The Importance of Bit Depth in GNSS Record and Playback Testing

Why bit depth quantisation matters when recording real-world signals for playback in the lab

Record and Playback Testing: Why Bit Depth Matters

When testing Global Navigation Satellite Systems (GNSS)-reliant equipment, many manufacturers and chipset integrators will use record and playback solutions to reliably test real-world signal environments in the lab.

However, depending on what bit depth your record and playback system (RPS) is capable of, the process of converting analog signals into digital testing files could create a flawed image of a signal environment – and compromise the fidelity of your testing efforts.

This paper explains how this happens; the impacts of using an RPS with low bit depth; and what manufacturers and chipset integrators can do to accurately recreate signal environments and ensure they test against authentic real-world conditions.

What Is Bit Depth?

Understanding Record and Playback Quantisation

RPS solutions work by recording a live radio frequency (RF) signal environment for playback later in the lab. To do this, an Analog to Digital Converter (ADC) is used to turn live analog signals into a digital file.

ADCs will use a certain number of bits when converting signals, and the number of bits used to digitise the RF signal determines the resolution of the measured signal. For instance, a 16-bit ADC can convert the signal into 65,536 different levels, whereas an 8-bit ADC only converts it into 256 levels.

<table>
<thead>
<tr>
<th>Bit Depth</th>
<th>No. of levels</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>4</td>
<td>16</td>
</tr>
<tr>
<td>8</td>
<td>256</td>
</tr>
<tr>
<td>16</td>
<td>65,536</td>
</tr>
</tbody>
</table>

The higher the bit depth used, the more levels at which the signal can be recorded – producing a clearer, more detailed interpretation of the analog RF environment.

1. https://commons.wikimedia.org/wiki/File:2-bit_resolution_analog_comparison.png
2. https://commons.wikimedia.org/wiki/File:4-bit_resolution_analog_comparison.png
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How Does Bit Depth Affect Testing?

The Impacts of Low Bit Depth on Testing

The bit depth of your RPS will have two main effects on the kinds of recordings you create – and how you can test with them:

1: Higher bit depth improves signal reproduction quality

In general, the more bits, the better the reproduction of the input signal. With better signal reproduction, your RPS will better represent real world signals during playback.

Using low bit depths also degrades the ability to reproduce the full carrier-to-noise ratio (C/N_o) of a GNSS signal. The C/N_o degradation depends on the chipping rate of the GNSS signal you’re recording, the recorded bandwidth, and the bit depth of your RPS.

<table>
<thead>
<tr>
<th>Bit Depth</th>
<th>Dynamic Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6dB</td>
</tr>
<tr>
<td>2</td>
<td>12dB</td>
</tr>
<tr>
<td>4</td>
<td>24dB</td>
</tr>
<tr>
<td>8</td>
<td>48dB</td>
</tr>
</tbody>
</table>

2: Bit depth determines the dynamic range of a recorded signal

Dynamic range is the difference between the maximum and minimum signals that an RPS can record. It's important to consider this as interference and jamming are becoming more common. You need to ensure the bit depth of your RPS system can cover the dynamic range to account for these problematic signals.

The dynamic range of an ADC is calculated by dividing the maximum and minimum amplitude and converting to decibels. In general, each bit used by an ADC increases the dynamic range by 6dB – as shown in the table below. This means that if there are two signals differing by more than 12B, a 2-bit quantisation will lose information, and won't be able to correctly record the RF spectrum.

Live RF signals contain a multitude of signals and codes. For instance, GPS L1 contains a code division multiple access (CDMA) waveform consisting of two spreading codes, coarse/acquisition (C/A) and the encrypted precision (P(Y)) code. To convert these into a suitable form for data processing, the signal is transformed into in-phase and quadrature, or I and Q. ADC is performed on each.

It's important to understand what the bit-depth is for both I and Q. Some RPS manufacturers state the overall bit-depth figure for both I/Q, i.e. 2 bits stated where there is only 1-bit I and 1-bit Q. This could be detrimental to your testing if true 2-bit I and Q conversion is required.

C/N_o Degradation: An Example

For the GPS L1 C/A signal with a 1.023Mbps chipping rate, the C/N_o will deteriorate as per the table below:

<table>
<thead>
<tr>
<th>Bit Depth</th>
<th>CNo degradation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-2.1dB</td>
</tr>
<tr>
<td>2</td>
<td>-0.63dB</td>
</tr>
<tr>
<td>4</td>
<td>-0.1dB</td>
</tr>
</tbody>
</table>

For signals with a higher chipping rate (e.g., 10.23Mbps for GPS L5, Galileo E5A and E5B) the C/N_o will deteriorate by between -2.3dB and -3.5dB for 1-bit quantisation, between -0.7dB and -1.2dB for 2-bit quantisation and between -0.15dB and -0.5dB for 4-bit quantisation.³

What Bit Depth Do I Need?

Different Testing Requirements Demand Different Bit Depths

In an ideal world you would want to record everything with a 16-bit RPS to get the highest resolution and largest dynamic range. However, this can produce a lot of data, making it a potentially poor choice for certain testing operations.

Here are a few common testing scenarios, with recommendations for what bit depth will be required, and why.

Example 1: Testing clean RF environments

If RF interference isn’t present, a 2-bit record and replay system is suitable for testing a 1-bit system - where C/N0 loss up to 3.5dB is acceptable.

