Prototype Galileo Receiver Development

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ABSTRACT

Over the past few years the Galileo signal specification has been maturing. Of particular interest to receiver manufacturers is the Binary Offset Carrier (BOC) modulation format. In preparation for the transmission of the first Galileo signals from space, NovAtel has initiated development of their first prototype Galileo receiver, capable of tracking BOC signals.

NovAtel is currently under contract with the Canadian Space Agency to develop an FPGA based hardware prototype of a Galileo BOC receiver. The receiver is based on NovAtel's new L5, FPGA based precise positioning receiver. The receiver FPGA and software is configured to track the open access BOC signal that will be transmitted on the Galileo L1 frequency. To reduce hardware design costs for this pre-production development, the design will be demonstrated at the L5/E5a frequency. No commercial Galileo hardware simulators are currently available to test the receiver. NovAtel is therefore modifying an existing prototype L5 signal transmitter, developed by NovAtel for Zeta Associates of Fairfax, Virginia, to output a BOC(1,1) test signal.

The current receiver/transmitter development effort will be discussed. An overview of the NovAtel FPGA based precise positioning receiver will be presented. The benefits of using the FPGA based receiver to verify the design will be presented, outlining how the receiver design team can handle changes in the signal specification.

INTRODUCTION

Receiver manufacturers are anxiously waiting for the moment when they can track the first Galileo signals sent from space. In the meantime, much work needs to be done to produce Galileo capable receivers. Multiple signal types, multiple frequencies, and the new binary offset carrier (BOC) modulation scheme make the receiver design challenging. Initiating the receiver design effort now, in advance of a finalized signal specification, reduces the design risk in years to come.

In December 2003, NovAtel began work on a contract from Canadian Public Works and Government Services (PW&GSC), sponsored by the Canadian Space Agency (CSA) under the Space Technology Development Program (STDP), for the development of a Galileo prototype receiver. Included in the contract, along with the development of the pre-production Galileo prototype receiver, is the modification of a GPS L5 transmitter to output a Galileo signal. The focus of the work is to track a single Galileo signal, specifically the open service BOC signal.

The familiar GPS C/A code is a binary phase shift keying (BPSK) signal with a chipping rate of 1.023 MHz. The notation BPSK(f_c) is used, where f_c represents a factor of 1.023 MHz. For BOC signals, the spreading code is mixed with a square wave at a given subcarrier frequency. The notation BOC(f_s,f_c) is used, where f_s represents the square wave subcarrier frequency in units of 1.023 MHz, and f_c represents the chipping rate in units of 1.023 MHz. The generation of a BOC(1,1) signal is shown in Figure 1, where the top line is a 1.023 MHz square wave, the middle line is a 1.023 MHz spreading code, and the bottom line is the resulting BOC(1,1) modulation signal.

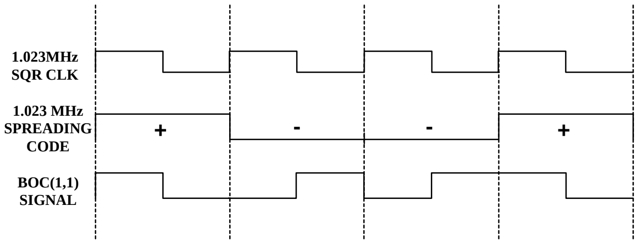

Figure 1 BOC(1,1) Signal Generation

The normalized ideal autocorrelation function for a BPSK(1) signal is shown in Figure 2. The autocorrelation function for a BOC(1,1) signal is shown in solid blue in Figure 3. The square wave subcarrier modulation used with BOC(1,1) causes the autocorrelation function to have a sharper main peak, and two smaller negative side peaks. The sharper main peak will result in improved code tracking performance for the BOC(1,1) signal, as well as improved multipath performance. The dotted red line in Figure 3 is the envelope of a BPSK(1) signal.

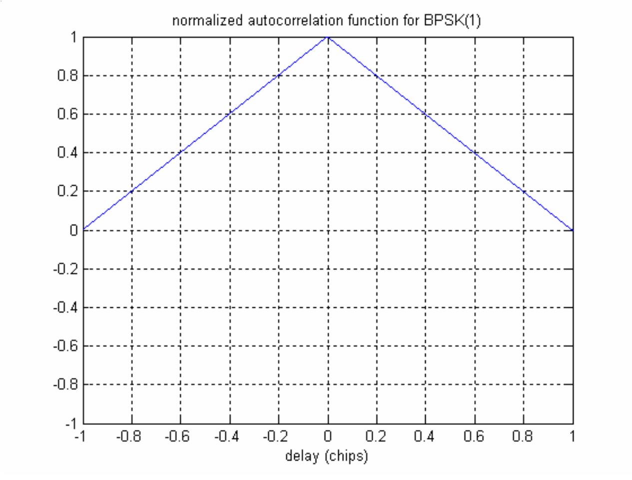

Figure 2 Correlation Function for BPSK(1)

