GPS Signal Simulation using Open Source GPS Receiver Platform

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ABSTRACT
Embedded GPS receivers have become commonplace with the proliferation of GPS navigation systems into all but the least expensive vehicle and cell phone lines. As more manufacturers embed low-cost GPS receivers into their products, the need for low-cost GPS signal simulators has also grown. Controlled virtual testing is vital in ensuring the expected system performance.

NAVSYS developed a low cost, SDR-based GPS signal generator to address a broad range of research, academic, industrial, and defense applications. The system is designed to be flexible, scalable, and most importantly, inexpensive.

The NAVSYS GPS signal simulator leverages the capabilities of the Ettus Universal Software Radio Peripheral (USRP) radio and the NAVSYS GPS Signal Simulation Toolbox to provide users with a GPS signal generation capability at a much lower cost than currently available on the market. The combination of the NAVSYS GPS signal simulation software coupled with the record and playback capability of the USRP makes for an extremely low cost, yet highly flexible, GPS signal simulation capability.

INTRODUCTION
As more manufacturers embed low-cost GPS receivers in to their products, the need for low-cost GPS signal simulators has also grown. Controlled virtual testing is vital in ensuring the expected system performance.

Many GPS signal generators are available that are designed specifically for high volume production test applications for devices that use commercial GPS/SBAS, GLONASS, and Galileo receivers. Often the cost of these high-end simulators is beyond the reach of small companies or universities. In response to this need, NAVSYS developed the NAVSYS SDR Control Unit (SCU) and GPS Signal Architect scenario software to address a broad range of research, academic, industrial, and defense applications.

Figure 1 shows the NAVSYS GPS signal simulator hardware. It is designed for use with commercial software designed radios such as the Ettus N210 USRP radio and is based on NAVSYS GPS Signal Simulation Toolbox[1].

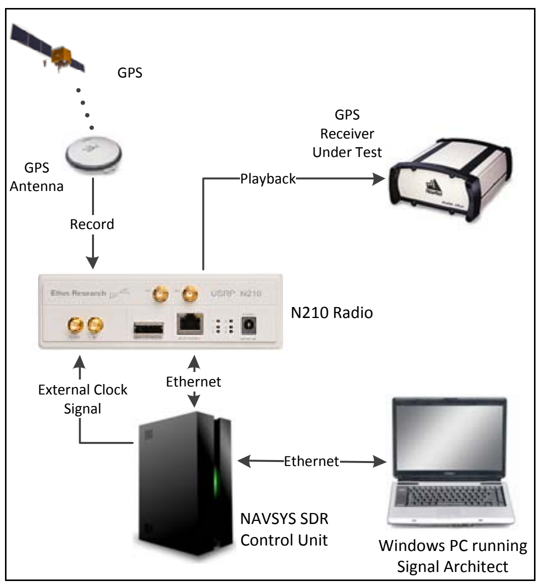

Figure 1 NAVSYS GPS Signal Simulator Hardware

In the configuration shown in Figure 1, the NAVSYS SDR Control Unit (SCU) is used to control the Ettus radio for record and playback operation. The SDR Control Unit also includes a 10 MHz frequency standard that is compatible with the USRP radio reference clock input. The NAVSYS GPS Signal Architect software can produce custom GPS scenario data files which can use the low-cost USRP to produce a GPS signal at RF.

Table 1 NAVSYS Signal Simulator System Specifications

NAVSYS Signal Architect SW	
OS	Windows XP/Win7
Multi-Core Support	Minimum Core i5
Supported GPS Signals	GPS L1 (1575.42 MHz) C/A and P
Future System Options	GNSS, multi-frequency (GPS/GLONASS[1])
NAVSYS SDR Control Unit (NSCU)	
RF In/Out	SMA - Input/Output antenna for RF signal record/replay
PC	Interface: Gigabit Ethernet (GbE) OS: Windows XP/Win7
RF Record/Replay	Channel 1 Center Frequency: 1575.42 MHz
	Sample Frequency: 2-20MHz
	Sampling: 1 or 2-bit I/Q
	Channel bandwidth set by RF pre-filter to match Nyquist BW (sample rate)
Future System Options	Multi-RF channel L1+L2+L5 +GLONASS*

*Notes: Expected to be released Fall 2011.

This paper provides a review of how the NAVSYS Signal Simulator uses the USRP family of radios as low cost RF record and playback devices using the Signal Architect files. In addition, the hardware design and supported signals are described and test results are presented showing the USRP providing simulated GPS signals to conventional GPS user equipment.

ETTUS RADIO 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 20 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.

Figure 2 USRP N210 Radio

While the GPS 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 radios, the N210 was chosen because it has the highest sample rate, greatest flexibility, and largest capacity for modification.

