APPLICATION NOTE

Radar/EW Applications

Choosing the right emitter generation source

KEYSIGHT TECHNOLOGIES

Introduction

Choosing the right emitter generation source to use for testing an Electronic Warfare (EW) application is a challenging task. Some of the difficulty arises because that decision must be informed by the test engineer's own requirements, along with the nuances of each application, and that means that no one source is ideal in every situation. The other key reason for the difficulty is a lack of understanding. Most engineers simply don't have the expertise to know what types of sources to use and when. And this issue isn't just applicable to EW applications; it's applicable to all Radar applications (e.g., landing systems, weather maps, etc.). In fact, any engineer testing either Radar or EW applications will at some point require an emitter generation source; whether to simulate warfare environments, run scenario testing by sending pulses into an environment to see how they and their receive systems react, or perform some other testing.

While selecting the right source might be challenging, it's a challenge well worth undertaking since not making the right selection can have a number of negative consequences. The engineer might incorrectly specify the wrong equipment or select equipment that doesn't offer the capabilities needed to get the job done. Likewise, the engineer might inadvertently over specify the equipment; a potential costly mistake forcing the use of expensive, fully featured equipment for a job that could have easily been accomplished with older, less expensive equipment. Fortunately for any Radar/EW test engineer faced with this dilemma, there is now some general selection criteria that can be used as a quick reference. This criteria not only helps narrow down the decision making process, but also ensures existing assets are well utilized. Depending on the test requirements, multiple types of EW sources may be used simultaneously.

Source Types

Generally speaking, there are four different types of emitter generator sources currently available from vendors today. These include Agile Signal Generators, Vector Signal Generators (VSG), Arbitrary Waveform Generators (AWG), and Analog Signal Generators.

An Agile Signal Generator is a Direct Digital Synthesis (DDS) based, wideband source, with the ability to switch carrier frequencies at sub microsecond rates across its entire operating span. A VSG is a combination of an arbitrary waveform generator and source with an I/Q modulator for upconversion. This type of source offers a middle ground between ultra-wideband AWGs and Agile Signal Generators. An AWG is an Arbitrary Waveform Generator with different ranges of resolutions and sample rates. Finally, Analog Sources are signal generators that lack I/Q modulation capabilities, but can generate Continuous Wave (CW) signals with analog modulations.

Key Evaluation Parameters

When evaluating these four types of sources, a number of different attributes and capabilities should be considered. Eight key attributes for all sources include:

- **Phase Noise.** Phase noise is one of the most important figures-of-merit of a signal generating device and is a measure of its spectral purity. It can well be a limiting factor in mission-critical applications in aerospace and defense, such as Radar and EW, where it can mask relatively small signals close to a carrier's noise sidebands in multi-emitter environments, and falsely simulate clutter in Doppler applications (Figure 1).

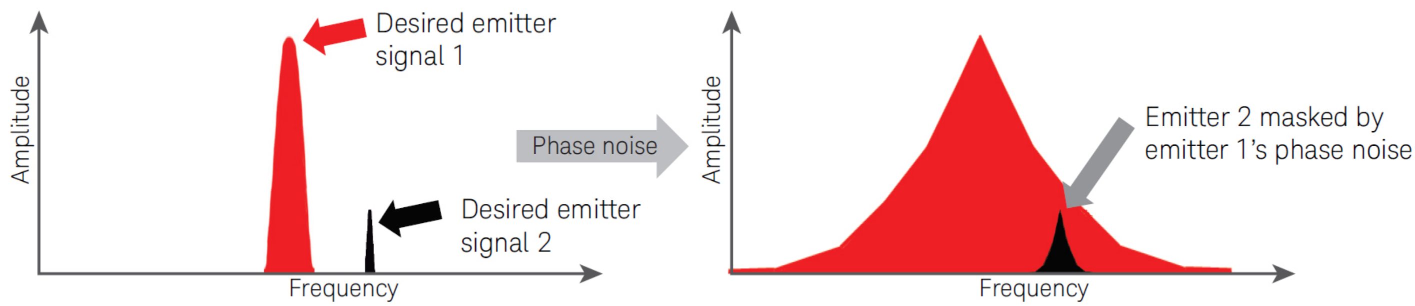


Figure 1. The phase noise profile of an emitter with relatively large amplitude is shown here masking a relatively low amplitude signal nearby.

- **Spurious Free Dynamic Range (SFDR).** SFDR is the ratio of the amplitude of the applied or fundamental signal generated by the source to the value of the strongest spurious signal in the output (largest harmonic). A high SFDR is vital in EW simulation to adequately test environments where large ranges of threat amplitudes may be present, as falsely generated threats create incorrect test scenarios (Figure 2). This is especially important in EW simulation due to the high sensitivities of receivers tested.

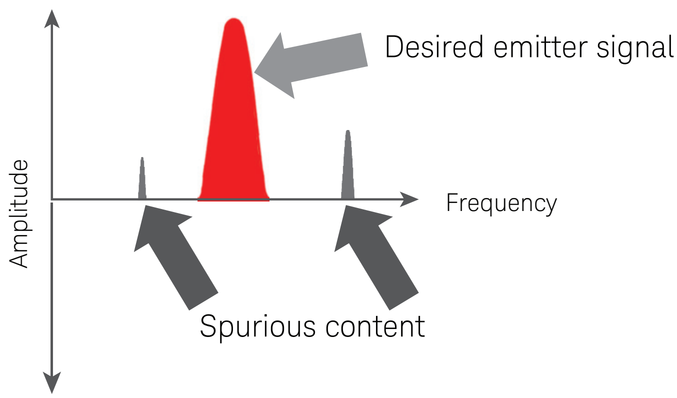


Figure 2. Spurious content can create false threats and Radar returns, resulting in incorrect test scenarios.

- **Amplitude.** Amplitude is a measure of signal strength. A large range of amplitudes is important to robustly simulate varieties of threats at different ranges and reflections. When using AWGs and Vector Signal Generators, amplitude capabilities are directly related to the resolution and quality of the Digital to Analog Converter (DAC) in the source, where each additional bit added to the Effective Number of Bits (ENOB) of the DAC can add approximately 6 dB of dynamic range to the source.

- **Pulse Switching Speed.** A source's pulse switching speed in frequency, phase and amplitude is important in EW testing for many reasons, such as adequately emulating an emitter's fast switching speeds, speeding up test times and higher pulse densities. Pulse density is the amount of pulses present in an environment per unit of time, so Agile sources with fast pulse switching capabilities can test more intense scenarios with less overhead (Figure 3).

