Design, simulation, implementation and testing of search and tracking modules for a FPGA-based GPS receiver

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INTRODUCTION

The use of Global Positioning System (GPS) receivers is of great importance for a wide range of applications: navigation in ground or aerial vehicles, launchers, satellites; precision agriculture, seismic measurements, logistics, to name a few. Nonetheless, commercial GPS receivers often have performance limitations for certain applications where, for example, refresh rate of the receiver's solution is not fast enough for navigation purposes or additional data is desirable as observables like pseudoranges, carrier wavelength shift or carrier Doppler shift in order to use advanced navigation techniques like tightly-coupled navigation algorithms. In other areas, for example, seismic measurements, high-rate GPS solutions are needed to provide precise, real-time positions of displacements.

RECEIVER FRONT END

The front end module conditions GPS RF signal so it can be subsequently processed in real time by the field programmable gate array (FPGA) modules.

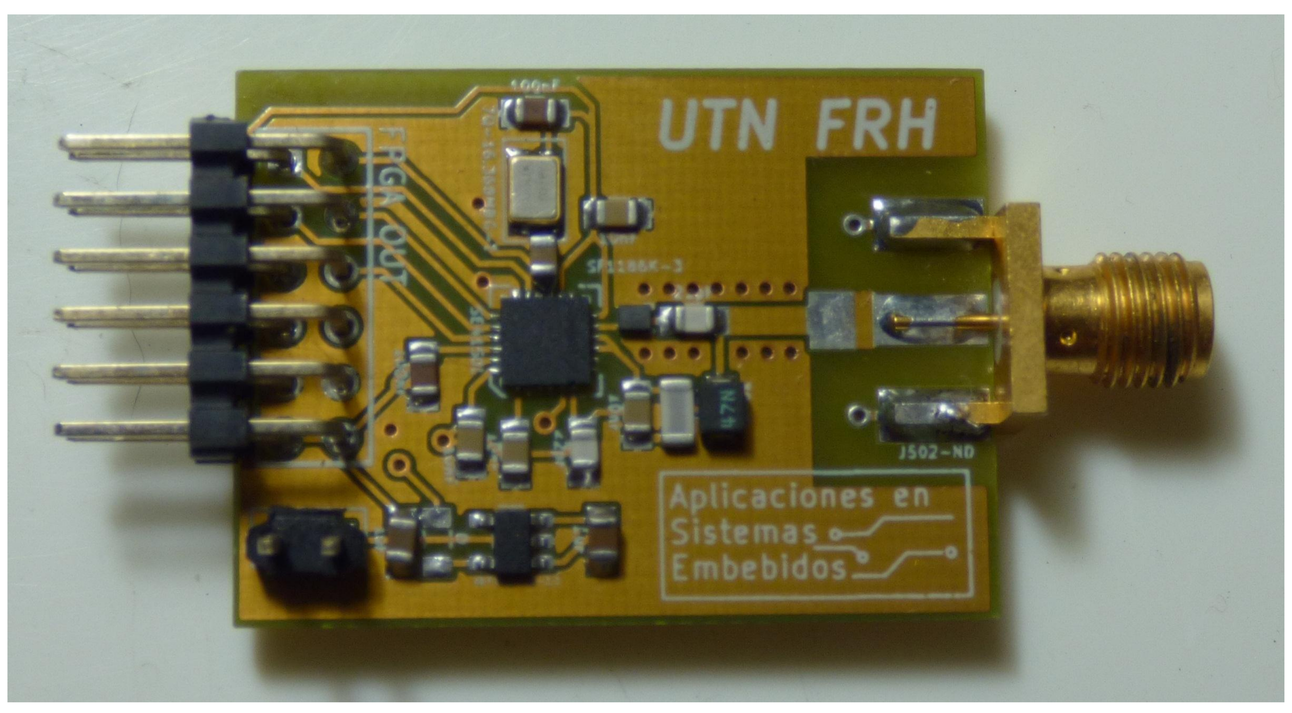

Fig. 1 – Front end printed circuit board

FRONT END PARAMETERS	
Parameter	**Value**
Intermediate frequency (IF)	4.092 MHz
Sampling frequency	16.368 MHz
Signal resolution	1 bit

SEARCH MODULE

Search algorithms are applied to the IF signal in order to determine if a given satellite is present, i.e. it is in antenna's line of sight and if this is the case, its C/A code phase relative to local C/A signal replica and carrier frequency displacement.

