Emulating 2.4 GHz Signal Behaviors to Characterize transceiver systems

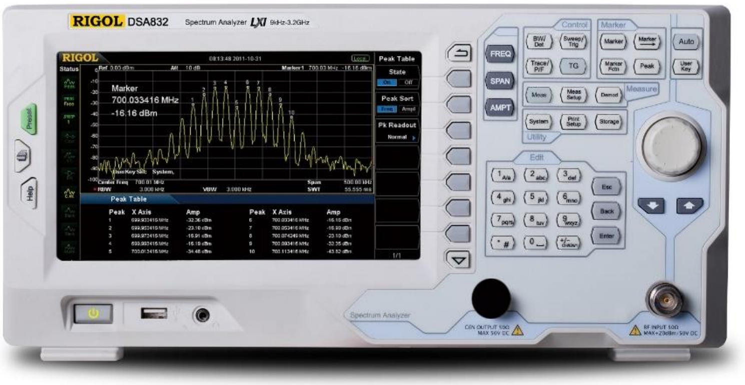


Figure 1: Rigol DSA832 3.2 GHz Spectrum

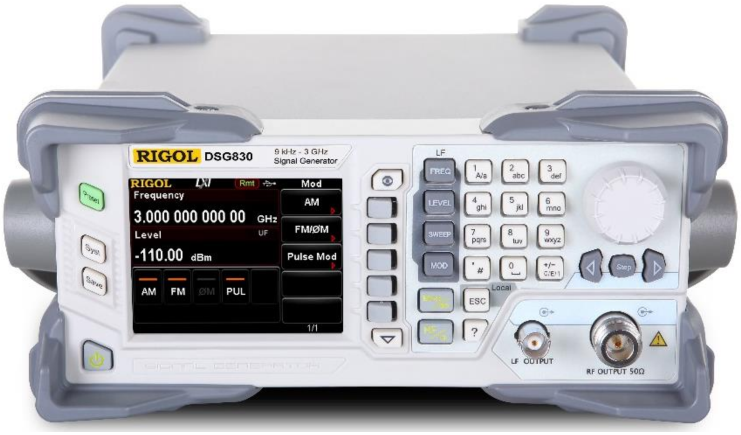


Figure 2: Rigol DSG830 Series RF Signal Source

Defining a Process for characterization

Today, more engineers are working with a wider variety of RF signals than ever before. From ubiquitous Wi-Fi and Bluetooth signals to simpler data transmissions using spread spectrum technology devices utilizing radio frequency communication continue to expand. With this explosion in use and application more engineers new to RF need to characterize and optimize their own transceiver designs.

In this application note, we will walk through the key phases of testing on a new RF device before bringing it to market. While there are many tests that can be conducted in the name of transceiver evaluation, we will focus on tests in the 2.4 GHz band that give us direct feedback on the strengths and weaknesses of the RF design while also being straightforward and cost effective to conduct. In these tests, we will establish the characteristics of our system, conduct stress tests, inject noise, and finally test external source interference.

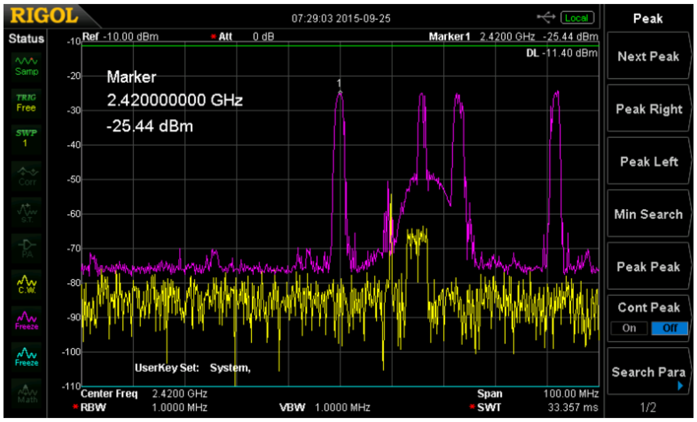
We will also review techniques and instrument capabilities that can be used in these different tests and discuss the advantages and limitations of each approach.