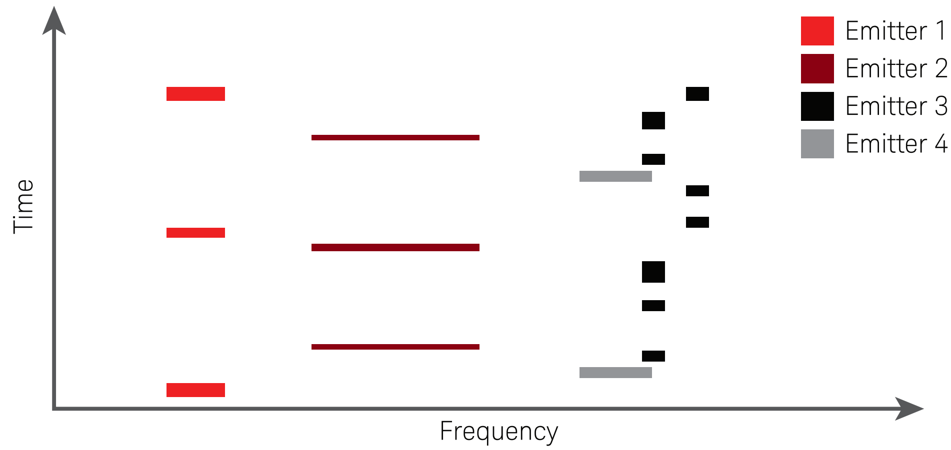


Figure 3. Pulse density is the amount of pulses present in an environment per unit time. A source with high switching speeds can have a higher pulse density and simulate more emitters.

- **Agile Range.** Agile range is the frequency range in which a source can switch at high rates. This parameter is important to know for two major reasons: pulse density coverage and coherency between emitter pulse changes. Agile range varies between source architectures and will be discussed more in later sections. Coherency between pulse changes is important to adequately simulate the phase of an emitter throughout a scenario due to the phase tracking of EW systems. For example, if a source was simulating two emitters at two different frequencies, the phase of both emitters' frequencies must be "remembered." That way, when the frequencies change, their phases should continue as if the frequencies were never switched (Figure 4).

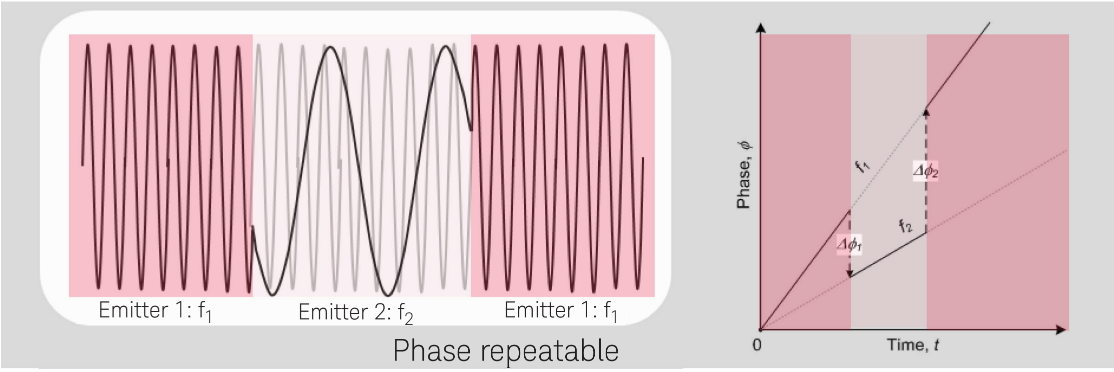


Figure 4. Two emitters at two different frequencies should maintain their phases to properly be simulated.

- **Modulation Bandwidth.** Modulation bandwidth is the modulation frequency range of the source. It affects rise times of pulses, as well as modulation parameters, such as an FM chirp's width and rate (Figure 5). VSGs and AWGs can output multiple emitters simultaneously within their modulation bandwidths, and their agile ranges are typically limited to whatever their bandwidths are for their given set frequency. A source's bandwidth depends on its DAC sample rate, as well as its analog characteristics (e.g., frequency band mapping).

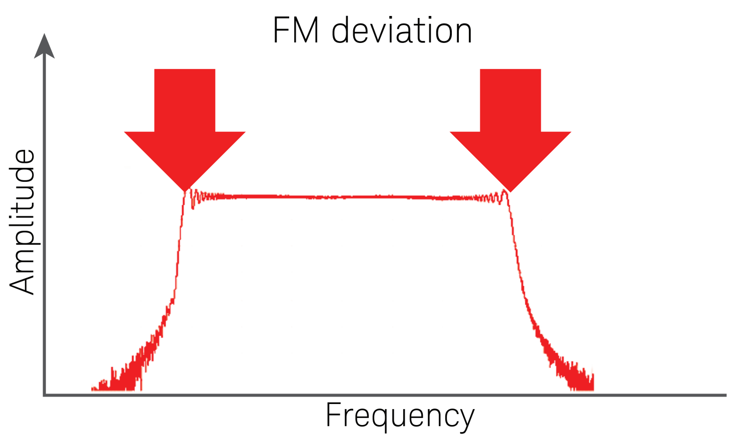
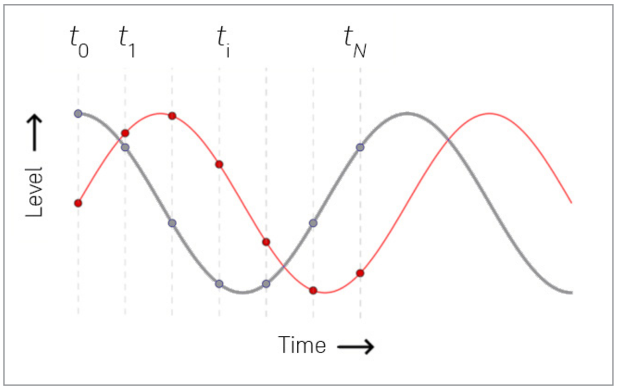


Figure 5. In order to correctly modulate this FM chirped signal, a source's modulation bandwidth must be greater than or equal to its frequency deviation.

- **Memory and Streaming Capabilities.** Scenario times in EW simulations can vary in time from microseconds to days. Because of this, sources must be capable of generating signals for these time lengths. Methodologies for such playback times vary in architecture and cost. For shorter play times, instruments often have internal memories to load I/Q data, or some compressed form of data that can be configured to be output on a particular event.

