

RF Studio for the USRP

Application Brief

Field-Testing GNSS Receivers in the Lab



OVERVIEW

GNSS receivers require a lot of testing and yet simulators only take you so far – at some point you have to go out into the field. As well, GNSS receivers are being deployed for countless applications in harsher environments than ever before, and there is more competition driving robust, high-performance options. Customers expect their devices to be accurate, fast to lock, and cost-effective whether for consumer-grade devices or for precision applications.

Some of the conditions that affect device performance, though, are very difficult to test using typical simulation techniques. How do you accurately simulate a busy urban canyon or periodic strong solar events and atmospheric variations? Any simulation would be based on mathematical models that are designed to approximate these conditions. No matter how good the model may be, it is still only an estimation of the complexity that exists in real-world environments. This is why engineers still need to field-test their designs against the realistic conditions in which they will be used.

While field testing is ultimately necessary, it is also time-consuming and expensive, and every iteration of the design or software on the device should be tested in the field before it is used by a customer. This can drastically slow down development, validation and support. While all RF products have intended physical environments in which they will be used, there are some common situations:

- Urban canyons
- Indoor navigation
- Dynamic environments (e.g., car or aircraft navigation)
- Atmospheric perturbations, such as:
 - Ionospheric scintillations due to solar flare or South Atlantic anomalies
 - Tropospheric variations with altitude or meteorological changes
- Limited availability for satellites, such as:
 - Constellations under deployment (e.g., Galileo, QZSS or Compass)
 - Constellations under modernization (e.g., GPS L5 or GPS L2C)

NI USRP AND RF STUDIO AVAILABILITY

The NI USRP and the RF Studio for the USRP software are available exclusively from National Instruments. For more information, see:

www.ni.com/usrp

www.ni.com/labviewtools/rfstudio

RF HARDWARE KIT AVAILABILITY

A complete kit of items 2-7 is available exclusively from Avera. For more information, contact:

sales@avera.com

Each of these scenarios makes it expensive to perform frequent and iterative field tests, and impossible to do them repeatedly, because the real world is never the same from one moment to the next. So, even if a test is done, the data analyzed and the algorithms tweaked, there is no absolutely sure way to fully repeat the test to ensure that the algorithm changes truly enhance the final product.

One way to solve these problems is to record the RF environment in such a way that it can be replayed later. This allows the testing to be done at any time and in any location – including a laboratory where all other factors can be controlled.

A cost-effective way to record and play back the RF environment is to use the National Instruments **USRP** with Avera's **RF Studio** software. The National Instruments USRP is a software-defined radio (SDR) that can sample up to 25 MS/s of complex I/Q data to capture GNSS signals, and RF Studio is a record-and-playback solution with an easy-to-use and intuitive GUI that enables RF recording, playback, analysis and storage.

REQUIRED HARDWARE

RF Studio for the USRP requires the following hardware:

1. NI USRP-2920 or USRP-2930*
2. Dell Latitude E6440**
3. u-blox ANN-MS GPS antenna
4. Attenuators
5. High-capacity/high-performance USB-3 Solid State Drive (SSD)
6. 1 DC block
7. 1 AC power supply for vehicle

* For GNSS applications, the NI USRP-2930 is recommended because it is an ideal software-defined platform for a cost-effective solution:

- It has both transmit and receive capabilities in a rugged, lightweight form factor.
- It covers all the GNSS frequency bands (L1, L2 or L5) with up to 40 MHz of bandwidth for any given frequency.
- It has a GPS-disciplined clock, which allows for long- and short-term stability close to GNSS clock reference. This ensures that the signal will not be degraded during playback.

When there is no access to open sky, the USRP-2930's OCXO provides short-term stability, enough for real-application recording.

** Customers intending to use the DriveView module should see the end of this document for additional computer and hardware requirements.

THE HARDWARE SETUP

The following diagram illustrates the major components and their connections.