An experimental approach to testing RF device integration

For these types of characterization studies, we will begin with a basic experimental process:

1. *Capturing* the RF signal
2. *Reproducing* the data
3. *Generating* the modulation
4. *Emulating* the complete RF environment

Our primary capture tool is a spectrum analyzer. Other instruments can be used to test and verify data before it is added to the carrier, but when it comes to monitoring RF a spectrum analyzer is usually a great place to start. We will use a DSA832 Spectrum Analyzer **(Figure 1)** to begin our investigation of our Transmitter-Receiver pair. Later, we will be using our DSG830 3 GHz RF Signal Source **(Figure 2)** to generate, emulate, and interfere with our devices based on what we learn from the signal investigation. Then, we will test specifics of duplicating the underlying data by adding an oscilloscope and waveform generator to the test system.



07:29:03 2015-09-25

Ref -10.00 dBm Att 0 dB

Marker1 2.4200 GHz -25.44 dBm

DL -11.40 dBm

Marker
2.420000000 GHz
-25.44 dBm

UserKey Set: System,

Center Freq 2.4200 GHz

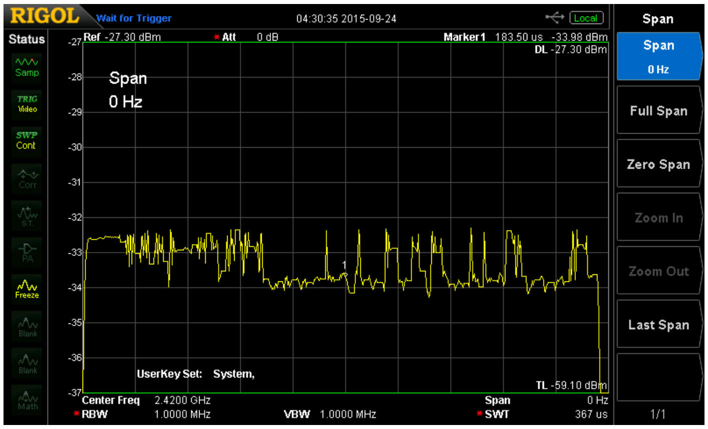
RBW 1.0000 MHz

VBW 1.0000 MHz

Span 100.00 MHz

SWT 33.357 ms

Figure 3: 2.4 GHz band Max Hold capture in purple with last sweep in yellow



Wait for Trigger

04:30:35 2015-09-24

Ref -27.30 dBm Att 0 dB

Marker1 183.50 us -33.98 dBm

DL -27.30 dBm

Span
0 Hz

UserKey Set: System,

TL -59.10 dBm

Center Freq 2.4200 GHz

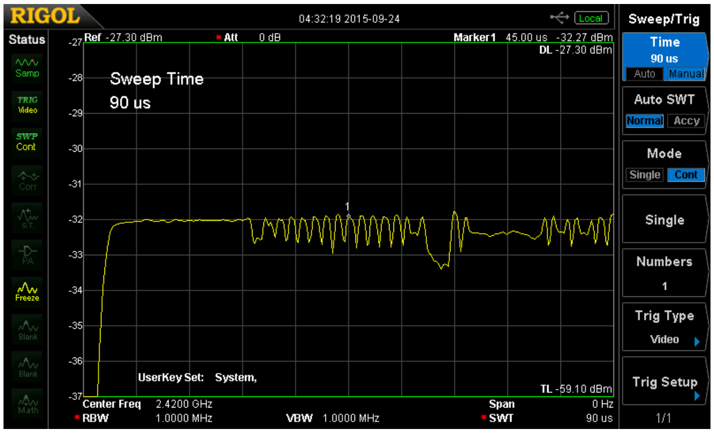
RBW 1.0000 MHz

VBW 1.0000 MHz

Span 0 Hz

SWT 367 us

Figure 4: Zero span capture of RF pulse from our test device - approximately 350 usec long



04:32:19 2015-09-24

Ref -27.30 dBm Att 0 dB

Marker1 45.00 us -32.27 dBm

DL -27.30 dBm

Sweep Time
90 us

UserKey Set: System,

TL -59.10 dBm

Center Freq 2.4200 GHz

RBW 1.0000 MHz

VBW 1.0000 MHz

Span 0 Hz

SWT 90 us

Figure 5: higher resolution capture of RF signal in zero span mode

Our test device is a commercially available remote control toy which operates on a spread spectrum signal in the 2.4 GHz band. When we start testing we don't know much else about this device.

Capturing the RF Signal

Using the DSA832 spectrum analyzer with a basic antenna we can easily view the RF power signal using max hold to capture the pulses **(Figure 3)**. We can see that there may be a number of devices in the lab operating in this range, but experimentally we see that the thin spikes correlate to activation of our remote. We can see that the transmitter is moving the carrier to different channels as part of its spread spectrum algorithm to maintain connection in crowded bandwidth.