  Directly loading data to instruments can be adequate for shorter play times, but as sample rates and scenario lengths increase, and hardware in the loop requirements arise, additional memory saving architectures and schemes must be used. One way sources can extend playtimes with limited memory is with sequencing and digital upconversion, which can index different memory segments to be indexed and looped, or change carrier frequencies depending on events such as software commands, or lower latency triggering. Depending on the scenario requirements, sequencing memory can significantly increase play times of signals.

  Another memory saving technique used involves data compression. If the instrument can abstract parameters of a signal that are common to all other signals, such as pulse width and modulation type, then fewer bits would be required to adequately describe the signal. EW has a common method of compressing emitter description data—Pulse Descriptor Words (PDW). PDW formats vary between systems and organizations, but they share enough of a commonality where this descriptor format is quite adequate in describing EW emitters. In many uses cases, usage of a PDW instead of I/Q data can reduce memory requirements by a few orders of magnitude, as well as simplify waveform programming (Figure 6).



*Time(us)	Frequency(MHz)	Power(dB)	Phase(rad)	Phase Mode	Markers	Dwell(us)	Pulse Mode	Pulse Width(us)	Chirp Rate(MHz/us)	Chirp Shape
0	10000	0	0	Coherent	ALL	100	On	0.01	0	
100	10000	0	0	Coherent	NONE	100	On	0.02	0	
200	10000	0	0	Coherent	NONE	100	On	0.03	0	
300	10000	0	0	Coherent	NONE	100	On	0.04	0	
400	10000	0	0	Coherent	NONE	100	On	0.05	0	
500	10000	0	0	Coherent	NONE	100	On	0.06	0	
600	10000	0	0	Coherent	NONE	100	On	0.07	0	
700	10000	0	0	Coherent	NONE	100	On	0.08	0	
800	10000	0	0	Coherent	NONE	100	On	0.09	0	
900	10000	0	0	Coherent	NONE	100	On	0.1	0	
1000	10000	0	0	Coherent	NONE	100	On	0.11	0	
1100	10000	0	0	Coherent	NONE	100	On	0.12	0	
1200	10000	0	0	Coherent	NONE	100	On	0.13	0	
1300	10000	0	0	Coherent	NONE	100	On	0.14	0	
1400	10000	0	0	Coherent	NONE	100	On	0.15	0	
1500	10000	0	0	Coherent	NONE	100	On	0.16	0	
1600	10000	0	0	Coherent	NONE	100	On	0.17	0	
1700	10000	0	0	Coherent	NONE	100	On	0.18	0	
1800	10000	0	0	Coherent	NONE	100	On	0.19	0	
1900	10000	0	0	Coherent	NONE	100	On	0.2	0	
2000	10020	-10	0	Coherent	NONE	100	On	0.2	100	Sawtooth
2100	10020	-10	0	Coherent	NONE	100	On	0.4	50	Sawtooth
2200	10020	-10	0	Coherent	NONE	100	On	0.6	33.33333333	Sawtooth
2300	10020	-10	0	Coherent	NONE	100	On	0.8	25	Sawtooth
2400	10020	-10	0	Coherent	NONE	100	On	1	20	Sawtooth
2500	10020	-10	0	Coherent	NONE	100	On	1.2	16.66666667	Sawtooth
2600	10020	-10	0	Coherent	NONE	100	On	1.4	14.28571429	Sawtooth
2700	10020	-10	0	Coherent	NONE	100	On	1.6	12.5	Sawtooth
2800	10020	-10	0	Coherent	NONE	100	On	1.8	11.11111111	Sawtooth
2900	10020	-10	0	Coherent	NONE	100	On	2	10	Sawtooth
3000	9960	0	0	Coherent	NONE	100	On	0.01	0	
3100	9960	-2	0	Coherent	NONE	100	On	0.02	0	
3200	9960	-4	0	Coherent	NONE	100	On	0.03	0	
3300	9960	-6	0	Coherent	NONE	100	On	0.04	0	
3400	9960	-8	0	Coherent	NONE	100	On	0.05	0	
3500	9960	-10	0	Coherent	NONE	100	On	0.06	0	
3600	9960	-12	0	Coherent	NONE	100	On	0.07	0	
3700	9960	-14	0	Coherent	NONE	100	On	0.08	0	
3800	9960	-16	0	Coherent	NONE	100	On	0.09	0	
3900	9960	-18	0	Coherent	NONE	100	On	0.1	0	

Figure 6. Data compression techniques such as PDWs can dramatically decrease memory requirements and simplify waveform creation Instead of using I/Q data (left), waveforms can be described in spreadsheets and loaded faster programmatically.

For ultimate timing flexibility, a source should have the ability to stream signals from an external controller running a simulator or a memory unit such as a RAID array. Depending on the data scheme, bandwidth can often be either a limiter or cost driver in a streaming source. However, using memory compression techniques such as PDWs can be a very effective workaround, as less data is required to output the same signals.

- **Synchronization Capabilities.** Many times, EW sources must be time and phase coherent, as multiple instruments may be used to output a common emitter, and different receiver tests may require multiple common wavefronts within sub-nanosecond time differences. The ability for signal sources to be time and phase coherent across multiple units is something that should also be looked at for potential expandability of test systems. Not only is sharing clocks and Local Oscillators (LOs) in different sources a necessity in such test requirements, but the ability to modify triggering and output times both repeatably and precisely is also just as important.

Source Type Selection Criteria

The following general selection information is provided as a means of comparing various aspects and specifications of the four different types of emitter generator sources when trying to determine which is most appropriate for use with a given application.

