GPS M'-Code and P-Code Signal Simulation Using an Open Source Radio Platform

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BIOGRAPHY

Alison Brown is the President and Chief Executive Officer of NAVSYS Corporation, which she founded in 1986. NAVSYS Corporation specializes in developing next generation Global Positioning System (GPS) technology. Dr. Brown has a PhD in Mechanics, Aerospace, and Nuclear Engineering from UCLA, an MS in Aeronautics and Astronautics from MIT, and an MA and BA in Engineering from Cambridge University. She is a fellow of the Institute of Navigation and an Honorary Fellow of Sidney Sussex College, Cambridge.

Bruce Johnson is the Technical Lead at NAVSYS Corporation on GPS/Inertial Systems. He holds an MS and PhD in Mechanical Engineering from MIT and a BS in Engineering-Physics from the University of California at Davis.

ABSTRACT

Current generation military simulators are expensive, increasing costs for GPS test and evaluation for military GPS user equipment developers. Inexpensive commercial GPS simulators are available that use signal simulation, record and playback techniques to test receivers under representative environment, but these commercial record and playback GPS simulators do not have the bandwidth needed to collect or simulate military GPS signals. NAVSYS' military version of the GNSS Signal Architect software, combined with their implementation of a full bandwidth record and playback capability with their GNSS Signal Generator provides an inexpensive test and evaluation tool for Y, M, P and C/A code (YMCA) receivers. The design of this product is presented in this paper with test results showing its performance with a GPS receiver.

INTRODUCTION

New demands on the existing GPS system led to an effort in 2000 to modernize the entire GPS system. The GPS modernization project involved adding new ground stations, new satellites, and most importantly, new navigation signals for both the military and civilian users. In 2005, the US Air Force launched the first IIR-M satellite carrying the modernized payload with the new military M-code signal and L2C civil signal. The M-code is transmitted on the same L1 and L2 frequencies already in use by the existing military P-code. M-code will improve the immunity to interference and provide enhanced security.

There are a large number of external environmental factors that can impact a receiver's navigation accuracy. Because the military receivers are not immune to these environmental factors it is essential that the military receiver designers test their hardware under controlled and repeatable conditions in the laboratory using a GPS simulator.

In response to this need, NAVSYS has developed a military version of their GNSS Signal Architect product that includes the capability to generate full bandwidth simulated signal Digital Storage Files (DSF) that can be played back through the low-cost GNU Radio Universal Software Radio Peripheral (USRP™) into military receivers under test. The current generation product allows for signal simulation of the civilian C/A code signals and the full bandwidth military P-code and M'-code signals.

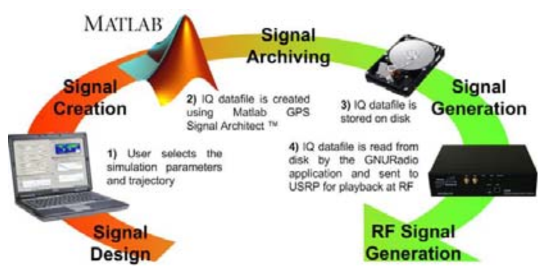

Figure 1 GNSS Signal Architect Software

GNSS SIGNAL ARCHITECT SOFTWARE

The NAVSYS GNSS Signal Architect software leverages the capabilities of the NAVSYS GPS Signal Simulation Toolbox to provide users with an inexpensive MATLAB-based GPS signal generation capability. The GNSS Signal Architect allows users to specify a trajectory and a complete set of simulation parameters and then creates an

IQ data file at baseband or an Intermediate Frequency (IF). The data file can then be used for subsequent analysis within MATLAB or can be provided to a Software Defined Radio (SDR) to create a GPS Radio Frequency (RF) signal suitable for playback into a GPS receiver.

NAVSYS has developed the GNSS Signal Architect software to be compatible with existing GNSS record and playback products[1] which can be used to simulate the civilian GPS and GLONASS signals. As illustrated in Figure 2, the civilian signals can be captured and played back using a narrow-band RF design. In order to capture and playback the military signals, a broadband RF design is needed.

