APPLICATION NOTE

8 Virtual Signal Generators on the M9484C

Emulate 8 Signals Simultaneously in Real-Time with One RF Output

KEYSIGHT

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Introduction

The M9484C VXG is Keysight's flagship signal generator, offering an impressive frequency range from 9 kHz to 54 GHz, wide bandwidths, and support for multichannel applications. The M9484C VXG sets industry benchmarks in capability, scalability, and performance.

This application note aims to highlight the M9484C's unique ability to emulate 8 simultaneous signals in real-time from a single source. It explores the operational principles and practical applications of this innovative functionality.

This advanced capability can dramatically improve ease-of-use when testing scenarios involving MIMO, interference analysis, carrier aggregation, and Electromagnetic Spectrum Operations (EMSO). It is a relevant capability across sectors ranging from cellular networks to aerospace defense and general communications.

Depending on the chosen configuration, the M9484C can emulate 32 signals, with each RF output supporting 8 virtual signals. The number of emulated signals can be further increased by synchronizing multiple M9484C instruments. This, as well as other configurations and options, is explored in a later section.

Advanced Technology

Before examining the capabilities of the M9484C VXG's 8 virtual signal generators, it is important to first understand the technological advances that enable these capabilities.

Keysight Direct Digital Synthesis

The M9484C VXG is Keysight's only signal generator capable of emulating 8 virtual signal generators in real-time with minimal distortion. This capability is primarily enabled by the advanced architecture and performance of Keysight's Direct Digital Synthesis (DDS) generators.

Traditional baseband generators, as shown in Figure 1, employ analog I/Q modulators for upconversion, whereas Keysight DDS generators, shown in Figure 2, utilize an entirely digital upconversion process, eliminating the need for an I/Q modulator. This architecture results in cleaner performance, without the distortion that results from I/Q modulator images, Local Oscillator (LO) feedthrough, and I/Q modulator instability. This distortion can be a limiting factor when generating multiple signals from a signal generator with a traditional baseband architecture, and eliminating it is a key step in enabling this capability on the M9484C VXG.

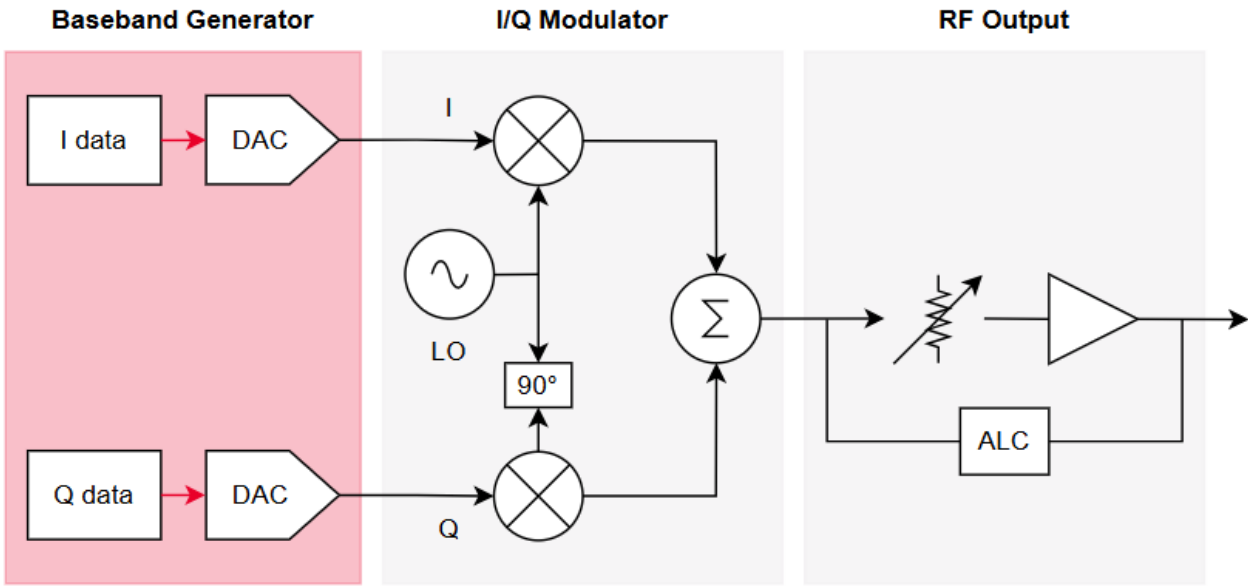


Figure 1. Block diagram of a traditional generator with an I/Q modulator. The red lines indicate a digital signal, and the black lines indicate an analog signal

