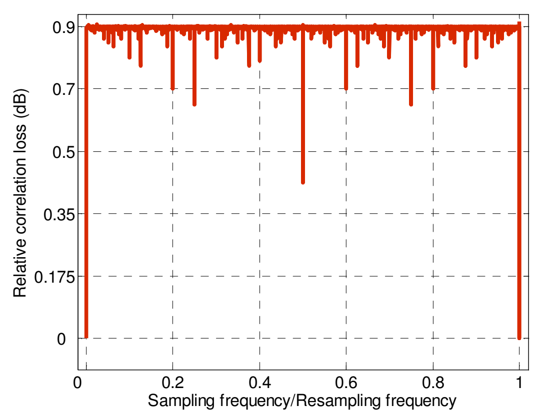

Figure 9. The sampling jitter loss for different ratios of sampling frequency to resampling frequency

On the other hand, for a desired resampling frequency, this loss is minimized for higher original sampling frequencies f_s. For f_{rs} =1.023 MHz, the correlation loss is plotted as a function of f_s / f_{rs} (see Figure 10). It can be observed from Figure 10 that the correlation loss drops down to zero for certain sampling frequencies. We call these as null frequencies. For null frequencies, the ratio of the sampling frequency to the resampling frequency is an integer number. Figure 9 and Figure 10 provide information for the decision of appropriate resampling frequency selection.

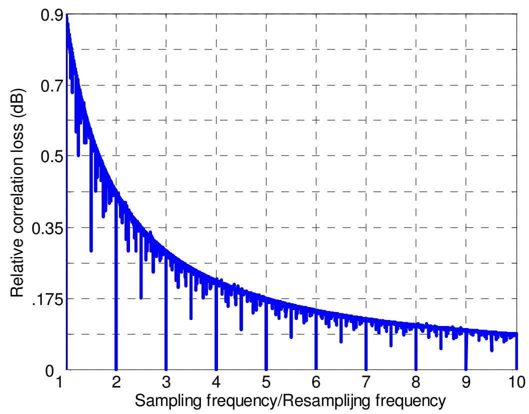

Figure 10. The correlation loss for f_{rs} =1.023 Mhz as a function of sampling frequency to resampling frequency ratio

IV. THE CASE STUDY ANALYSIS

As a case study for the proposed acquisition method, we selected 819.2 KHz as the pre-correlation filter cut-off. This cut-off frequency suggests a minimum sampling frequency of 2 $\times$ 819.2KHz =1.6384 MHz. The L2C code spectrum with this cutoff frequency is shown in Figure (11). This new sampling frequency provides 32768 samples in 20 milliseconds of L2C signal that will fit into a 32 K FFT. A power-of-2 FFT size is selected for its simplicity and ease of implementation. However our analysis in this work remains valid for any 'non-2^N' (where **N** is an integer) FFTs as well.

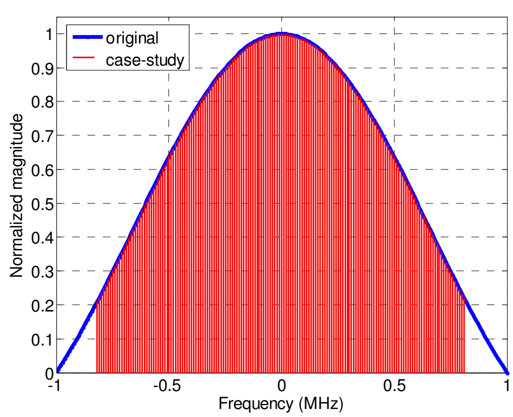

Figure 11. The L2C spectra selected for the case-study analysis

i. Simulation Results

The L2C autocorrelation was performed using Table 1 parameters, for a range of SNR levels for both the proposed and the standard acquisition approaches. For each case, the ratio of peak-to-subpeak was recorded. Figure 11 shows the performance comparison of the two approaches for various SNR levels. It can be observed from Figure 11 that for weak SNR levels the proposed approach has a minimal loss compared to the standard approach while the two performance curves diverge as the desired signal becomes strong. This is because filtering of strong signals causes more of the information loss.

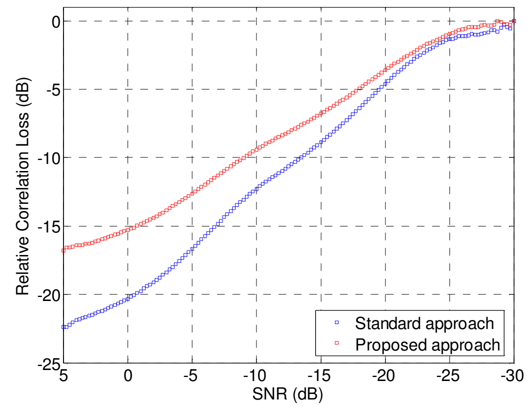

Figure 12. Perfomance comparison of the proposed technique with the standard acquisition approach for L2C signal.

ii. Experiments With Real Signals

Real L2C signals were collected with two different GPS receivers. (UNSW's 'Namuru' GPS Receiver and Nord-Nave Rxx2). Table 2 summarizes the specifications of these signals. Signal acquisition was performed in the Matlab environment with both the standard acquisition approach and the proposed filtering approach and the results are compared.