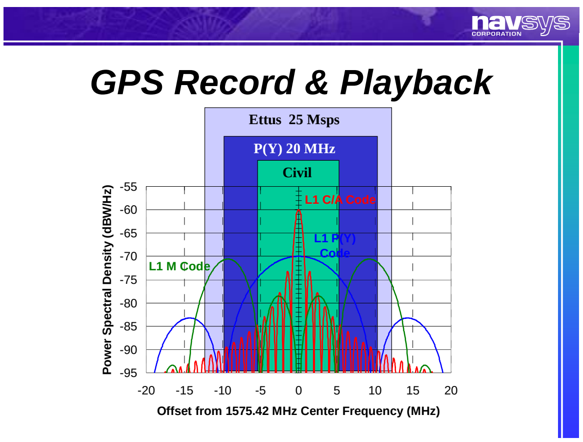

Figure 2 GPS Record and Playback Spectrum

In this paper, we describe the design for integrating the GNSS Signal Architect software with the GNU Radio USRP to allow it to transmit a GPS signal at RF with the full bandwidth YMCA GPS signal.

GNU RADIO USRP

The GNU USRP family provides a low cost development platform which provides an interface between high speed analog-to-digital converters, high speed digital-to-analogconverters and an Ethernet interface. Daughterboards available for the USRP provide an interface from the baseband signals present at the data converters to the GPS frequency bands. The USRP can also be used to record and playback the GPS signal in a static or mobile environment. The GNSS Signal Architect software is flexible enough to cover the GNSS frequency bands for L1, L2, and L5 to allow operation with the new civil GPS L5 frequencies, and with the NAVSYS GNSS Signal Architect software can also be used for record and playback of the full bandwidth (25 MHz) GPS signals. The combination of the NAVSYS GNSS Signal Architect signal simulation and record and playback capability using the commercial USRP hardware make for an extremely low cost, yet highly flexible GPS signal simulation capability.

Figure 3 shows the NAVSYS GNSS Signal Generator hardware. It is designed for use with the Ettus N210 USRP.

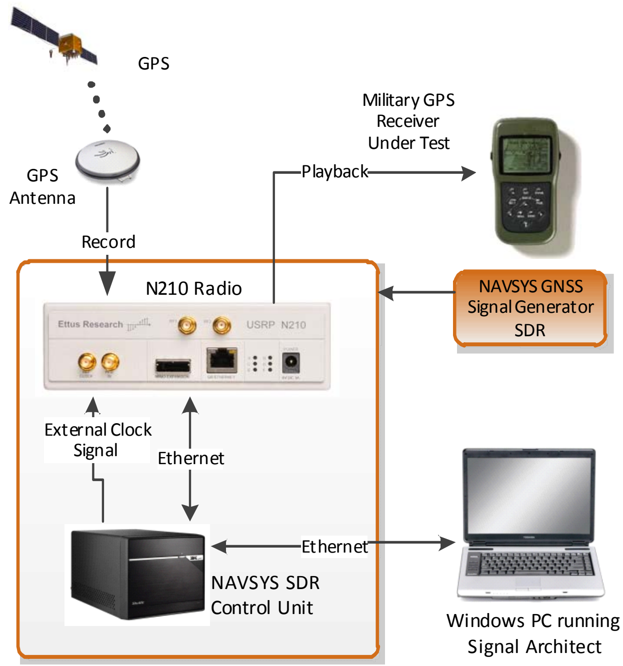

Figure 3 NAVSYS GNSS Signal Generator Hardware

The ETTUS USRP radio family provides a low cost development platform for software defined radios. The USRP can also be used to record and play back the GPS signal in a static or mobile environment. The system operator can then reproduce the signal on the bench either from a simulated profile or from a previously recorded test environment. An advantage of the Ettus radio is that it supports a wideband transceiver front-end that can accommodate the full 25 MHz of the GPS signal band and can be tuned to operate at any of the GPS signal frequencies (L1:1575.42 MHz, L2:1227.60 MHz or L5: 1176.45 MHz). This allows record and playback of both the civil and military GPS codes.