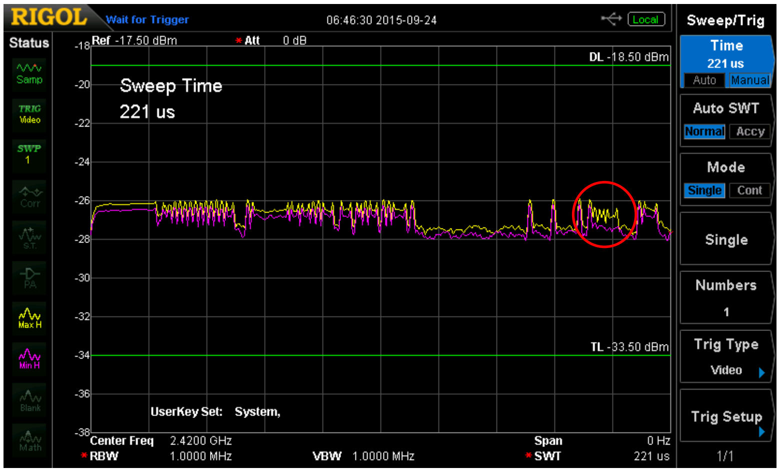
We set the center frequency to the peak we select at 2.42 GHz. Now, we can switch into zero-span mode on the analyzer. This allows us a time domain view of the signal. We can also use a trigger line to align the signal for viewing. Now we can adjust the sweep time in zero span to set the time across the display. Once we capture the signal we can see that it is a pulse of 350 microseconds encoded with data **(Figure 4)**.

This step is important because it explains how the RF signal is changing over time which is how it is being modulated. This means that data is being encoded in these changes. Just looking at the frequency content is not enough to understand what is being transmitted by this device.

To get a clearer view of this data we want to make sure our RBW is set to a wide bandwidth such as 1 MHz. This enables us to view the data changes over time with as little attenuation as possible. This is the best way to sample the data as it was sent and will benefit us later when trying to duplicate the data and emulate the RF signals.

Then we can adjust the time window down further to zoom in on the signal. **Figure 5** shows the close up view of the beginning 90 microseconds of this pulse. This shows more clearly the header for this pulse that includes a series of high bits followed by some alternating 1s and 0s that may help the receiver to align to capture the rest of the data.

Further evaluation of these pulses demonstrates that they are highly repetitive even with different controls being activated on the transmitter. **Figure 6** highlights the data segment that appears to correlate with control input changes. There is a 20 microsecond segment that changes consistently. This is therefore a good area to remember during emulation, functional verification, and interference testing.



Ref -17.50 dBm Att 0 dB

DL -18.50 dBm

Sweep Time
221 us

TL -33.50 dBm

UserKey Set: System,

Center Freq 2.4200 GHz Span 0 Hz

RBW 1.0000 MHz VBW 1.0000 MHz SWT 221 us

Time 221 us

Numbers 1

Figure 6: Capture highlighting data change based on control input

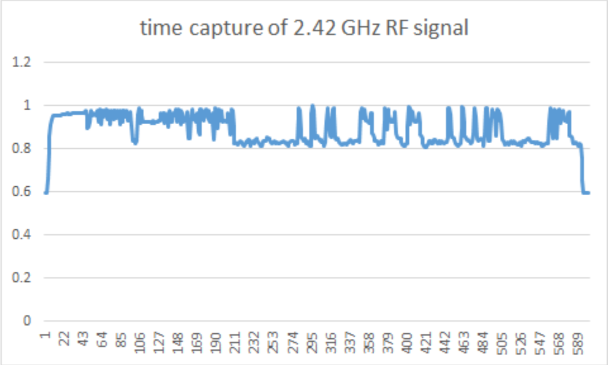
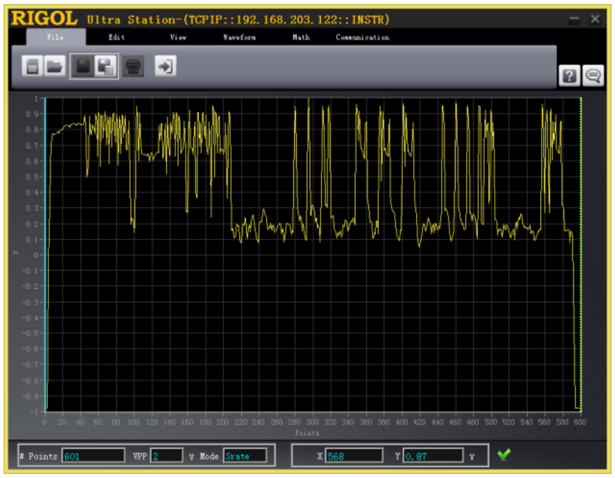