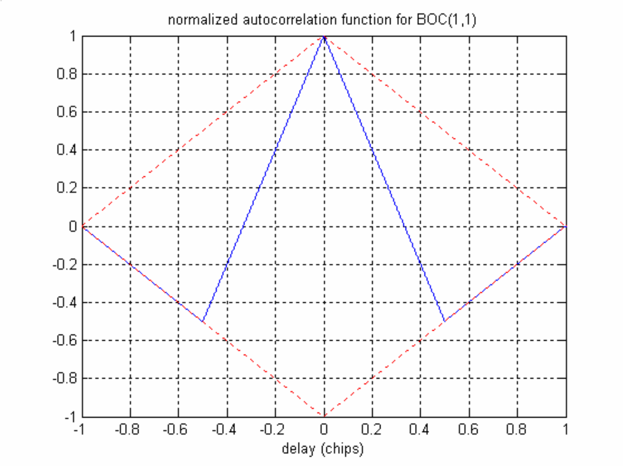

Figure 3 Correlation Function for BOC(1,1)

TRANSMITTER

NovAtel originally developed the prototype L5 Transmitter shown in Figure 4 for Zeta Associates of Fairfax, Virginia. The transmitter is packaged in a 1U high, 19 inch enclosure and includes: a NovAtel OEM4 receiver engine for the main processor; an FPGA to generate the spreading codes to transmit; and an L5 RF deck to up-convert the signal to the L5 transmit frequency of 1176.45 MHz. The L5 Transmitter was designed to transmit GPS L5, and therefore modulates data and pilot spreading codes in phase quadrature. Figure 5 is a screen capture from a spectrum analyser, with the transmitter in L5 GPS mode. The spectrum analyser was set for a centre frequency of 1176.45 MHz, 24 MHz span, and 10 kHz resolution bandwidth.

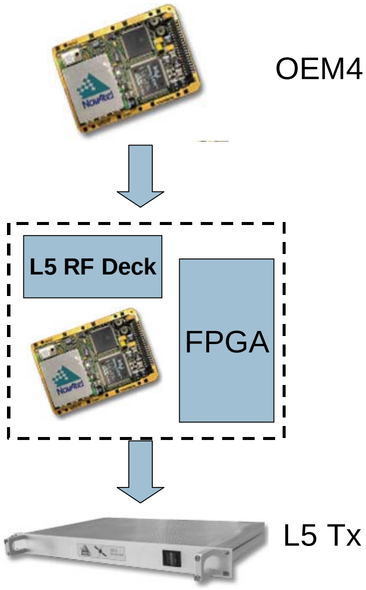

Figure 4 L5 Transmitter

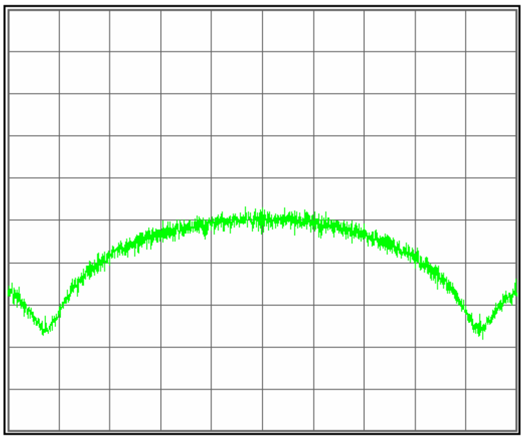

Figure 5 Transmitter Output - GPS L5

The software-defined nature of the transmitter allows for new spreading codes to be generated with relative ease. For this contract, the transmitter was reprogrammed such that the user can select either a BPSK(1) spreading code, or the same spreading code with a BOC(1,1) modulation. To minimize hardware re-design the data and pilot codes are transmitted in phase quadrature, instead of coherent adaptive subcarrier modulation (CASM) that is currently being proposed for Galileo. The spreading code length is 4092 chips (4 ms), with forward error correction (FEC) encoded data on the in-phase channel (250 symbols/second), and a length 25 secondary tiered code (100 ms) on the dataless quadrature channel.

