Keysight Technologies

Using Flexible Digital Modulation in the Testing of Satellite Regenerative Payloads

Application Note

KEYSIGHT TECHNOLOGIES

Introduction

Regenerative payloads pose challenges not found in conventional analog bent-pipe satellite testing. There are two major reasons for this. First, these are mixed-signal systems that carry analog and digital representations of modulated signals. Second, the digital modulation formats may be wideband, higher-order or custom.

The process of understanding what happens along the signal chain will benefit from continuity across design, simulation, signal generation and signal analysis. Achieving a high level of continuity across an integrated design-to-test flow will help reduce risk during the actual system-integration process.

This application note focuses on solutions for the issues that create risks in the integration of such systems. The necessary measurements can be achieved with a combination of software and hardware tools: Keysight SystemVue with the companion digital modem library and Keysight 89600 VSA software; the Keysight M8190A arbitrary waveform generator (AWG), the Keysight E8267D PSG vector signal generator, the Keysight Infiniium 90000 Q-Series oscilloscope and the Keysight 16850 Series logic analyzer with the FPGA Dynamic Probe application. Examples focus on measurements of error vector magnitude (EVM), which is a key figure of merit for modulated signals implemented in either analog or digital form.

Sketching the challenges

The use of digital satellite links has become more prevalent because they provide a variety of advantages over analog links. From a design perspective, digital interfaces are easier to manage than analog connections.

Within a satellite, regenerative payloads are mixed-signal systems that carry analog and digital representations of modulated signals. During testing, it can be difficult to deal with the format changes that occur as signals travel through the transmitters and receivers. For example, signal amplitudes that were once represented by analog voltages are now digital samples carried on a signal bus that has many different voltage levels. To further complicate matters, the signal is often represented on dual time-sampled buses that carry the in-phase and quadrature (I/Q) signals.

Successful troubleshooting often requires cross-format analysis between the digital and analog parts of the system. This includes cross-domain analysis of the modulation parameters carried by the digital and analog signals that occur on either side of an analog-to-digital or digital-to-analog blocks within the system.

Diagnosing digital issues requires different interfaces to specific hardware elements. As a result, the probing of I/Q buses with many test connections becomes essential. Probing becomes more complicated when the system contains FPGAs because many of the test points many not be readily accessible from outside the chip.

Quantifying signal quality

In the macro view, the digital-signal bit error ratio (BER) is the end-to-end measurement that defines the end-user's experience (Figure 1). System operators demand predictable and consistent BER across all user terminals. This is challenging in part because it depends on what happens when switching from one ground station to another and this makes it difficult to guarantee acceptably low levels of BER in all situations.

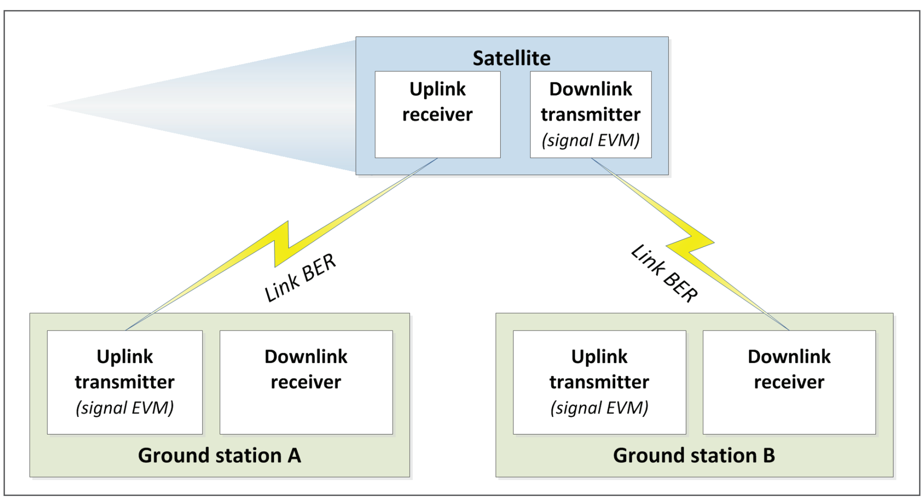

Figure 1. Link BER defines the end-user's experience while EVM characterizes the signal quality of analog and digital modulated signals.

