

Namuru: A Platform for GNSS Research

**Andrew G Dempster, Peter Mumford, Kevin Parkinson, Sana Qaisar,
Jinghui Wu, Asghar Tabatabaei Balaei, Eamonn Glennon,
University of New South Wales, Sydney 2052 Australia**

Abstract

The UNSW open-source GPS L1 receiver, “Namuru”, is an FPGA-based design, making it ideal for research topics that require modification not just of the receiver firmware, but also of the baseband digital hardware. This paper examines some of the early research projects that have used the board as a platform.

New signal acquisition: In early 2007, the Namuru board was used to acquire both the Galileo GIOVE-A L1 signal and the GPS L2C signal (with a modified front end). The process of acquiring these signals is described and results are presented.

Interference “sniffer”: Using the RF front end to isolate the L1 band, it is possible to design a circuit that is not a GNSS receiver at all, but rather processes the spectrum to identify interference. This design is briefly described.

Cross-correlation mitigation: Two patented approaches to mitigating cross-correlation (the near-far problem) in GPS C/A code both require modification to the correlator baseband hardware. These designs are also described.

A new version of the Namuru board is also due for release soon and its features will be presented, including USB2 logging and dual front end.

1. The Namuru Board

“Namuru” means “to see the way” in the language of the Eora people who are the original inhabitants of the Sydney basin. The board by that name that we developed with NICTA is an open-source, FPGA-based GPS L1 receiver [1]-[8]. It uses a standard Zarlink front end and when compared to other Zarlink-based receivers, it has similar or better performance [3, 4, 5, 6].

There are two key points about the design that are novel. The first is that it is completely open-source, including the board layout and bill of material, and the VHDL/ Verilog that describes the FPGA design. The compiled code is also available and we are close to releasing the source code, in C (the complications as to why the compiled code has always been available but not the source code can be discussed with any of the authors...). Secondly, because the receiver was designed around an FPGA, i.e. not simply using the FPGA as a prototyping stage, the hardware design is flexible and can be modified by the user. This means that it is ideal as a research platform, where different correlator designs can be compared. It can also be used for “one-off” type designs, with special processing requirements. It is this second point that is of most interest here, where new research directions are discussed using Namuru as a platform. Specifically, we examine:

- i) Acquisition of new signals. The new L2C GPS signal and the signal transmitted by the GIOVE-A prototype Galileo satellite have both been acquired using Namuru.
- ii) Interference “sniffer”. Removing the GPS functionality completely, a device has been designed that can detect very low levels of CW interference in the L1 band.
- iii) Cross-correlation mitigation. Two new cross-correlation techniques both require new correlation hardware, and are being prepared on the Namuru platform.

2. New Signal Acquisition

2.1 L2C

On the 26th September 2005, the first satellite carrying a L2C payload was launched. At the time of writing, three GPS satellites (PRNs 17, 31 and 12) are transmitting on L2C. The signal has the same bandwidth as L1 GPS but has several new characteristics [9], which require different approaches for the correlator design [10].

The L2C signal consists of two separate codes named as L2 CM (civil moderate) and L2 CL (civil long). The CM code has a period of 20 milliseconds and contains 10230 chips. The CL code has a period of 1.5 seconds and has 767250 chips. Each of the two codes is running at a speed of 511.5 kcps (kilo chips per second). The two codes are multiplexed together on a chip-by-chip basis and this combined code has a speed of 1.023 Mcps. This combined code modulates the navigation data and L2 carrier (1227.6 MHz.) to generate the L2C signal.