Agile signal generators

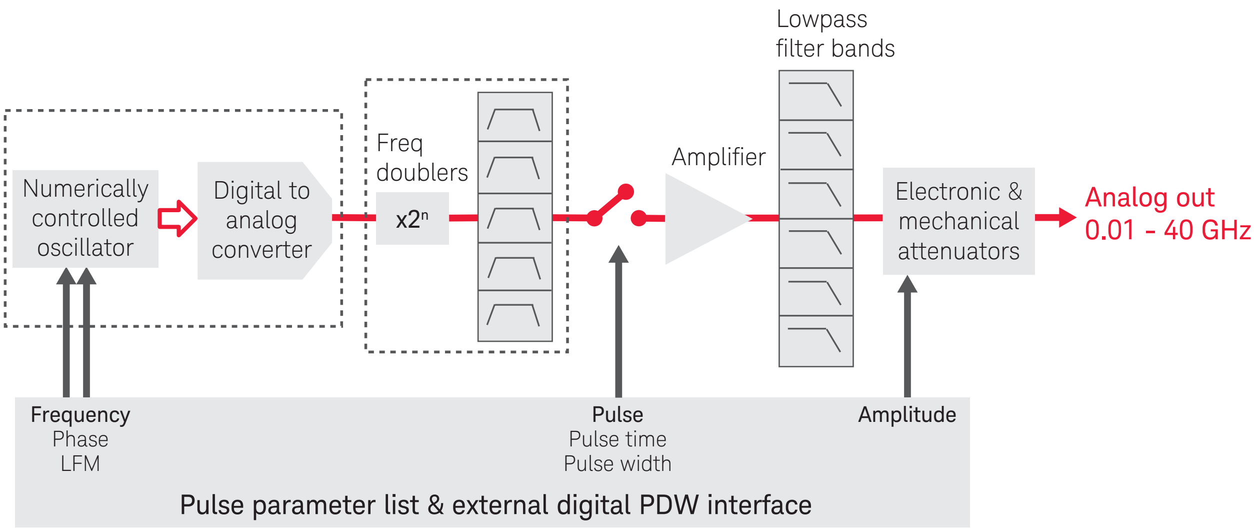


Figure 7. A typical Agile Signal Generator block diagram is shown here.

Use Cases: These types of sources are used to simulate single or multiple emitters across very wide frequency spans and fast hopping LOs in subsystems (Figure 7). Because of their DDS architecture, they can also be tightly synchronized for multi-channel testing.

Pros: Agile Signal Generators offer unparalleled performance in many EW Simulation use cases. Because of their DDS architecture, they can be phase coherent and/or continuous across their entire span, and synchronization of multiple instruments can be done easily and with very high resolution. Also, Agile Signal Generators can utilize PDW formats to describe the signals they output, allowing for streaming at sub microsecond update rates. As a result, they can emulate multiple emitters across their entire span and across multiple sources with potentially infinitely long playback times.

Cons: The drawback to Agile Signal Generators is that they output PDWs on a First In, First Out (FIFO) basis, meaning that one instrument cannot output two simultaneous PDWs. This is less of a concern with low-duty cycle emitters. The test engineer can output simultaneous PDWs and drop fewer pulses by adding another Agile Signal Generator and then synchronizing (Figure 8), however, this may be less cost effective given the requirements of the system.

Key attributes

- Frequency range: 10 MHz to 40 GHz
- Modulation BW: 3 GHz
- Coherent/continuous across entire range (10 MHz to 40 GHz)
- Channels: 1 to 6 coherent
- PDW Update rate: 180 ns to 30 µs
- Data scheme: PDW-Based (highly compressed)
- PDW throughput, from datasheet:
- Minimum width = 4 ns
- Update rate = 180 ns
- Max. rate = 1/(minimum width+ update rate) = 1/(184 ns) = 5.4348 MPDW/sec
- Time resolution: 10 ps
- Streaming capability

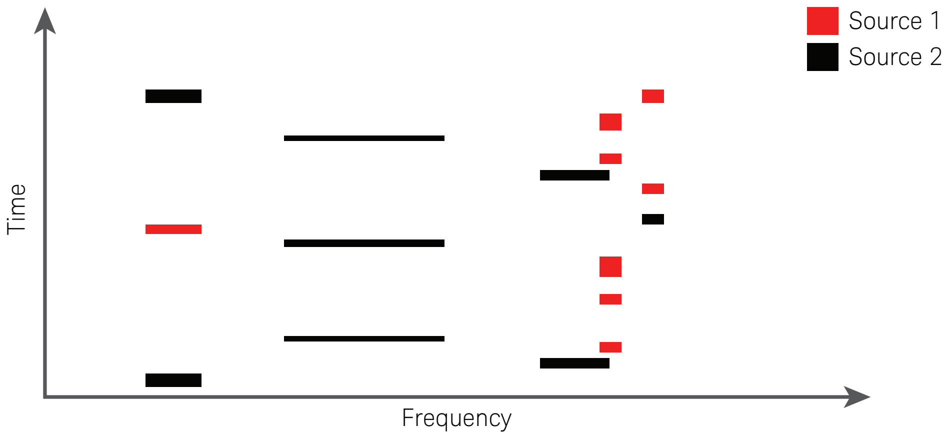


Figure 8. Shown here is a pulse density scenario implemented with Agile Signal Generators. To prevent dropped pulses, PDWs are spread across two synchronized sources.

An example of an Agile Signal Generator is the Keysight Technologies, Inc. N5193A UXG Agile Signal Generator (Figure 9).

Figure 9. The N5193A UXG is a high-performance Agile Signal Generator designed for EW test with high-performance streaming, PDW switching and synchronization capabilities.

