PSEUDOLITE SIGNAL TESTS

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ABSTRACT. Pseudolites are ground based GNSS signal transmitters that have already been used in the project where visibility to the GNSS satellites is limited, however there are still many issues that need enhancement. A prototype of a low-cost pseudolite is being designed and assembled at the University of Warmia and Mazury. The goal of the project is to apply the pseudolite as an augmentation to GNSS positioning tasks in geodetic engineering projects. This paper presents the results of first prototype testing in the area of code generation, carrier frequency and signal power.

Keywords: pseudolite, GNSS signal transmitter.

1. INTRODUCTION

Pseudo-satellites or, pseudolites are ground based transmitters of GPS-like signals. They can be used either as stand alone systems, for example, in indoor navigation Proгри (2001), or navigation on other planets Lemaster (1999) or as augmentation to GNSS positioning in navigation of vehicles Brekke (2008) and in monitoring structural deformation Dai (2000) and ground deformation Chrzanowski (2007) in areas of limited visibility to the satellites. Though pseudolites are well known devices Wang (2002), there are still many issues that need investigation and enhancement. For example, enhancement of signal structure, navigation message structure Rapinski (2012), linearization problem, near-far problem, GNSS integration and many others. To investigate these problems, the prototype of pseudolite was designed and built at the University of Warmia and Mazury in Olsztyn. This paper presents first tests of the pseudolite signal. Tests and measurements of the correctness of C/A code, carrier phase and modulation are presented. All of the tests were successful, and we were able to track the pseudolite signal with a receiver.

2. C/A CODE

The prototype of a pseudolite uses one of thirty six C/A codes available for GPS satellites. Codes are generated in the real time by pseudolites FPGA (*Field Programmable Gate Array*). The software used for code generation is written in VHDL (*Very High Speed Integrated Circuits Hardware Description Language*). The correctness of the generated C/A code was validated in three ways:

1. using Quartus logic analyser (IDE for Altera FPGA programming),
2. using digital oscilloscope,
3. using software receiver.

The Quartus II Web Edition IDE (*Integrated Development Environment*) has a built-in tool for validation of logic states on FPGA output. Using this tool a check of FPGA output C/A code for all the PRN's was performed. Output was compared with C/A code generated in Matlab using the algorithm described in Borre (2007). All of the codes generated by FPGA were exactly the same as those generated in Matlab. Figure 1 depicts this test. The C/A code for consecutive PRN codes are visible in subsequent lines.

Fig. 1. C/A code in Quartus logic analyser.

Second test was performed with digital oscilloscope. The RF board of the pseudolite has a few two connectors before modulator. One of them is a 1.023 MHz clock, second is C/A code signal used to drive the BPSK modulator. Channel one of Agilent oscilloscope was connected to 1.023 MHz output, second channel was connected to the C/A code output. Pseudolite has an option to turn the C/A code on and off during operation. The measurement was triggered with this feature (first rising edge of C/A code output). Figure 2 depicts first twenty bits of C/A code on the oscilloscope. Also this test proved the correctness of generated C/A codes for each PRN number.

Fig. 2. C/A code measured with oscilloscope

The third test was a best confirmation of the C/A code correctness. The SX-NSR software receiver was used in this test. The receiver was able to track a pseudolite's signal for each PRN. Details of this test are presented in section "Signal tracking test with software receiver".

3. CARRIER FREQUENCY

The nominal frequency of GPS L1 signal is 1.575420 GHz. At the receiver level, after travelling 20 000 km from the satellite, this frequency appears with -127.5 dBm (dB in comparison to 1 mW). For the pseudolite, both carrier frequency and signal power level were investigated. In pseudolite carrier wave is generated with ADF4350 from Analog Devices. It is a wideband frequency synthesizer with Integrated VCO (*Voltage Controlled Oscillator*) with output frequency range of 137.5 MHz to 4400 MHz. The reference clock used to drive the synthesizer is a TCXO (*Temperature Controlled Crystal Oscillator*) operating at 16.368 MHz. The center frequency of the pseudolite signal has a carrier frequency pitch shift of about 300 Hz. This frequency is in the bandwidth of GPS receivers and should be tracked properly. Figure 3 shows pseudolite signal measured with digital oscilloscope. Since main leaf is 2 MHz wide, the pitch shift is not visible. This measurement was made with log period antenna on the transmitter side and Wurth SMD multilayer chip antenna (1555-1595 MHz). Both antennas were passive and the measurement was made at 1 m distance.

In this configuration the maximum power of received signal is -69.7 dBm. At this level, pseudolite signal would cause interference with much weaker GPS signal, therefore external attenuation is required. Constant attenuators, mounted on the transmitter antenna cable, are used in various configurations to achieve signal level comparable with satellite signal.

Fig. 3. Pseudolite signal spectrum

4. MODULATOR

Correct modulation of the signal is necessary for the receiver to track it. In GPS a BPSK (*Binary Phase Shift Keying*) modulation is used. In this type of modulation the phase of carrier wave is shifted by 180 degrees. Original wave presents logical 0 and 180 degrees shifted presents logical 1. During the modulation test the VCO signal level was $VCO_{Pout} \approx +5dBm$. Output pin in FPGA was set to 8mA current in 3.3-LVTTL standard. Since 1023 bits of C/A code would be difficult to compare, test sequence of the following sixteen bits was used: 0101 0110 1010 0011. Signal was measured with Tektronix DPO7254 oscilloscope with digital demodulation option. During the signal acquisition oscilloscope sampling rate was 40GHz with 200MHz bandwidth. Figure 4 depicts the test. On the left side of the figure, decoded binary sequence is visible. It is exactly the same as the test signal. On the right side there are two plots: signal spectrum on the bottom and signal constellation on the top. The signal constellation is in line with expectations – Two points on constellation are characteristic for the BPSK modulation.

Fig. 4. Modulation test

5. SIGNAL TRACKING TEST WITH SOFTWARE RECEIVER

The final test of pseudolite signal was made using the SX-NSR software receiver from IFEN. Software radio technology provides an opportunity to process navigation signals and evaluate position estimation algorithms in a software radio Pany (2010). The choice of software receiver instead of standard geodetic off-shelf receiver was intentional. Standard receivers have many error detection algorithms. If the navigation message is not correct or the distance to the satellite is not in a certain range, the receiver neglects such a signal. Therefore standard receivers locks pseudolite signal for few seconds, then after performing few tests the signal is neglected and the channel in the receiver is freed for another satellite. Software receiver hasn't got this limitations. User can specify which PRN will be tracked on which channel despite the signal does not entirely comply with GPS standard.

The receiver was placed about 60 meters from the transmitter antenna. At this distance the attenuation of 35 dB was used. PRN number 24 was chosen for this test as this satellite was not in view during the measurement. During the measurement, the receiver was able to track the pseudolite signal along with signals from satellites. Both phase and code measurements were available. As expected, the code measurement was not correct since the pseudolite clock is not synchronized with GPS.

Fig. 5. SX-NSR window during pseudolite test

Figure 5 depicts the software receiver operating with pseudolite in view. Two plots shows high correlation in both signal acquisition and code correlation. Correlator PLL is locked and the signal is continuously tracked along with another satellites (PRN 1, 11, 14, 19). As mentioned above, the pseudorange to the pseudolite is much larger than for satellites.

6. CONCLUSIONS

The measurements and tests presented above, shows that the pseudolite prototype is operational. All of the tests were successful, C/A code is generated correct, carrier frequency is close to the nominal value and modulator works properly.

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