Testing BER is especially challenging because it varies with signal level and a variety of component characteristics. This makes it difficult to determine which parameters to test and where to measure them.

Before BER can be optimized, it is necessary to optimize the modulated waveform across a variety of physical signal representations, from digital to microwave. This must be done consistently, independent of the physical form of the signal. Fortunately, EVM measurements can be used to quantify the quality of modulated signals in either digital or analog form.

Focusing on modulation techniques and EVM

The ongoing challenge for satellite operators is all about packing more bits into the available spectrum and achieving faster throughput. This can be done using higher-order modulation techniques that fit within the constraints of existing satellite systems (e.g., bandwidth).

As a generalization, the more complex the modulation technique, the more information it can carry. For example, quadrature amplitude modulation (QAM) is a complex scheme that uses multiple amplitude levels to carry more information. The net result is often the ability to carry more data in the same RF bandwidth.

In satellite applications, less complex methods such as frequency-shift keying (FSK), phase-shift keying (PSK) and amplitude phase-shift keying (APSK) tend to be favored. One advantage: transmitters can be operated closer to saturation, optimizing output power to match the dynamic range of the amplifier.

Specific examples are contained in the Digital Video Broadcast Satellite Second-Generation Standard (DVB-S2). DVB-S and DVB-S2 were defined to provide a limited number of modulation and data configurations, and the goal was to help ensure interoperability between receiver boxes produced by different manufacturers. To meet that goal and also accommodate the data rates needed for HDTV, broadcast-quality feeds and backhaul video, DVB-S2 added three modulation schemes: 8 PSK, 16 APSK and 32 APSK.

Displaying complex signals

As modulation becomes more complex, it becomes increasingly difficult to view a time-domain waveform or frequency spectrum and understand or troubleshoot problems in signal quality. This is especially true for current techniques that utilize I/Q modulation. Instead, a vector signal analyzer or VSA software is used to demodulate the signals and then display them as constellations, shown conceptually in Figure 2.

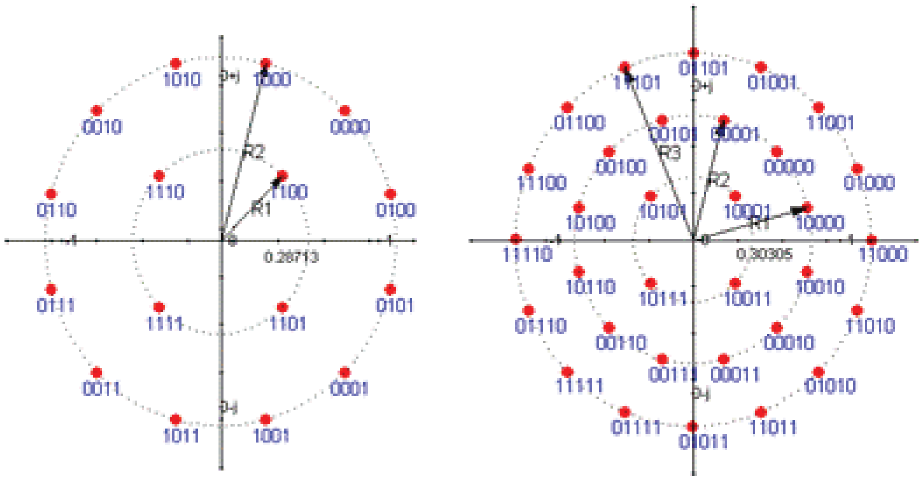

Figure 2. Constellations make it easier to quickly identify I/Q impairments that affect, for example, 16 APSK (left) and 32 APSK (right) transmissions.