Vector signal generators

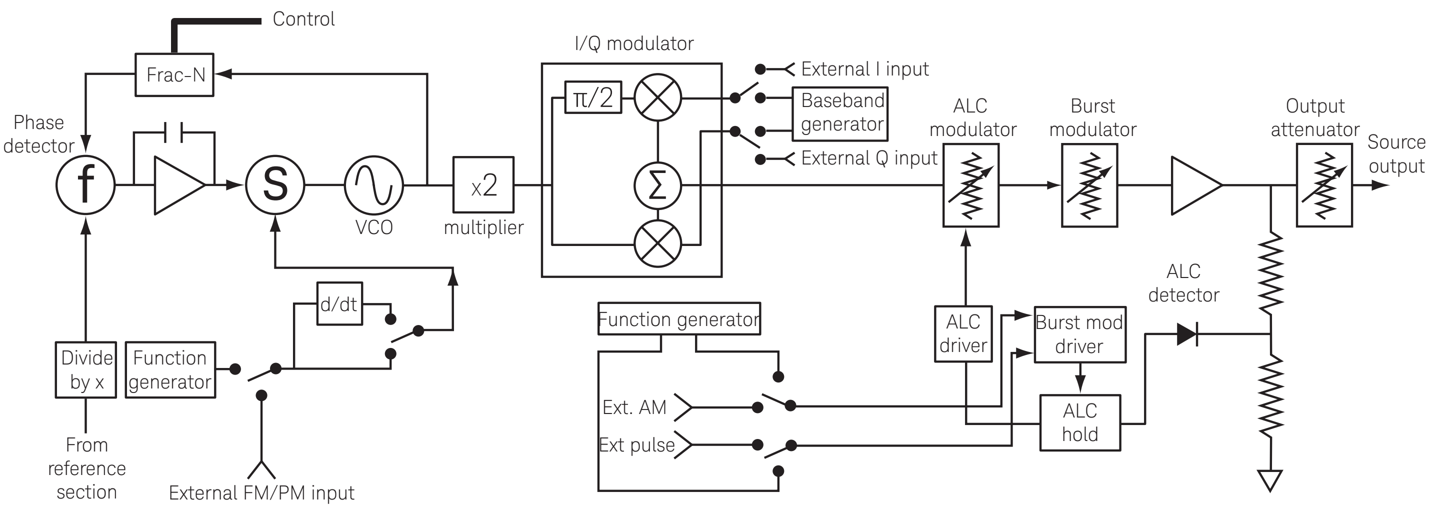


Figure 10. Shown here is a block diagram of a typical vector signal generator. A Vector Signal Generator comprises a frequency synthesizer with an I/Q modulator that gives it the capability to create vector modulated (also known as digital or complex) signals, hence the name Vector Signal Generator.

Use Cases: VSGs are used to generate single emitters with different modulation bandwidths, or multiple emitters that are spaced closely together. A typical block diagram for a Vector Signal Generator can be seen in Figure 10. VSGs are often used to simulate a specified bandwidth due to their architectures. They can vary in their frequency ranges and bandwidths, and higher performance solutions can drive the I/Q modulator of a vector source with a high-performance AWG for very wideband capabilities of up to a few gigahertz.

Pros: Due to their higher resolution DACs, VSGs offer higher dynamic range than ultra-wideband AWGs. They can also output multiple simultaneous signals at once, although the dynamic range of each simultaneous signal will be impacted on these events. And, they can be used to simulate communications signals in test environments, adding to their versatility. If they are I/Q data based, they can provide more flexibility for factors such as environmental effects. Streaming of lengthy recordings is also possible with VSGs.

Cons: These types of sources upconvert a baseband signal generated to a fixed carrier frequency and are only coherent across their modulation bandwidth. Consequently, they can only emulate multiple emitters along their modulation bandwidth. As an example, if a carrier frequency is set to 20 GHz and the modulation bandwidth is 2 GHz, then the wideband VSG can only effectively operate from 19 to 21 GHz (Figure 11). Also, if the source uses uncompressed I/Q data to describe the signal, it limits playback and streaming capabilities, and adds complexity to describing the signal. Furthermore, most VSGs will lose their phase repeatability if they change their carrier frequencies.

Key attributes

- Frequency range: 100 kHz to 44 GHz
- Sample rate: Up to 12 GSa/s,
- Time resolution: down to 83.3 ps
- Modulation bandwidth: up to 2 GHz
- Coherent/continuous across modulation bandwidth
- Memory: Up to 2 Gsa with sequencing and streaming capabilities
- Amplitude resolution: Up to 16 bits
- Channels: 1 to 6 coherent
- Data scheme: I/Q based

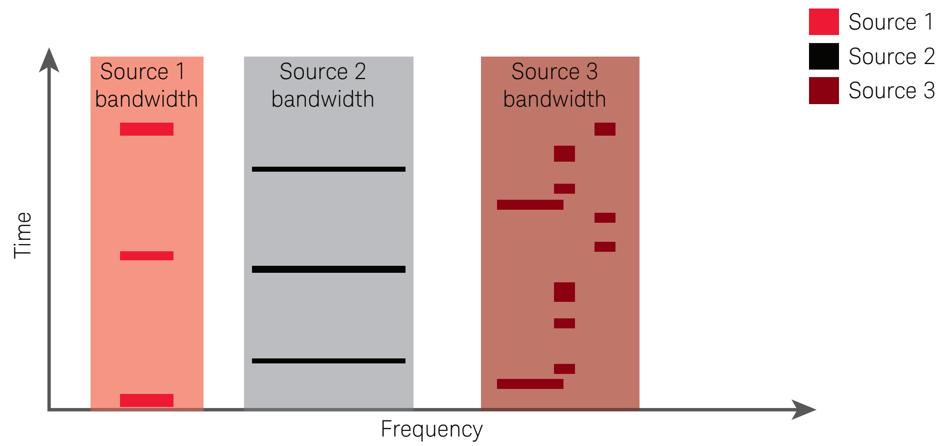


Figure 11 Shown here is a pulse density scenario implemented with wideband Vector Signal Generators. Due to the limitations of their bandwidths, the scenario must be split across three wideband VSGs. The first emitter's bandwidth requirements allow for a source with an internal modulator, while the bandwidth and pulse update rates require an external high-performance AWG to drive the modulator.

Some examples of Vector Signal Generators are shown in Figures 12-14.

Figure 12. The Keysight N5182B MXG Vector Signal Generator can generate signals up to 6 GHz with modulation bandwidths of up to 160 MHz. It also has the capability to be linked to multiple MXGs to create multiple, coherent signals for multichannel applications.

Figure 13. The M9381A can generate signals up to 6 GHz with modulation bandwidths up to 160 MHz. Its modular form factor allows it to synchronize with multiple M9381As in a space saving manner.

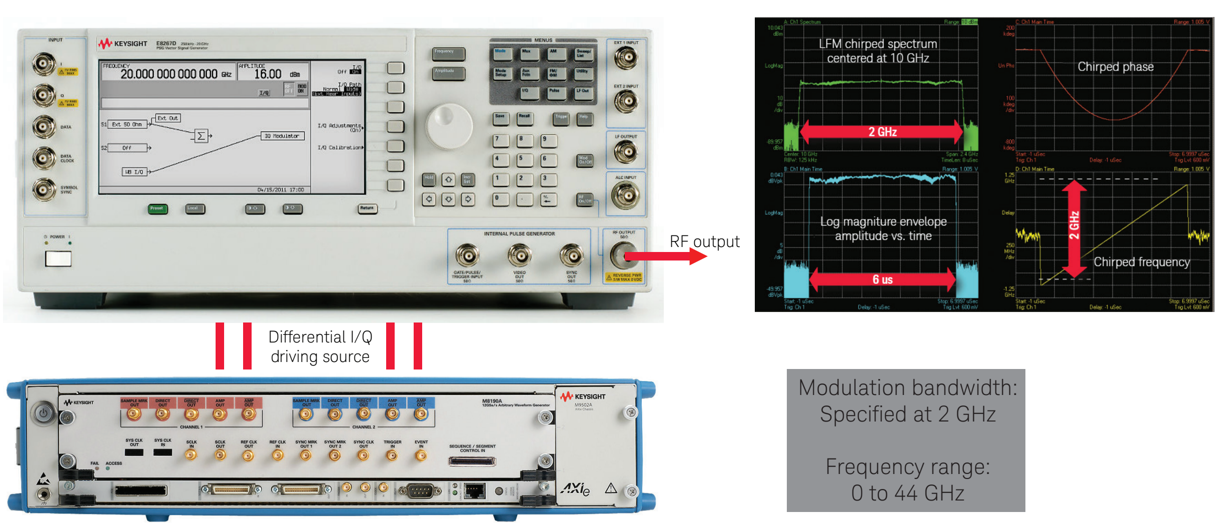


Figure 14. Driving a Vector Signal Generator with the high-performance M8190A Arbitrary Waveform Generator allows for a system with a frequency range of 0 to 44 GHz and 2 GHz of modulation bandwidth, as well as multi-channel synchronization and memory capabilities that include sequencing, streaming and digital upconversion.