Figure 7: Microsoft Excel chart view of an arbitrary wave created from a spectrum analyzer capture



Ultra Station-(TCPIP::192.168.203.122::INSTR)

Points 601 VPP 2 V Mode Srate

X 568 Y 0.87 V

Figure 8: UltraStation view of an arbitrary wave created from a spectrum analyzer capture

Reproducing the encoded data

Now that we have identified and captured the basic output format of our transmitter, the next step in our testing is to reproduce the data the receiver is expecting to see during normal operation. Then, we will test some other configurations to learn as much as we can about the stability and functionality of our RF connection.

The best way to reproduce this data so that we can then put it back onto our own carrier is to create it in an arbitrary waveform. We will use the Rigol DG1062Z waveform generator to output the desired wave. The high fidelity signal capabilities of the DG1062Z should be more than capable of reproducing our captured data stream. It is important to have a generator with 2 coordinated output channels. This will make it possible to align multiple modulation types as we emulate different interference and noise.

We generate the arbitrary wave by viewing the zero span captures on the spectrum analyzer then exporting that data to a CSV file we can view in Microsoft Excel (**Figure 7**). From there we can manipulate it as needed and create the arbitrary wave in the UltraStation software **(Figure 8)**.

Generating the modulation

Now we have a sample of the signal we want to encode on the carrier. The data is clearer the more you zoom in on the signal, but it is also important to understand the limitations of how you will later emulate the signal. To understand these relationships more completely, look at the modulation schemes available on the DSG800 series RF signal source and their respective pros and cons in the appendix at the end of this application note.

Now we will take the data we have recovered from our capture and use the arbitrary waveform as an input to a series of modulation schemes. Then, we will complete more advanced emulations by adding noise and interference.

First, we will use the list sweep function to emulate a pulse at 36 msec wide. Then we can add AM signal modulation to this in the form of our arbitrary wave. We can start the sweep and the arb simultaneously by using the trigger in for the sweep and the external modulation input for AM.

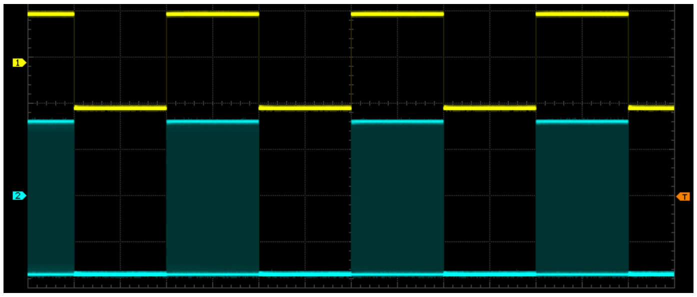


Figure 9: Oscilloscope view of aligned waveforms for modulation inputs

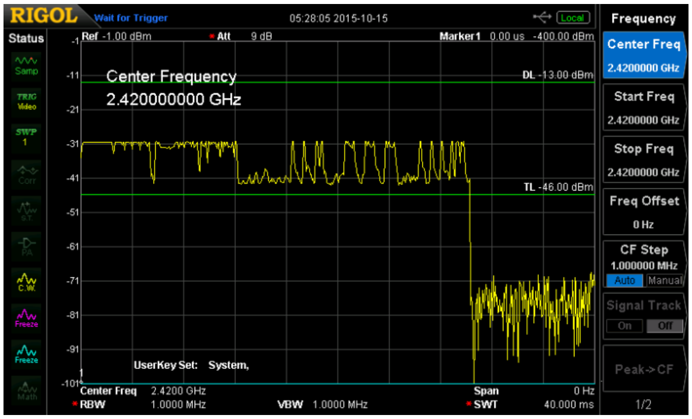


Figure 10: Time domain capture of a signal using sweep and AM modulation functions

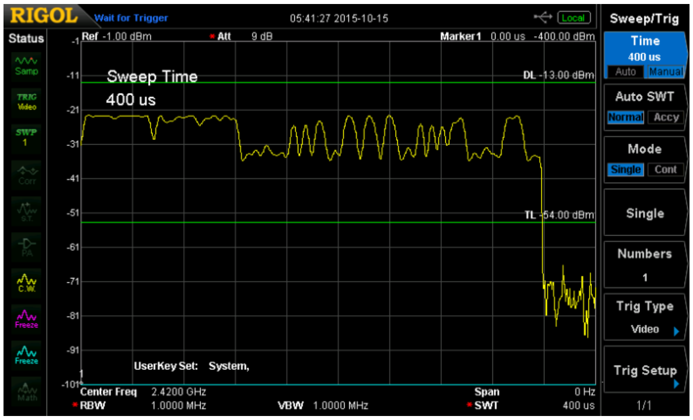


Figure 11: Example of Pulse and AM modulation creating a data stream on a 2.42 GHz signal