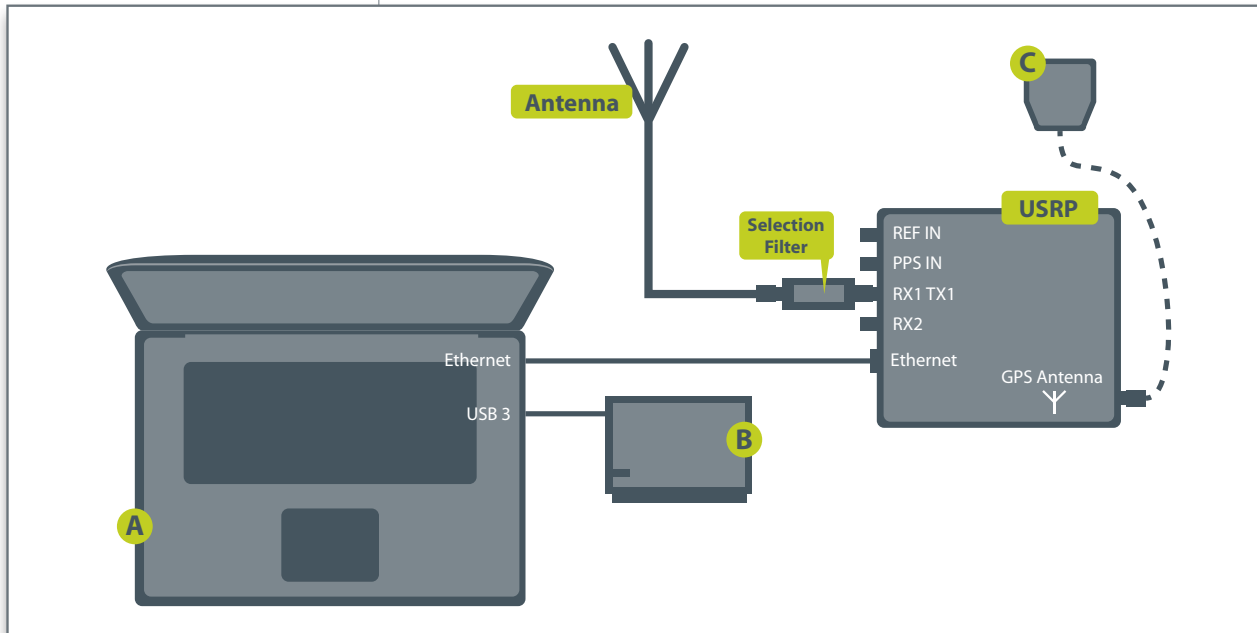


Figure 1: RF Studio for the USRP – Recording Setup

- A) Laptop
- B) External USB-3 SSD
- C) GPS Antenna

The main recording system controller is the laptop computer, where you install RF Studio. RF Studio controls the system configuration, and initiates the recording and playback processes. RF Studio is Windows 7 compatible and is simple to install and set up. By storing configuration details independently of the application data, RF Studio ensures that no data is lost if the software is updated.

As shown in the above diagram, the NI USRP-2930 is controlled by the laptop via an Ethernet connection. Baseband I/Q-sampled data is passed to the laptop and then streamed to the external SSD over a high-speed USB-3 link.

DATA THROUGHPUT

With the above setup, you will be recording a large amount of data from the USRP. See Table 1 for a data-throughput matrix for storage information.

The USRP incorporates a 16-bit I/Q complex data digitizer, sampling the RF spectrum at a rate of up to 25 MS/s. The architecture of the USRP also allows this digitizer to be used in an 8-bit mode with a sampling rate of 50 MS/s. For several applications, this means that by reducing the bit resolution, the RF bandwidth recorded can be increased, which usually results in reduced signal accuracy. However, based on the specifics of GNSS signals, they can be recorded with 8-bit resolution with practically no loss of signal accuracy.