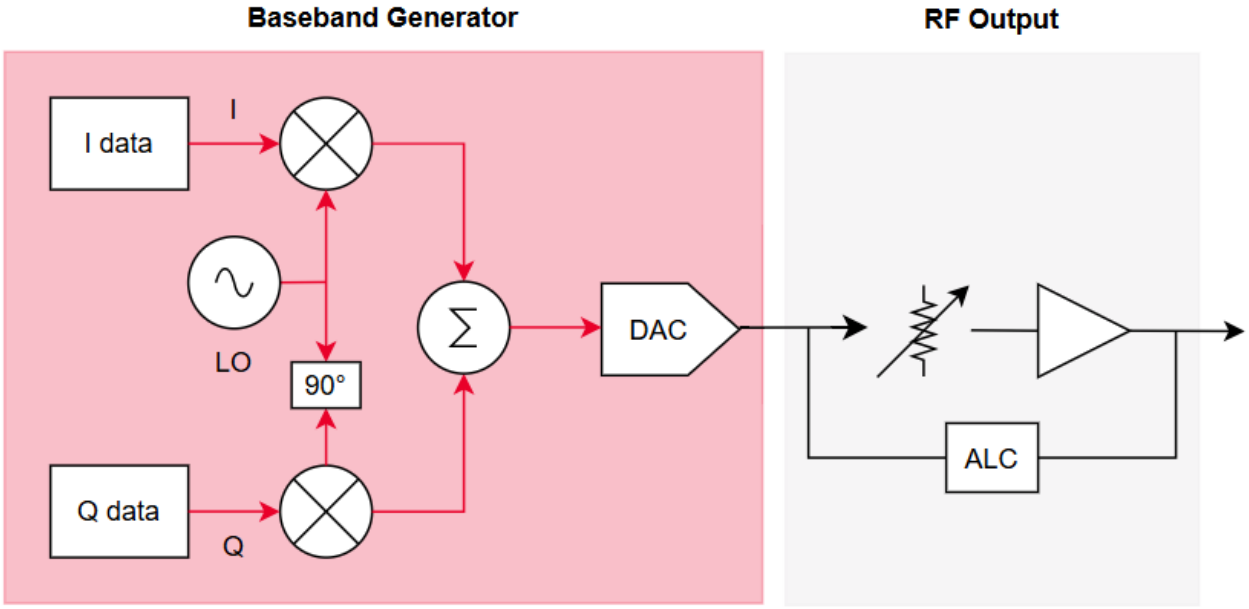


Figure 2. Block diagram of a DDS generator with digital upconversion. The red lines indicate a digital signal, and the black lines indicate an analog signal

Before reaching the DAC and upconversion stages, the data stream undergoes extensive digital signal processing within the instrument's ASIC. The ASIC architecture is complex; therefore, Figure 3 presents the simplified ASIC architecture of a single RF channel with 8 virtual signal generators.

First, the desired waveform is selected from the FPGA memory and constructed by a data generation source. In Figure 3 this is shown as an Arbitrary Waveform Generator (AWG) or as Additive White Gaussian Noise (AWGN). After data generation, the signal is digitally processed using fading, resampling, a Numerically Controlled Oscillator (NCO) for digital frequency translation and independent phase control, and amplitude scaling.

After these several stages of DSP, each virtual signal — along with a separate signal from the Adjustment AWGN — passes to a summation block, where the signals are independently released based on triggering conditions. The flatness correction filter utilizes predistortion to correct for IF and RF effects, and the resulting data is sent to the DAC for further processing.

The waveform memory of up to 4 GSa is shared between the generation sources. Each RF channel has its own independent memory, separate from other channels. This memory architecture allows a single data generation source to be replaced with a real-time signal from applications preloaded on the FPGA.