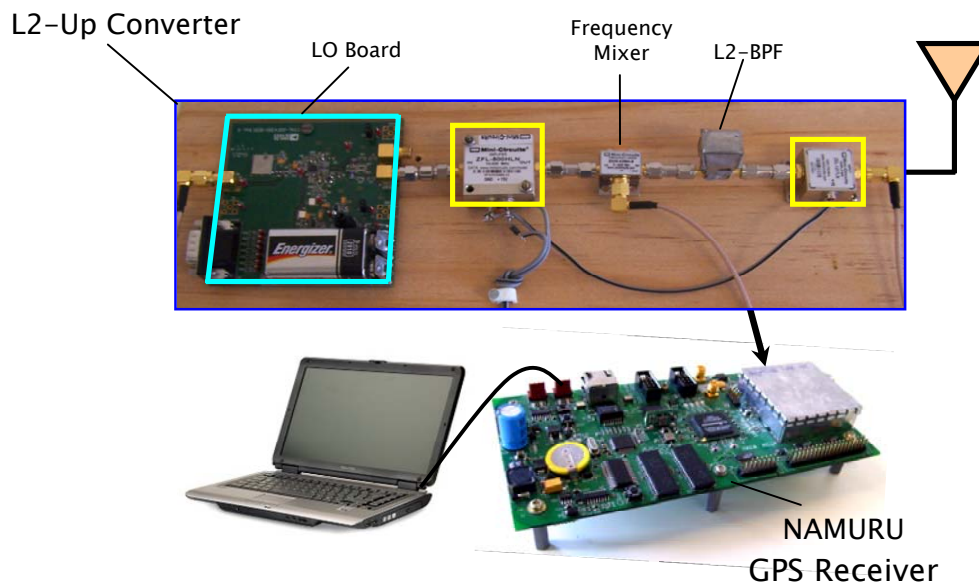


Figure 1 L2C Signal Acquisition Setup

In order for the Namuru receiver to be able to process the L2C signal, it was upconverted from the L2 frequency to L1 (see Figure 1). It could then pass through the RF front end in the same way that an L1 signal would, and then be processed

using the new codes. In this way, all three L2C signals have successfully been acquired [11].

2.2 GIOVE-A L1 (or E1)

On the 28th December 2005, the first Galileo satellite was launched. It was a prototype called GIOVE-A and it transmits on L1 (sometimes called E1), and either E5 or E6. In this case, the L1 signal uses the same carrier as GPS L1 but has a wider bandwidth, because the carrier is spread using binary offset carrier (BOC) modulation (in this case equivalent to Manchester encoding) instead of BPSK.

The first problem to overcome was that the Europeans did not publish the codes for this satellite – they needed to be cracked. This was first achieved by Montenbruck et al [12] and full codes were first published by Cornell [13], and a Stanford group [14]. ESA did finally publish the GIOVE signal specification [15], but not until after we had completed the acquisition task, using the Cornell codes.

We used the Namuru RF front end without modification (a filter internal to the RF chip prevents this) and were thus trying to acquire the signal in half the signal bandwidth. Simulations suggested this should be possible, and indeed we found the signal – a correlation from Namuru is shown in Figure 2 [11].

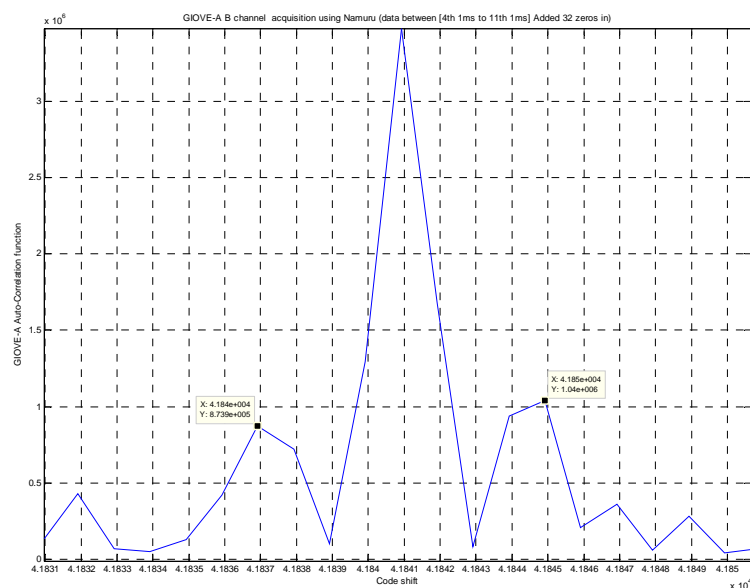


Figure 2 Zoom of the correlation function of the GIOVE-A B channel

3. Interference “Sniffer”

Work at UNSW has found that by using statistical inference techniques, it is possible to detect interference in the L1 band that is below the noise [16]. We are using the Namuru receiver as a platform to exploit these algorithms. The L1 RF front isolates the band of interest, but the hardware design that follows it in the FPGA is entirely new. In fact there remains nothing of the GPS receiver that originally occupied the chip. It is now replaced with a set of FFT-based algorithms that “zoom in” on detected interference so that its effect on signals in a GPS receiver can be characterised.

A block diagram of the “sniffer” is shown in Figure 3. It is currently under construction and results should be available mid-2007.