Whether sampling with 8 bits at 50 MS/s or 16 bits at 25 MS/s, this implies that RF data needs to be streamed to the SSD at a rate of up to 100 MB/s. For example, when you use a 500-GB SSD, this allows for a recording period of about 80 minutes. However, the recording period can be increased. Again, because of the nature of GNSS signals, the bit resolution of recorded data can be further reduced with little to no loss of accuracy. So by reducing the resolution, fewer bits need to be stored, thus increasing the recording time. The table below shows approximate recording times for various sampling rates and stored bit resolutions when using a 500-GB SSD.

Sampling Rate (MS/s)	Recording Bandwidth (MHz)	Recording Capacity* in Minutes at:				
		16 bits	8 bits	4 bits	2 bits	1 bit
50	40		80			
25	20	80	160	330	660	1330
16.6667	13.33336	120	240	490	990	1990
12.5	10	160	330	660	1330	2660
10	8	200	410	830	1660	3330
8.333	6.6664	250	500	1000	2000	4000
6.25	5	330	660	1330	2660	5330
5	4	410	830	1660	3330	6660
3.125	2.5	650	1300	2600	5200	10400
2.5	2	830	1660	3330	6660	13330
1.25	1	1660	3330	6660	13330	26660
0.625	0.5	3320	6660	13330	26660	53320

Table 1:
RF Studio for the USRP –
Data Throughput Matrix

*NOTE: Bit-compression options are dictated by bit-resolution settings on the USRP. For example, if you leave the USRP at 16-bit, then you can set bit compression at 8, 4, 2 or 1 for the laptop. However, if you change the bit resolution on the USRP, you are limited to that setting for bit compression.

CALIBRATING THE SYSTEM

System calibration is important in order to take advantage of advanced features like the Noise Figure and automatic signal detection; RF Studio’s default calibration capabilities will suffice for most use cases by maintaining the power level at different frequencies while compensating with more or less gain.

RECORDING RF SIGNALS

It's straightforward to configure the system to capture GNSS signals – you only need to make a few connections.

RF Studio for the USRP helps simplify the task of making high-quality RF spectrum recordings. It can be tricky to capture GNSS signals, or any low-power satellite signal for that matter, because GNSS uses low-power spread-spectrum signals that are covered by the RF noise floor. This means that when you use a Spectrum Analyzer to view the frequency range of interest, it will be difficult to use traditional RF instrumentation cues to validate that the recorder has been optimized for distortion or signal-to-noise ratio, etc., which would lead to poor-quality recording sessions.

CONFIGURING THE RECORDING PARAMETERS

RF Studio simplifies the recording process, assuring a high-quality recording that can effectively be used to bring the real-world environment back to the lab. The RF chain Configuration view (Figure 2) allows you to clearly, easily and quickly set parameters for each element of the recording system.