I/Q modulation impairments cause deviations from the defined location of each constellation symbol. The type and intensity of those deviations provide vital information about the nature of the impairments, and a few basic examples are shown in Figure 3.

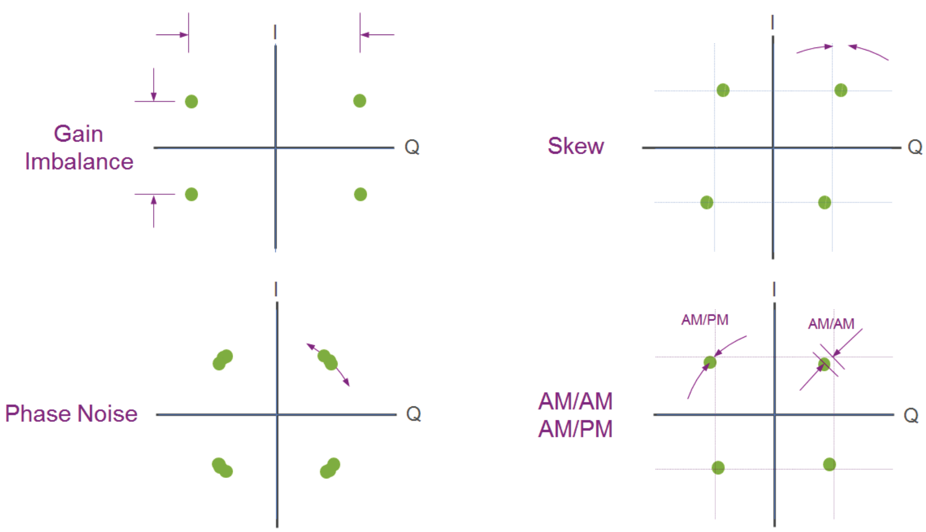

Figure 3. Each type of deviation provides clues about the underlying I/Q impairments that are affecting signal quality.

If the constellation is more rectangular than square (upper-left example), this is called gain imbalance and it indicates improper scaling of the I and Q signal magnitudes relative to each other. Skewing in the quadrature relationship between I and Q can distort the constellation shape relative to the decision boundaries (upper right). Linear distortion such as AM/AM conversion and AM/PM conversion create symbol points that are rotated in phase and fall short of the desired amplitude. In the fourth example (lower left), phase noise can cause an angular smearing of the symbol points.

In constellations as complex as 32 APSK, these impairments become a critical tool in achieving the desired overall level of system performance because there is less room for error between the decision boundaries. This may require the system engineer to tighten the transmitter performance budgets to support higher data rates.

Utilizing EVM

At its simplest, EVM is the difference between a reference vector and the vector of the actual received signal. To measure EVM, the measurement tool must support the modulation standard being tested.

This is why the 89600 VSA software generates reference vectors for more than 70 standards and formats, including those commonly used in satellite systems. For developers working with proprietary, non-standard signals, Option BHK adds custom I/Q modulation analysis with capabilities including a constellation editor, customizable I/Q-mapping presets and long symbol lengths.

Because EVM provides an aggregate summary of many types of impairments, it is an ideal way to detect issues in modulated signals. It is also a convenient way to quickly observe signal degradation between points within the system block diagram. Careful examination of EVM measurements makes it possible to identify modulation imperfections, trace them back to their origin and determine the fundamental mechanism that caused the problem.

Diagnosing issues in digital modulation

Comparative signal analysis is a very effective way to diagnose signal issues with EVM and other high-level VSA measurements. For any given component in the system, the input and output signals are measured and compared. Any differences reveal signal impairments that may have been added by the component. Working through the system block by block, it is possible to minimize modulation impairments and achieve signal implementations that are close to the theoretical optimum.

In today's satellites, transmitters and receivers may be implemented using digital devices or designs. The ability to achieve continuity in identifying and diagnosing the impairments added by each component requires cross-format tools that can interface equally well with modulated signals in either analog or digital form (Figure 4).