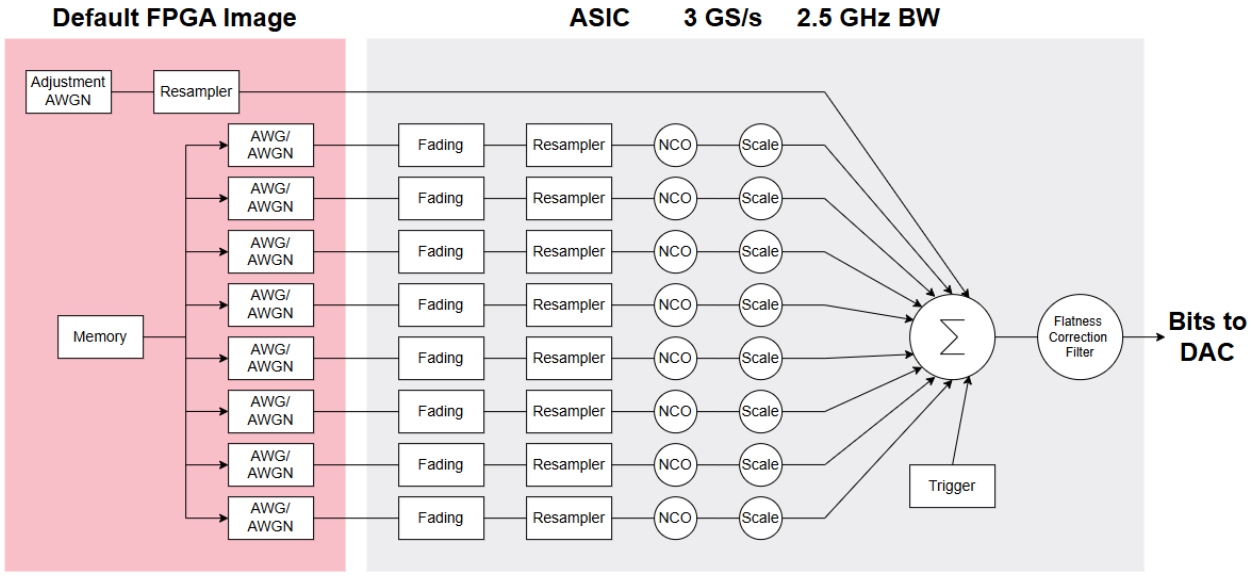


Figure 3. Block diagram of a single RF channel with 8 virtual signal generators

Theory of Operation

The following sections will present a demonstration of 8 virtual signals, provide descriptions of the per-signal features, discuss relevant operating parameters, and highlight additional notable features.

Demonstration of 8 Signals at Once

The following figures briefly demonstrate how to generate 8 virtual signals and display them on a Keysight Signal Analyzer. This demonstration incorporates a diverse selection of signal types, including LTE, WCDMA, AWGN, WLAN, GSM, and multiple 5GNR modulations. It serves as an example, as numerous other modulation formats can also be used.

Figure 4 below is the M9484C user interface home page and details specific signal settings. Figure 5 is also the M9484C user interface, but this screen provides a Signal Summary of the 8 virtual signals generated for this demonstration. The M9484C is connected to a Keysight Signal Analyzer, with the 8 signals clearly displayed and labeled in Figure 6.

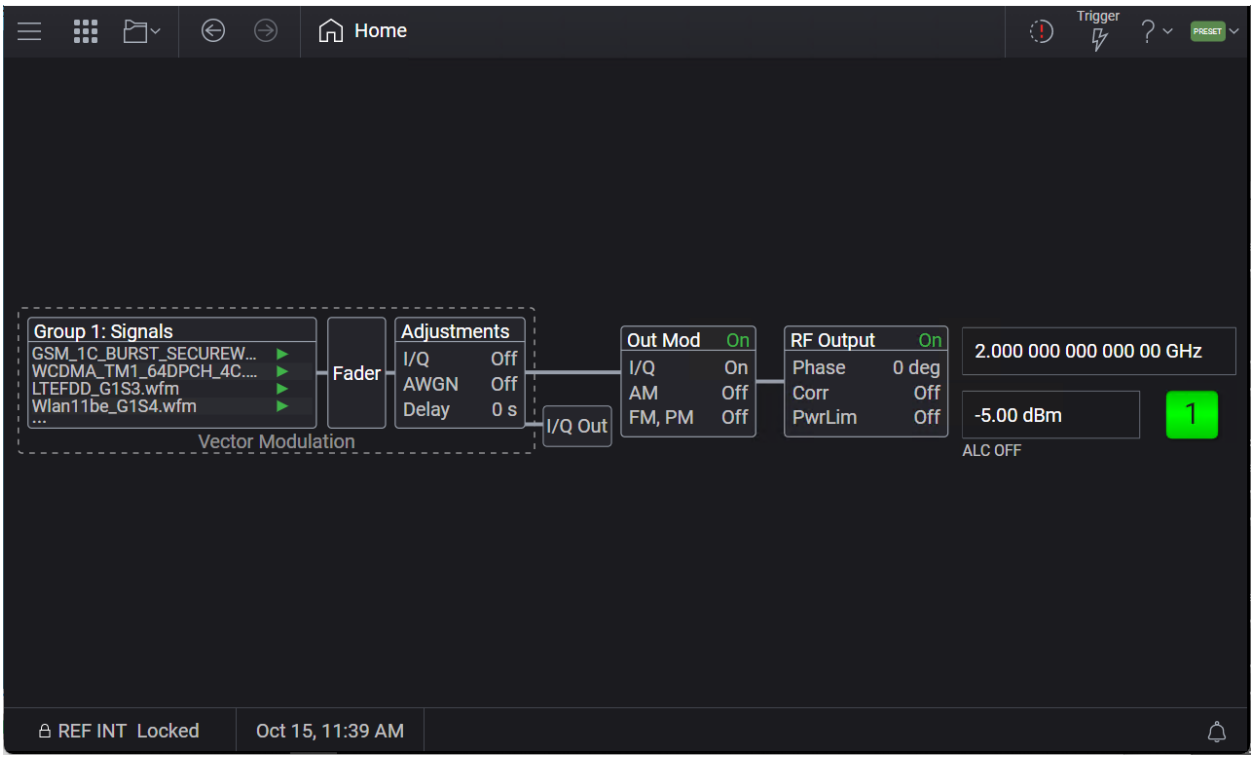


Figure 4. M9484C home page displaying center frequency, power level, and additional configuration settings