Figure 6 is a screen capture from a spectrum analyser, with the transmitter in BPSK(1) mode (24 MHz span, 10 kHz resolution bandwidth). Figure 7 is the spectrum analyser screen capture with the transmitter in BOC(1,1) mode. Figure 7 illustrates how the square wave subcarrier modulation used in BOC(1,1) shifts the main lobe of the frequency spectrum to higher and lower frequencies.

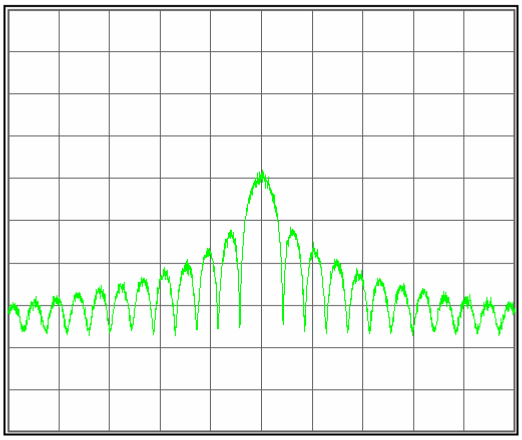

Figure 6 Transmitter Output - BPSK(1)

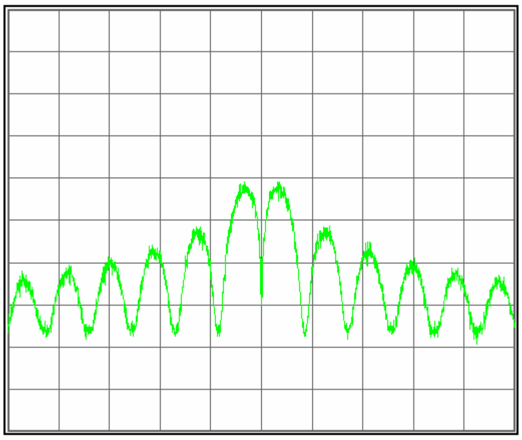

Figure 7 Transmitter Output - BOC(1,1)

SOFTWARE DEFINED RECEIVER

Software defined receivers are an ideal approach for prototype receiver development. The NovAtel Euro-L5 (see Figure 8) is a software defined receiver, developed for use in the WAAS Ground Uplink Station (GUS) receiver. The receiver is a Eurocard format receiver, based on the NovAtel OEM4-G2. The L5-Euro is available in a standalone ProPak^{TM} enclosure (see Figure 9). The receiver is populated with an FPGA and can be configured to track the 4 channels of L5 WAAS or 4 channels of L5 GPS (compliant to RTCA/D0-261 NAVSTAR GPS L5 Signal Specification, December 14, 2000). The receiver also includes digital pulse blanking to mitigate in-band pulsed interference. Both the FPGA and baseband processor can be reprogrammed with new firmware via the serial port interface.

The Euro-L5 was modified for this contract to track the Galileo BPSK(1) and BOC(1,1) signals output by the transmitter. The design cycle is: (a) implement new BPSK and BOC reference codes; (b) update baseband signal processing algorithms; (c) synthesis/compile design; (d) reprogram FPGA and baseband processor via serial port interface. The design cycle time is very quick compared to traditional ASIC design. For example, changes to the spreading code specification can be implemented and tested the same day.

Figure 8 NovAtel Euro-L5 Receiver Card

Figure 9 NovAtel ProPak^{TM} Enclosure

TEST CONFIGURATION

The test configuration for the Galileo transmitter/receiver pair is shown in Figure 10. The Galileo transmitter, Galileo receiver, digitally controlled attenuator, and OEM4-G2 GPS receiver are all controlled from a host PC via serial port interfaces. The Galileo transmitter outputs a ‘clean’ signal, to which noise must be added. A wideband noise source outputs a constant noise power. The digitally controlled attenuator is used to adjust the noise power. The Galileo signals and attenuated noise are combined together at the L5 frequency using an RF combiner. The test configuration is calibrated to output the desired signal strength to the Galileo receiver. At any time, the expected C/No value input to the receiver may be adjusted by issuing a command from the host PC to the attenuator. The OEM4-G2 GPS receiver is used to provide an initial time solution to the Galileo receiver. The time is transferred via a serial data log and a 1PPS timing signal.

