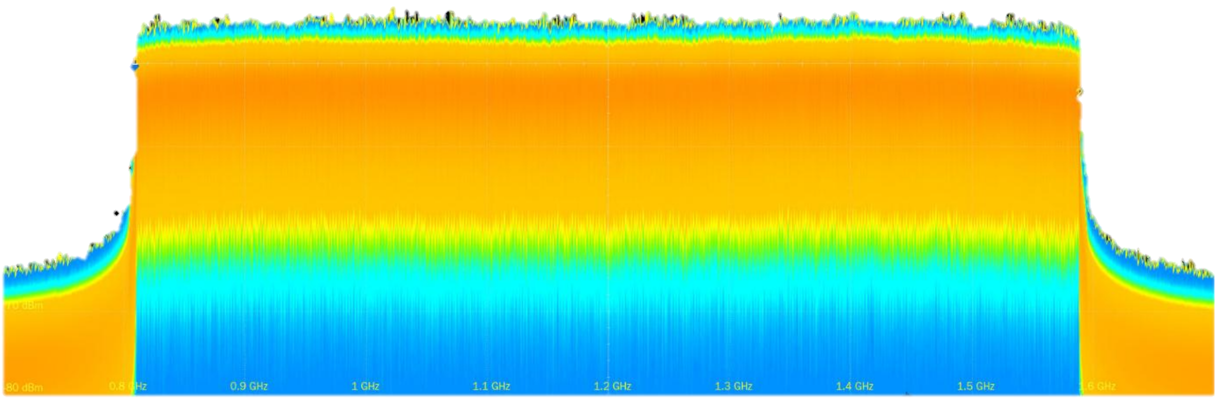
RF Signal Generation

Capabilities, Notes, and Use Cases

Application Validation & Instrument Selection



RF Signal Generation Capabilities Contents:

Overview

RF signal generation capabilities include 3 classes of instrumentation with different application specialties. Primarily, these include analog RF generators, Vector RF generators, and arbitrary generators.

Analog generators create clean signals with basic modulation options. Typically, AM, FM, and ΦM (phase modulation) are available as well as pulse modulation. The key differentiation of analog RF signal generators is the phase noise. Phase noise is the relative amount of RF power in frequency space near to the carrier. Typically, this is referred to as noise in a 1 Hz bandwidth at a 10 kHz offset from the carrier. The units are dBc/Hz at a given carrier frequency. Analog generators core applications include clean carrier signals for LO or other frequency standards and can be used as interference sources with some modulation.

Vector generators add the capability to create complicated waveforms in quadrature, meaning two carriers 90° out of phase at the same frequency. Both of these carriers can be modulated separately creating IQ modulated waveforms and a broad set of modulation formats. These can be characterized by their RF bandwidth, or across how wide of a frequency span they can accurately generate RF at one time. Vector generators can be used to transmit data or as interference or noise sources. They may have a baseband generator built in which sets limits for the clock speed of data transmissions and the length of data segments. Application areas include data transmission, emulation, and interference for design and debug of transmitter/receiver systems.

Arbitrary generators serve a slightly different function in the context of RF signal generators. These are typically lower frequency devices that can generate complex waveforms. The generators we are discussing here can create low frequency IQ signals or be used as IF or baseband generators that can be fed into vector generators with external inputs. Depending on the application, this use of baseband generation can extend capabilities of the RF generator. Key specifications typically include arbitrary memory depth, output sample rate, and software or utilities for supporting wave generation.

This note will summarize Siglent's portfolio in terms of key specifications, use cases, and limitations in these RF signal generation applications.

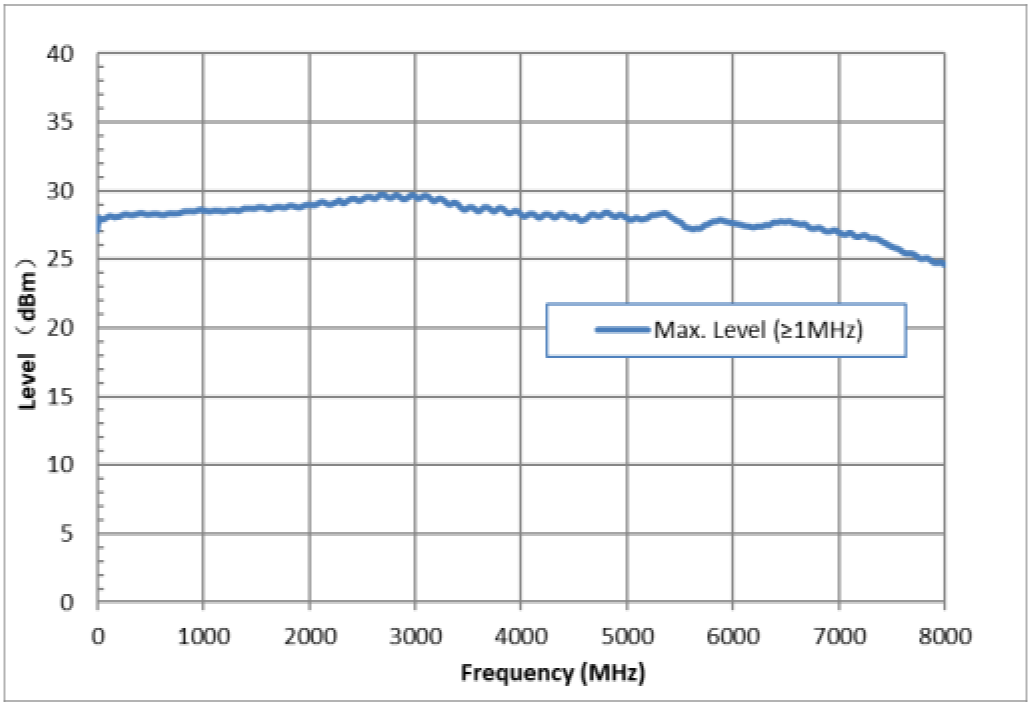
Power Output

Power output is an important metric for RF generation. Both analog and vector generators are typically specified for their peak power output in CW mode. Here are the max output powers by model or series:

Max Power output in performance range (dBm) in CW mode

Frequency	SSG3000X	SSG5000X	SSG5000A	SSG6083/5A	SSG6087A	SSG6082A-V
9 kHz-100 kHz	7	4	3			8
100 -300 kHz	10	13	15	13	8	8
300 kHz-1 MHz	10	13	15	13	8	20
1 - 3 MHz	13	20	23	13	8	24
3 MHz - 1 GHz	13	20	23	22	16	24
1 - 2 GHz	13	20	23	20	16	24
2 - 3.2 GHz	13	20	23	18	16	24
3.2 - 4 GHz		20	23	18	16	24
4 - 6 GHz		20	21	15	12	20
6 - 8 GHz			20	17	12	20
8 - 15 GHz			20	17	12	
15-18 GHz			15	17	12	
18 - 20 GHz			15	14	12	
20 - 40 GHz					12	

These values are for the performance or specified range. By virtue of their design, these generators have additional capabilities for higher power output at the top of the dac setting. These can not be specified and can be non linear, but as an example, here is the CW Signal Maximum Output Power vs Frequency ($f \geq 1$ MHz) for the SSG6082A-V:



Even though the specified range for the SSG6082A-V maxes out at 24 dBm, it is possible to get up to 30 dBm at certain frequencies by utilizing the space beyond the specified range.

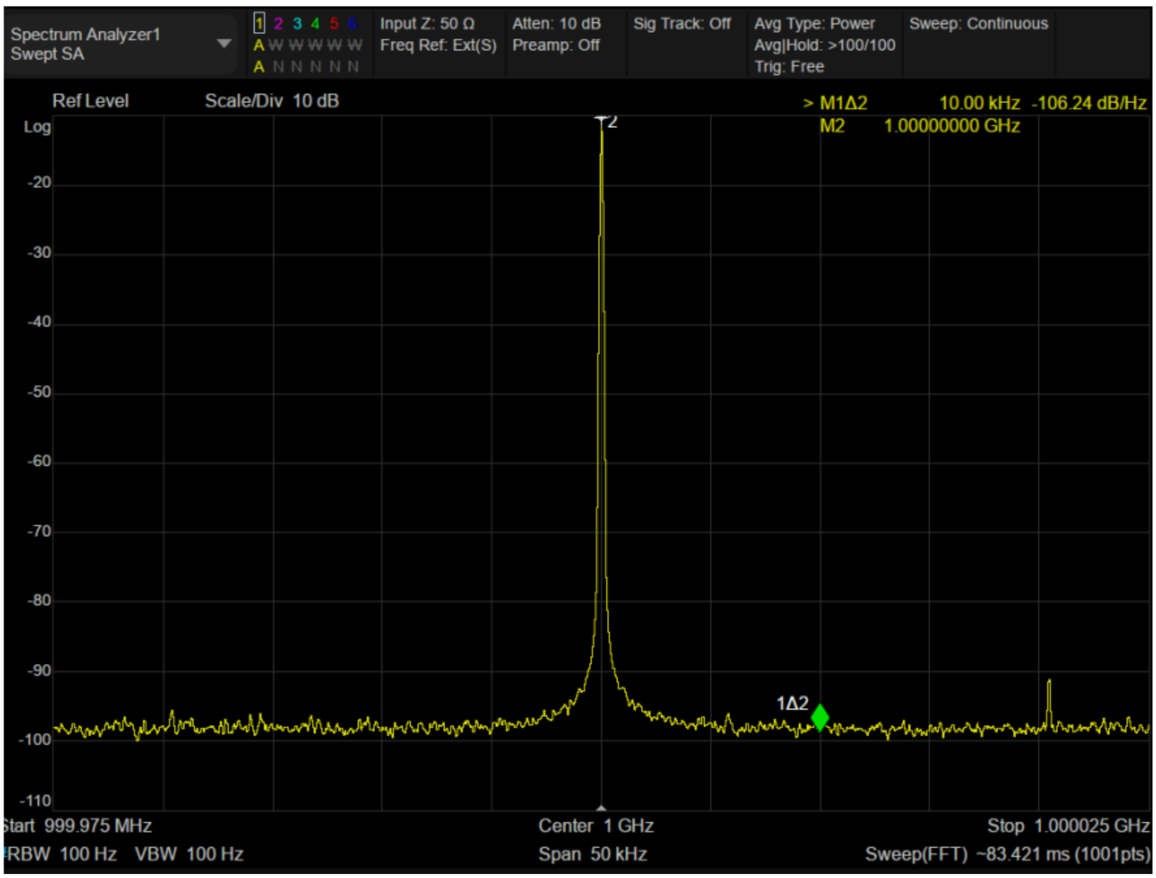
The minimum output levels are also important in many applications. Above 100 MHz, the output minimums are:

Model/Series	Minimum power setting (dBm)
SSG3000X	-110
SSG5000X	-140
SSG5000A-LP	-130
SSG6000X	-130
SSG6082A-V	-140

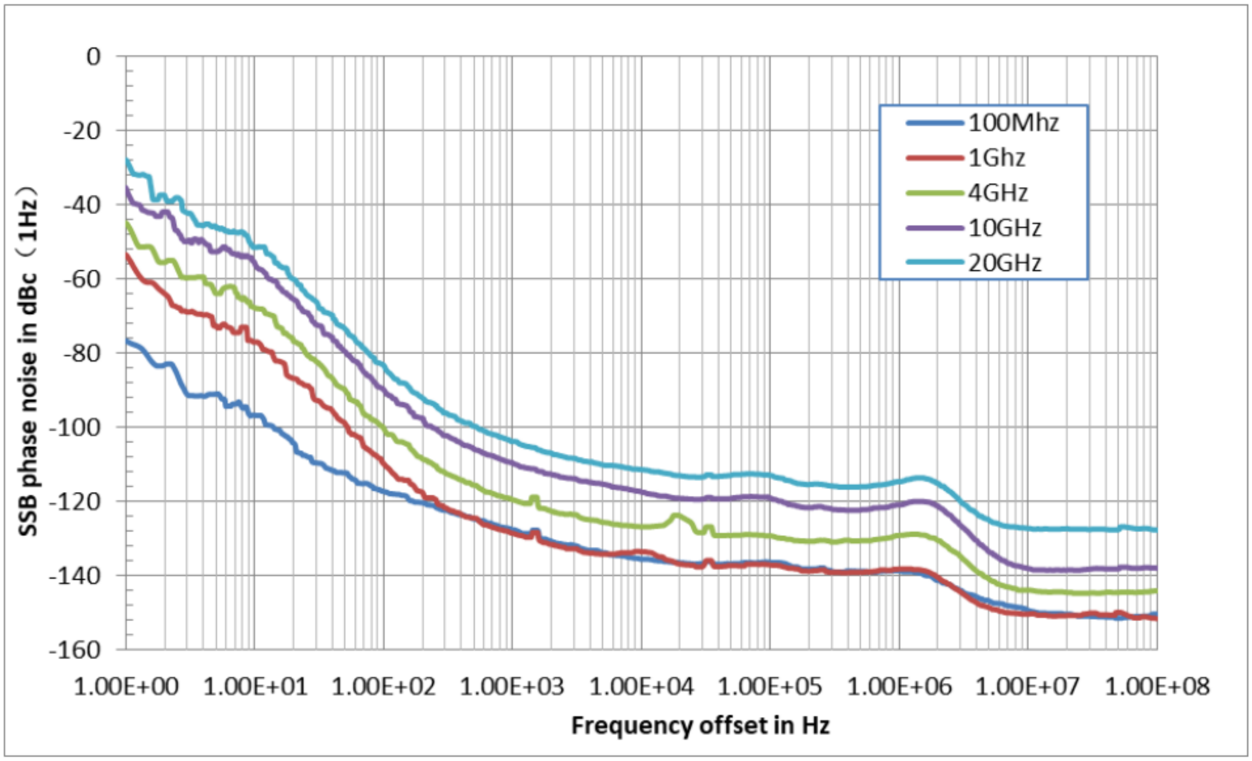
For specific information on the SSG5000A models and the impact of the LP hardware option, please review the section titled: “SSG5000A series power profiles explained”.