PRN	RF Front-End	fs (MHz)	IF (MHz)
17	GP2015	5.714	4.309
17	Nord-Nav Rxx2	16.367	4.1304

Table 2. Specifications of real L2C signals used for experiments

Acquisition Results of Real Signal Experiments

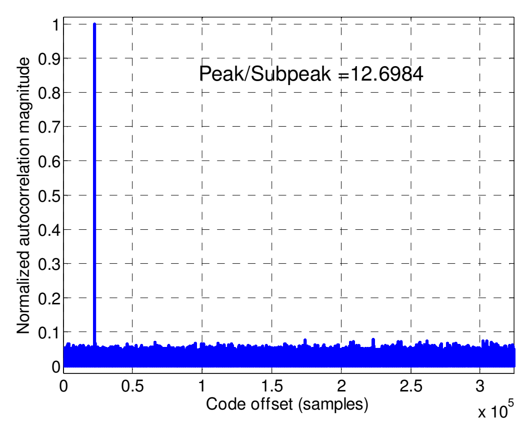

Figure 13. L2C acquisition result with 'Namuru' GPS receiver, using the standard approach

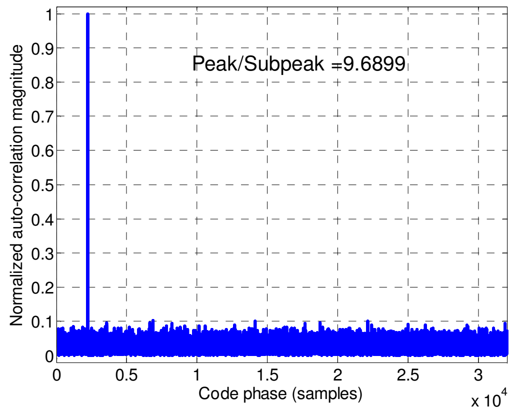

Figure 14. L2C acquisition result with 'Namuru' GPS receiver, using the propsed acquition method

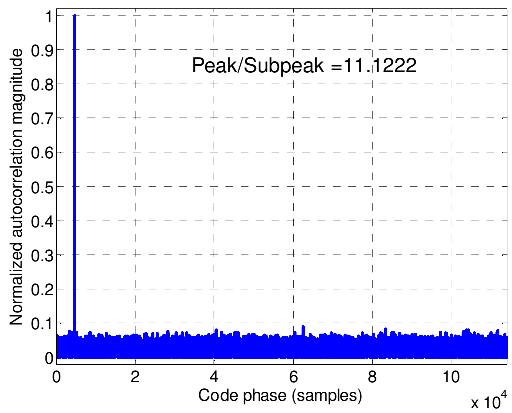

Figure 15. L2C acquisition result with 'NordNav Rxx2' GPS receiver, using the standard approach

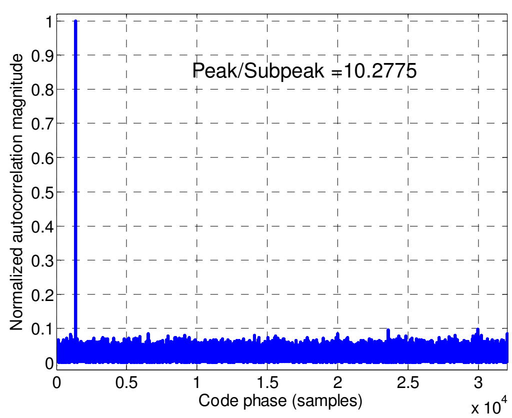

Figure 16. L2C acquisition result with 'NordNav Rxx2' GPS receiver, using the proposed approach

From the above figures, it is evident that the correlation loss is very low with the proposed approach. On the other hand the FFT size is reduced from 520K to 32K for the NordNav recorded signal and from 130K to 32K for the 'Namuru' receiver case.

V. CONCLUSIONS

An acquisition strategy for the new L2C signal is proposed. The proposed strategy exploits the spectrum envelope and performs filtering of the main lobe of spectrum to reduce the number of samples in the CM-code period, leading to use of shorter FFTs for frequency domain acquisition. A significant reduction in the FFT computational load is achieved at the cost of minor correlation loss. The proposed acquisition approach makes frequency domain searches more feasible to implement.

ACKNOWLEDGEMENTS

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