Ultra-Wideband AWGs

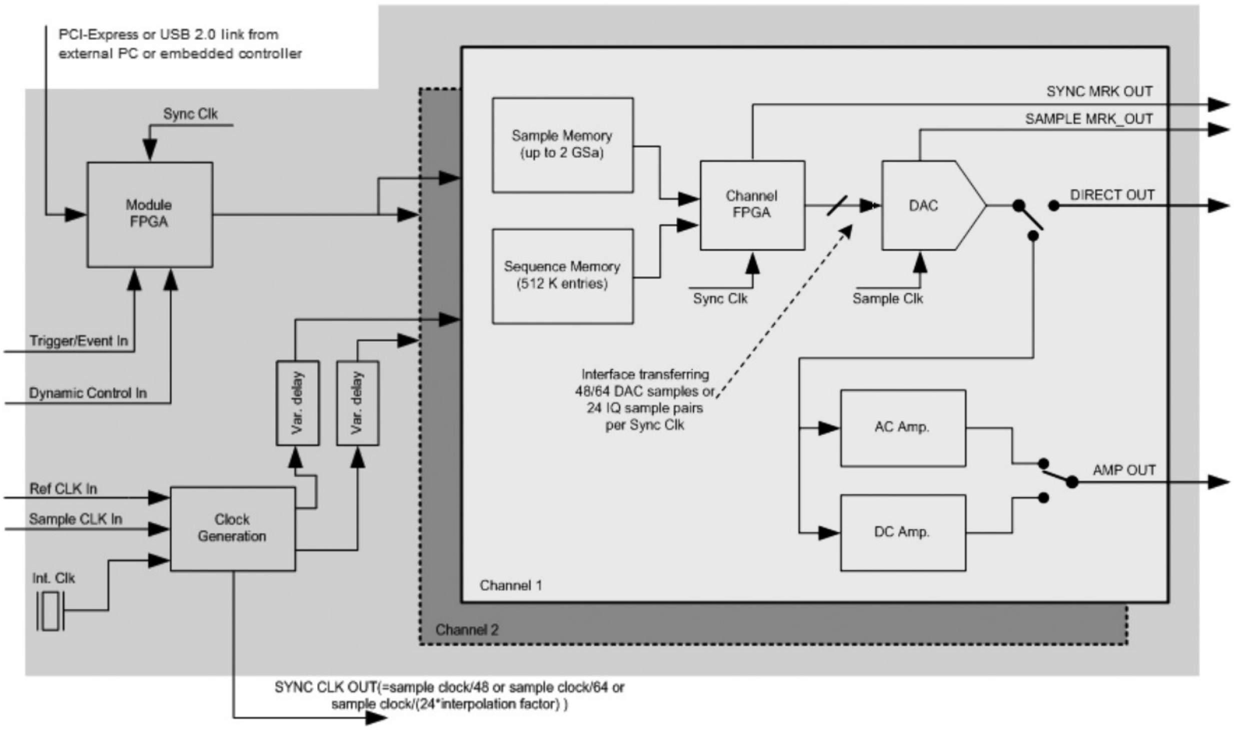


Figure 15. Modern Arbitrary Waveform Generators are comprised of much more than DACs. Such new capabilities involve memory sequencing, clock sharing for synchronization, and different output paths to optimize signals depending on the application. Shown here is the block diagram for the high-resolution M8190A Arbitrary Waveform Generator.

Use Cases: Arbitrary Waveform Generators can vary in regards to sample rate and resolution, and those two parameters are often times inversely related (Figure 15). AWGs with higher sample rates will have lower resolutions than those with lower sample rates, and vice-versa. AWGs can be used to simulate high density Radar signals and communications signals within their bandwidths.

Pros: Ultra-wideband AWGs have extremely wide bandwidth, which allows for the generation of single and multiple emitters across wide frequency spans. High resolution AWGs can output signals with high dynamic range within narrower bandwidths. Key capabilities include support for simultaneous pulses (pulse-on-pulse) and the ability to modify I/Q data to allow for environmental effects. Multiple channels can also be synchronized rather easily for tests requiring multiple coherent channels.

Cons: In contrast to other source types, ultra-wideband AWGs tend to have lower resolution and dynamic range. They also have shorter playtimes due to their extremely high sample rates. High resolution AWGs have lower bandwidths, although they can be upconverted using the correct hardware as discussed in the section on Vector Signal Generators (Figure 16).

Key attributes

- Sample rate: Up to 65 GSa/s
- Time resolution: Down to 15.39 ps
- Analog bandwidth: Up to 20 GHz
- Memory: Up to 16 Gsa with sequencing and streaming capabilities
- Resolution: 8 bits to 14 Bits
- Channels: Up to 12
- Maximum output power: 10 dBm
- Phase coherent across entire span (up to 20 GHz)
- Data scheme: I/Q based