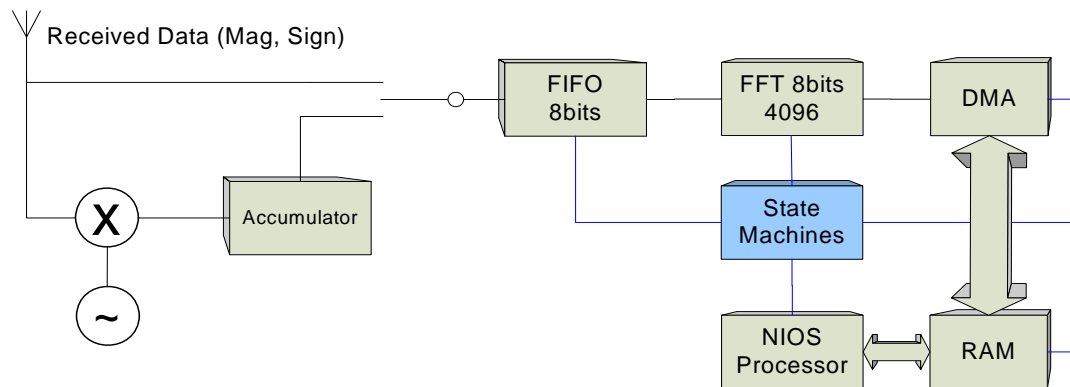


Figure 3 Interference “Sniffer” block diagram

4. Cross-correlation mitigation

GPS was not designed to work indoors, so some characteristics of the signal were never designed to cope with weak signal environments. One of these characteristics is the cross-correlation margin, which for the C/A codes is 24dB. Put simply, what this means is that if signal A is attenuated by more than 24dB, then the receiver will acquire signal B (not attenuated) when it is looking for signal A. In practice, this margin is much less, with variations in signal level due to antenna patterns, and the effects of Doppler. Therefore a strong signal can “jam” a weak signal.

Two new techniques were introduced recently for which we have applied for patents (e.g. [17]). In the first, some chips in the weak signal code are “flipped” so that the cross-correlation is driven to zero [18, 19]. In this technique, up to three strong signals can be dealt with. If a two-bit code is used, a further strong satellite can be mitigated.

A better technique [20] is shown in Figure 1Figure 4. In this Delayed Parallel Interference Cancellation (DPIC) technique, the strong signal is subtracted away from the weak signal after the integration and dump phase. This has a number of advantages over subtraction at earlier stages, but requires extra hardware – a “slave” correlator for each strong signal to be removed must be added to each weak signal correlator.

Both of these techniques require “special” correlator circuits, i.e. they cannot be implemented using standard GPS chipsets. We are therefore implementing them in the Namuru, because of its programmable hardware. We hope to be able to report results from these designs by mid-2007.

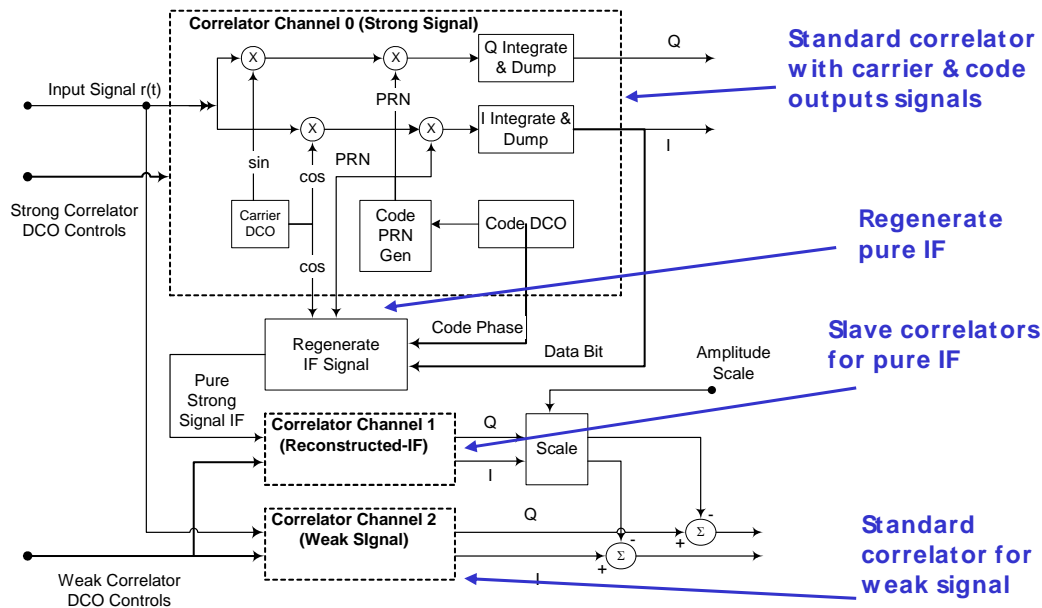


Figure 4 Delayed Parallel Interference Cancellation (DPIC) block diagram

5. Namuru II

A new version of the Namuru will be available Q3 2007. The improvements to the board will be:

- i) Dual front end. The new board will have two front ends, both based around the Zarlink 2015 L1 GPS front end chip. However, by also providing an L2C upconvert circuit on-board, there will be an option for one of the front ends to be either L2C or L1. The board could thus be dual-frequency or could have two L1 front-ends, which is useful for applications such as bistatic radar, or attitude determination.
- ii) 3-axis gyros and accelerometers. Integration of GPS and inertial sensors is a very popular area of research, so it makes sense to integrate these sensors onto the board. They will, however be low-cost MEMS sensors which will not be appropriate for high-performance applications.
- iii) USB2 port. A USB port at the sampled IF enables several useful tasks – logging of IF data to file for later processing, real time download to run a software receiver, and real-time upload where logged data can be replayed through the FPGA receiver hardware.