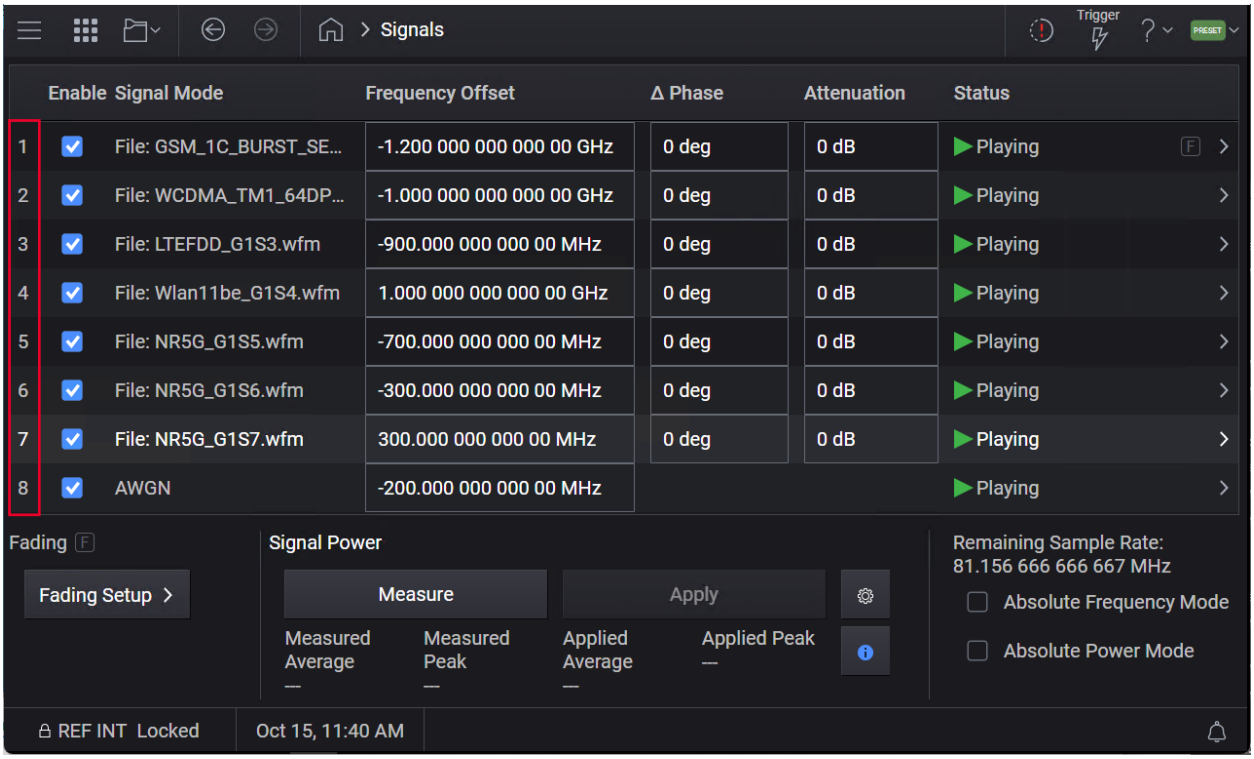


Figure 5. M9484C signal summary page for 8 virtual signals

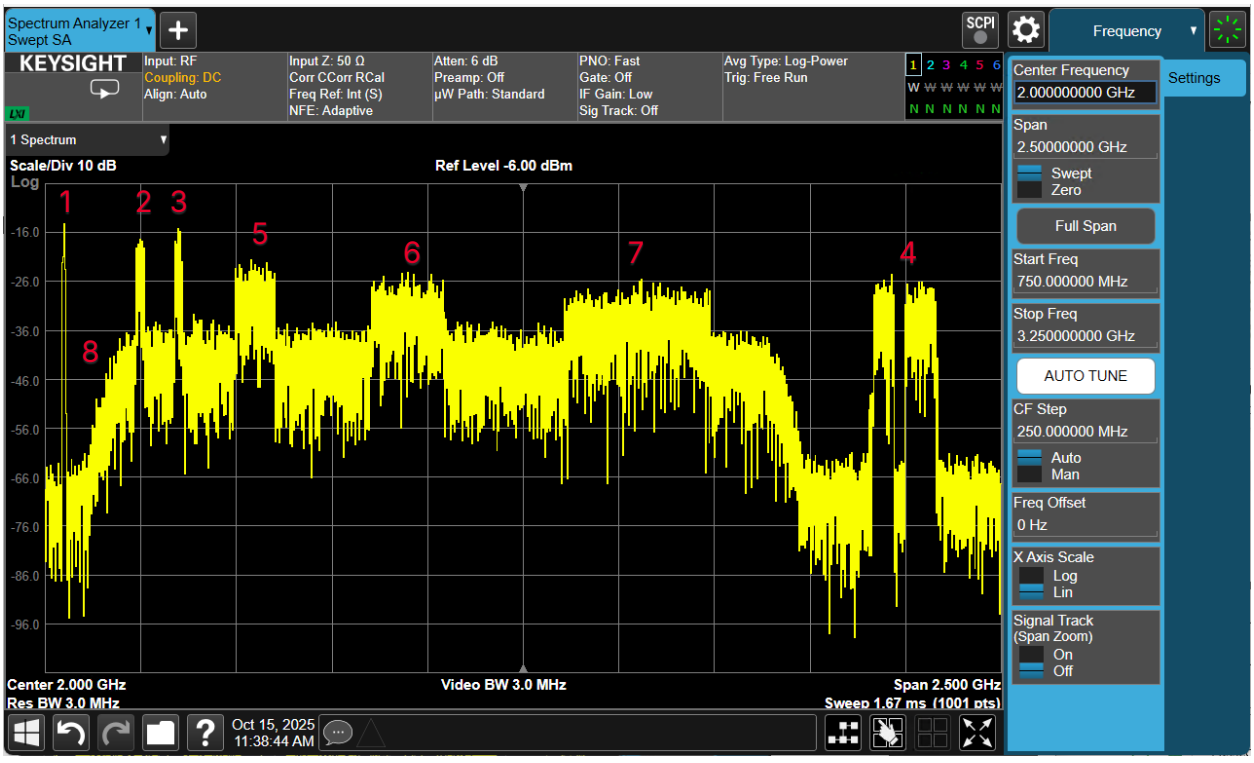


Figure 6. Keysight Signal Analyzer showing 8 virtual signals

Per-Signal Features

The features outlined below enable the signals to function independently. However, it is important to note that not all features are non-disruptive. In cases where a feature is disruptive, the signals will require retriggering.

A summary table at the end of this section lists per-signal features, their absolute or relative presentation, and their disruptive or non-disruptive behavior.

State

This feature allows the engineer to simply turn off or on the specified signal. This is a disruptive feature, and all remaining signals must be retriggered to update correctly.

Frequency

Frequency can be presented in two ways: absolute or relative. Both presentations are non-disruptive, so changing one frequency does not require the engineer to retrigger the remaining signals.

To specify an exact frequency, the engineer should use the absolute frequency presentation. This is shown in Figure 7 below.

If an engineer prefers to set a signal's frequency based on the RF channel's center frequency – commonly called the frequency offset – then the recommended presentation is relative frequency, as shown in Figure 5 above and Figure 8 below.