Phase Noise

Phase Noise is one of the primary specifications for a RF signal source. This is primarily a function frequency accuracy. For any RF signal, the phase noise is the amount of power that appears at nearby frequencies for a given setting of offset frequency and resolution bandwidth setting. For instance, a 1 GHz CW carrier measured with a 1 Hz measurement bandwidth might look like this on a spectrum analyzer:

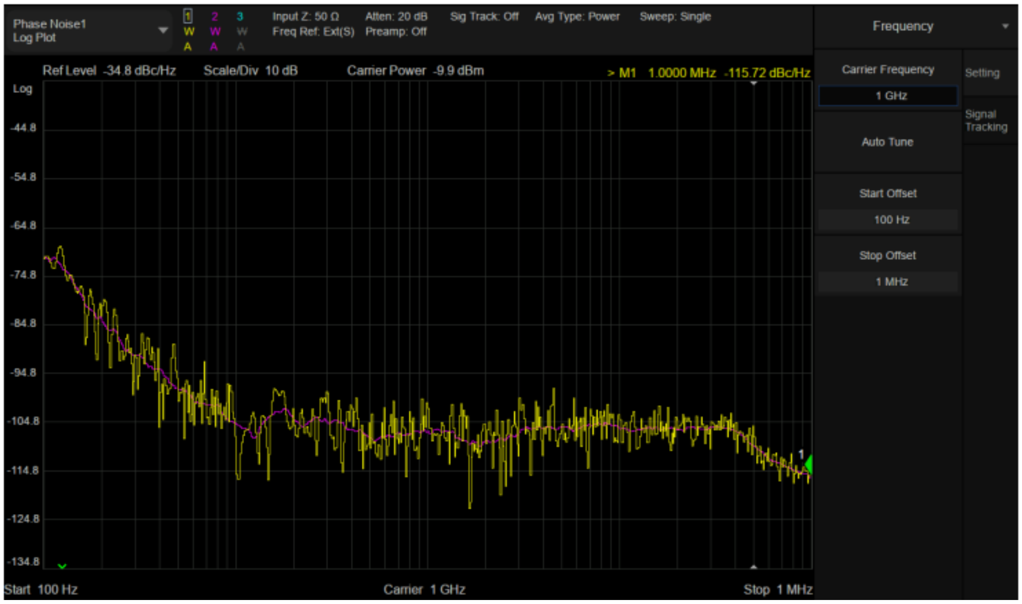


The SSB phase noise of this signal is the noise level measured down from the peak in dBc/Hz at a frequency typically 10 or 20 kHz from the carrier frequency. A spectrum or phase noise analyzer can measure sequences of these phase noise values and plot them together. In a plot like this one below showing phase noise for the SSG6000A, each carrier frequency is a series. The phase noise is plotted from right next to the carrier to further away. This shows the noise sources and profile for highly accurate studies:



When measuring phase noise, it is critical that the analyzer has a better phase noise specification than the source or signal otherwise you will simply measure noise from the measurement system.

Siglent's SSA5000A series spectrum analyzer includes an optional phase noise analysis package that can automate a series of these measurements and return the datapoints as a combined series in a plot by offset:



Because phase noise is so central to frequency accuracy, it is a primary specification for a RF signal source, but improving it is also a difficult design challenge. Therefore, significant improvements in phase noise often imply moving to a higher performance instrument series. This table shows the typical specified phase noise values for the different series of RF signal source from Siglent:

offset	**10 kHz**	**20 kHz**	**10 kHz**	**10 kHz**
Frequency	**SSG3000X**	**SSG5000A/X**	**SSG6000A**	**SSG6082A-V**
100 MHz	-118	-122	-130	-132
1 GHz	-110	-120	-135	-132
2 GHz				-128
3 GHz	-105			-126
4 GHz		-106	-123	-123
5 GHz				-120
6 GHz		-105	-119	-119
7 GHz				-118
8 GHz				-117
10 GHz		-99	-116	
20 GHz		-93	-109	
40 GHz			-102	

Phase Noise in dBc/Hz (typ.)

Due to the way it is measured, phase noise is really about frequency *stability*. The absolute accuracy of the frequency can be off, but as long as the relative position of the carrier to the measurement is stable a generator can exhibit excellent phase noise.

It is also important for RF signal sources to have tight absolute frequency accuracy. All Siglent RF generators have the ability to provide a 10 MHz clock output or accept a 10 MHz clock input. This makes it possible to synchronize devices in a lab for improved accuracy across sources and measurements. Some models may include an oven controlled crystal oscillator (OCXO). The temperature control of this module provides a more precise frequency reference for the instrument itself.

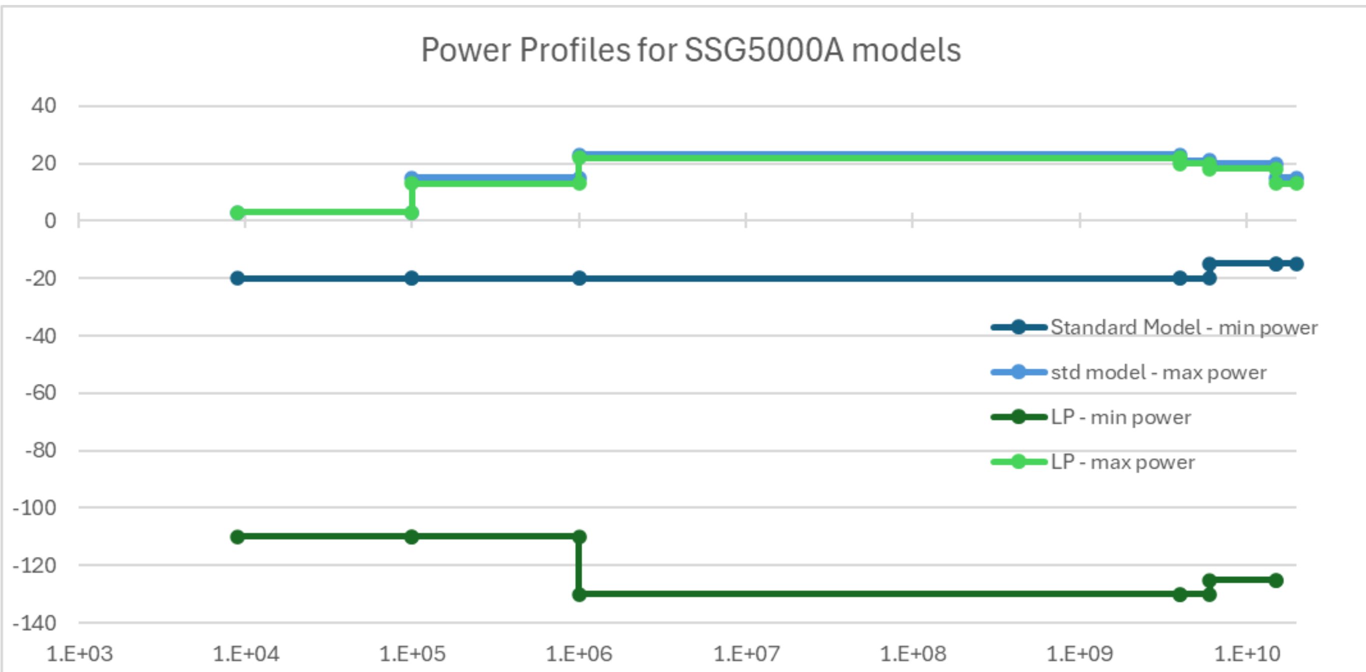
SSG3000X models do not have an OCXO option. The SSG5000A and SSG6000A (including the SSG6082A-V model) series include an OCXO reference as a standard feature. The SSG5000X series has an optional OCXO module that can be purchased as part number: 10M_OCXO_L.

SSG5000A series power profiles explained

The SSG5000A series RF generators have a factory installed option that must be selected at purchase time. This is the SSG5080A-LP option.

This option adds a step attenuator and additional calibration to the RF output of the instrument allowing it to accurately output lower power levels.

Here are the max and min calibrated power levels by frequency for the models without and with the step attenuator:

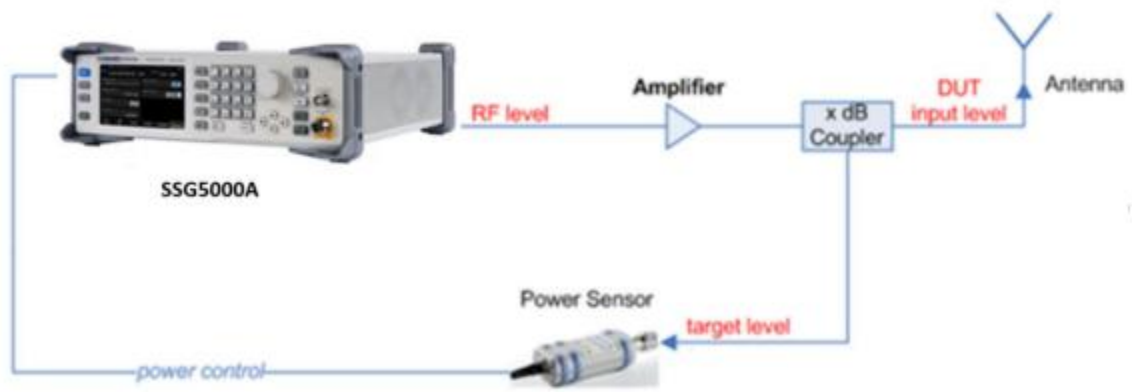


As you can see, the max power profiles are very similar. But the lower level output values are significantly different thanks to the added range of the step attenuator.

It is also important to highlight the step up at 6 GHz. The standard model minimum power goes from -20 dBm to -15 dBm and the LP model minimum power goes from -130 to -125 dBm. It is important to note these calibrated power limits especially when sweeping across the 6 GHz mark.

One additional method for extending the power profile for a target application is the power meter level control feature. Using this feature and a USB power meter an external attenuator or amplifier can be added to the instrument and calibrated into the system. This helps to guarantee optimal accuracy at the device under test and extend the power profile into additional areas of power over frequency.

Level Control is an advanced function that utilizes the power meter in live measurements using an RF splitter. A typical setup might look like this:



You can learn more about this function in our power meter control note or the user’s manual.

Selecting the correct options and having the correct test setup for accurate RF signal generation will make an important difference in breadth of power level accuracy in the application.

Power Meter Control

Improving power accuracy on Siglent RF Signal Source Generators with the power meter control function

Power Meter control is an important function for dealing with cable loss and guaranteeing accuracy of RF signals. Currently, these families of signal sources have the capability to work with a variety of USB power meters for improved accuracy control:

- SSG3000X Series
- SSG5000X Series
- SSG5000A Series
- SSG6000A Series

All models currently support the following models of USB Power Sensor:

Table 8-1 Power sensor model supported

Manufacturer	Model
R&S	NRP6A, NRP18A
	NRP8S, NRP18S, NRP33S, NRP40S, NRP50S, NRP67S
	NRP40T
Keysight	U2000A, U2001A, U2002A, U2004A
	U2000B, U2001B
	U2000H, U2001H, U2002H

The USB power meter connects to the instrument over USB feeding back accurate power reading at the DUT connection point. To achieve this connect the USB cable from the power sensor to the front of the signal generator and connect the RF connection on the power meter to the end of the cable where it will meet the device under test like so:

Once the connections are made, utilize the sensor menu to access the features:

When correctly connected, turn on the Sensor State. The measurement field will now update in real time. You can select the units from:

dBm, dBµV, uV, mV, V, nW, uW, mW, or W

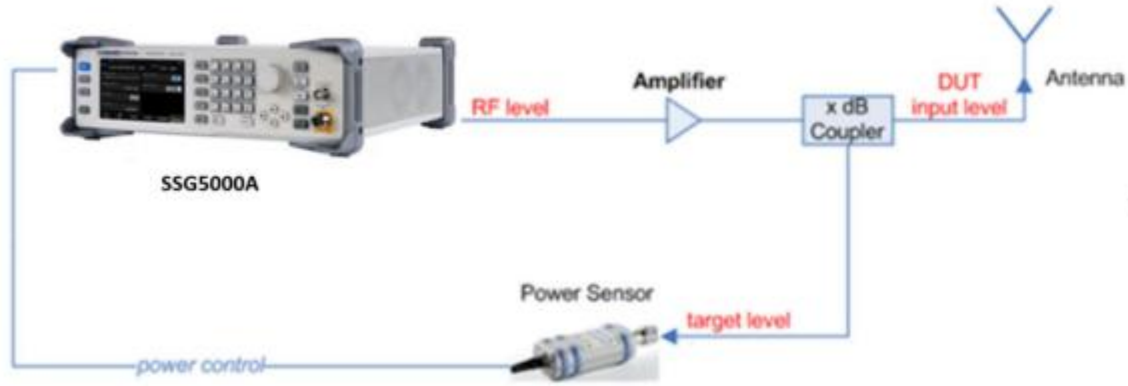
Statistics can also be shown for more complete analysis of the power over time.

Auto Zero performs a zeroing function on the power meter itself. This can improve measurement accuracy in a given test setup, but needs to be performed with the signal power off.

To reduce the impact of noise and zero deviation on the measurement results, it is recommended to zero the power sensor in the following situations:

- Warm-up phase just after connecting to the signal source
- Temperature change exceeds 5 ℃
- Connect the power sensor to the RF output at high temperature
- The power sensor has not been zeroed in the past 24 hours
- Before measuring low-power signals, such as signals with expected measured power more than 10 dB below the lower limit of the measurement range

Level Control is an advanced function that utilizes the power meter in live measurements using an RF splitter. A typical setup might look like this:



In this mode, the power meter continually measures a portion of the signal from the coupler or splitter. The ratio is defined in the level control menu allowing the generator to accurately deliver power to the DUT and the power sensor together.

This feature has an additional use case on the SSG5000A specifically. One of the options on this series is the -LP option that includes a built-in step attenuator for reaching lower power levels. Alternatively, engineers can use the level control function on the standard unit with a USB power sensor and an external attenuator to set lower power levels at the DUT as well.

Using the SSG5083A and an NPR6A power sensor, we used the basic sensor mode to correct for signal loss in our primary test cable.