The USRP provides an interface between high speed analog to digital converters, high speed digital to analog converters 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.

For this project an ETTUS WBX[3] transceiver daughtercard was installed in the USRP radio. The tunable range of the WBX (50 MHz to 2.2 GHz) covers all the current GNSS frequencies. An RF pre-filter is used to band-limit the GNSS signals to the sample rate selected for use in the SCU to avoid spectral folding from the N210 40 MHz channel bandwidth. For example, a 2 MHz filter centered at L1 is optimal based on the Nyquist sampling frequency of 2 MHz I/Q. If sampling at 20 MHz, then a 20 MHz pre-filter should be used.

NAVSYS SDR CONTROL UNIT (SCU)

The NAVSYS SDR Control Unit includes a Linux SBC with software developed to run under the GNU Radio Companion and control the GNU SDR for RF record and playback under control of the GPS Signal Architect software through an Ethernet connection to a standard PC. This enables the user to tap into the excellent USRP community support for their project and benefit from the close relationship between the GNU Radio project and Ettus Research. The Ethernet connection is also used to download and upload recorded or simulated signal files from the Signal Architect signal simulation software.

SIGNAL ARCHITECT SIGNAL SIMULATION SOFTWARE

The NAVSYS GPS Signal Architect hardware and software provides users with a MATLAB-based GPS signal generation capability. If the NAVSYS MATLAB GPS Toolbox[1] is purchased, the Signal Architect GPS simulation can be run under the MATLAB environment. For the non-MATLAB user, the Signal Architect software is bundled as a stand-alone executable.

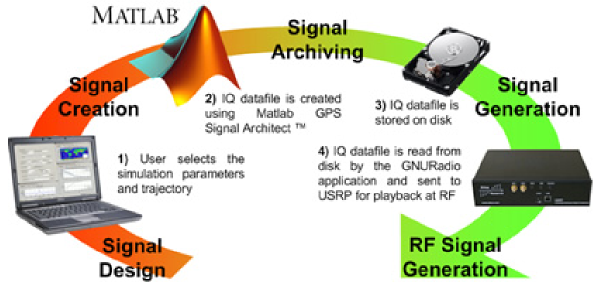

Figure 3 Signal Architect Simulation Flow

Using a simple, intuitive GUI, the user specifies a trajectory and a complete set of simulation parameters to create an IQ data file. The Signal Architect software also ships with preloaded scenario files that the user can run right out of the box into the NAVSYS SDR Control Unit using the Ettus radio. The Signal Architect software supports computers with multi-core processors and will automatically configure to run on all available processors. The Signal Architect software will generate either static or dynamic simulation profiles. The Signal Architect GUI allows the operator to easily modify a wide range of scenario variables from the pre-set defaults. Complete scenarios are easily shared between NAVSYS Signal Simulation systems, supporting collaborative testing between similar projects and reducing the amount of time spent developing test tools.

The signal data file can then be used for subsequent analysis within MATLAB using the MATLAB GPS Toolbox or can be provided to the SDR Control Unit and Ettus radio to create a GPS signal suitable for playback into a GPS receiver. 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 Signal Architect code.

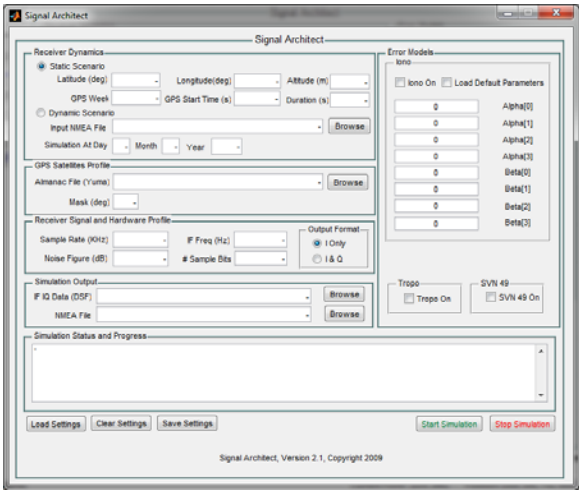

Figure 4 Signal Architect GUI

SIMULATION TEST RESULTS

To demonstrate the high fidelity of the NAVSYS Signal Simulator signal record and playback capability, a series of a stationary GPS simulations were ran. In these tests the N210 radio was used to record and playback GPS C/A signals at the L1 band (1575.42 MHz). The NAVSYS SCU and Ettus N210 radio was connected to a rooftop mounted GPS L1 antenna. The GPS signal was split between the NovAtel GPS receiver and the N210 radio to allow the operator to monitor the GPS receiver while the N210 was recording the GPS signal.