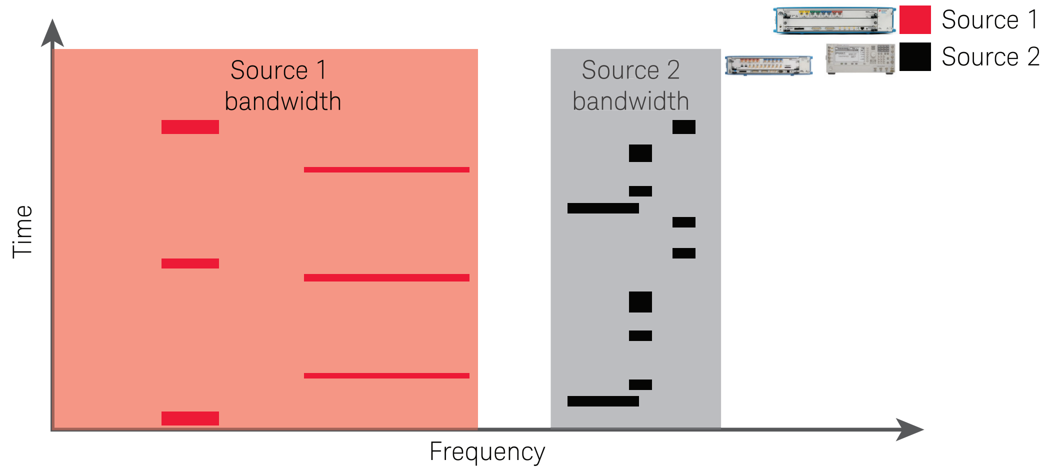


Figure 16. This pulse density scenario is implemented with Arbitrary Waveform Generators. Due to the limitations of their bandwidths, the scenario must be split across two sources. The second source must be upconverted by driving an I/Q modulator of a Vector Signal Generator. It is worth noting that, because of the high sample rate and lower relative dynamic range of the Ultra-Wideband AWG used as source 1, the play time is shortened dramatically and the signal quality may not be as good as other sources.

Some examples of Ultra-Wideband AWGs are shown in Figures 17 and 18.

Figure 17. The M8195A is a high performance, 8-Bit Arbitrary Waveform Generator with sample rates of up to 65 GHz and an analog bandwidth of 20 GHz.

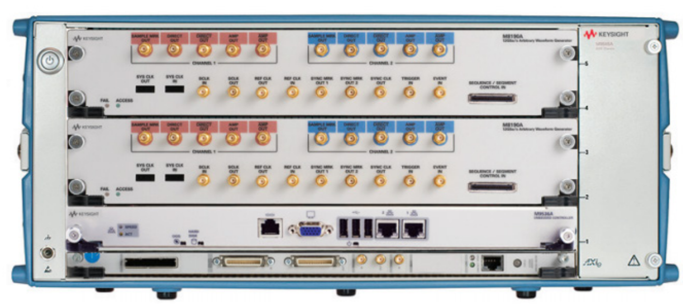


Figure 18. The Keysight M8190A 12 GSa/s is a high-resolution AWG with up to 14 bits of resolution that can support up to 12 synchronous channels with sub nanosecond time adjustments, which are important capabilities in multi-channel test scenarios. Shown here are four channels synchronized to such levels on a four-channel oscilloscope.

Analog sources

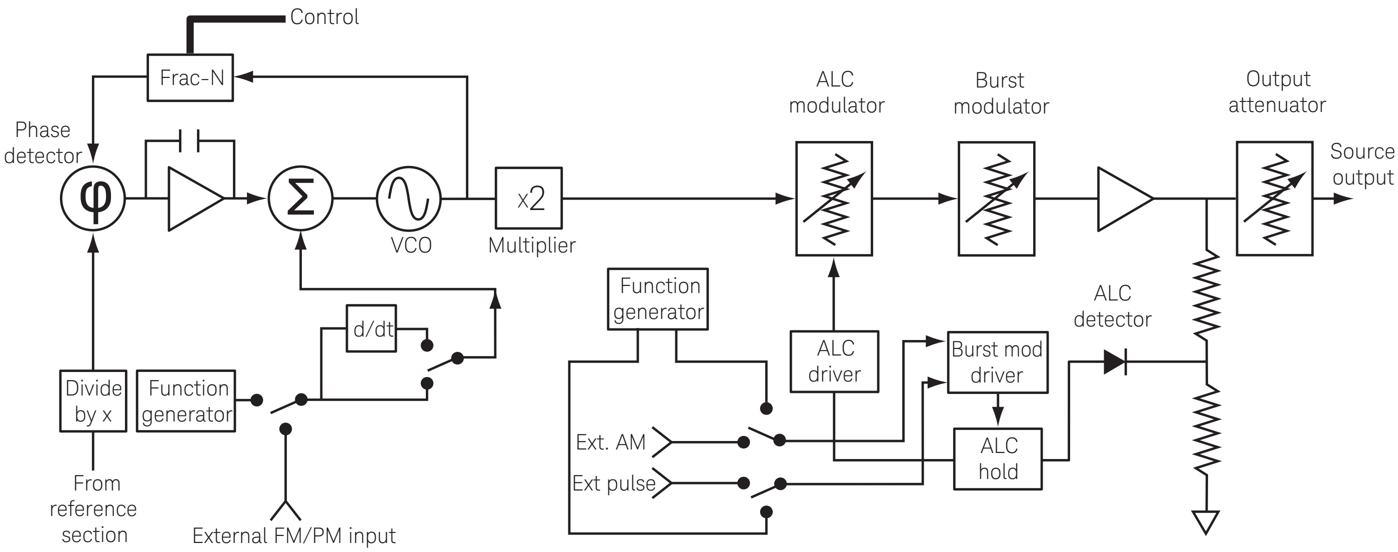


Figure 19. Shown here is a typical Analog Signal Generator block diagram. Analog Signal Generators lack I/Q modulators, but most have the capability to perform analog modulations such as frequency, amplitude, and phase, as well as pulse modulation, hence the name Analog Signal Generator.

Use Cases: Analog Sources can be used as cost-effective simulator tools for generating pulsed signals with lower pulse repetition intervals (PRIs). They often have analog modulation capabilities so they can be used for generating modulated signals, as well as for CW jamming sources in scenarios.

Pros: The benefit to using Analog sources is their cost and simplicity. Although they cannot generate arbitrary waveforms, they can be a cost effective solution in adding less complex signals to a test scenario. (Figure 20).

Cons: Analog Sources lack the vector signal generation capabilities of the other sources mentioned, and are therefore limited in the types of waveforms they can create.