It is important to note that signals can overlap, and any signal extending beyond the edge of the Baseband Flat Bandwidth will roll off.

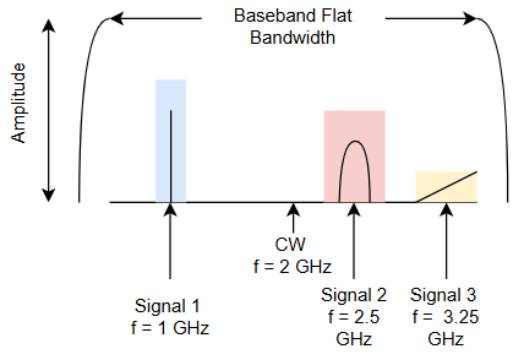


Figure 7. Absolute frequency presentation

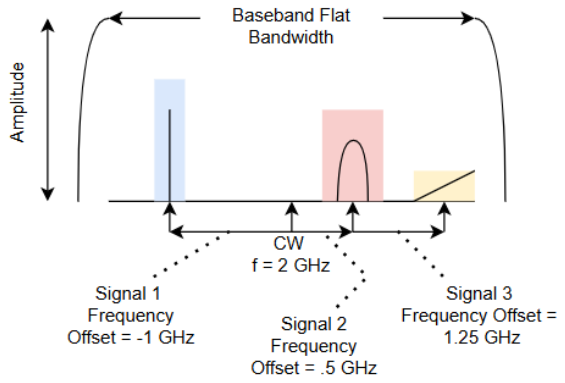


Figure 8. Relative frequency presentation

Power

As with frequency, power can be presented in two formats: absolute and relative. Both presentations are non-disruptive.

Absolute power is the specific power value set by the engineer and is displayed in dBm. The total power represents a summation of all the signals. For example, assuming 100% scaling, the total power of the signals in Figure 9 would be calculated as shown in Equation 1.

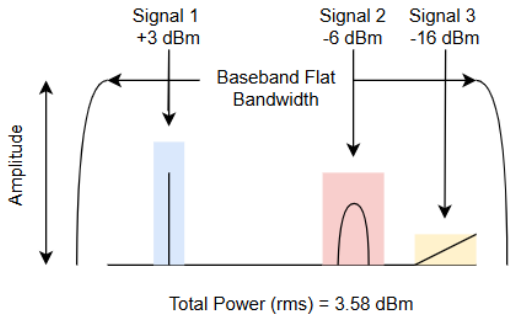


Figure 9. Absolute power presentation

$$Convert\ from\ dBm\ to\ mW$$

$$3\ dBm \cong\ 2\ mW$$

$$-6\ dBm \cong\ .25\ mW$$

$$-16\ dBm \cong\ .03\ mW$$

$$P_{total} \cong 2 + .25 + .03 = 2.28\ mW$$

$$Convert\ from\ mW\ to\ dBm$$

$$P_{total,dBm} \cong 3.58\ dBm$$

Equation 1. Calculation of total power for Figure 9

Relative power has additional complexities. The relative or per-signal power, represented in dB, reflects the power relationship between signals. The total power is again calculated in dBm, but it is independent of the relative power of each signal.