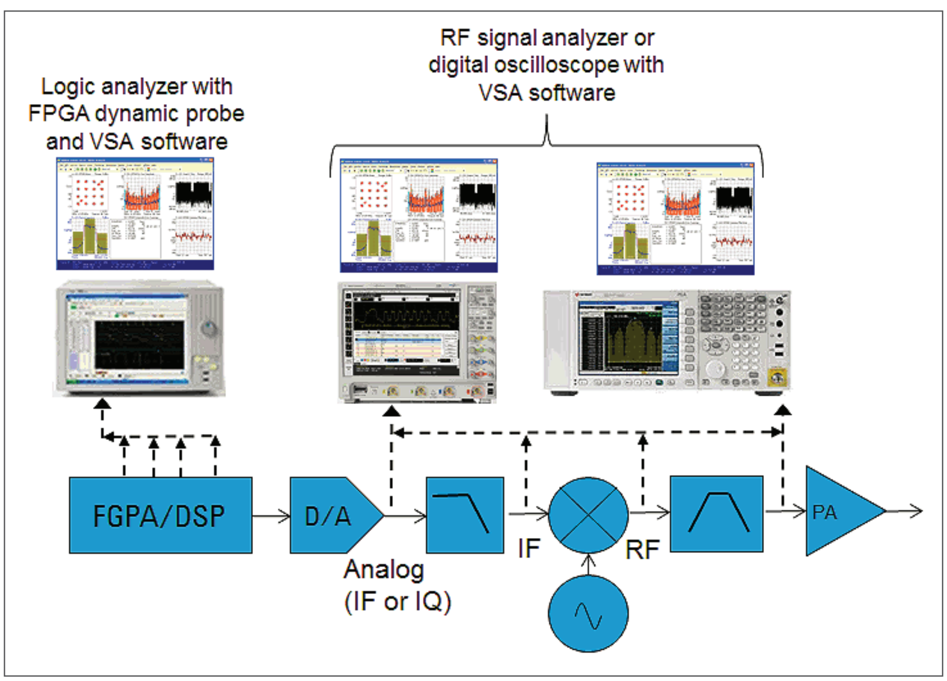

Figure 4. Comparative signal analysis enables identification and diagnosis of impairments at virtually any point within a system that carries analog and digital modulated signals.

Diagnosing digital issues requires specific interfaces for different types of devices or buses. As a result, the ability to probe I/Q buses with many test connections becomes essential. Probing is often complicated when the design includes FPGAs because many of the test points are not readily accessible from outside of the chip. Fortunately, many of these issues can be easily addressed with a logic analyzer, and this is why the 89600 VSA software runs on the Keysight 1680, 1690, 16800, 16850 and 16900 platforms. Those platforms also support FPGA dynamic probe capability, which is used to select internal FPGA signal banks that are then demodulated by the 89600 VSA software.

The same VSA software can be used with many Keysight digital oscilloscopes, X-Series signal analyzers, modular digitizers and modular signal analyzers. This enables cross-domain probing—and high quality measurements—throughout the design. It also enhances essential tasks such as the search for impairments, the debugging of performance problems and system-level performance budgeting. It also helps ensure continuity in measurements performed throughout the block diagram and across the design process.