It should be remembered when choosing a receiver that a 1-bit module will experience a loss of up to 3.5dB C/N0. This loss can make the difference between locking onto, or not locking onto, a satellite – especially those with a low elevation angle. This can reduce the number of tracked satellites and weaken their geometry, resulting in worse position and accuracy estimates.

In all cases it’s important to ensure the fidelity of your RPS is better than the system you are testing. So, if you were testing an 8-bit receiver, using a 2-bit RPS would degrade the signal before it even enters your receiver under test. This would be a poor choice if your goal is test with precision and accuracy. The key outcome of the testing is to establish the limits of your device, not your test equipment.

Example 2: Real-world testing

In the real world, RF interference is a common and often complex problem. For instance, in an area with a high density of telecommunication signals (common in today’s world) spurious signals can interfere with the GNSS band. Similarly, urban environments provide a plethora of tall buildings and angled surfaces that can cause signal refractions, interfering with receiver performance.

Very often, interference does not completely block GNSS signals. Instead it degrades them to the point that equipment reacts in unexpected ways. If you’re testing your latest receiver in these environments, it’s important to reproduce realistic environments to see how your equipment will react in real-world conditions. 1-bit and 2-bit systems lack the bit depth to accurately replicate complex environments.

If a low bit RPS is used, the quantisation process could modify interference signals. This could lead to a receiver performing adequately under that altered interference, when in the real world that same interference would alter or hinder performance.

We recommend you test using an RPS with greater bit depth than the system under test if you suspect any interference will be present during operation.

Example 3: Jamming and interference mitigation

If you are working to understand and mitigate the effects of jamming and interference on your equipment, you need a way to accurately replay interference in the lab. Low bit RPS systems do not have the dynamic range to cover typical interference or jamming, so you will need high bit depth (8 or 16-bit) RPS to accurately replay the signals and interference used in your tests. The graphs on the following pages help to highlight this.
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Introducing The Spirent GSS6450
Spirent GSS6450: A Flexible 16-Bit RPS Solution

The GSS6450 RF Record Playback System from Spirent can offer up to 16-bit quantisation to ensure your testing reflects the real-world environments your equipment will operate in. Housed in a small chassis, battery powered, and portable, the GSS6450 can record signal environments with a range of bit depths and bandwidths of up to 50MHz.

The Spirent GSS6450 can help testing engineers and system integrators:
- Test equipment against real-world GNSS signals
- Ensure realistic RF playback with up to 16-bit depth support
- Improve testing flexibility with a compact, rugged design
- Operate for up to 1.5 hours on a built-in battery
- Test using all major all major GNSS constellations and signal bandwidths

GSS6450 Dynamic Range Comparison
Dynamic Range Across RPS Bit Depths: A Comparison

Using the RF spectrum analysis tools built in to the Spirent GSS6450, a range of tests were conducted to better understand how different bit depths impact the dynamic range of signal recording. The tests were all conducted using the same input signals, but changing the bit depth each time.

A multi tone signal was generated at the GPS L1 centre frequency of 1575.42MHz, approximately 24dB above the noise floor. A jammer signal was added at approximately 1585.5MHz. This is roughly 31dB above the level of the multi-tone signal, and is designed to emulate real world signals where a jammer is 30dB above the noise floor. The spectrum of this input signal is shown in Figure 1 below.

![Figure 1 - Input signal](image)
The Spirent GSS6450 was then set to Live Test Mode and the spectrum was monitored. The plot below (Figure 2) shows the spectrum at 8-bit resolution. With a theoretical dynamic range of 48dB, this system has no problem correctly representing the two signals 30dB apart.

![GSS6450 Spectrum Analysis 8-bit resolution](image)

The bit depth of the sampled signal was then reduced to 4 bits and a change is noticed in the spectrum (see Figure 3).

![GSS6450 Spectrum Analysis 4-bit resolution](image)

With a dynamic range of just 24 bits, the 4-bit RPS can’t accurately recreate the signal. So, the 30dB jammer starts to corrupt the spectrum. The jammer signal’s relative amplitude hasn’t changed, but the multi-tone signal at the centre frequency has been suppressed by 2dB and some spurious signals have started to appear.

The bit depth was then reduced down to 2 bits and saw a more significant change in the spectrum (Figure 4). The multi-tone signal at the centre frequency has further dropped down to 18dB and multiple spurious signals have appeared.
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Figure 4 - GSS6450 Spectrum Analysis 2-bit resolution

The bit depth was reduced to 1 bit and further degradation is observed (Figure 5).

Figure 5 - GSS6450 Spectrum Analysis 1-bit resolution

Here, the signal at the centre frequency has been suppressed by 10dB and there are multiple spurious signals across the spectrum.
What the Experiments Show

The analysis shows that the greater the bit depth you use when recording a signal, the better the playback fidelity – both in terms of maintaining C/N₀ levels, and dynamic range.

When in the presence of a single source of interference, the recorded spectrum deteriorates if you use too low a bit depth. In the real world, a GNSS system is likely to encounter many interference sources in the course of a typical field test, meaning the real world presents an even more demanding environment than shown in these tests.

The tests show that it is important to choose an RPS with the right bit depth based on your testing requirements and the kinds of interference your equipment will encounter. If the real-world RF environment is not recorded and played back with high fidelity, it won’t correctly reproduce the real-world signals required, and can compromise the testing process.
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Next Steps

See how Spirent can help

To find out more about the Spirent GSS6450 RPS, and how it offers up to 16-bit RPS quantisation, check out the GSS6450 data sheet.

Or, if you would like to discuss your unique testing and record and playback challenges with a leading team of GNSS testing experts, get in touch.