As illustrated in Figures 10 and 11, changing the total power value does not affect the relative power values since total power functions as an independent variable. While the absolute power values would change, as above, the relative power values remain constant.

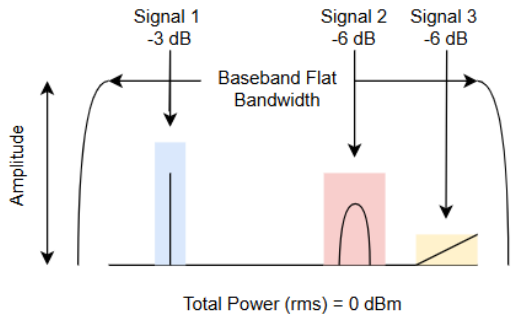


Figure 10. Relative power presentation with a total power of 0 dBm

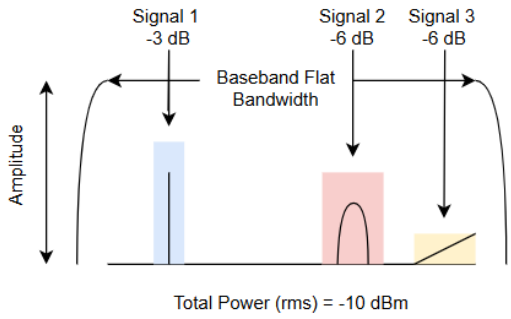


Figure 11. Relative power presentation with a total power of -10 dBm

Signal mute and attenuation

Muting or attenuating a signal modifies the power level of that signal without altering the system's total power setup and is therefore non-disruptive. Essentially, muting a signal is functionally equivalent to attenuating the signal to zero, as shown in Figures 12 and 13 below.

It is important to note that muting or attenuation does not optimize the dynamic range. Instead, the engineer can assess the impact of muting or attenuation on the reduced dynamic range.

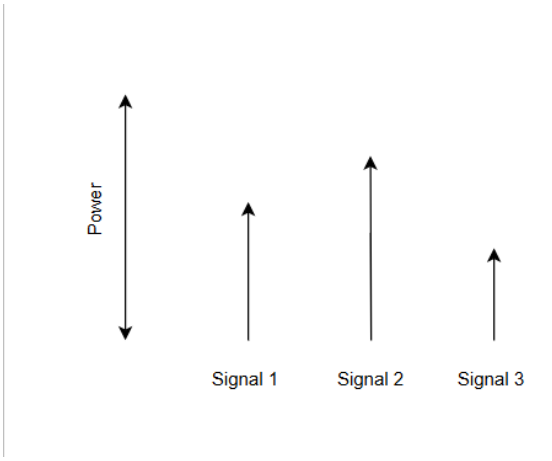


Figure 12. Signal power diagram without muting or attenuation

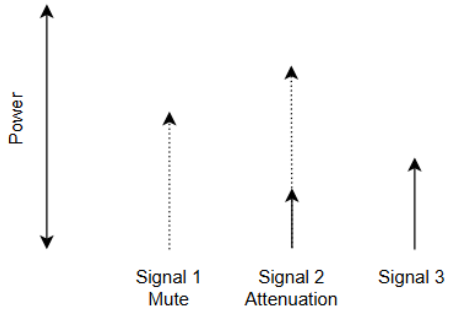


Figure 13. Signal power diagram with Signal 1 muted, Signal 2 attenuated, and no change to Signal 3

Phase

The phase of each signal can be controlled independently and when changed, it is non-disruptive.

Trigger delay

By default, each instrument is configured with three external trigger connectors. With Option AN1, fifteen additional general purpose inputs/outputs are available on channel 1 and can be configured for use as triggers or markers. Changing the trigger source or trigger type will impact all the signals and is disruptive.

However, each virtual signal can also have a per-signal trigger delay. This is not an external trigger, but rather a value between 0 and 41 seconds with a resolution of 333.333 picoseconds. Per-signal trigger delays are defined relative to one another across signals and can rely on different trigger events. The signals can also be set up to be asynchronous with respect to each other.

Adjusting the per-signal trigger delay does not affect other signals, therefore this feature is non-disruptive.

Signal modulation capabilities

The M9484C VXG utilizes Keysight's PathWave Signal Generation Software to create virtual signals. Depending on the instrument's software licenses, the engineer can select from a wide range of modulation types – from analog to real-time – suitable for applications in cellular, digital, and defense industries. For more information, refer to the Resource section at the end of this application note.

Additionally, the M9484C supports waveform files created by third-party software, including MATLAB and ASCII formats.