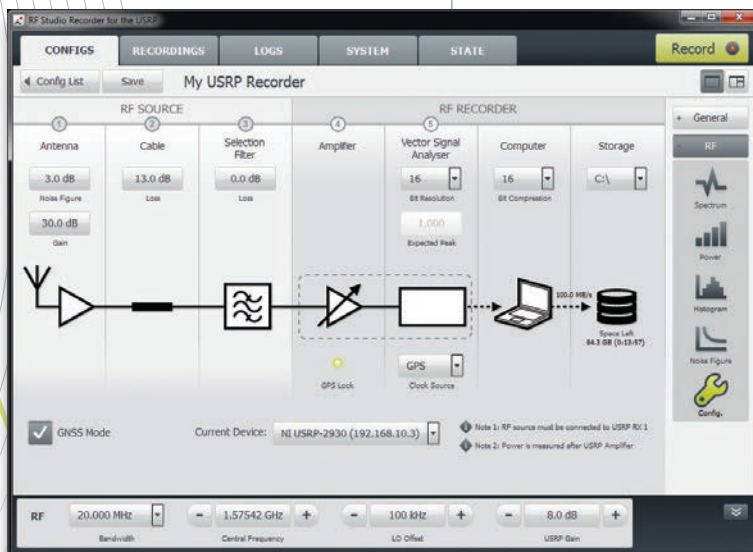


Figure 2: RF Studio for the USRP – Configuration Setup

RF PERFORMANCE SETTINGS

- **Antenna:** Here you enter the characteristics of the antenna. There are two basic factors of interest – the antenna's Noise Figure and Gain. This information should be included in the specification data that comes with the antenna.
- **Cable:** The cable between the antenna and the USRP's RX port will create a loss of signal – the longer the cable, the greater amount of the signal will be lost.
- **Selection Filter:** This may not always be needed for GNSS recording because the amplifier in the antenna often acts as a filter as well. If a filter is included, enter the loss of the filter.
- **Bandwidth:** When recording civil GPS signals, the bandwidth typically should be at least 2 MHz (4 MHz is common practice). To cover the GPS P code or GLONASS band, select the full bandwidth of 20 MHz. With 8-bit resolution, signals up to 40 MHz of bandwidth can be recorded.
- **Central Frequency:** This should be set to the central frequency of the signal to be recorded. When recording GPS and GLONASS signals, select the central frequency in the middle of the two constellations (e.g., 1586 MHz).

Also on the Configuration screen, you can set the parameters for storing your RF spectrum data.

DATA STORAGE SETTINGS

- **Vector Signal Analyzer (Bit Resolution and Expected Peak):** This is done on the USRP. By default, the Analyzer's bit resolution is 16 bits. However, when working with GNSS signals, it is possible to retain the full fidelity of the signal with fewer bits through proper processing of the digital data. By specifying 8 bits, you can significantly reduce the file size, allowing you to make much longer recordings when necessary. Note that if you lower the bit resolution, you must also specify the Expected Peak value, which you cannot change during the recording.
- **Computer (Bit Compression):** Unlike the Bit Resolution, this is done on the laptop and the expected peak value is automatically calculated and dynamically updated to optimize the bit usage. Here you specify a value of 16, 8, 4, 2, or 1.
- **Storage:** Here you specify where to store your digital data. The biggest consideration for choosing which drive to store your data on is the drive's performance – it needs to be sufficient to continuously stream the digital data.

USING THE NOISE FIGURE TO SET GAIN

Once you have set all the RF parameters, the Noise Figure (Figure 3) is calculated, which is dependent on the system's RF gain. Using this information, you can create a Noise Figure chart to help determine the optimal gain for your recording.

When recording a GNSS signal, do not degrade the signal-to-noise-density ratio (C/No), because this is a key parameter that determines the signal quality. Using the graph, you can choose the system gain with the lowest Noise Figure (best C/No) or use the recommended setting (system gain shown in the green bar). Also shown on the Noise Figure chart for GNSS recordings are three important factors:

- The minimum gain required for signal detection
- The maximum gain before distortion is introduced into the recording, and
- The optimal gain range to get the best optimization for signal detection and a large dynamic range for recording interference or jamming signals.

Click the Information (i) button to view these values numerically.

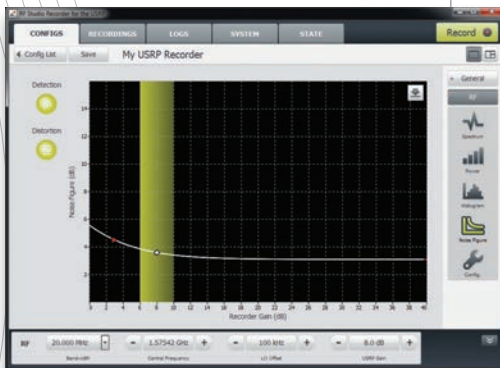


Figure 3: RF Studio for the USRP – Noise Figure View

MAKING THE RECORDINGS

At this point, you are ready to begin recording RF signals. Simply click the Record button in the upper right corner of the screen (Figure 3). This button changes to a Timer (Figure 4). When your recording is complete, simply click the Timer again to stop the recording.