While the GNSS Signal Architect tools can be easily adapted for use with any commercial SDR, Ettus was chosen due to their reasonable price, quality construction, and extensive support by the GNU Radio project[2]. Of the Ettus USRP family of radios, the N210[3] was chosen because it has the highest sample rate, greatest flexibility, and largest capacity for modification.

The USRP provides a standard Ethernet interface between high speed analog-to-digital converters and high speed digital-to-analog converters. Daughterboards available for the USRP provide an interface from the baseband signals present at the data converters to the GPS frequency bands.

For this project an ETTUS WBX[4] transceiver daughterboard was installed in the USRP radio. The tunable range of the WBX (50 MHz to 2.2 GHz) covers all the current GNSS frequencies. The WBX allows up to 14 bits of data can be captured per channel.

The NAVSYS SDR Control Unit shown in Figure 3 includes a Linux SBC with software developed to run the GNU SDR for RF record and playback under control of the GNSS Signal Architect software through an Ethernet connection to a standard PC. The Ethernet connection is used to download and upload recorded or simulated signal files.

MILITARY GPS SIGNAL SIMULATION

The NAVSYS GNSS Signal Architect hardware and software provides users with a MATLAB-based GPS signal generation capability. Using a simple, intuitive GUI (see Figure 4), the user specifies a trajectory either from an NMEA or a KML file from Google Earth, and an almanac file used to define GPS satellites to be simulated. The user defines the mask angle for the satellite selection and the signal/noise ration to be simulated. The GNSS Signal Architect software then generates a simulated digital storage files (DSF) including the selected codes (C/A, P and/or M').

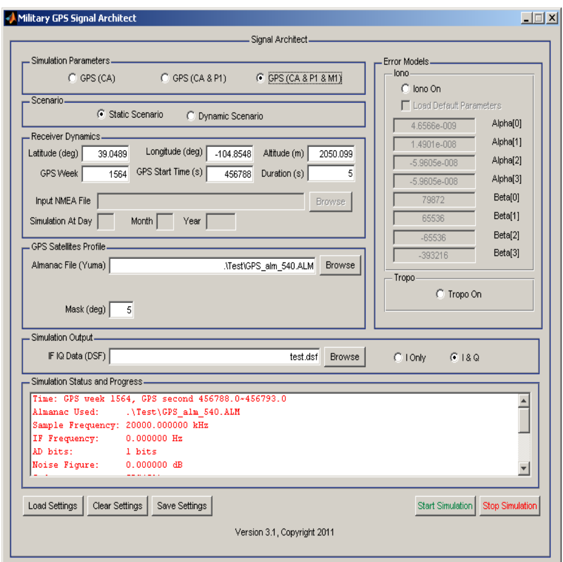

Figure 4 GNSS Signal Architect GUI

For RF playback, the GNSS Signal Architect software transfers DSF files to SDR Control Unit (SCU) which controls the USRP for playback of the DSF files to generate the simulated RF signal

If the MATLAB GPS Toolbox is purchased, the user has complete flexibility to manipulate the signal at various stages of generation or post-generation to simulate GPS anomalies. Without the Toolbox, the user is restricted to using only the standard error modeling provided by the compiled GNSS Signal Architect code.

SIMULATION TEST RESULTS

To demonstrate the high fidelity of the NAVSYS Signal Simulator signal record and playback capability, a series of tests were run. In the first test, data was recorded from the live GPS satellites and then replayed back into a GPS receiver under test. As shown in Figure 5, the C/N0 tracked using the playback signal was very close to the C/N0 of the live satellite tracking, demonstrating there is little signal degradation in the record and playback capability using the Ettus USRP.