Key attributes

- Frequency range: 100 kHz to 67 GHz
- Amplitude range: up to 30 dBm
- Modulation types: FM, PM, Pulsed, AM
- Power and frequency sweep capabilities

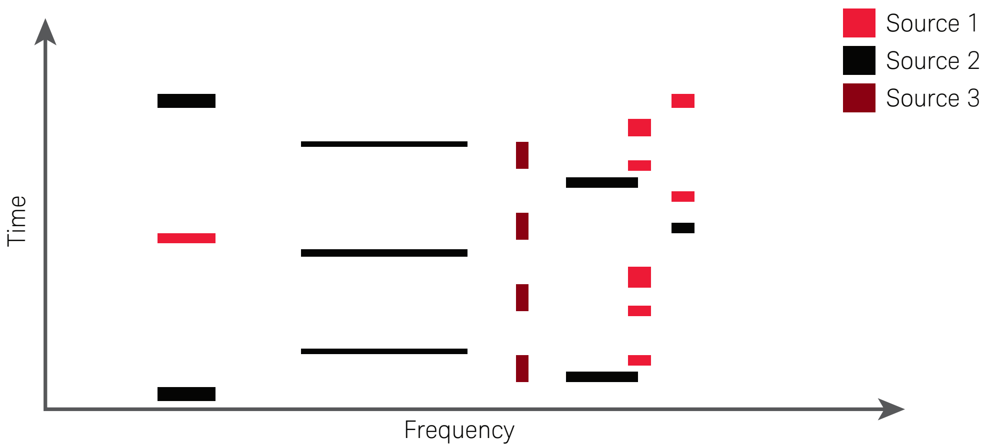


Figure 20. Revisiting the example scenario, adding a lower performance analog source when possible can decrease costs. Shown here, an additional emitter can be simulated with a less expensive analog source (purple).

An example of an Analog Source is shown in Figure 21.

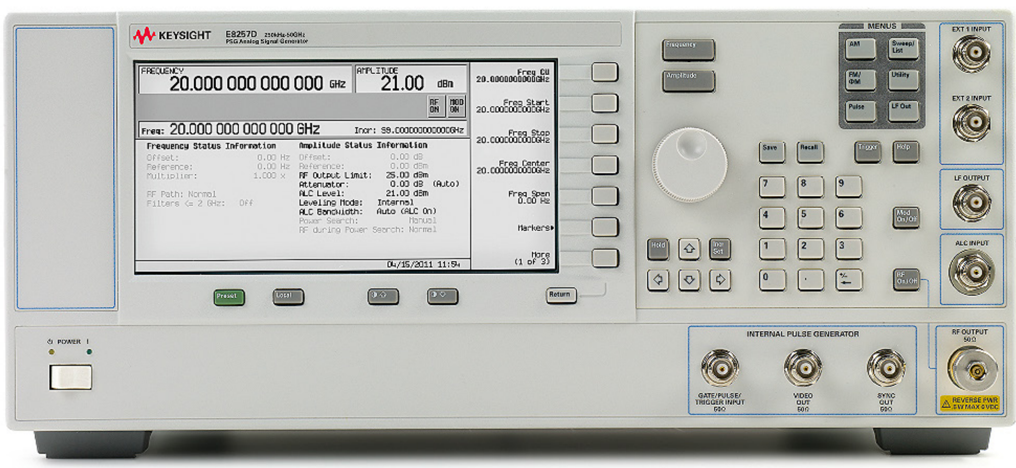


Figure 21. The E8257D Analog Signal Generator has a frequency range of 100 kHz to 67 GHz, as well as analog modulation capabilities.

Important Questions to Ask

In addition to the major metrics outlined for EW sources, there are a number of questions that should be considered when trying to determine which source is most appropriate for a given scenario. These questions, along with the related instrument capabilities to consider, include:

Question 1: What are the frequencies of the emitters in my scenario?
Metrics to consider: agile frequency range, frequency range, pulse switching speed, and synchronization capabilities

Question 2: What are the modulation types and modulation bandwidths of those emitters?
Metrics to consider: modulation bandwidth, agile frequency range, and pulse switching speed

Question 3: What are the RF performance requirements of my scenario?
Metrics to consider: amplitude range, frequency range, spurious free dynamic range, phase noise, and amplitude resolution

Question 4: How long is the scenario?
Metrics to consider: memory, sequencing, streaming, I/Q data compression, and sample rate

Question 5: How many channels will exist in my scenario?
Metrics to consider: synchronization capabilities, agile frequency range, and modulation bandwidth

Question 6: What is the pulse density (pulses per second) of my scenario?
Metrics to consider: agile frequency range, frequency range, pulse switching speed, synchronization capabilities, memory, sequencing, streaming, I/Q data compression, sample rate, phase noise, spurious free dynamic range

In addition to these questions, a table like that shown in Table 1 can be very helpful when choosing a source for a given test scenario.

Table 1. This table summarizes some of the main attributes of the examples referenced in the source type comparisons.

	M8195A **Arbitrary waveform generator**	**M8190+E8267D** **Vector signal generator**	**N5193A** **Agile signal generator**	**E8257D** **Analog signal generator**
Frequency range (GHz)	0-20	0-44	.01-40	0.0001-67
Modulation bandwidth (GHz)	20	2[1]	3[2]	N/A
Memory (GSa)	16	2+ 80 MHz Streaming	2 GPDWs+ Full BW Streaming	N/A
Resolution (bits)	8	12/14[3]	n/a	N/A
Sample rate (GSa/s)	65	12	n/a	N/A
Data scheme	I/Q based	I/Q based	PDW	N/A
Channels	1-4 (2-I/Q pairs)[4]	1-12[5]	1-N[5]	N[5]
Max amplitude (dBm)	10	23	10	30
Coherent across channels	Yes	Yes	Yes	Yes
Agile bandwidth	20 GHz	4 GHz	40 GHz	N/A
Source retune time	15.4 ps	35 ms	180 ns/30 µs[6]	35 ms

1. Center frequencies >3.5 GHz
2. Banded frequency filters
3. Sample rate dependent
4. 4-channel card that can run with 2, I/Q pairs
5. Number of channels dependent of design
6. Depends on band crossings of frequencies
7. Bandwidth where PDW update rate and coherency is maintained
8. Analog

Conclusion

When testing Radar and EW applications, choosing the right emitter generation source is crucial. Selecting the wrong source can mean incorrectly specified or over specified equipment and access to wrong or missing capabilities. Selecting the right source, on the other hand, can lead to better measurement results and allows for proper utilization of existing assets. Using the selection criteria offered in this application note can serve as an essential guide in helping test engineers explore their options in deciding configurations for emitter sources.

Related Literature

Solutions for Wideband Radar and Satcom Measurements, Application Note, literature number 5990-6353EN

*8 Hints for Making Better Measurements Using Analog RF Signal Generator*s, Application Note, literature number 5967-5661E

8 Hints for Making Better Measurements Using RF Signal Generators, Application Note, literature number 5988-5677EN

Electronic Warfare Signal Generation: Technologies and Methods, Application Note, literature number 5992-0094EN