6. Conclusion

The Namuru open source FPGA-based GPS receiver was designed as a platform for GPS research. In this paper, we have presented examples of the types of research possible: processing of new signals, interference detection and cross-correlation mitigation. The board is very versatile and has attracted interest from people requiring some flexibility from the hardware, in particular the correlators. Bistatic radar is a particularly popular application that researchers are finding for the board. By talking to people who are interested in a platform like Namuru, it has been possible to work out

which are the best features to add to the new version, which will be available soon to researchers outside UNSW.

7. References

- [1] Engel, F., Heiser, G., Mumford, P., Parkinson, K., & Rizos, C., “An open GNSS receiver platform architecture”, *Journal of GPS*, 3(1-2), 63-69., 2004.
- [2] Parkinson, K., Dempster, A.G., Mumford, P., & Rizos, C., “FPGA based GPS receiver design considerations”, *Int. Symp. on GPS/GNSS*, Hong Kong, 8-10 December 2005, paper 8C-05
- [3] Mumford, P.J., Parkinson, K., & Dempster, A.G., “Open GNSS receiver platform”, *Proc IEEE/ION PLANS*, San Diego, California, 25-27 April 2006, 1108-1113
- [4] Parkinson, K., Dempster, A., Mumford, P., Rizos, C., “Improving signal quality in FPGA based GPS receiver designs. Symp. on GPS/GNSS (*IGNSS2006*), Surfers Paradise, Australia, 17-21 July 2006
- [5] Mumford, P., Parkinson, K., Dempster, A. “An Open GNSS Receiver Research Platform”, *Symp. on GPS/GNSS (IGNSS2006)*, Surfers Paradise, Australia, 17-21 July 2006
- [6] Mumford, P., Parkinson, K., & Engel, F., “An open GNSS receiver platform architecture”, *Coordinates*, 2(1), 28-31, 2006.
- [7] Mumford, P.J., Parkinson, K., & Dempster, A.G., “The Namuru Open GNSS Research Receiver”, *Proc. 19th Int. Tech. Meeting of the Satellite Division of the U.S. Inst. of Navigation*, Fort Worth, Texas, 26-29 September 2006., 2847-2855.
- [8] Peter Mumford, Kevin Parkinson and Andrew Dempster, “The ‘Namuru’ Open GNSS Research Receiver: An update”, *Coordinates*, Volume II issue 10, October 2006, p6-9
- [9] IS-GPS-200D, “Navstar GPS Space Segment/Navigation User Interfaces”, 7 Dec 2004
- [10] Andrew Dempster, “Correlators for L2C: Some Considerations”, *Inside GNSS*, October 2006, pp32-37
- [11] Sana Ullah Qaisar, Jinghui Wu and Andrew G Dempster, “Loud and Clear: Receiving the new GPS L2C and Galileo signals”, to be published in *Position*, June 2007
- [12] O Montenbruck et al, “GIOVE – A initial signal analysis”, *GPS Solutions*, vol 10 no 2, pp146-153
- [13] Mark L Psiaki et al, “Searching for Galileo”, *GPS World*, June 2006, pp66-72

[14] Gao, Grace, Spilker, James, Walter, Todd, Enge, Per, and Pratt, Anthony, "Code Generation Scheme and Property Analysis of Broadcast Galileo L1 and E6 Signals", Proc ION_GNSS, Fort Worth, 2006

[15] ESA-DEUI-NG-ICD/02703, GIOVE-A Navigation Signal-in-Space Interface Control Document, iss 1, 2 Mar 2007

[16] Asghar T.Balaei, "Statistical Inference Technique in Pre-Correlation Interference Detection in GPS Receivers" ION/GNSS Fort Worth, USA. September 2006 (student prize winner)

[17] E. Glennon, A. Dempster, "Apparatus and Method for Mitigation of Cross-Correlation in GPS Systems", US patent application 11/460,692, 28 July 2006

[18] E.P. Glennon, A.G Dempster, "A Novel Cross Correlation Mitigation Technique", Proc ION-GNSS 2005, Long Beach, CA, Sep 14-16, 2005

[19] E. P. Glennon, A.G. Dempster, "Cross Correlation Mitigation by Adaptive Orthogonalization Using Constraints - New Results", Proc ION-GNSS, Fort Worth, Texas, 27-29 Sep 2006

[20] E. P. Glennon, R C Bryant, A.G. Dempster, "Delayed Parallel Interference Cancellation for GPS C/A Code Receivers", Proc IAIN/GNSS 2006, Jeju, Korea, 18-20 Oct 2006, pp 261-266