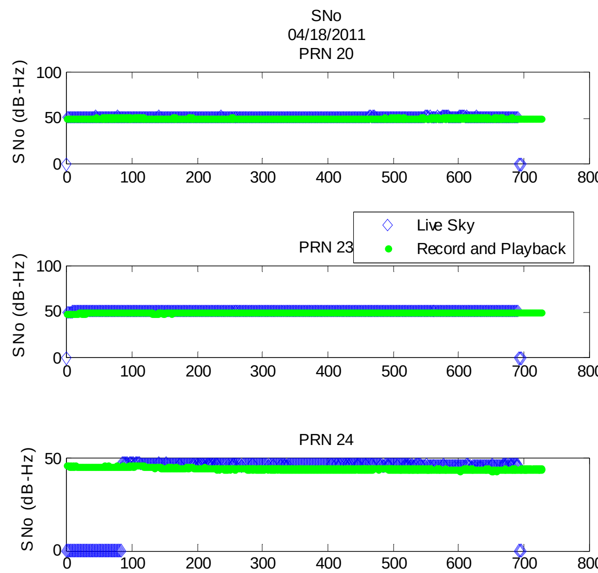

Figure 5 C/N0 Tracking Demonstration

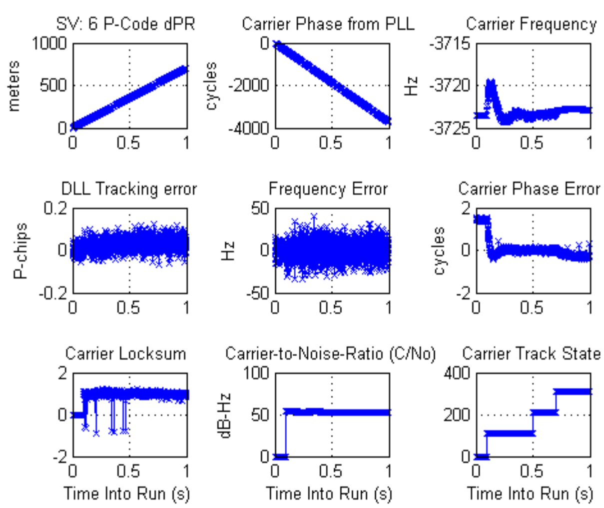

Figure 6 P-Code Tracking Results

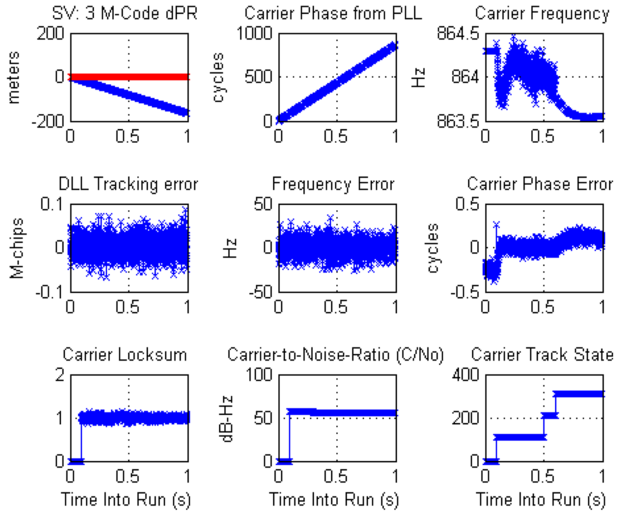

Figure 7 M'-Code Tracking Results

In Figure 6 and Figure 7 we show results from tracking the P-code and M'-code signals generated using the GNSS Signal Architect software. These results were generated using a NAVSYS Software GPS Receiver[5].

GNSS SIGNAL SIMULATION TOOLBOX

Using the optional full NAVSYS' MATLAB Toolbox to augment the GNSS Signal Architect software, users can simulate complex scenarios, including antenna modeling, and can also insert jamming and interfering signals and complex error models to simulate multipath and other effects in the signal simulation files. Figure 8 shows how the MATLAB Toolbox 3D Models can be used to simulate satellite reception in an urban environment using Google Earth 3D models. The Google 3D Warehouse[6] web site includes downloadable city models. NAVSYS has developed a MATLAB tool that allows exports from this warehouse to be captured into a 3D model file which is then read by our MATLAB toolbox as a shape file for simulation. User paths can be entered using Google Earth as KML file and a simulation can be generated including satellite shadowing in a complex 3D urban environment.

In Figure 9 we show an example of a 3D model for downtown New York that was generated, converted into a shape file and used to estimate satellites in view in the urban canyons at the specified time for the simulation.