Modifying the modulation of a signal is disruptive, so all the signals will need to be retriggered.

Summary Table of Per-Signal Features

Feature	Absolute/Relative/Both Presentation	Disruptive/Non-Disruptive
State	Absolute	Disruptive
Frequency	Both	Non-Disruptive
Power	Both	Non-Disruptive
Signal mute and attenuation	Absolute	Non-Disruptive
Phase	Relative	Non-Disruptive
Change to trigger source or trigger type	Absolute	Disruptive
Trigger delay	Relative	Disruptive
Signal modulation capabilities (examples: waveform, sample rate)	Absolute	Disruptive

Operating Parameters

Consider the following operating parameters carefully before testing with 8 virtual signal generators.

Shared sample rate

The total shared, or summed, sample rate of the 8 virtual signal generators is limited to 3 GSa/s, which can be split among them in any way if the sum does not exceed this limit. For example, if the full sample rate is allocated to the first five signals, no additional signals can be generated.

Changing the sample rate is disruptive to the system and requires all the signals to be retriggered.

RF output power

Each signal has a crest factor for its waveform, which is a back-off from a normalized amplitude of 1. The signals are summed with the proper power ratio between them, and then all signals must be scaled to get the worst-case peak to be a normalized value of 1. Thus, dynamic range of the DAC is shared between all signals. The peak value maps to Peak Envelope Power (PEP).

The RF output power (RMS) maps to the combined RMS of all signals, with the assumptions that the waveforms are noise-like and non-correlated, and that they all play at the same time. When only one signal is playing, the output will be the power level of that signal.

Baseband flat bandwidth

The maximum Baseband Flat Bandwidth is determined by the unit's configuration, with Option R25 offering the greatest RF bandwidth of 2.5 GHz. For more information on configurations and options, view the Resource section at the end of this application note.

All center frequencies must be positioned within the Baseband Flat Bandwidth. Signals centered near the bandwidth edge will experience roll-off effects if their offset bandwidth exceeds the Baseband Flat Bandwidth.

Waveforms

It is important to note that the 8 virtual signals must be waveforms designed and loaded onto the instrument by the engineer. This can be done using Keysight software directly on the instrument or by uploading external files.

Notable Features

The Keysight M9484C VXG is distinguished by its exceptional performance, accuracy, and ease of use. The following sections outline several notable features pertaining specifically to the generation of 8 virtual signals.

Improved dynamic range

As noted earlier in this application note, the Keysight DDS generators enable the M9484C to achieve a dynamic range improvement of 20-40 dB over traditional generators. This enhanced performance positions the Keysight M9484C as an exceptionally reliable solution within the industry.

Figures 14 and 15 provide a performance comparison between analog I/Q upconversion and digital upconversion architectures. Figure 14 illustrates how traditional analog I/Q upconversion produces image rejection, LO feedthrough, and instability over time and temperature. In contrast, the digital upconversion used by Keysight DDS generators avoids distortion and maintains stability under the same conditions, as shown in Figure 15.

The digital dynamic range is shared between the 8 virtual signal generators, which must be considered when testing simultaneous signals.

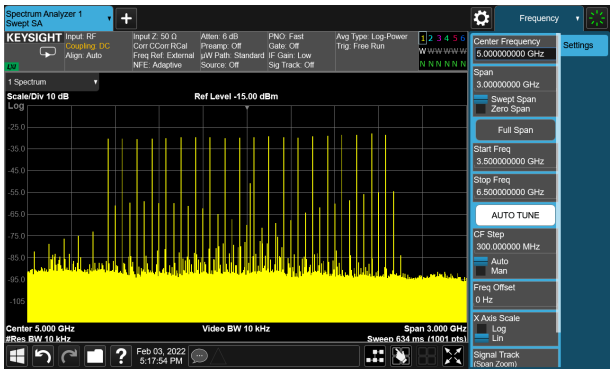


Figure 14. Effects of analog I/Q up-conversion found in traditional generators

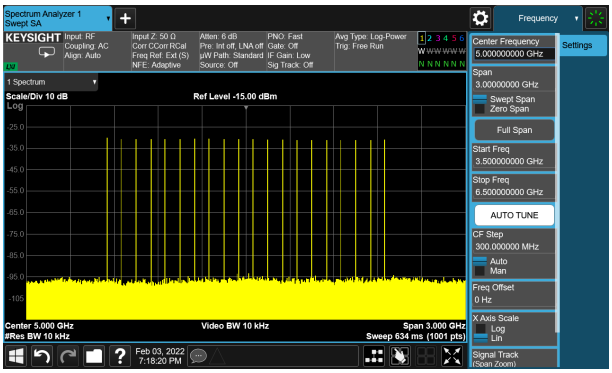


Figure 15. Performance of digital up-conversion found in Keysight DDS generators

The DDS generator not only eliminates the need for an I/Q modulator and thus provides significantly improved dynamic range, but it also enables the M9484C to achieve industry-leading phase noise performance. It delivers substantial phase noise improvements at wide offsets while supporting extremely fine frequency tuning resolution. In addition, it allows engineers to control the phase relationship between channels.