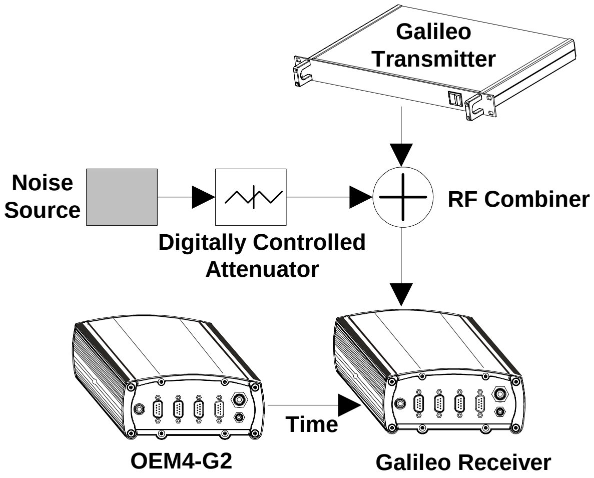

Figure 10 Galileo Receiver Test Configuration

With the Galileo receiver in the test configuration shown in Figure 10, and the transmitter and receiver both set to BOC(1,1) mode, an initial tracking test was initiated. For this initial test no checks were made in the receiver to ensure that the correct peak of the BOC(1,1) correlation function was being tracked. When the receiver initially acquires and tracks the BOC(1,1) signal, the receiver may be tracking one of the two side peaks located at +/- 0.5 chips from the main peak, with a power 6 dB lower than the main peak power (see Figure 11).

The receiver was set to search for the transmitted BOC(1,1) code on multiple channels. Cases were observed where one channel would acquire and track the main peak, while another channel would acquire and track the side peak. This is shown in Figure 12, where the channel tracking the main peak is at the expected power of 48 dB-Hz, while the channel tracking the side peak is at the expected side peak power 6 dB lower at 42 dB-Hz. The software defined Galileo receiver was then updated with a new firmware load to monitor and correct for side peak tracking. The new firmware load mitigated the side peak tracking problem.

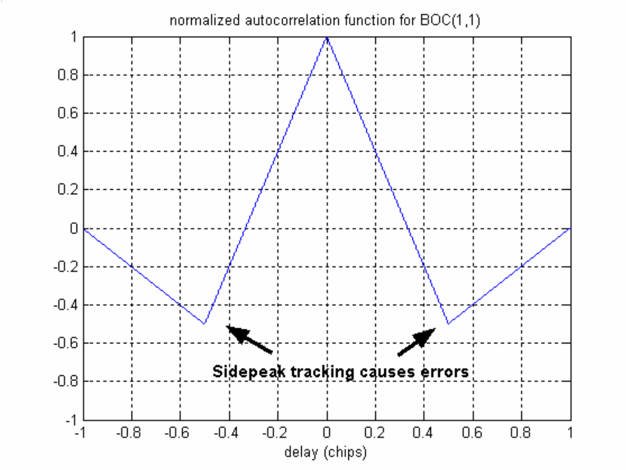

Figure 11 BOC(1,1) Correlation Function - Multiple Tracking Points

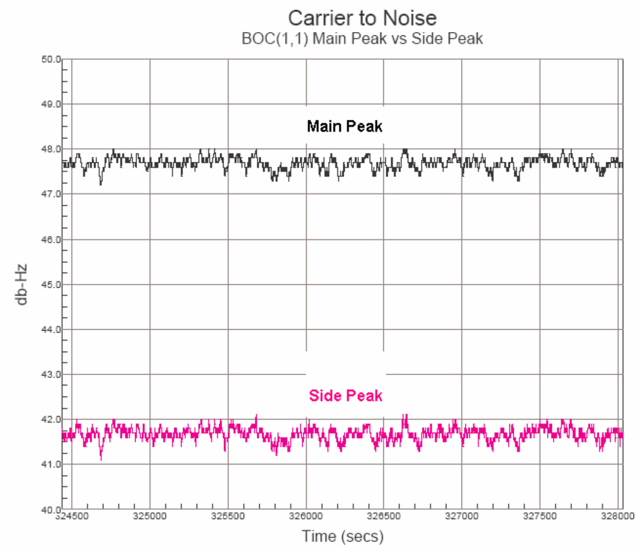

Figure 12 C/No Main Peak - 48 dB-Hz, C/No Side Peak 42 dB-Hz

CONCLUDING REMARKS AND FUTURE WORK

The NovAtel Galileo prototype receiver, based on the NovAtel Euro-L5 hardware, is successfully tracking the BOC(1,1) and BPSK(1) test signals. A monitoring algorithm has been implemented to mitigate side peak tracking.

The project is now entering the final testing phase where the code tracking performance of BPSK(1) and BOC(1,1) will be evaluated over a range of C/No values, and compared to theoretical values.

Future work includes updating the receiver to track the evolving Galileo signal in space specification, and implementation and testing of other Galileo signal types.

ACKNOWLEGEMENTS

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REFERENCES

None