In record mode, the I/Q data is written from the N210 radio to a file on the NAVSYS SDR Control Unit. In playback mode, the data is read from the file by the N210 radio to generate the RF signal. The RF signals are output to the GPS receive through an external variable attenuator. The attenuator allows the operator to adjust the signal power into the GPS receiver as different lengths of antenna cable are added or as the signal is split to other GPS receivers.

To demonstrate the NAVSYS GPS Signal Simulator performance, representative data was collected in a series of two laboratory tests. The first test demonstrates the system performance as a record and playback GPS signal simulator. The second test results demonstrate the system performance when using the NAVSYS Signal Architect software to generate custom GPS scenario files for playback into the GPS receiver.

In the first test the NAVSYS EGS-100 GPS Simulator hardware was configured as shown in Figure 5. The NovAtel GPS receiver and Ettus N210 radio were connected to a NovAtel GPS-702GG antenna. The antenna was located at a known location with a clear view of the GPS constellation. The signal from the GPS antenna was split between the GPS receiver and the Ettus N210 radio so that the data could be logged by the NovAtel receiver software at the same time as it was being recorded by the NAVSYS SDR Control Unit.

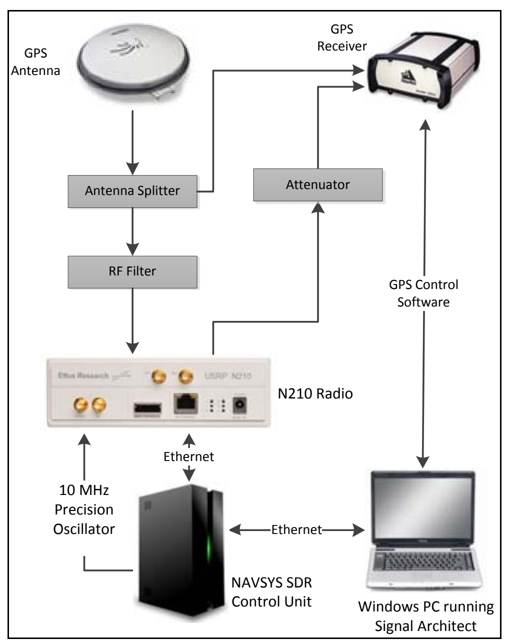

Figure 5 NAVSYS EGS-100 GPS Signal Simulator Record and Playback GPS Simulation

The simulated satellite constellation is shown below in Figure 6.

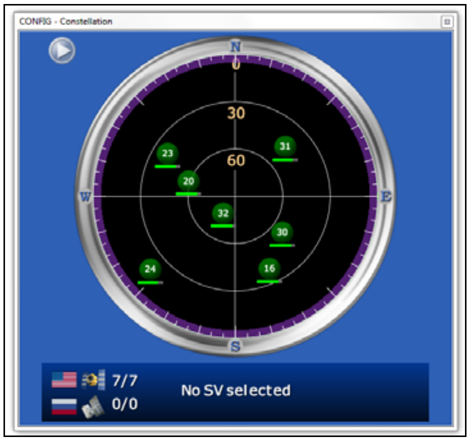

Figure 6 Simulated Satellite Constellation

The 2-D position error from the simulated signal is shown below in Figure 7.

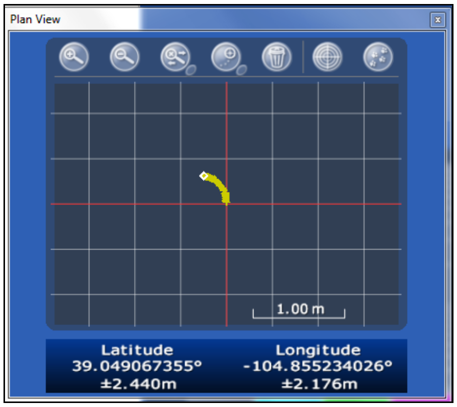

Figure 7 North-East (2-D) Position Error (m)

The following series of plots show the signal to noise measurements from the GPS receiver for both the live sky data and for the recorded signal when played into the GPS receiver by the EGS-100 for three of the GPS receiver channels. The S/No data collected from the GPS antenna is shown in blue, the S/No from the Ettus N210 radio is shown in green.