While the recording is in progress, we recommend that you keep the RF Studio dashboard visible. This shows the RF spectrum as well as the status of signal detection, distortion, data streaming, and disk usage.



Figure 4: RF Studio for the USRP – Recording Dashboard

USING RF STUDIO TO PLAY BACK YOUR RECORDINGS

THE HARDWARE SETUP

The playback setup for GNSS signals (Figure 5) is simple. Here are the hardware requirements:

1. An Ethernet cable to connect the computer to the USRP-2930
2. 1 RF cable – SMA (M) to SMA (M)
3. 1 DC block – needed because the device under test (DUT) will typically provide DC voltage to turn on the antenna amplifier, and this DC voltage could damage the USRP-2930's RF input
4. 1 attenuator – needed for playback at the same power level the recording was made at

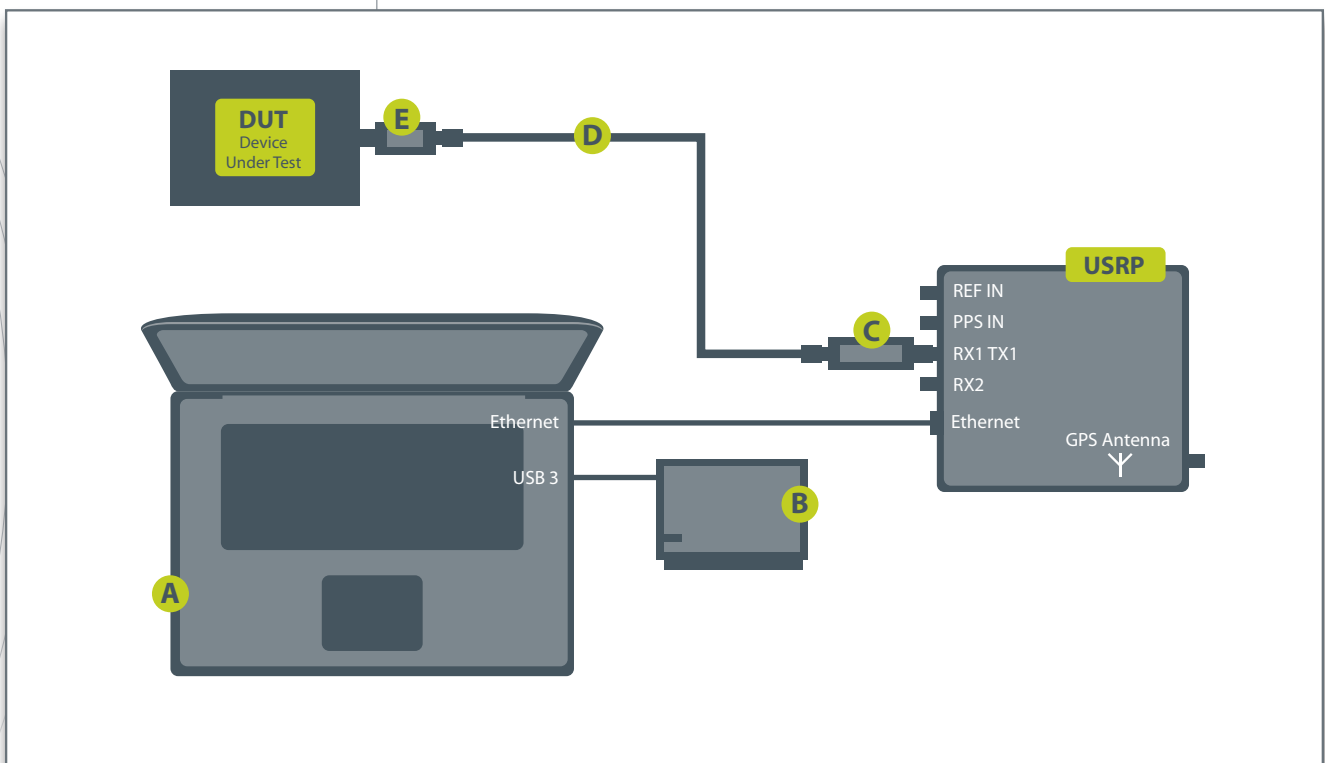


Figure 5: RF Studio for the USRP – Playback Setup

- A) Laptop
- B) External USB-3 SSD
- C) Attenuator
- D) RF Cables
- E) DC Block

NOTE: If an open-sky view is available during signal playback, a GPS antenna should also be connected to the USRP-2930 for improved performance (to take maximum advantage of the GPS-disciplined OCXO clock).

PLAYING BACK THE RECORDING

RF Studio's software architecture makes it easy to play back your GNSS recordings – simply select them from the Recordings tab, then click Play (Figure 6). The recorded data is played at the USRP's TX port. A device under test (DUT) will not detect the difference between the recorded playback and signals from a real antenna.

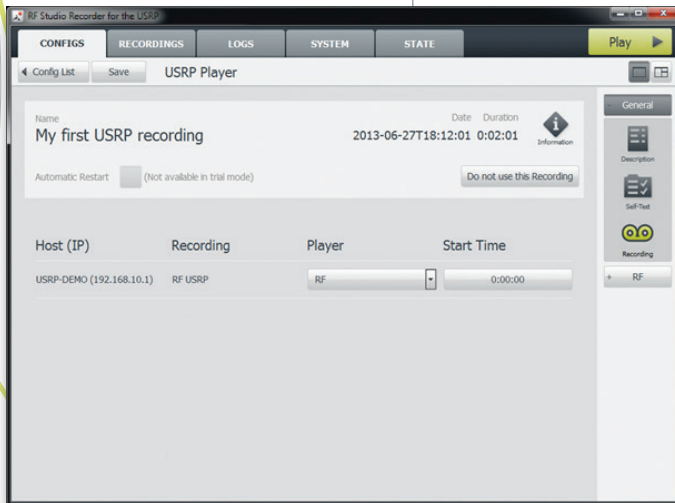


Figure 6: RF Studio for the USRP – Playback Mode

And unlike field testing, the testing done with your recordings can consistently be reproduced because the playback will be the same each time. This cannot be done with actual field testing because it is impossible to accurately recreate a test scenario – satellite locations will be different, atmospheric and weather conditions may be different, and the physical landscape may have changed.

BENEFITS OF USING RF STUDIO RECORDINGS

Several factors may make RF field testing impractical or even impossible at times. Conditions such as solar flares or atmospheric conditions are often available for only very short durations. Likewise, in the case of an incomplete constellation, there may be small and infrequent windows of opportunity for field testing. Another factor is that any tests that are performed will be impossible to accurately reproduce in the field.

Any RF recording can help overcome many of these factors. Additionally, you can make RF recordings in remote or distant locations and then return to the lab with them. This provides two important advantages – the ability to test without incurring additional travel expenses, and the ability to test in a controlled environment.

RF Studio for the USRP provides a very reliable and cost-effective way to make these recordings and do this testing.

ADDITIONAL APPLICATIONS FOR RECORD AND PLAYBACK

Throughout this document, the recording and playback of GNSS signals has been discussed. However, both the general-purpose edition of RF Studio and the USRP-2930 have been developed with a large degree of flexibility that allows the system to be used for more than just GNSS recording.

For example, automobile infotainment systems have become major features in vehicles. Some vehicle manufacturers dictate what the user interface to these systems will look like. The uniform user interface makes it easier for the manufacturer to market these systems, but makes it difficult to differentiate between the various systems. One of the differentiating factors that still exists is RF performance.