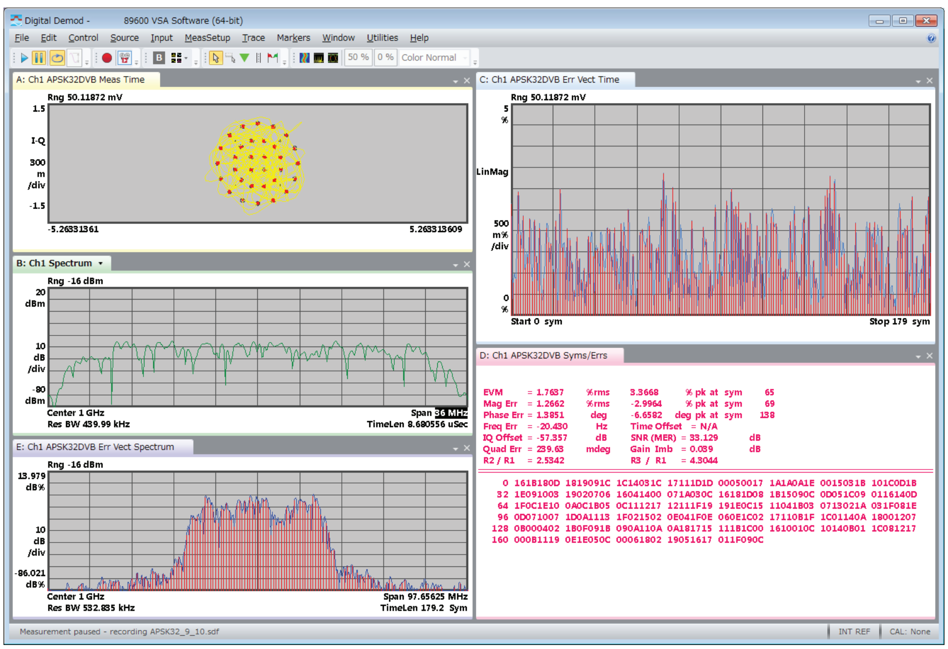

Figure 5. To ensure continuity in comparisons of EVM, the 89600 VSA software provides a nexus for measurements of analog and digital modulated signals made with Keysight logic analyzers, digital oscilloscopes and signal analyzers.

Creating and analyzing wideband signals

Combining design simulation with a precision AWG and a high-quality microwave vector signal generator is a flexible way to create many types of signals that can be used as test stimuli. An example configuration, created with off-the-shelf building blocks, is shown in Figure 6.

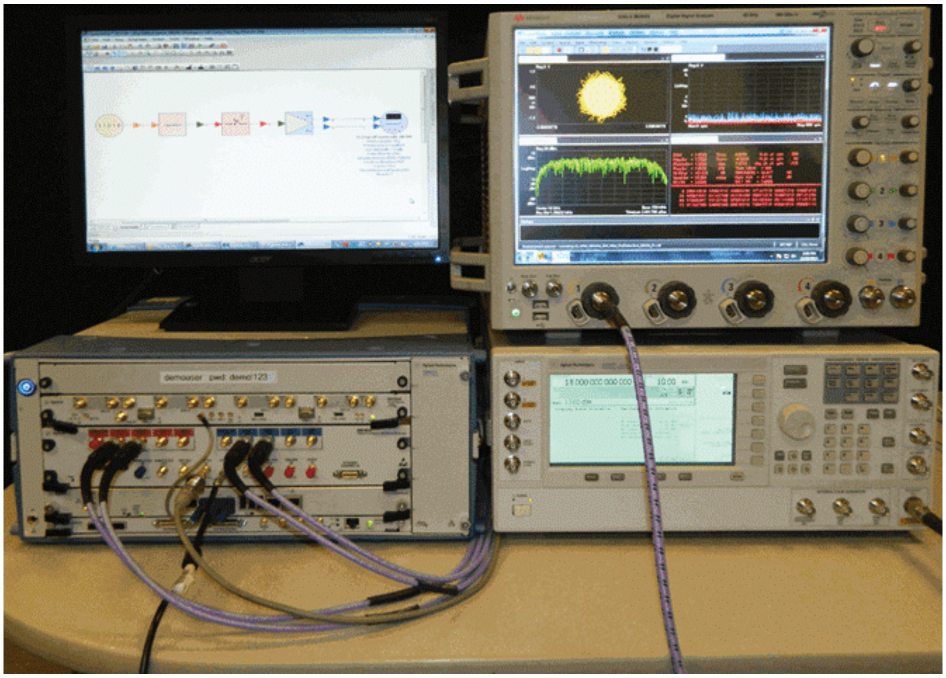

Figure 6. This combination of off-the-shelf hardware and software can be used to create and analyze a wide range of test stimuli.