Amplitude Accuracy Test with and without Power Meter (all in dBm)			
Frequency	SSG5083A Source Levels	6 GHz Power Meter	With cable and no power meter (spot checks)
500 MHz	-10	-9.97	
	-20	-20.03	
1 GHz	-10	-9.95	
	-20	-20.01	
2 GHz	-10	-9.93	
	-20	-20	
3 GHz	-10	-9.94	-11.4
	-20	-20	-21.36
4 GHz	-10	-9.91	
	-20	-19.95	
5 GHz	-10	-9.84	
	-20	-19.91	
6 GHz	-10	-10.09	
	-20	-19.91	-21.8

Even with a decent quality cable, the power sensor adjustment would be required to meet or exceed the ≤ 0.7 dB level accuracy rating of the generator at the DUT connection point. As one would expect, the cable loss becomes greater as frequency increases making it more important in higher frequency applications.

Power meter control is a great capability for getting the most accuracy out of RF signal generators. This capability is included as a standard (free) feature on Siglent's line of RF signal sources from 2.1 GHz to 40 GHz.

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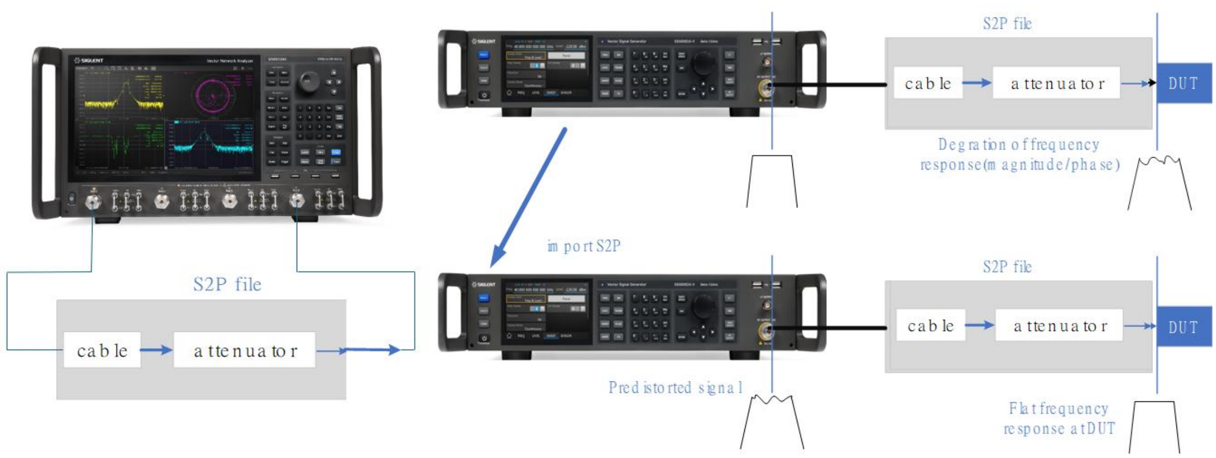
Signal Compensation using S2P files

One additional method for improving signal generator accuracy is an advanced compensation mode that affects amplitude and phase at the device under test. S2P file compensation is available on the SSG6082A-V and is a standard feature. S2P files are traditionally associated with vector network analyzers. Using a network analyzer, you can generate the S2P file. This file explains how a signals characteristics are changed by a RF network. Here, we can use it for cables, attenuators, amplifiers, and the like to improve the signal quality at our device.

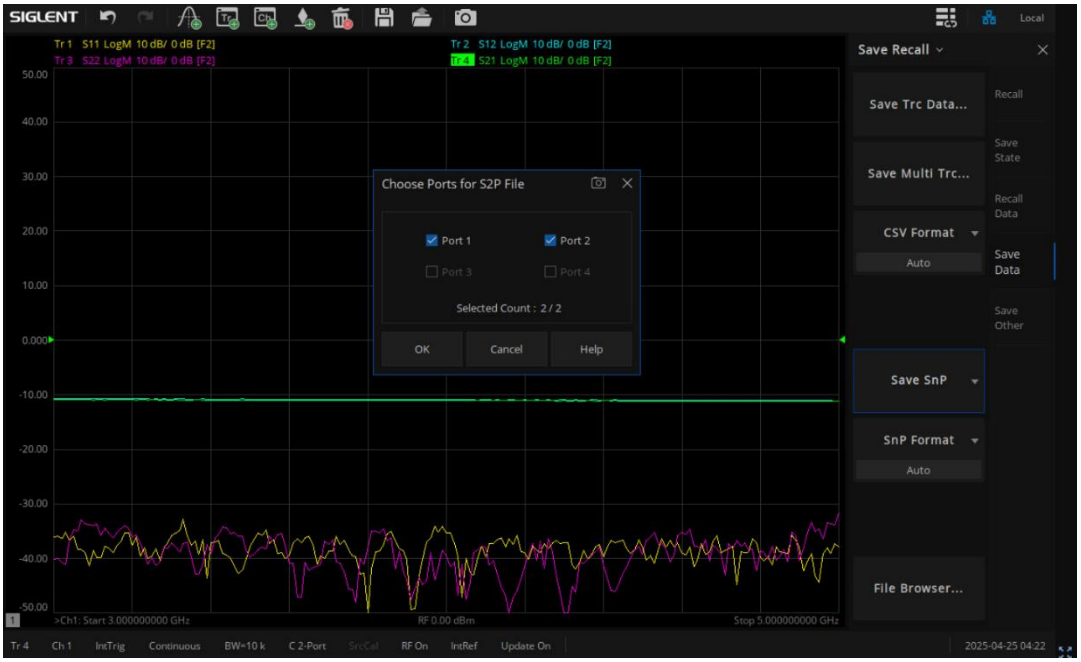
First, we characterize our connection to the device. In this case, we have a cable and inline attenuator set. We connect this to the VNA for evaluation:



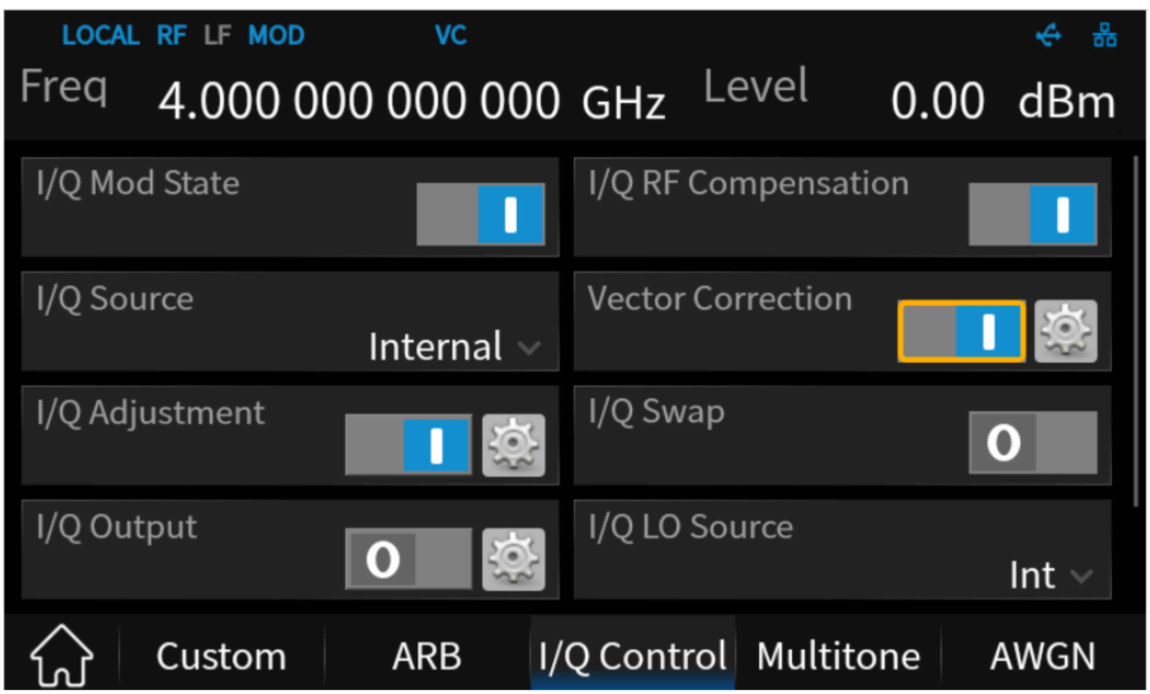
S2P file for receive link from testing with vector network analyzer

Import the S2P file into the SSG6082A-V to compensate the output signals

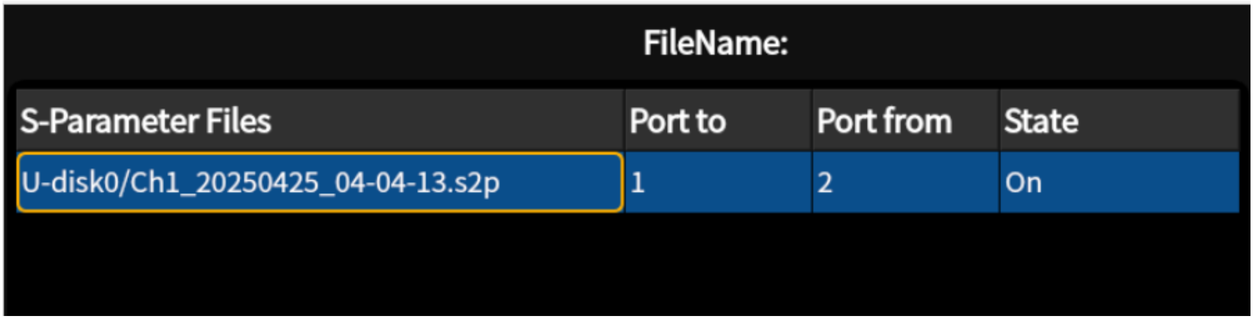
After calibration, we can connect and characterize the DUT. Then, we can save the data directly to a S2P file:



We save the S2P file and move it to the generator. Now, we can use the vector compensation tool to load and apply this compensation:

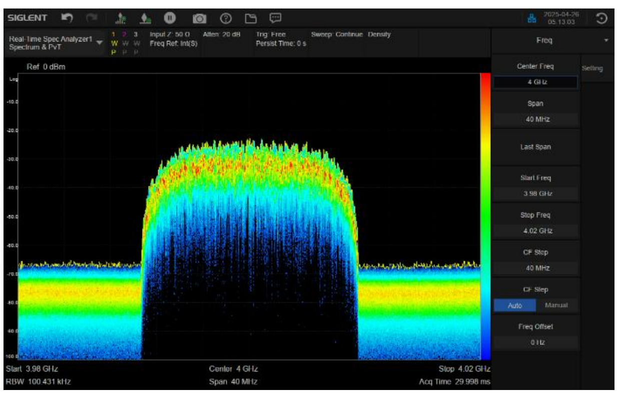


Vector Correction in the I/Q Control menu of the SSG6082A-V

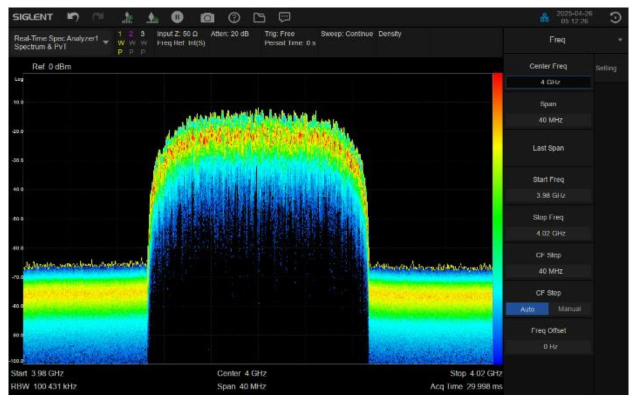


S2P file config in the user S Parameter file menu of the SSG6082A-V

Now, we can view the before and after effects of this compensation on the signal that appears at our device under test:



Before vector correction



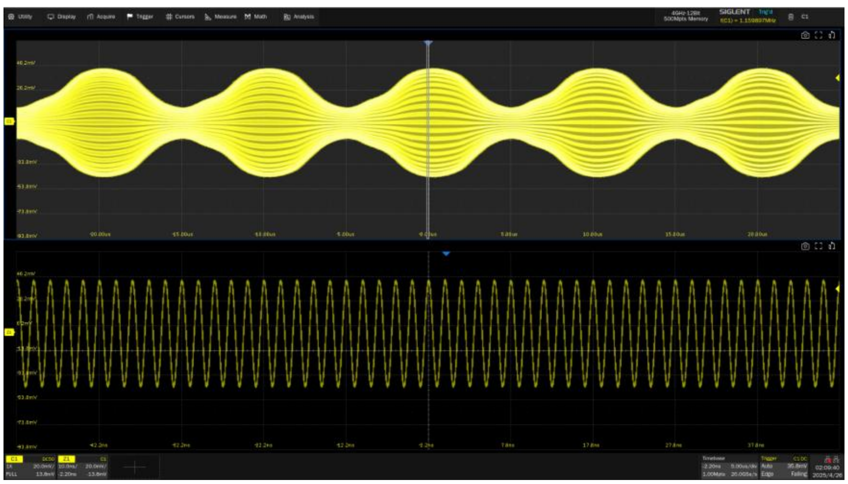
After vector correction

This correction format is excellent for improving signal integrity at the dut and only requires the common S2P file format for the connecting network.

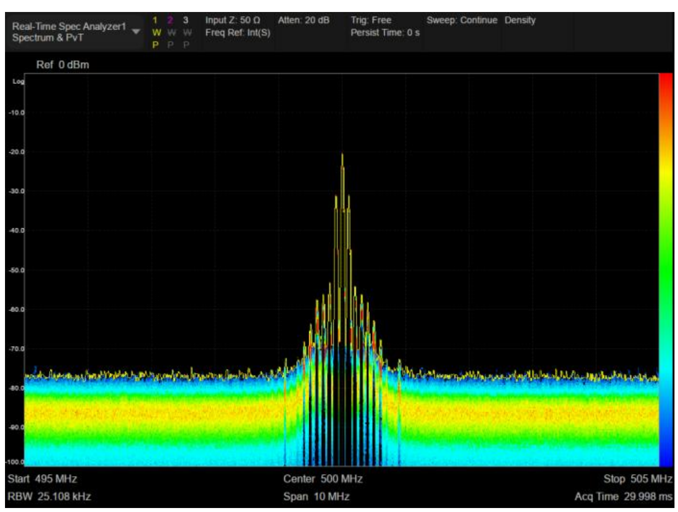
Analog Modulation Settings and Limits

Analog modulation is a common function for RF signal sources. These include amplitude modulation (AM), frequency modulation (FM), and phase modulation (PM or ΦM). We will also discuss pulse modulation here.