IF signal is correlated with a local replica composed by the IF carrier mixed with a given C/A code for a predetermined satellite. C/A code phase and carrier frequency of the local replica are then varied and the value of correlation of both signals is calculated for each pair.

The variation of both parameters constitutes a bidimensional domain, i.e. a matrix, through which the IF signal is tested. Octave scripts were written to implement the described algorithm and applied to a real GPS IF signal. If a given satellite is not present a 'flat' correlation matrix is obtained. Inversely, if a given satellite is present a correlation matrix with a distinctive peak can be distinguished. This procedure can be repeated for each satellite in order to obtain which ones are present in a given IF signal.

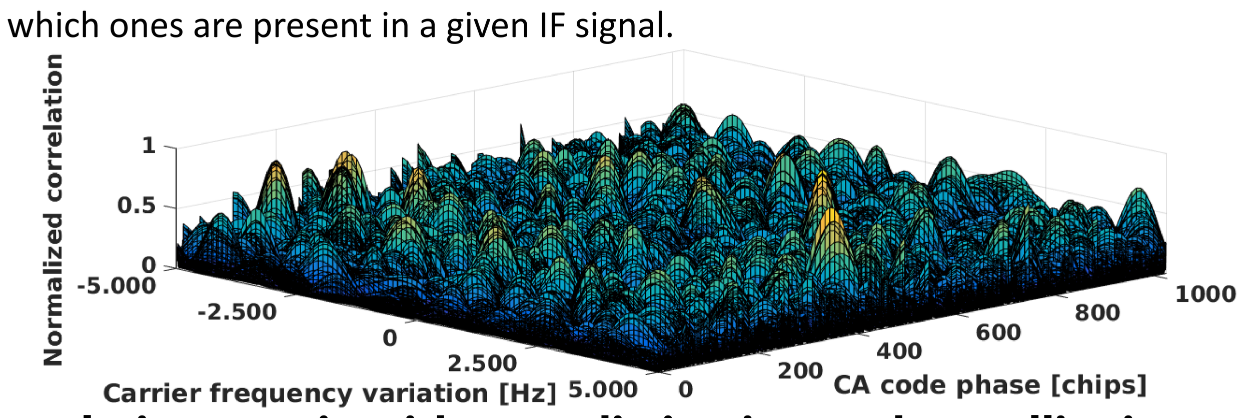

Fig. 2 – Correlation matrix without a distinctive peak: satellite is not present

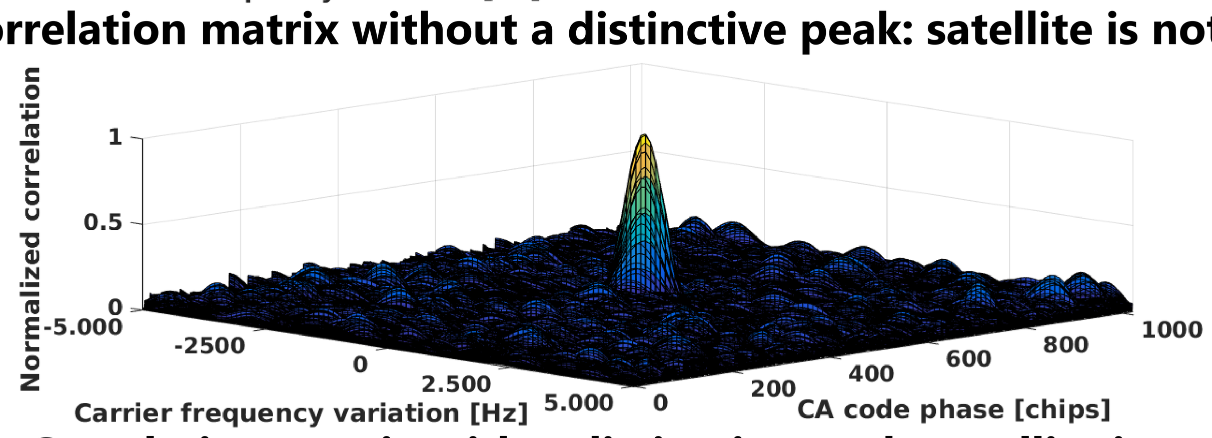

Fig. 3 – Correlation matrix with a distinctive peak: satellite is present

TRACKING MODULE

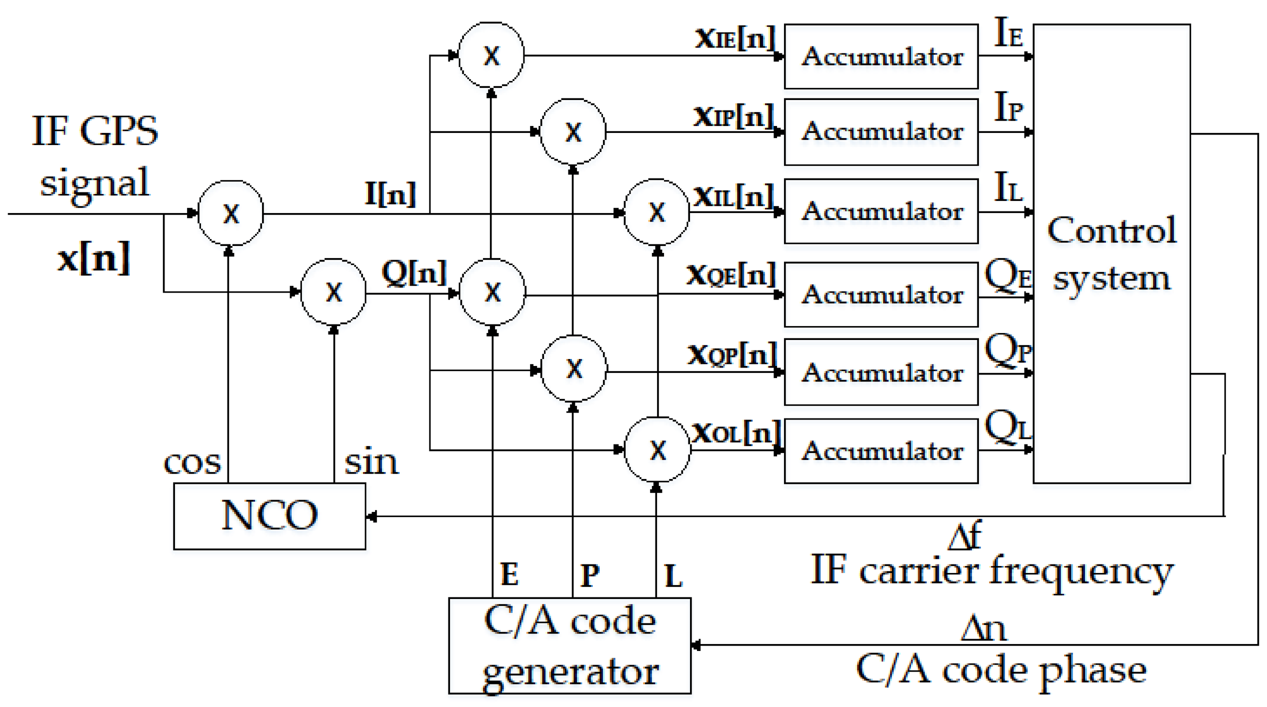

Fig. 4 – Tracking loop structure

Demodulation of GPS IF signal is performed synchronically by the tracking module providing its actual C/A code phase and carrier frequency displacement are known. IF GPS signal is mixed with the quadrature IF carrier pair produced by the numerically controlled oscillator (NCO) and then each branch is mixed again with three C/A code replicas named *Early*, *Prompt* and *Late* which are separated by half a chip each. Finally, each branch is accumulated to provide a correlation value. These are the inputs of the control system which is composed by a carrier controller and a code controller.

Code controller receives the correlation values and determines if correction is needed. If the incoming signal is in phase with the local C/A code replica the local C/A phase does not need any correction. As the local C/A code replica diverges in phase with the IF signal C/A code, *Early* and *Late* branches differ and a corrective action is generated. For instance, if the incoming C/A code phase is delayed from the local replica, *Early* correlation value becomes greater than *Late* value and the control system adjusts this situation. The code loop filter is composed by a proportional loop which is both simple to implement and is able to maintain synchonization with the incoming C/A code.