There are four key hardware elements:

- An AXIe chassis with embedded controller (lower left)
- A Keysight M8190A 12 GSa/s AWG, installed in chassis
- A 62-GHz Keysight Infiniium oscilloscope (upper right)
- A Keysight E8267D PSG vector signal generator (lower right)

The PSG is configured with Option 016, wideband differential external I/Q inputs.

Keysight's SystemVue electronic system-level (ESL) software is running in the embedded controller and is shown on the monitor resting atop the chassis. The SystemVue installation includes the digital modem library (W1092), which is a simulation add-on that includes signal sources that can be configured for standard and custom digital-modulation formats including custom APSK.

SystemVue is used to create and then download waveforms into the M8190A AWG. The M8190A produces the I and Q signals that are fed into the wideband I/Q inputs of the PSG, which generates a modulated X- or Ku-band carrier signal (a higher-frequency PSG can be used to address Ka-band applications).

The X- or Ku-band signal can be measured using the oscilloscope and analyzed with the 89600 VSA software, which is running inside the scope.

Enhancing signals with adaptive equalization

Waveforms generated by test equipment can include imperfections such as noise, variations in amplitude and phase, and other impairments that may degrade waveform quality. These issues can be significant in waveforms that have bandwidths greater than 1 GHz.

To help improve performance, corrections can be applied to the I/Q waveform before the signal is downloaded to the AWG. This is accomplished using the real and imaginary frequency response and the adaptive equalization (EQ) function in the VSA software.

As an example, this can be done to improve the EVM performance of an APSK signal. First, a wideband APSK signal with 1-GHz modulation bandwidth is downloaded from SystemVue to the M8190A AWG. Next, the outputs of the AWG drive the wideband I/Q inputs of a PSG generating an 18-GHz modulated carrier signal. Third, the resulting signal is measured using the digital oscilloscope and analyzed with the VSA software; adaptive equalization is applied to determine the necessary real and imaginary responses for the adaptive equalizer. Next, SystemVue is used to read the coefficients from the VSA software and store them in an ASCII file. The final step is to apply those values to the test signal by re-simulating the waveform using a complex FIR filter that applies the required equalization response. The revised signal is then downloaded to the M8190A.

Actual results for a 32 APSK signal are shown in Figure 7. The FIR filter in SystemVue is applying the real and imaginary adaptive EQ responses to the simulated signal. Relative to the original waveform, the corrections produce a signal with substantially improved EVM of 1.28 percent.