Amplitude modulation changes the amplitude of the wave over time. It appears like this in the time and frequency domain:



Time Domain – Oscilloscope view of modulation and carrier



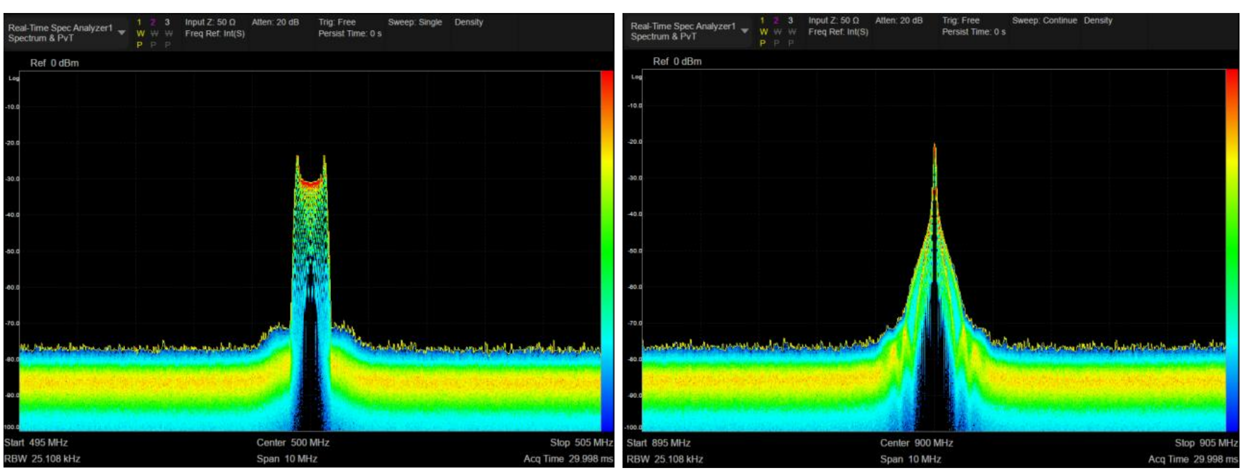
Frequency Domain – Spectrum view of AM signal

Siglent generator models support amplitude modulation up to 100% depth (% change in amplitude). They are specified to enable modulation frequencies (speed of the modulation cycle) from 10 Hz to 100 kHz at up to 80% depth.

Amplitude modulation of a carrier is a key use case in immunity testing for radiated and conducted emissions work.

All Siglent RF sources can use either an internal or external source to drive these modulations.

Frequency modulation (FM) is changing of the signal frequency over time. Frequency and phase modulation (PM or ΦM) are not used together since the concept of a phase difference lacks meaning when comparing two waves at different frequencies. Here are the frequency domain views for frequency and phase modulation:



Frequency Domain – FM and Phase Modulation views

The specification limitations for these signals is dependent on the start or base frequency. Use these tables to determine the variable N for these specifications based on the model or series:

N values by Series			
Frequency	**SSG3000X**	**SSG5000X**	**SSG5000A**
9 kHz -1 MHz	0.25	0.25	0.25
1 - 3 MHz	0.5	0.5	0.5
3 MHz - 250 MHz	0.5	0.5	0.5
250 MHz - 500 MHz	0.125	0.125	0.125
500 MHz - 1 GHz	0.25	0.25	0.25
1 - 2 GHz	0.5	0.5	0.5
2 - 3.2 GHz	1	1	1
3.2 - 4 GHz		1	2
4 - 6 GHz		2	2
6 - 8 GHz			2
8 - 16 GHz			4
16-18 GHz			8
18 - 20 GHz			8

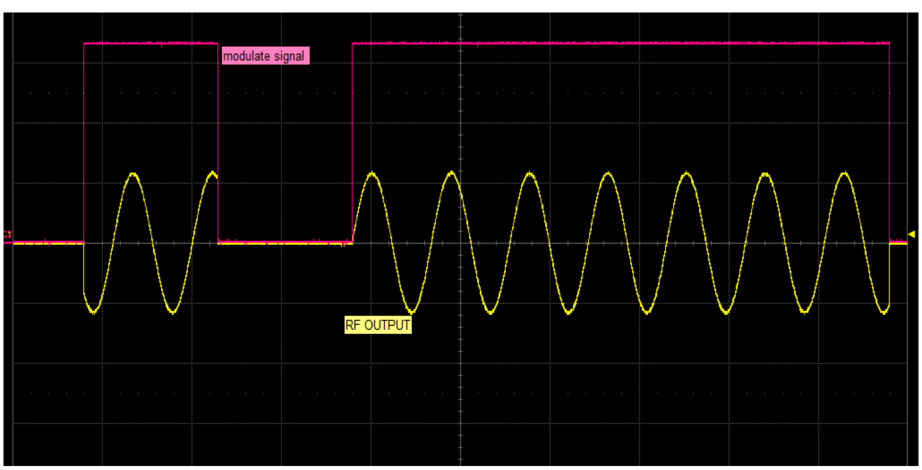
N values by Series		
Frequency	**SSG608#A**	**SSG6082A-V**
9 kHz ＜f ≤ 1 MHz		1
1MHz ≤f≤ 250 MHz	0.125	0.125
250MHz ≤f≤ 400 MHz	0.03125	0.03125
400MHz ≤f≤ 800 MHz	0.0625	0.125
800MHz ≤f≤ 1600 MHz	0.125	0.25
1600MHz ≤f≤ 3200 MHz	0.25	0.5
3200MHz ≤f≤ 6400 MHz	0.5	1
6400 MHz ≤f≤ 8000 MHz	1	1
8000MHz ≤f≤ 12800 MHz	1	
12800MHz ≤f≤ 25600 MHz	2	
25600MHz ≤f≤ 40000 MHz	4	

Frequency and phase modulation also operate from 10 Hz – 100 kHz. The key limitations are in deviation – that is plus and minus change from the base frequency in MHz or the plus and minus change from reference phase 0 in radians. Here are the setting limits for deviation:

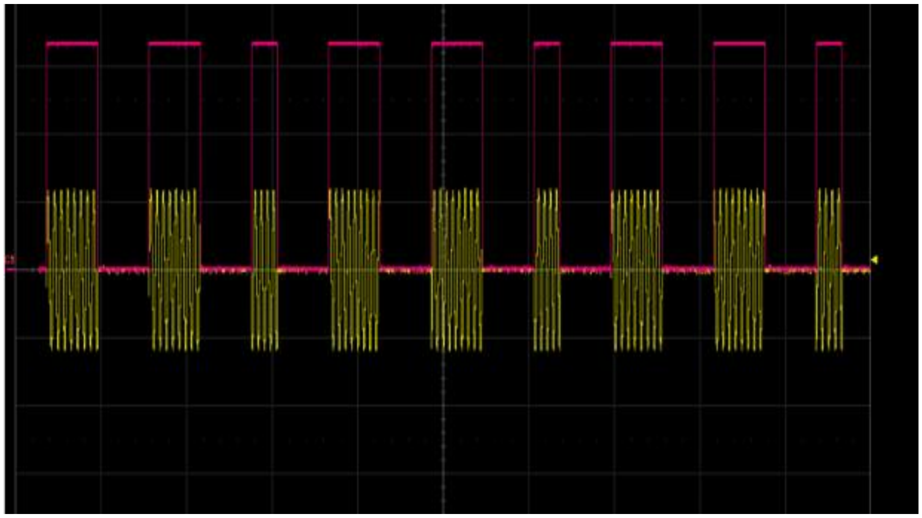
Series	FM max deviation	PM max deviation
SSG3000X	N*1 MHz (typ.)	N*5 rad
SSG5000X	N*1 MHz (typ.)	N*5 rad
SSG5000A	N*1 MHz (typ.)	N*5 rad
SSG6000A	N*5 MHz (typ.)	N*5 rad
SSG6082A-V	N*4 MHz (typ.)	N*5 rad

Pulse modulation has several important specifications. First, the pulse modulation feature has both single and double pulse configurations with settable pulse widths, periods, and a delay between two pulses in double pulse mode. For more complex pulse configurations add the pulse train generator option available on any of the models.

The minimum pulse width can be set as low as 20 nanoseconds with the pulse period being set down to 40 nanoseconds. These values can be set at 10 nanosecond intervals and can be set as long as 300 seconds across all of the models. Here are examples of pulse and pulse train operation in the time domain:



Pulse Modulation with a SSG6082A-V



Pulse Train Modulation with a SSG6082A-V

The SSG6082A-V supports pulse modulation up to an 8 GHz carrier. It has high dynamic range with on-off ratio >80dBc and rise-fall time <15ns.

Pulse signal fidelity is typically specified by this on-off ratio. It specifies the level change during the off period. This table shows the ratio for different generators:

	On/off ratio (typ.)				
Frequency	**SSG3000X**	**SSG5000X**	**SSG5000A**	**SSG6000A**	**SSG6082A-V**
Pulse Mod Availability	**Standard**	**Standard**	**Option**	**Option**	**Option**
1 MHz < f ≤ 2.5 GHz	> 70 dBc	> 70 dBc	> 70 dBc	> 70 dBc	>80 dBc
2.5 GHz < f ≤ 3.2 GHz	> 63 dBc	> 70 dBc	> 70 dBc	> 70 dBc	>80 dBc
3.2 GHz < f ≤ 4 GHz		> 70 dBc	> 70 dBc	> 70 dBc	>80 dBc
4 GHz < f ≤ 6 GHz		> 65 dBc	> 70 dBc	> 70 dBc	>80 dBc
6 GHz < f ≤ 8 GHz			> 80 dBc	> 80 dBc	>80 dBc
8 GHz < f ≤ 13.6 GHz			> 80 dBc	> 80 dBc	
13.6 GHz < f ≤ 20 GHz			> 75 dBc	> 75 dBc	
20 GHz < f ≤ 40 GHz				> 75 dBc	

Often modulations can be used in combination to create even more complicated wave types. This may even include IQ signals. IQ signals incorporate two carriers at the same frequency in quadrature – 90° out of phase. For a more in-depth look at IQ signal generation go to the section titled: Vector Modulation Settings and Limits.

This table explains which modulation schemes can be used in tandem on Siglent RF generators:

Analog modulation					
	Simultaneous modulation				
	Amplitude modulation	Frequency modulation	Phase modulation	Pulse modulation	IQ modulation
Amplitude modulation		●	●	(●)	●
Frequency modulation	●		×	●	●
Phase modulation	●	×		●	●
Pulse modulation	(●)	●	●		(●)
IQ modulation	●	●	●	(●)	
●=compatible, ×=incompatible, (●) =compatible limitations; NO specification Applies to AM distortion. In IQ mode, if open the RF Blank function in the marker utility, you cannot use the pulse modulation.					

IQ Modulation cannot be used with other modulations on the SSG3000X-IQE models. IQ modulation is not available on the SSG5000A and SSG6000A models (the SSG6082A-V is an exception).

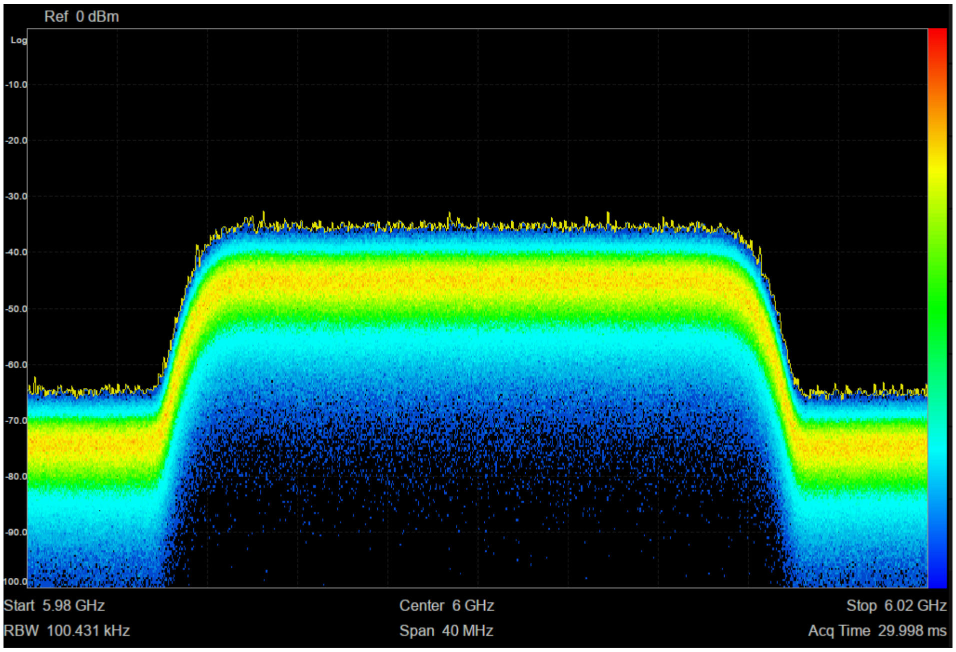
Digital Modulation Settings and Limits

There are multiple methodologies for creating digital modulation formats in Siglent RF signal generators. There are built in modulation formats that enable pattern creation from the front panel, there are built in arbitrary or custom files that make it possible to access standard modulations that are more complex, and there is the SIgIQPro software that enables more fully customizable solutions that can be downloaded directly to the instrument.

Built in modulation types that can be customized from the front panel include:

- AWGN (Additive White Gaussian Noise)
- Multi-tone
- IoT signals (SSG5000X-V only)
- Stream file (SSG5000X-V only)
- Custom digital modes
- Arbitrary

AWGN or Additive White Gaussian Noise creates noise in the RF channel. The use can set the bandwidth of the noise which is centered around the center frequency like so:



AWGN noise can be generated up to the full bandwidth of the generator. 75 MHz or 150 MHz (with the option) for the SSG5000X-V models and 500 MHz or 1 GHz (with the option) for the SSG6082A-V.

Multi-tone signals are covered in the section titled: “Multi-tone Signal Generation”.

IoT signals include the ZigBee and Z-Wave. These waveforms include oversampling ratios, frames, length, marker, and trigger settings. Users can also customize PPDU and PSDU settings in the ZigBee format. These waveforms can also be produced in SigIQPro for either the SSG5000X-V or the SSG6082A-V. See the chapter titled: “SigIQPro Signal Generation Software” for more information.