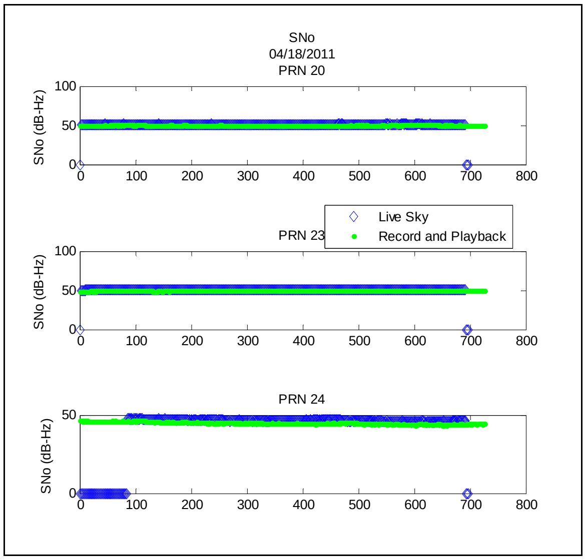

Figure 8 SNo - Record and Playback vs. Live Sky Collection

As shown, the signal to noise (SNo) was 1-2 dB lower in playback mode when compared to the data collected from the GPS antenna. The signal loss is due to the 1-bit sampling of the incoming GPS signal by the Signal Architect software. One-bit and 2-bit quantization are used in many commercial GPS receivers. The rule of thumb states that 1-bit quantization degrades the signal-to-noise ratio by 1.96 dB and 2-bit quantization degrades the signal-to-noise by 0.55 dB[4]. These results show that 1-bit I/Q sampling is sufficient for reproducing GPS L1 C/A code signals with the Ettus N210 radio.

In the second test the NAVSYS Signal Architect software was used to generate a 10 minute static GPS C/A L1 scenario file. The NAVSYS SDR Control Unit used the Ettus N210 radio to generate the GPS signal.

Shown below in Figure 9 are the number of satellites the GPS receiver was able to track. When using the NAVSYS GPS Signal simulator system to playback the Signal Architect scenario file the GPS receiver was able to track all the simulated satellites in the scenario file. The time necessary for the

GPS receiver to acquire and track the satellites is consistent with the performance you would expect from the GPS receiver when connected to an external antenna.

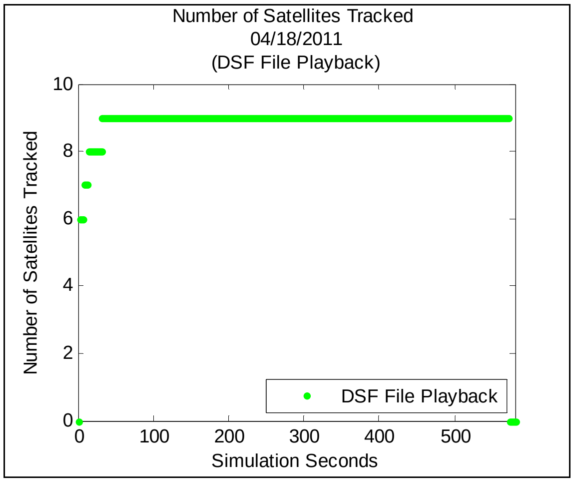

Figure 9 Number of Satellites Tracked, (DSF File Playback Mode)

The following plot shows the signal to noise measurements from the GPS receiver for three of the receiver channels. The scenario file SNo data is shown in blue. There were nine satellites in this static scenario file. The S/No for all the satellites are stable for the duration of the scenario playback.

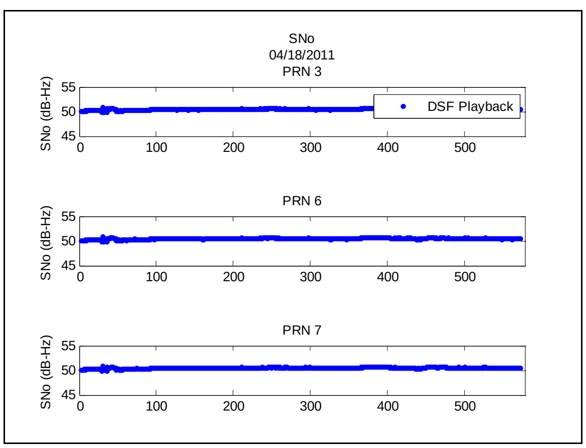

Figure 10 SNo, DSF Playback Mode

CONCLUSION

The combination of the NAVSYS GPS Signal Architect software, SDR Control Unit, and Ettus radio has proven to be an ideal 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 for playback through the Ettus SDR The initial release of the GPS Signal Architect and SCU supports L1 operation and C/A and P-code signal simulation or C/A and P(Y) code record and playback.

Our team of GPS and RF experts are continually developing and updating the system in order to provide additional functionality. Future releases of our Signal Simulator will include support for multi-frequency SDR hardware and the capability to simulate other civil and military GPS signals and also other GNSS satellite systems.

ACKNOWLEDGMENTS

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REFERENCES

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