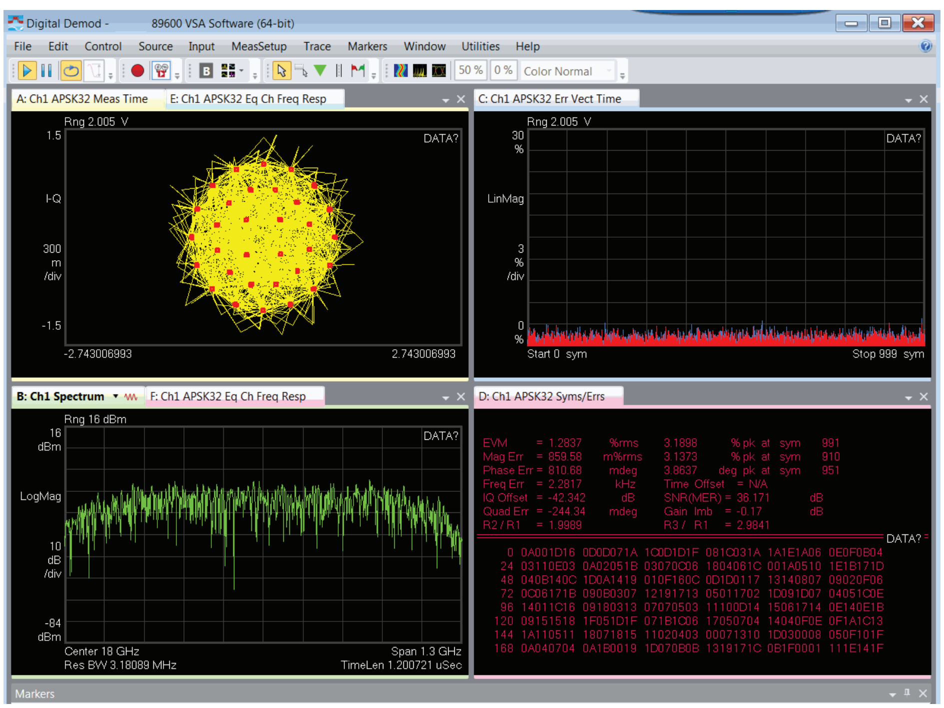

Figure 7. Digital demodulation in the 89600 VSA software enables detailed analysis of the corrected signal.

Customizing APSK signals

Custom waveforms may be of interest in satellite applications. SystemVue and the digital modem library can be used to create, for example, a custom 32 APSK signal by defining the number of constellation states for each ring as well as the ring magnitude (or spacing) and ring phase. Entering the same configuration into the 89600 VSA software will enable demodulation and analysis of the custom signal.

As an example, varying the ring ratio spacing may be used to counteract gain compression in a power amplifier (PA)—and this can be simulated in SystemVue. The series of traces shown in Figure 8 illustrate what can be done. The trace on the left shows the original signal and its constellation (upper left), error vector time (upper right), spectrum (lower left) and symbols-and-errors table (lower right; includes EVM). On the right, the upper trace reveals distortion of the constellation reveals the effects of gain compression; the associated EVM value is 10.56 percent. Adjusting the ratio of the outer ring from 4 to 5 produced the lower trace: the constellation shows the wider spacing of the outer ring and this contributes to an improved EVM of 6.99 percent.