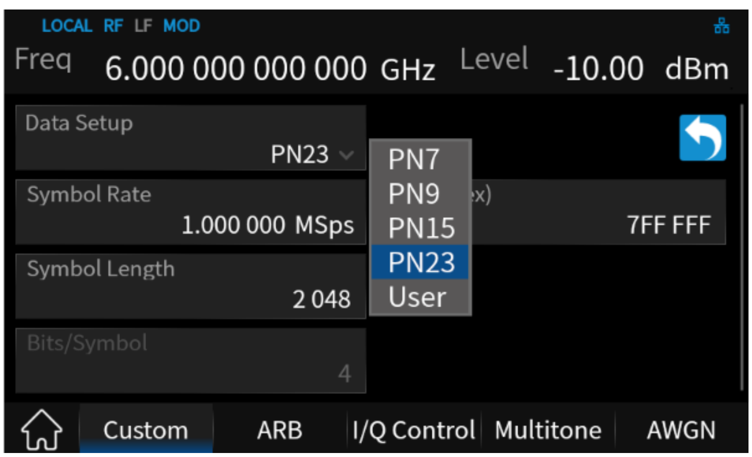
Stream files are a direct way of importing binary IQ data to the SSG5000X-V instrument. Use SigIQPro software to import custom files on the SSG6082A-V as well. The main user settable values for a stream file are:

sample clock (up to 5 MHz), modulation attenuation, and a baseband offset frequency.

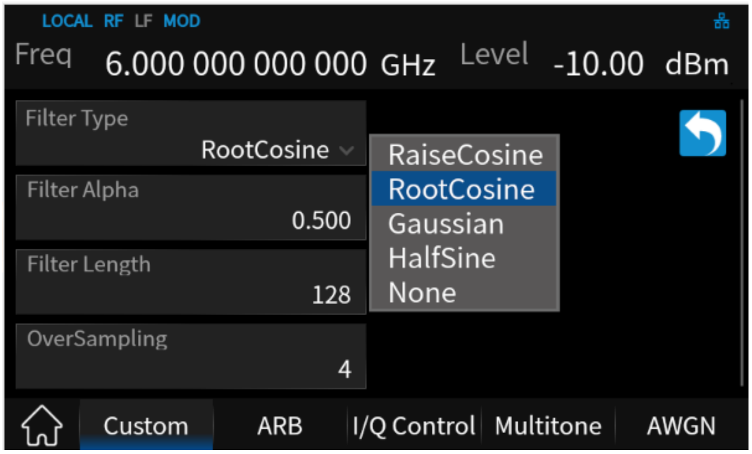
Many custom digital modes are built in with some configurability. These include:

Custom digital modulation mode		
Modulation type	PSK	BPSK, QPSK, 8PSK, DBPSK, DQPSK, 8PSK, OQPSK, PI/4-DQPSK, PI/8-D8PSK
	QAM	16QAM ,32QAM ,64QAM ,128QAM ,256QAM ,512QAM
	MFSK	2FSK ,4FSK ,8FSK ,16FSK, MSK
	ASK	2ASK,4ASK,8ASK,16ASK

There is also a user modulation type where the user can customize a constellation diagram and allocate symbol values in a table. Those are the custom modulation types. In addition to the modulation type, users can also set the data values. Data options look like:



Here, users can set the symbol rate up to the maximum based on the instrument bandwidth. Also, set the symbol length. Bits/Symbol are set by the modulation type. There are also front panel options for setting the filtering:



With front panel editing of the modulation type, filtering, and data these signals can be significantly customized for many applications.

The final category of IQ modulation available from the front panel is the ARB mode. Arbitrary mode enables users to load pre-saved files to the baseband generator. See all the files preloaded in the SSG5000X-V or SSG6082A-V in the preloaded data section. They include preloaded datafiles for 5G NR, Bluetooth, CDMA2000, GSM, LTE FDD, LTE TDD, WCDMA, and WLAN.

This is also the menu where users can access the multi-carrier capabilities by essentially loading a file separately to different channels. Alternatively, the waveform sequence tool can also be activated here. Instead of simultaneous IQ signal files across multiple channels you can sequence between files on a single carrier. This creates long data sequences for complex interoperation tests. Both the SSG5000X-V and the SSG6082A-V instruments can sequence up to 1024 wave segments and up to 65535 wave repetitions.

The SSG6082A-V has significantly more memory with a max playback capacity of 2048 MSa and a segment length of up to 2 GSa. The SSG5000X-V is limited to 200 MSa for both max length and total capacity.

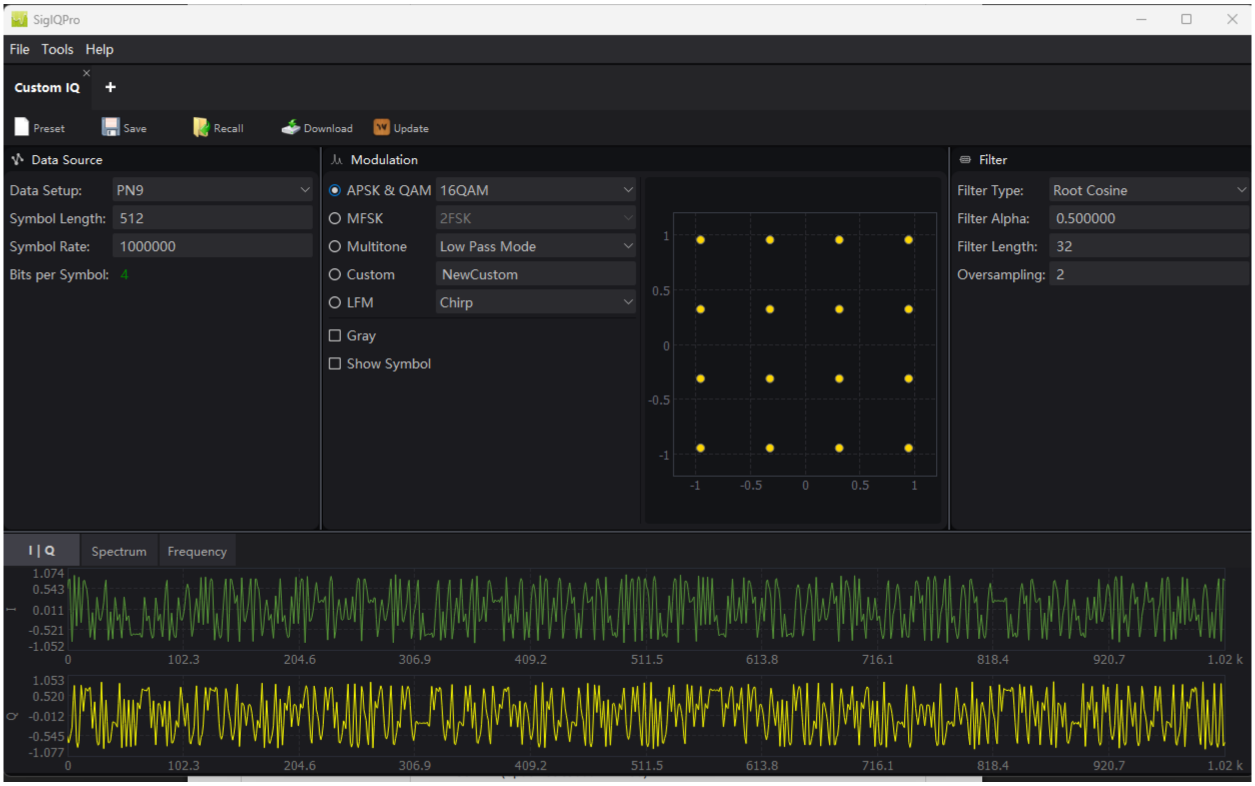
Additional wave customization is possible using the SIGIQPro PC software.

Vector Signal Generation Methodologies

The SSG5000X-V vector signal generators provide IQ modulated signals on carrier in 2 ways. First, they can use external I and Q inputs. These are analog inputs with typical bandwidth of 200 MHz. I and Q are put in separately. This is ideal for IQ data easily expressed in the time domain. A two channel waveform generator like a SDG1000X Plus can provide signals in the MHz range that are then expressed as IQ on the carrier. To reach the full bandwidth capability of the IQ generator, you would need a more powerful generator like a SDG6032X which can pulse at 150 MHz. Any of these generators can produce arbitrary waveforms that are phase aligned across channels for proper IQ modulation. Arbitrary waves can be created using EasyWaveX free software or can be created programmatically or imported from a csv file. Make sure the arbitrary memory depth supports the full length of your needed waveform at a high sample rate.

The other option is to use the internal generator built into the SSG5000X-V. The internal baseband channels can provide a sample rate up to 120 MHz or 240 MHz with the B150 option. That creates RF bandwidth of up to 150 MHz. The arbitrary waveform memory of the internal generator is up to 200 million points. The internal generator can be loaded using the higher level SigIQPro software. Instead of defining waveforms in the time domain, use this software to define modulation schemes in the RF domain and the software creates and loads the underlying IQ data like so:

RF Signal Generation Capabilities



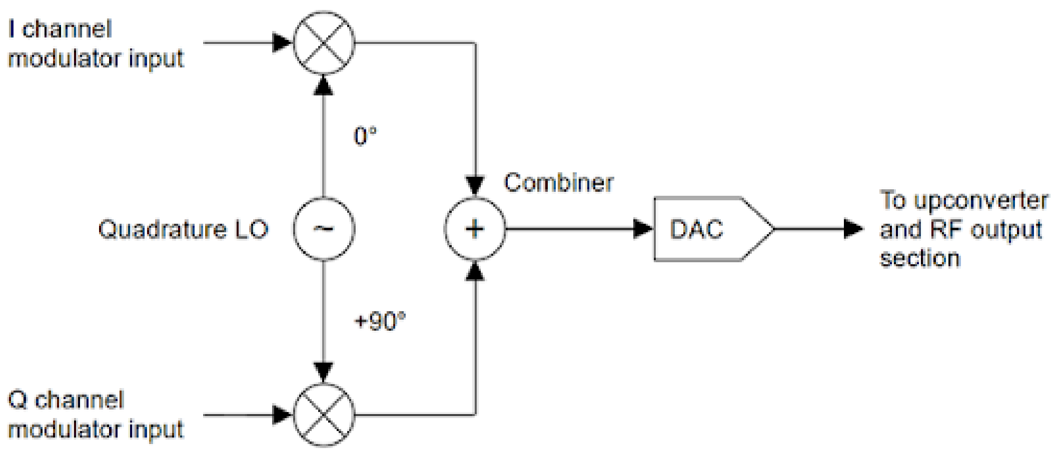
Signal Generation Option Table:

Model	Sample Rate	Arb Memory Depth	Software Toolkit
SDG1000X Plus	250 MSa/s	8 Mpt	EasyWaveX
SDG6000X	300 MSa/sec	20 Mpt	EasyWaveX
SDG7000A	2.5 GSa/sec	512 Mpt	EasyWaveX
SSG5000X-V internal	240 MHz	200 Mpt	SigIQPro
SSG6082A-V internal	1250 MHz (opt)	2048 Mpt	SigIQPro

There are additional considerations beyond sample rate and memory. As speed and bandwidth increase there is often a trade off in error vector magnitude (EVM). Review the section on Vector Modulation Settings and Limits for more details on EVM in different modulation schemes and symbol rates.

Vector Modulation Settings and Limits

Vector signal generators add the capability to put complex, IQ waveforms up onto a carrier. The SSG3000X-IQE models do this from external I and Q inputs only. Most vector generators also have the ability to create or load IQ data directly to the instrument. This is a basic block diagram of an internal IQ modulation generator:



Once combined and on a carrier these signals are typically slotted into bandwidth channels based on the modulation scheme.

We already discussed sample rate and arbitrary memory as limiting factors for instrument selection among vector generators. Here, we will dig further into the key specifications that define signal fidelity for these complex signals. The most important of which is bandwidth. IQ bandwidth determines how wide of a channel or set of channels the generator can create signals in at once. Therefore, this also impacts the signal breadth available in multi-carrier mode. Here is the RF bandwidth for vector models with built in baseband generators:

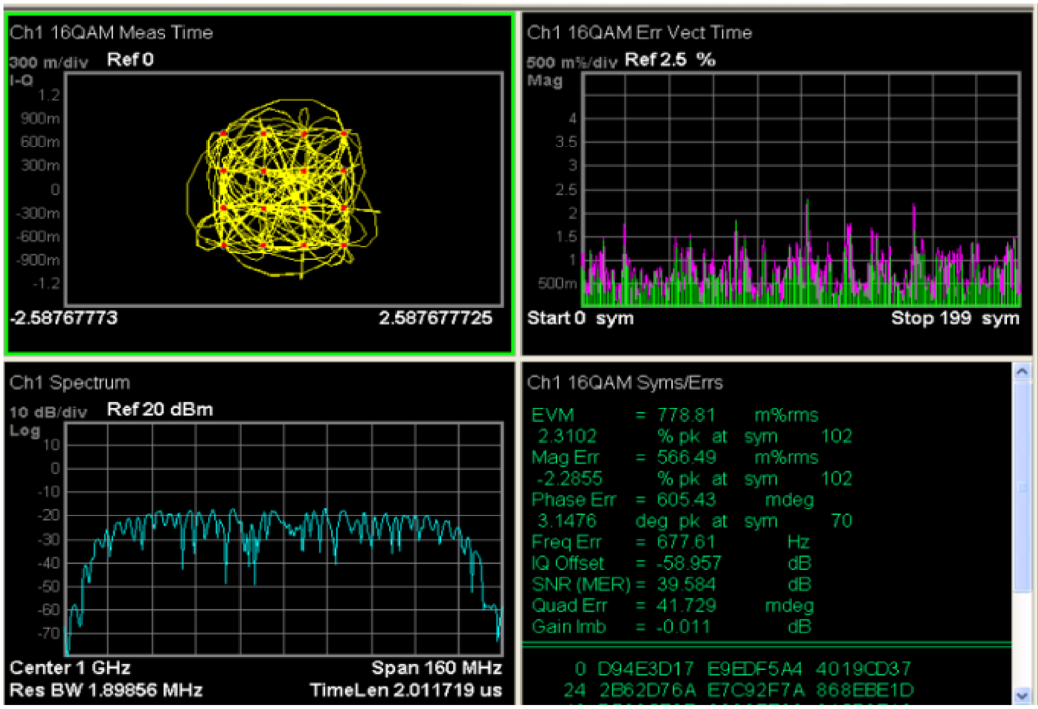
IQ Bandwidth	Standard	Option
SSG5000X-V	75 MHz	150 MHz
SSG6082A-V	500 MHz	1 GHz

Wider bandwidth is a critical specification as many modern modulation schemes include wider channels. This is especially true of the newer advanced WiFi protocols:

protocol types	Maximum required modulation bandwidth
LTE FDD&TDD	20MHz
LTE TDD	20MHz
5G NR	100MHz
WiFi 6 / 802.11ax	160MHz
WiFi 7 / 802.11be	320 MHz

Vector signal generators with arbitrary baseband generators can create multiple signals within the IQ bandwidth potentially occupying multiple channels for emulation and interference applications.