Carrier controller receives the correlation values of *Prompt* branches in order to detect the phase difference between IF GPS signal and local carrier replica. This difference is then processed by a proportional integral (PI) carrier loop which along with the NCO conforms a second order loop. This loop structure allows tracking with zero error for a frequency step reference

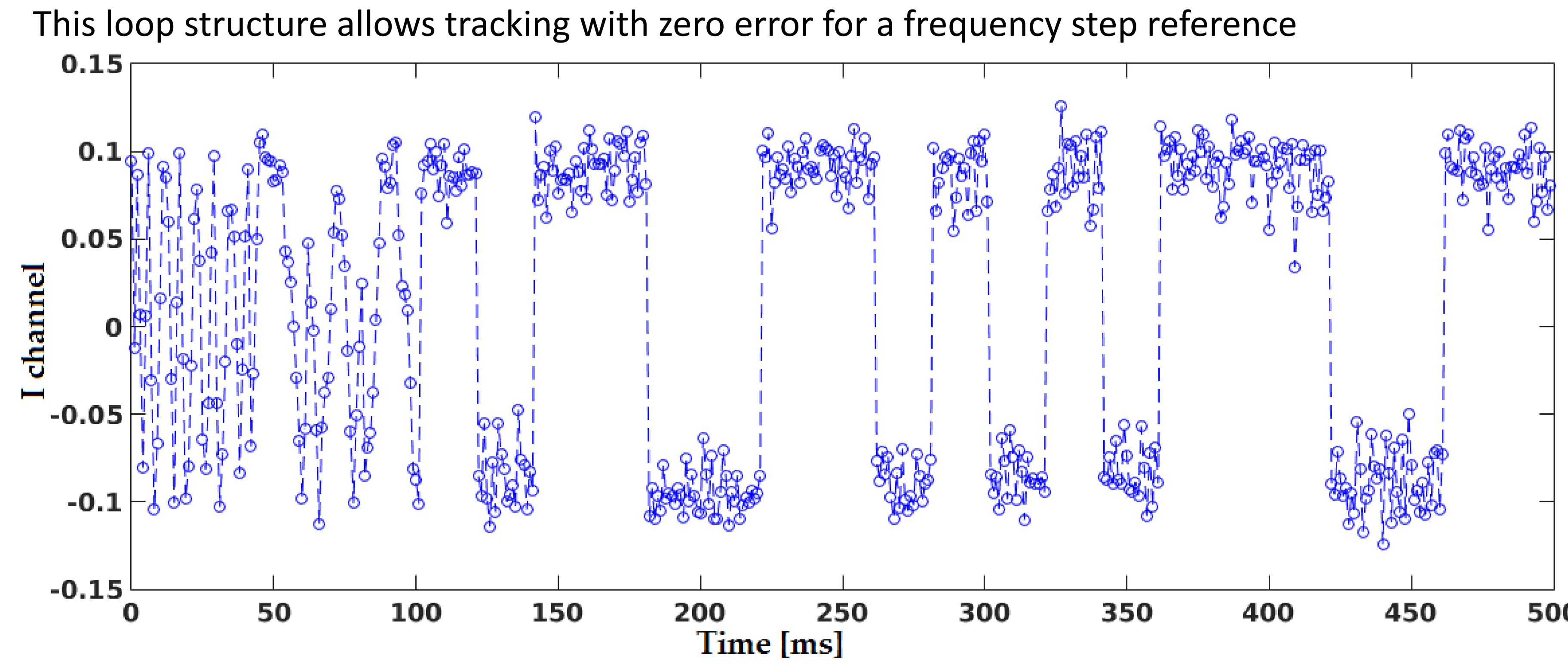

Fig. 5– GPS navigation message: tracking loop in-phase channel

CONCLUSIONS

GPS L1 search and tracking modules were designed, verified and validated with synthetic and real signals. Methodology adopted proved to be useful in development of the receiver blocks and, presumably, it could be adapted for design of FPGA-based communication systems blocks.

Additionally, use of FPGA resources was modest: 5% slices were used for the search module and 3% for the tracking module demostrating that description of the modules in the low level using a FSMD architecture was adequate for this purpose. This encourages that the receiver can be implemented in a low-middle range FPGA thus reducing component costs.

ACKNOWLEDGMENTS

The author would like to thank Universidad Tecnologica Nacional (UTN) which funded this project through UTN PID 4525, and the continued support of the Electronic Engineering Department and Research and Postgraduate Secretary of UTN FRH.