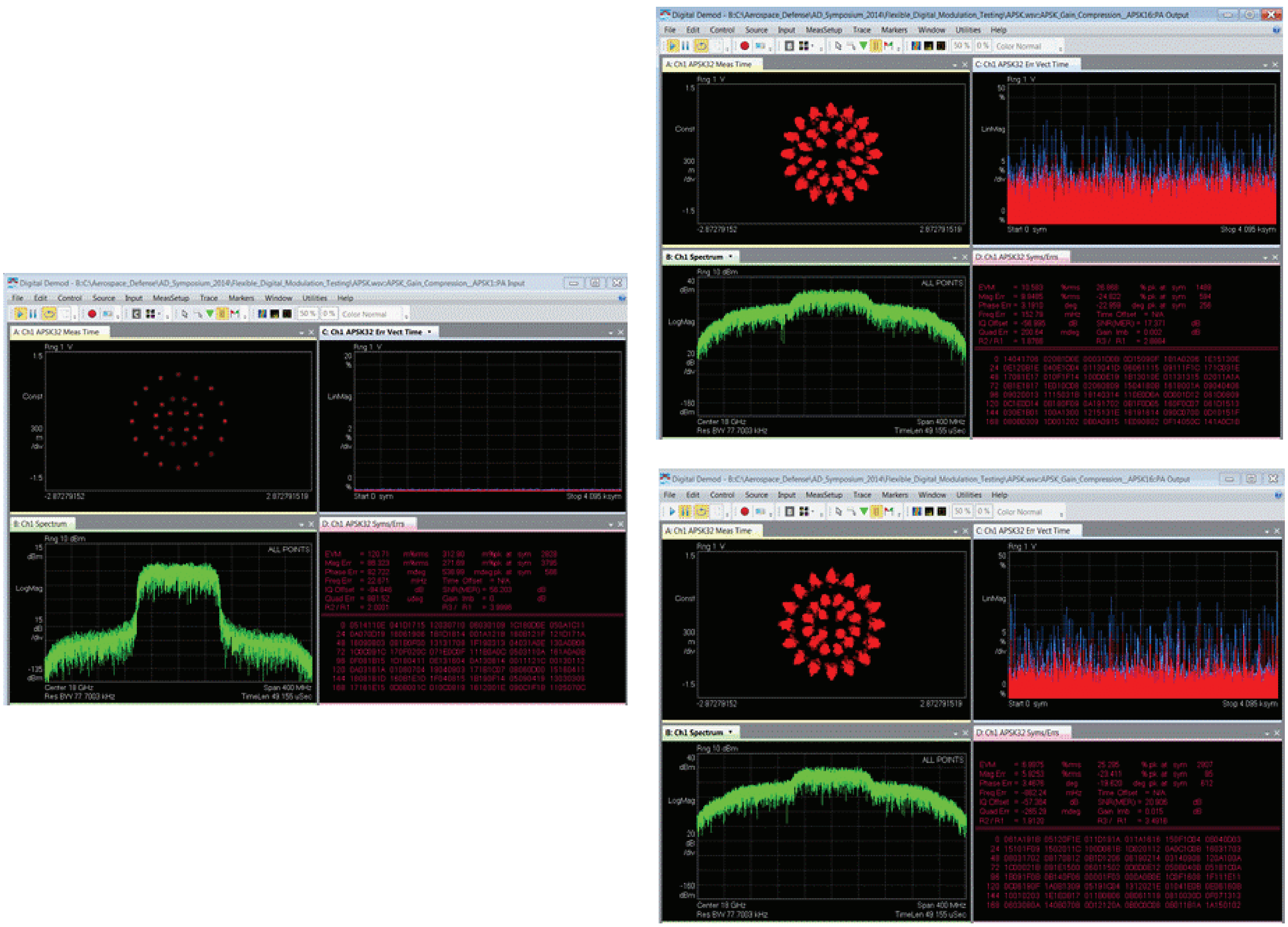

Figure 8. The input to the PA is on the left and the original output (upper right) shows signs of gain compression. Adjusting the ring ratio resolves some of the effects and improves EVM to 6.99% (lower right) from 10.56%

Conclusion

Even though BER provides an end-to-end performance metric, it is necessary to first optimize the modulated waveforms in either analog or digital form. When using comparative signal analysis to assess those modulated signals, EVM is more than the key metric: it provides continuity in the comparative evaluation of analog and digital signals throughout the block diagram and across the design process. This is accomplished using the 89600 VSA software, which enhances essential tasks such as the search for impairments, the debugging of performance problems and system-level performance budgeting. The ability to run the VSA software inside a variety of Keysight instruments—oscilloscopes, signal analyzers and logic analyzers—further extends the continuity of measurement.

In the creation of wideband signals, either during design or for testing, SystemVue ESL software and its digital modem library provides a powerful set of tools. The ability to download I/Q signals into an AWG and use them to drive the external modulation inputs of a vector signal analyzer enables useful testing of individual blocks within the satellite payload. Performance improvements can be tried and adjusted by modifying these signals with adaptive EQ in the 89600 VSA software.

To explore the possibilities, please visit the Keysight website and download free trials of SystemVue and the 89600 VSA software.

Related Information

- *Data Sheet: W1902 SystemVue Digital Modem Library*, publication 5991-3123EN
- *Brochure: 89600 VSA Software: See through the complexity*, publication 5990-6553EN
- *Data Sheet: M8190A Arbitrary Waveform Generator*, publication 5990-7516EN
- *Flyer: Keysight PSG, MXG and EXG Microwave Signal Generators*, publication 5991-3594EN
- *Data Sheet: Keysight Infiniium 90000 Q-Series Oscilloscopes*, publication 5990-9712EN
- *Data Sheet: Keysight M9502A and M9505A 2- and 5-Slot AXIe Chassis*, publication 5990-6584EN
- *Data Sheet: Keysight 16850 Series Portable Logic Analyzers*, publication 5991-2791EN

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