Beyond the basic sample rates of the generator, symbol rate is an important specification. Protocols are often defined with fixed timing. Emulated signals must be able to achieve set symbol rates. The symbol rate is the speed of demodulation. The I and Q waveforms are in quadrature on the carrier and they must settle into a position on a constellation diagram at the correct time in order to be interpreted correctly for demodulation. Here is an example of a QAM16 constellation and the resulting spectrum:



The constellation at the top right shows the I and Q waveforms over time in yellow and the points at which they are demodulated in time are the red dots. In a QAM modulation like this, the I and Q waveforms are both changing their amplitude. Intuitively, moving more quickly between points increases noise and creates additional signal artifacts.

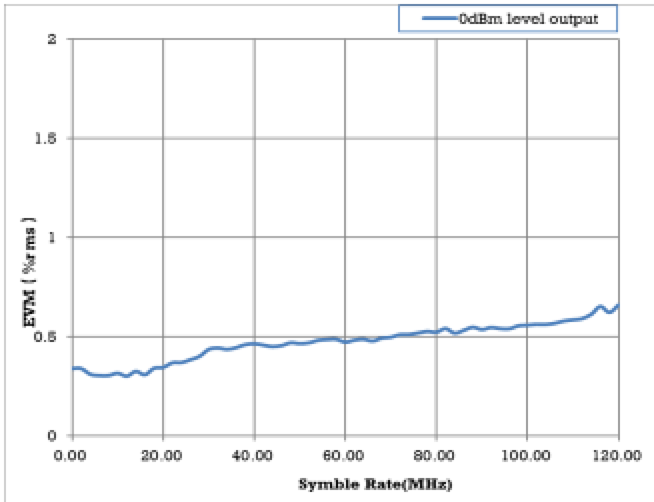
We can investigate this further looking at the custom digital modulation mode. This mode can be used to create a variety of modulation types including:

Custom digital modulation mode		
Modulation type	PSK	BPSK, QPSK, 8PSK, DBPSK, DQPSK, 8PSK, OQPSK, PI/4-DQPSK, PI/8-D8PSK
	QAM	16QAM ,32QAM ,64QAM ,128QAM ,256QAM ,512QAM
	MFSK	2FSK ,4FSK ,8FSK ,16FSK, MSK
	ASK	2ASK,4ASK,8ASK,16ASK

On the SSG6082A-V, you can also create 1024QAM. This difference is because of the symbol rate requirements. Here are the symbol rate limits for the instruments:

Custom digital modulation mode - Symbol Rate		
Series	**Standard**	**Option**
SSG5000X-V	60 Msps	120 Msps
SSG6082A-V	312.5 MHz	625 MHz

The tradeoff with faster symbol rates is increasing error vector magnitude (EVM). Essentially, the amount of noise and error at the measured points versus their ideal location on the constellation diagram. This chart shows that relationship. The EVM of a signal increases with the symbol rate. In this case using a QPSK signal on a 2.2 GHz carrier on a SSG5000X-V generator:



Measured EVM performance vs symbol rate @2.2 GHz， QPSK

Keeping EVM low while producing wider bandwidth signals at higher symbol rates is a difficult technical challenge and shows the true performance capabilities of an instrument like the SSG6082A-V.

RF Signal Generation Capabilities

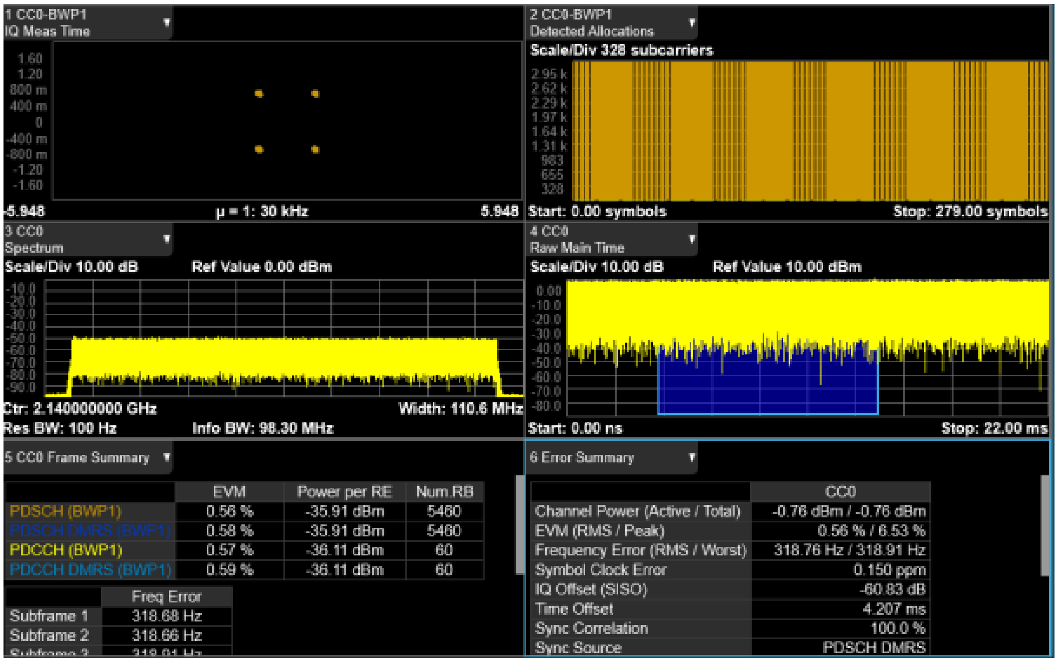
This table summarizes the EVM for particular formats and different modulation rates for the SSG6082A-V:

EVM Performance					
Format	W-CDMA	LTE FDD	GSM	EDGE	CDMA2000
Modulation type	QPSK	64 QAM	GMSK (burst)	3 pi/ 8PSK (burst)	QPSK
Modulation rate	3.84 Mcps	10 MHz BW	270.833 Ksps	70.833 Ksps	1.2288 Mcps
Channel configuration	1 DPCH	E-TM 3.1	1 timeslot	1 timeslot	Pilot channel
Frequency	1800-2200 MHz	1800-2200 MHz	800-900 MHz; 1800-1900 MHz	800-900 MHz; 1800-1900 MHz	800-900 MHz; 1800-1900 MHz
EVM power level	< 4 dBm				
EVM	< 0.4%	< 0.45%	< 0.4 %	< 0.8%	< 1.1%

For the same signals above, here are the EVMs for the SSG5000X-V:

EVM	<1.2 %	<0.5 %	<1.3 %	<1.3 %	<1 %

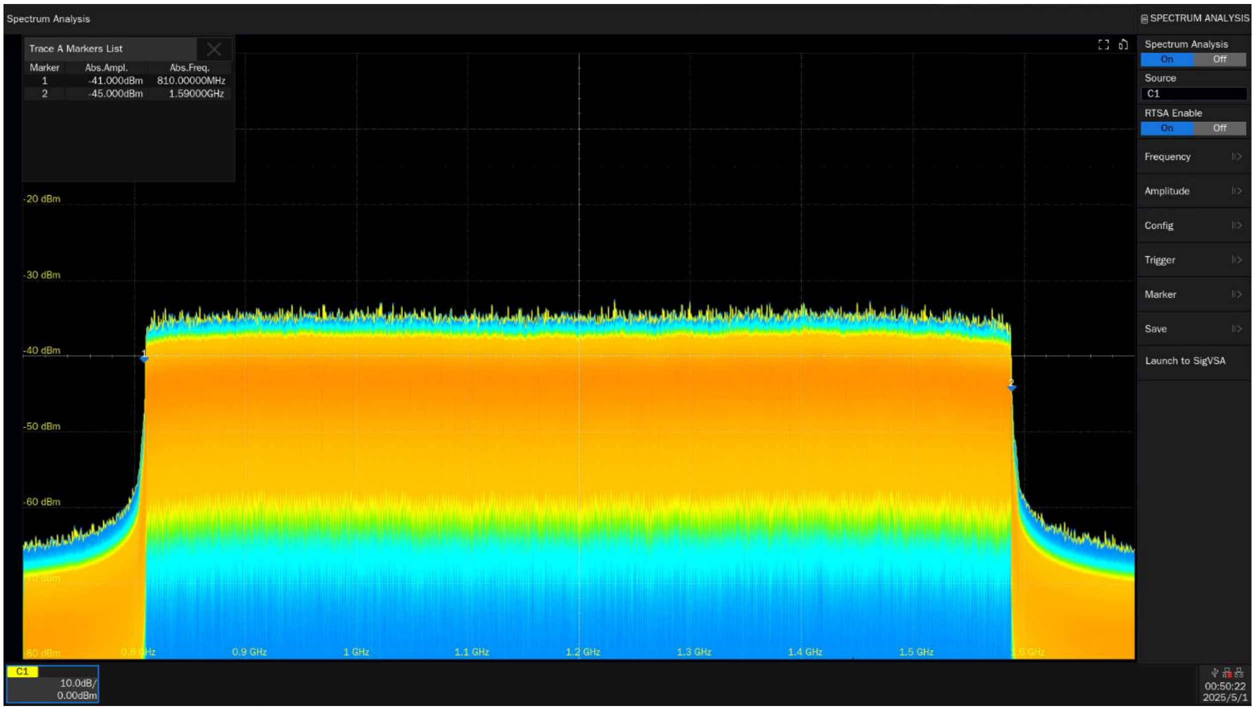
One additional datapoint is shown in the next figure. A 5G NR signal with 100 MHz of bandwidth is generated from the SSG6082A-V and analyzed to have <0.6% EVM:

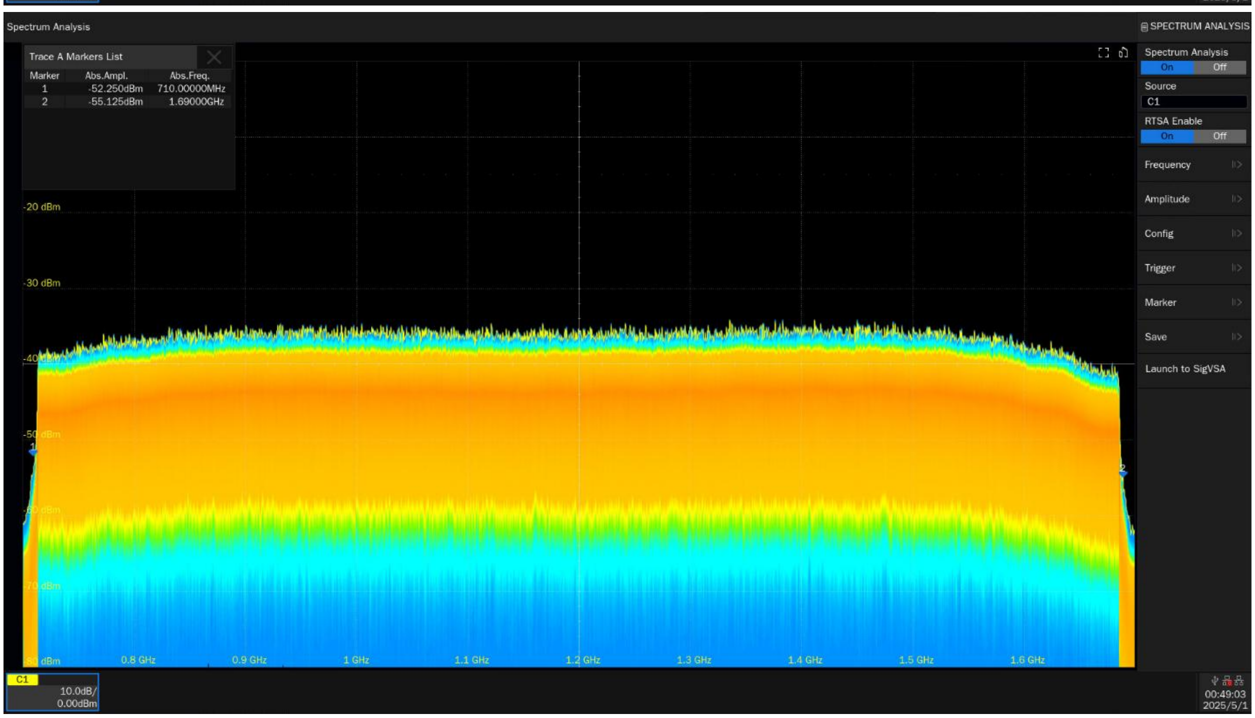


5G NR Test Mode TM1.1 100M Bandwidth 3.9G Carrier, EVM Test Value

Here is one additional view of a IQ signal at max symbol rate across the full 1 GHz of bandwidth from a SSG6082A-V:

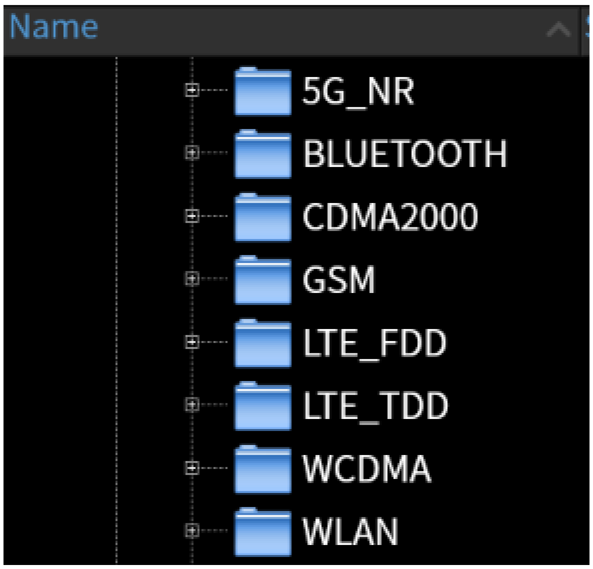
Here are two images of the IQ signal at near the full 1 GHz of bandwidth from a SSG6082A-V with a real time view from an oscilloscope with RTSA:



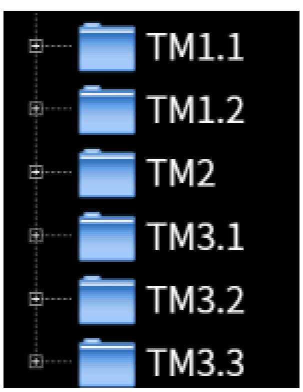


Preloaded Arbitrary Signals

Listing of preloaded files in the SSG5000X-V and SSG6082A-V. Both instruments contain similar sets of default waves in these categories and folders:



The 5G_NR folder contains examples of 5G New Radio signals sorted into FDD and TDD subcategories. Each subcategory includes these folders:



There are 7 files in each of these categories named for their type like:

NR-FR1-TM1.2-TDD-100MHz-30kHz-3.5G

The Bluetooth folder includes DH1 and DM1 bursting and standard packets.