Perhaps one of the best measures of performance is how well the radio performs in difficult environments. Testing in these environments often presents challenges similar to that of GNSS testing – remote locations that require travelling with new equipment, difficult-to-reproduce field tests, and changing testing environments.

The wide operating range of the USRP – both in frequency and power levels – and the flexibility of the general-purpose edition of RF Studio allow the same system to be used to bring most broadcast radio signals into the lab, including:

- DAB
- DVB
- FM radio (including HD and RDS)
- Sirius and XM*
- Broadcast television

This flexibility makes RF Studio for the USRP a valuable addition to the design and validation process for many different RF applications.

DRIVEVIEW™ MODULE

With RF Studio's DriveView module, plus some additional hardware, you can video-record your field recording sessions and capture comprehensive location (NMEA) data, which you can see in Figure 7.

Note that the DriveView setup requires the following additional hardware:

- An **Axis P1344 IP** camera. This is a high-quality camera with a built-in microphone that is useful for dictating comments during the recording process as well as a line-in port for the captured audio.

NOTE: The camera requires an Ethernet port, which can be shared with the USRP (though reducing RF bandwidth) or you can use a computer with two Ethernet ports.

- A **u-blox EVK-T6 GPS** receiver. This product has an easy-to-use remote user interface for setting up the receiver and retrieving full satellite, position, and timing information.

- Appropriate cables to connect the IP camera and GPS receiver.

For more information about RF Studio's DriveView module, contact Avera at support@avera.com.

* IMPORTANT NOTE:

Care should be taken when recording and playing back Sirius and XM signals, as the embedded timing signals could be intentionally or accidentally used for RF signal spoofing, and SiriusXM reserves the right to disable radios when potential fraud is detected.

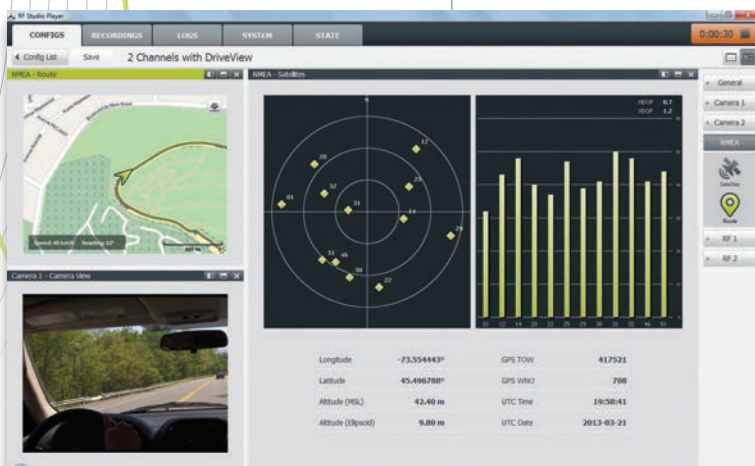


Figure 7: RF Studio for the USRP – DriveView Playback Mode

RF Studio for the USRP

AVERNA URGES SAFE DRIVING

While using RF Studio in a vehicle, place the laptop and other equipment where it will not interfere with the driver's view or the safe operation of the vehicle. Avera strongly recommends that you have a designated RF Studio operator in the vehicle; the driver should not operate RF Studio or other equipment while driving.

IMPORTANT LEGAL NOTE:

Every country has different laws governing the transmission and reception and/or recording of radio signals. Users are solely responsible for using RF Studio for the USRP in compliance with all local and applicable laws and regulations governing the transmission and reception and/or recording of radio signals. Avera Technologies Inc. does not accept liability for such use of our products. Avera recommends that you determine what licenses may be required and what restrictions may apply prior to use.

We are a leading NI Platinum Alliance Partner and have over 50 certified NI LabVIEW™, NI TestStand™, and LabWindows™/CVI™ architects, developers, and instructors on staff.



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MORE INFORMATION

For additional details about using this RF record-and-playback solution, see the *Avera RF Studio for the USRP Quick Start Guide*.



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