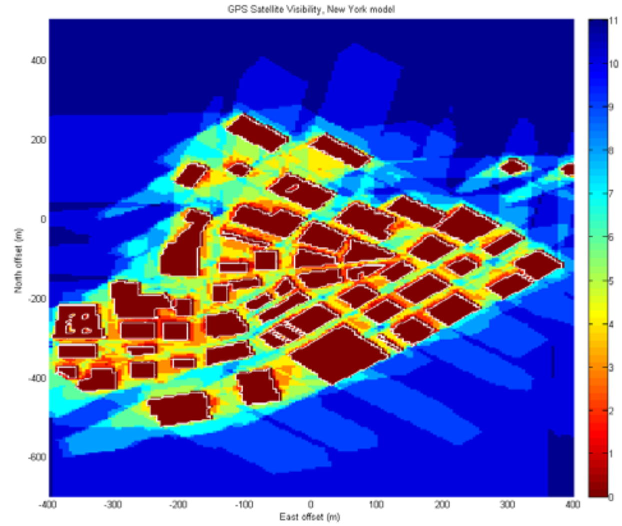

Figure 8 New York SV Visibility Simulation

CONCLUSION

The combination of the NAVSYS GNSS Signal Architect software and the GNSS Signal Generator record and playback product provides a low cost GPS signal simulation tool with the capability of simulating or recording the complete GPS signal spectrum including both the civil and the military codes. The initial release of the Military GNSS Signal Architect and GNSS Signal Generator supports L1 operation and C/A, P and M'-code signal simulation or C/A, P(Y) and M-code record and playback.

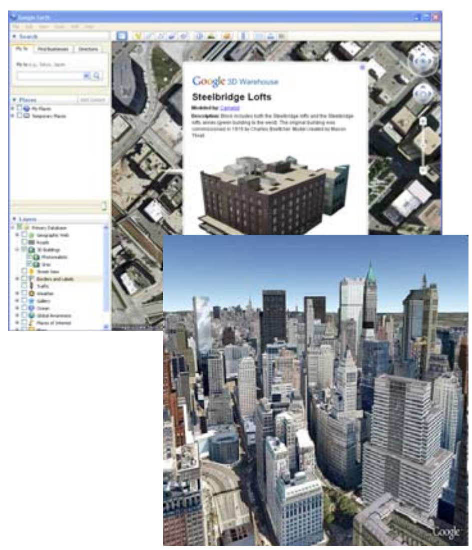

Figure 9 MATLAB 3D Model Import

Further upgrades are in progress that will also allow dual frequency operation (L1, L2 and L5) and simulation of the modernized civilian codes (L2C and L5) and also other Global Navigation Satellite Systems (see Figure 10).

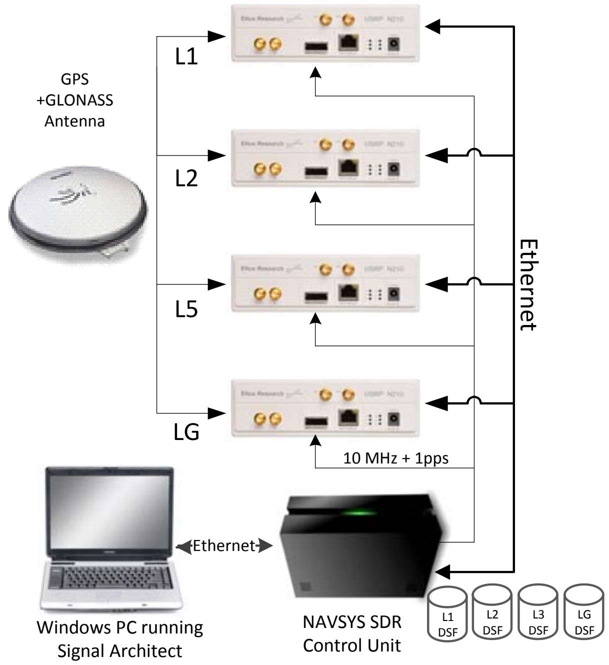

Figure 10 Future Multi-Frequency GNSS Signal Generator Configuration

ACKNOWLEDGMENTS

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