The CDMA2000 folder includes 2 filetypes. The GSM folder contains 4 GSM and Edge files. The LTE_FDD folder contains 36 files and the LTE_TDD folder contains 27 files.

The WCDMA folder contains 15 files and the WLAN folder includes an 802.11agjp_OFDM_20M arb file.

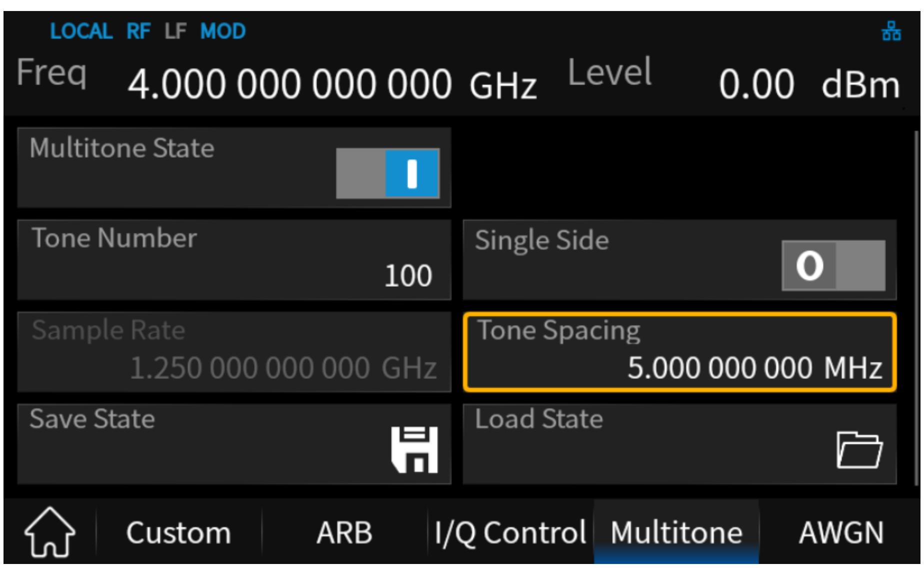
In total, the SSG6082A-V contains more than 160 example files to build sequences and waves from.

Multi-tone Signal Generation

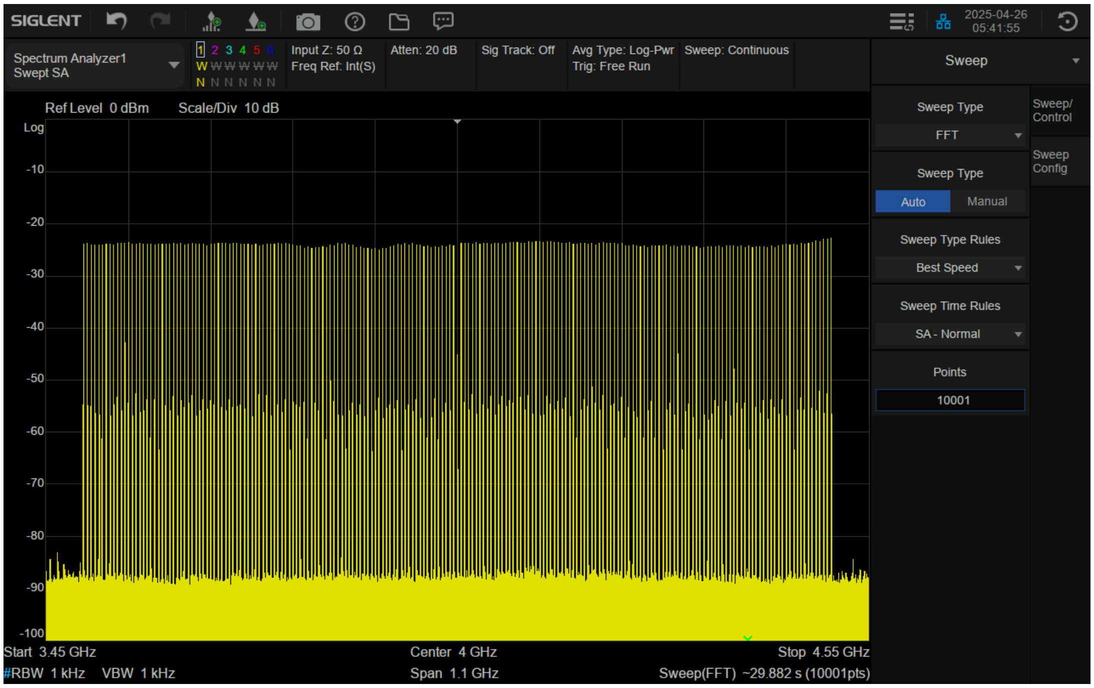
Multi-tone generation is important in a number of applications. With sufficient bandwidth and power, a generator can operate as a comb signal generator. Certain device characterization and basic immunity or interference tests may utilize function. This application strongly benefits from wider IQ bandwidth. Due to this, the SSG6082A-V has a distinct advantage in creating multi-tone signals:

Multi-Tone Operation			
Series	**Number of Tones**	**Max Spacing**	**Phase**
SSG5000X-V	40	120 MHz	Fixed
SSG6082A-V	65536	±500 MHz (opt)	Fixed or Random

The instrument menu allows the user to set the number of tones and tone spacing. Tones can be single sided or grouped around the center frequency:



Tones all appear simultaneously and continuously across the signal bandwidth:



This type of multi-tone signal is useful for receiver linearity testing, intermodulation distortion, and blocking characterization. This is also commonly used to test the intermodulation products of an amplifier. When multiple channels of more complex signals are called for, we recommend the next section on multi-carrier signal generation.

Multi-Carrier Signal Generation

Multi-Carrier generation significantly expands the capabilities of a generator. Creating one waveform type for a channel may work for basic emulation or debugging, but complete test setups often require immunity and interference testing which may require multiple channels to be occupied at once. This is a capability where signal bandwidth, sample rate, memory, and symbol rates all work together.

This example shows signals in 3 channels with >100 MHz between channels from a single generator:

Using the SSG6082A-V it is possible to generate a number of carriers within a single IQ file. It is limited by the overall symbol rate, spacing, and design of each carrier group.

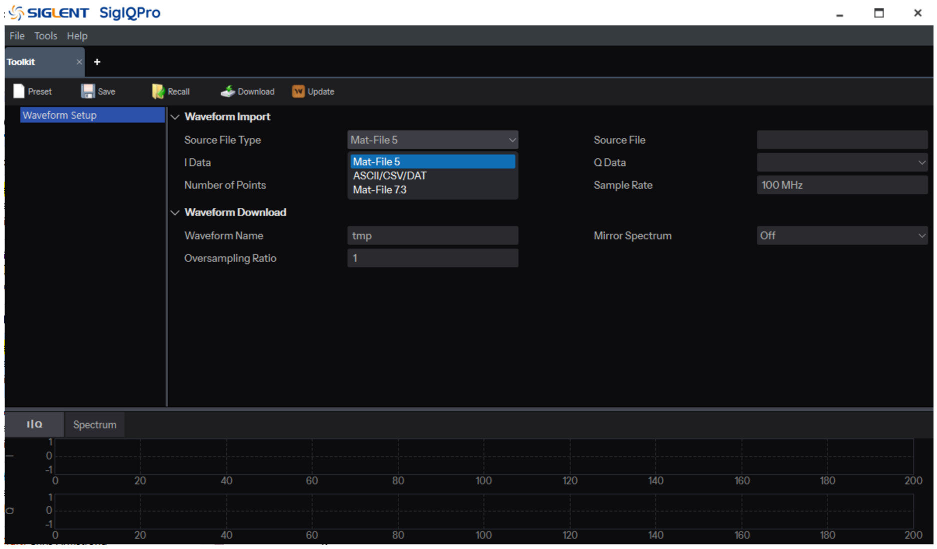
SigIQPro Signal Generation Software

SigIQPro is Siglent's custom signal development software. Signals can be created and loaded directly to IQ generating baseband generators that are stand alone or within RF signal sources. The latest version of the PC software can be downloaded from the SigIQPro product page here.

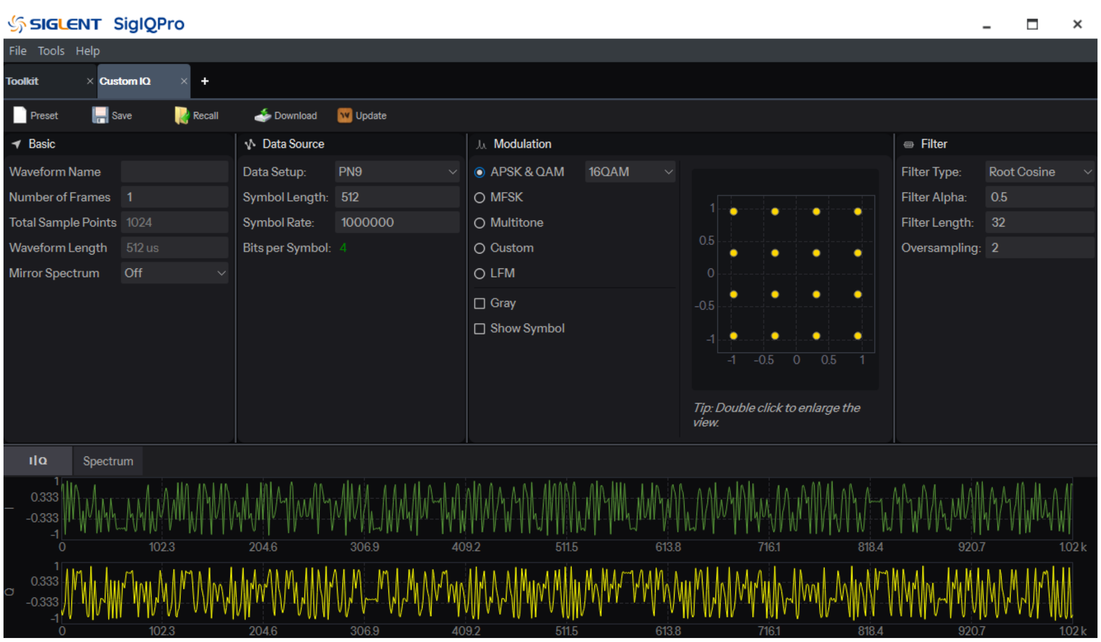
The current version at the time of this article is 2.0.0.2.5 and includes the following file type options:

Signal Option Model Name	Signal Description	Instrument Compatibility
SigIQPro-BT	Bluetooth Signals generation	SDG7000A with SDG7000A-IQ, SSG5000X-V, and SSG6082A-V
SigIQPro-IoT	IoT Signals generation	SDG7000A with SDG7000A-IQ, SSG5000X-V, and SSG6082A-V
SigIQPro-OFDM	Custom OFDM signal generation	SDG7000A with SDG7000A-IQ, SSG5000X-V, and SSG6082A-V
SigIQPro-5G NR	5G NR signal generation	SSG6082A-V
SigIQPro-LTE FDD	LTE FDD signal generation	SSG6082A-V
SigIQPro-LTE TDD	LTE TDD signal generation	SSG6082A-V
SigIQPro-IEEE.802.11.ax	IEEE.802.11.ax signal generation	SSG6082A-V
SigIQPro-IEEE.802.11.be	IEEE.802.11.be signal generation	SSG6082A-V
SigIQPro-IEEE.802.11 b/g/a/n/ac	IEEE.802.11 b/g/a/n/ac signal generation	SSG6082A-V
SigIQPro-GSM/EDGE	GSM/EDGE signal generation	SSG6082A-V
SigIQPro-WCDMA/HSPA+	WCDMA FDD HSPA/ /HSPA+ signal generation	SSG6082A-V

The SigIQPro software offers a number of free options for evaluation and testing with a signal generator. The toolkit section allows for import of CSV, MAT, or DAT files directly as IQ data. This is ideal for import and upload of custom signals engineers have created in other tools. This feature is permanently free and can be used without restriction:



Furthermore, the Custom IQ signal types can be used for free permanently with a Siglent RF signal generator. This includes definitions for all of the types of signals that are available from the instrument front panel with additional customizations available. Specifically, the SigIQPro interface can simplify the loading of custom data files and customized constellation definitions:

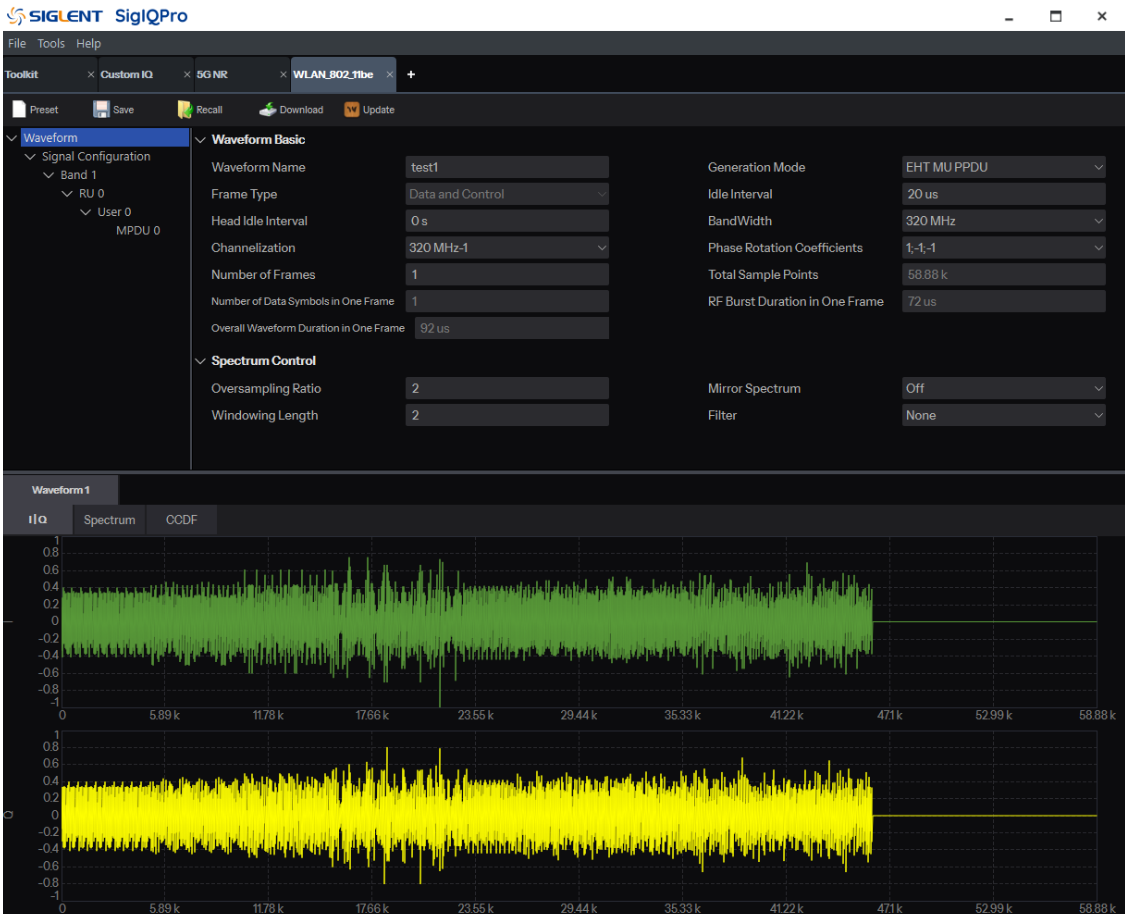


All other signal types from the option list above can be built and loaded from here as well. Each of these will create and upload 30 separate binary files to a specific serial number for free. After 30 files have been created and loaded to a specific instrument, engineers require the appropriate SigIQPro license for that type of signal.

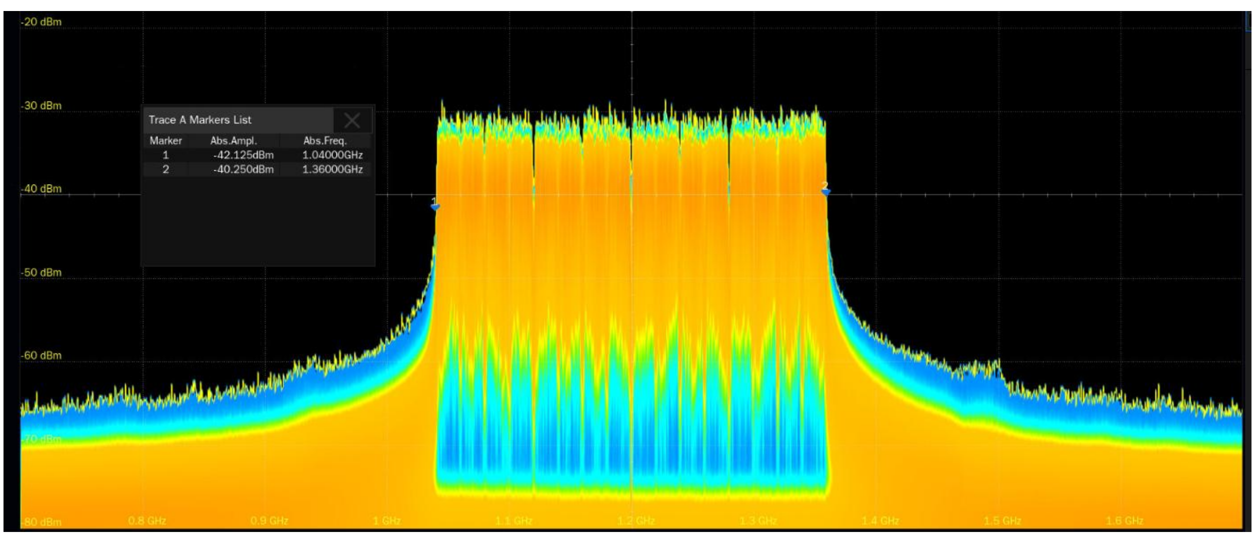
Licenses are tied to the instrument, so once an instrument SigIQPro license is purchased, signals can be loaded to that instrument from any number of PCs that may connect to that instrument with the software configured. This license toolkit facilitates engineering evaluations of signals and software, and in many cases, supports long term use without additional cost. Dynamic generation of custom signals over time requires the additional license purchase.

New signal types have significant customization and configuration requirements. Utilize these free trials to test the configuration capabilities of the software or generate signals in some other toolkit and import using the standardized tools.

Here is a view of the configuration window for a WLAN 802.11be signal in a 320 MHz channel:



And here is the resulting waveform in real-time:



SiglQPro provides a software platform for customizing and delivering complex signals to a RF signal generator. Standard custom IQ waveforms and the ability to import additional waveforms is free permanently. The software adds free trials for additional signal manipulation of each optional type. All of these included capabilities make SigIQPro an excellent signal evaluation and verification toolkit when partnered with a Siglent RF signal source.

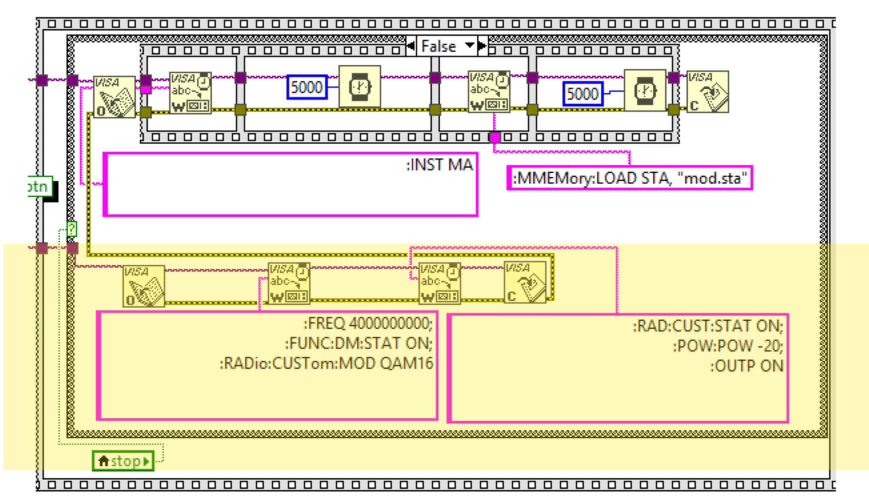
IQ Modulation Programming Examples

With the need for dynamic signal generation, interference, and complex RF environment tests, the ability to automate and process a variety of signals quickly is an important capability. Like all Siglent instruments, these RF signal sources utilize a SCPI text based API over USB or ethernet. Each series includes a programming manual that outlines how to communicate using these SCPI commands with the VISA protocol.

One critical aspect of automation for a signal generator like this is to dynamically load custom IQ files that may be saved internally or transferred from the SigIQPro software beforehand.

Let's look at a couple of basic signal configurations for these generators and the commands we use to set them up:

First, let's look at how to load and activate a QAM16 signal remotely to the instrument. Here is a view of the LabVIEW code. The highlighted area controls the generator:



In this vi, these 6 commands are sent in 2 batches:

:FREQ 4000000000 sets the center frequency to 4 GHz

:FUNC:DM:STAT ON activates the IQ modulation system

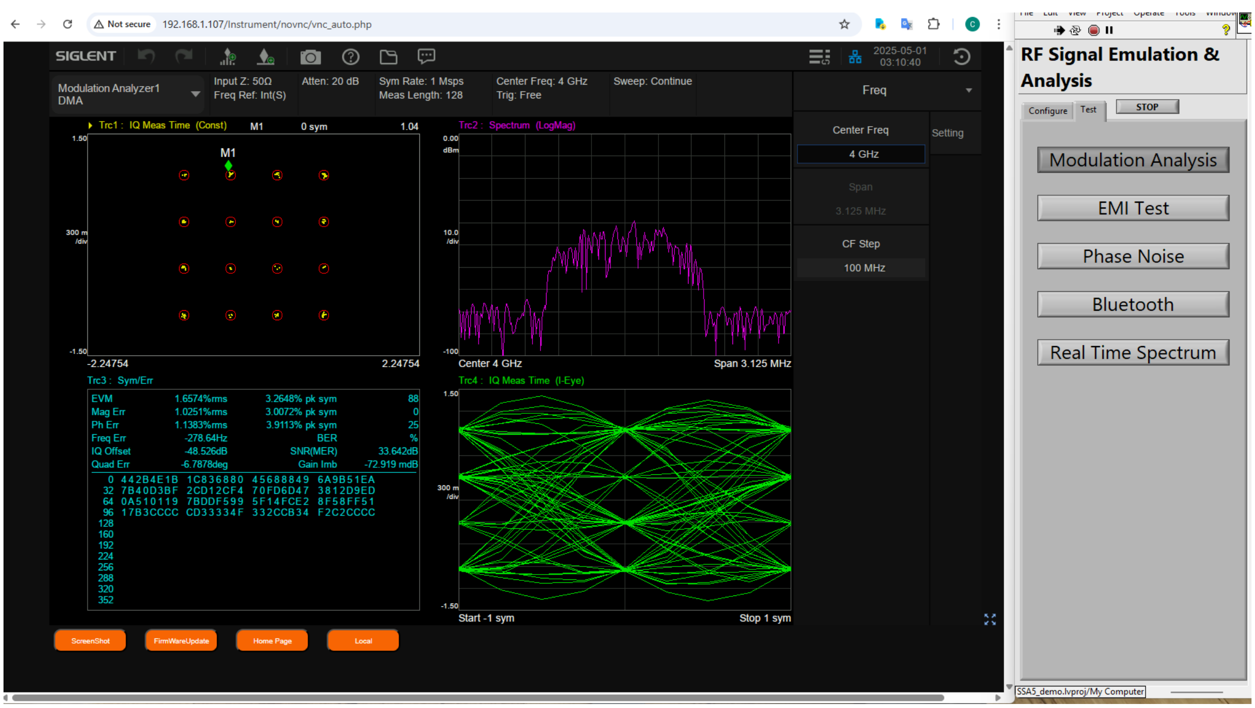
:RADio:CUSTom:MOD QAM16 sets the custom modulation to QAM16

:RAD:CUST:STAT ON activates the custom modulation system

:POW:POW -20 sets the power level to -20 dBm

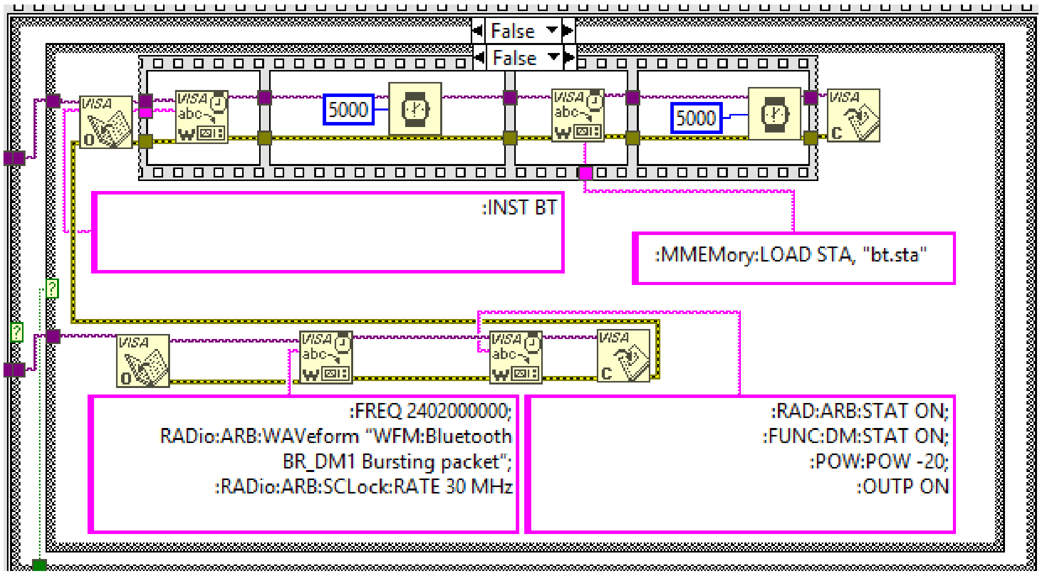
:OUTP ON turns on the generator main output

The code in that vi above the generator code sets up a SSA5000A spectrum analyzer to view the demodulated signal. This is achieved simply by loading the mode (MA for Modulation Analyzer) in this case and then loading a saved setup with all of the matching settings. The output of this code appears on the analyzer as:



Obviously, subtle changes to that code can adjust the modulation or turn off the IQ modulation operation.

Let's look more closely at a complex configuration for a Bluetooth signal:



This code shows the 8 commands necessary to load and execute a Bluetooth signal. Most important is the command to locate and load one of the preexisting Bluetooth arb files:

RADio:ARB:WAVeform "WFM:Bluetooth BR_DM1 Bursting packet"

Depending on the model, the command for loading the waveforms from the file system differ slightly.

Then to set the arb symbol clock rate: :RADio:ARB:SCLock:RATE 30 MHz

And finally, to activate the ARB radio system: :RAD:ARB:STAT ON

Consult the programming manual for the model generator you are using for complete programmatic control.