Global trigger

The global trigger works with the 8 virtual signal generators in two modes: cross RF channel and cross instrument.

Cross RF channel mode, included in option PCH, allows for one repeatable trigger across multiple channels. The global trigger can be distributed to up to four RF channels, depending on the instrument's configuration. It maintains a global trigger jitter of ±10 nanoseconds relative to the asynchronous external system trigger event. After synchronization alignment, the global trigger also maintains channel-to-channel relative trigger repeatability, with all channels starting on the same clock edge.

The cross-instrument capabilities are included in option SNC. This supports a repeatable global trigger across multiple chassis, aligned with a 100 MHz clock, and performing within the same specifications as the cross RF channel mode.

Additional virtual signals

Each RF channel can generate up to 8 virtual signals. Each M9484C is configured with 1 to 4 RF channels, therefore the system can emulate 8 to 32 virtual signals. Using multiple M9484C instruments increases the maximum number of virtual signals per test setup.

Customer Insights & Applications

The 8 virtual signal generators of the M9484C are especially useful in reducing test complexity and achieving accurate results. This capability is vital across numerous industries and test applications, extending beyond those highlighted below. The following sections simply illustrate situations where this capability proves particularly valuable.

MIMO and Beamforming Testing

Each virtual signal can emulate an individual transmit antenna or beam by applying independent phase, amplitude, timing, and frequency offsets. This capability is especially valuable when simulating multi-antenna systems such as MIMO or beamforming setups.

For example, when testing various MIMO configurations, the 8 virtual signals can each represent a separate transmit antenna. These virtual signals are then digitally combined and output through a single RF channel of the M9484C. The resulting composite waveform represents the signal that would be captured by a receive antenna. This output can then be applied to the Device Under Test (DUT) for demodulation and performance evaluation.

The engineer will need one physical RF channel per receive path of their design. In the case of 2x2 MIMO, the engineer would need two physical RF channels.

Interference and Coexistence Testing

The 8 virtual signal generators are especially useful for interference and coexistence testing. Among other scenarios, the signals can be designed to emulate overlapping signals, adjacent channels, or Wi-Fi/*Bluetooth*® co-channel interference.

For example, the engineer can generate the desired signal and up to 7 interfering signals. Then the engineer can measure how the DUT maintains performance under desensitization by increasing the power of the interfering signals or how well the DUT operates in the presence of interference.

Carrier Aggregation Testing

Another powerful application of the 8 virtual signal generators is carrier aggregation and multi-carrier testing. Carrier aggregation combines multiple component carriers to expand total transmission bandwidth and increase data throughput. Each virtual signal can represent a specific component carrier, with a different frequency, signal bandwidth, power level, waveform, and phase offset.

For example, carrier aggregation is commonly used in communications systems like 5G NR. The 8 virtual signals can be used to generate multiple component carriers and evaluate the receiver's ability to demodulate and combine them. This allows the engineer to simulate realistic conditions and verify the performance of their DUT.

Spectrum Monitoring & Electronic Warfare Testing

Most spectrum monitoring and Electronic Warfare (EW) systems are designed to detect and identify potential RF threats. A live RF environment includes countless emitters transmitting signals of all frequencies, power levels, and modulations, often overlapping in time and frequency. The 8 virtual signal generators of the M9484C help the engineer simulate a live RF environment. With a four channel M9484C, the engineer can simulate up to 32 threat emitters.

For example, an engineer may be evaluating a spectrum monitoring system designed to detect radar threats. The engineer can simulate these threats with virtual signal generators, using triggering and offsets to create a dynamic RF environment simulation, and test the DUT's ability to detect each simulated radar, identify the modulation, and report any threats.

Conclusion

The M9484C VXG, Keysight's flagship signal generator, sets a benchmark in the industry through its extensive frequency range, wide bandwidths, support for multichannel applications, and 8 virtual signal generators. The M9484C can emulate 8 signals simultaneously in real-time per RF channel using a single source.

This functionality is especially beneficial for testing scenarios involving MIMO, interference analysis, carrier aggregation, and EW. Evaluating these scenarios is essential in sectors ranging from cellular networks to aerospace defense and general communications.

The Keysight M9484C VXG's versatility and performance make it an indispensable instrument for achieving greater efficiency, accuracy, and confidence in even the most demanding RF test applications.

Resources for Additional Information

For more information on technology, specifications, or configurations explained above, check out the following links:

For more on PathWave Signal Generation, check out the PathWave Signal Generation Brochure or the PathWave Signal Generation Keysight webpage

For datasheet specifications, check out the M9484C VXG and V3080A Data Sheet

For configurations, check out the M9484C VXG Configuration Guide

For a detailed example of how to set up 8 virtual signal generators, check out the VXG Signal Generator and X-Series Signal Analyzers Measurement Guide

For an overview of the M9484C VXG signal generator, check out the M9484C VXG Vector Signal Generator eBook

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