Coordinating the timing is simple because the generator handles this automatically. We want them to align as shown in **Figure 9**. Channel 1 in yellow shows the trigger transition to execute the sweep when channel 2 (blue) shows the modulation shape. This is the same alignment we will use later on the pulse settings, but in that mode we can attempt quicker pulses. **Figure 10** shows the output of our signal source as a slowed down swept and AM modulated signal. This is a high quality signal, but is being generated here two orders of magnitude slower than the original.

Another approach to interfering with the transmitter/receiver connection would be to use the pulse modulation to simulate faster transmissions. In this mode, we can create the same 350 usec pulses we saw from the device's transmitter and add AM modulation to it. The AM modulation doesn't provide as much bandwidth as the original signal had so you can simulate attenuation of the data stream (**Figure 11**) and see its effect.

Emulating the complete RF environment

Now that we have tested the signal generation through different modulation schemes then we want to characterize our device especially with added noise or interference.

Using the generator we can easily switch from using our arb signal to modulating with only noise. This provides a different type of potential interference for our device and is shown in **Figure 12**.

There are several methods we can use to inject different types of noise into this pulse that will potentially confuse or interfere with the receiver or the transmitter / receiver connection in different ways. **Figure 13** shows 3 separately captured pulses overlaid. The yellow trace shows just our data arb being used as the AM source. The purple trace shows an FM square wave being injected for noise as well as the AM data and the overall pulse. The blue trace shows phase modulation injected during the pulse instead of the FM injection. These all have similar bandwidth on the modulation, but they interfere with the primary signal in different ways.

If we need to test even higher speed noise or signals, there is a multi-instrument configuration worth discussing. We can use our synchronized pulses to create dual pulse modulations on separate DSG830 instruments. Since, they are overlapping they appear as a pulse signal with a faster pulse modulating on top utilizing the additional bandwidth capabilities of pulse mode for the data pulse. This creates the high bandwidth digital signal emulation shown in **Figure 14**.

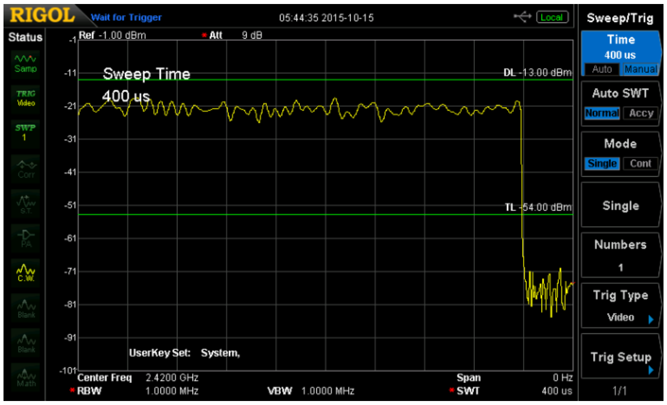


Figure 12: Time domain capture of a signal using pulse and AM modulation functions with AM noise

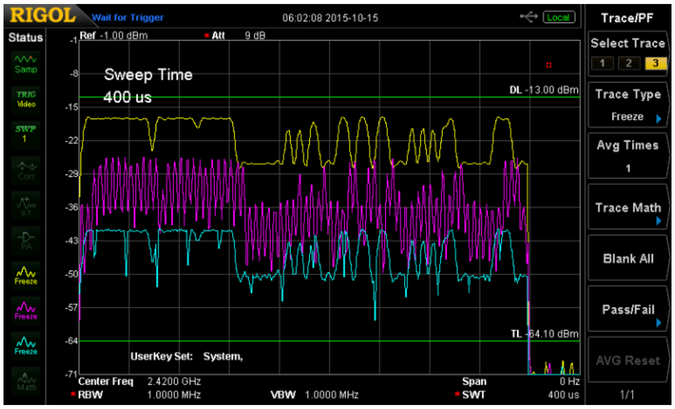


Figure 13: Examples of Pulse modulation and AM data modulation mixed with FM or Phase modulation noise

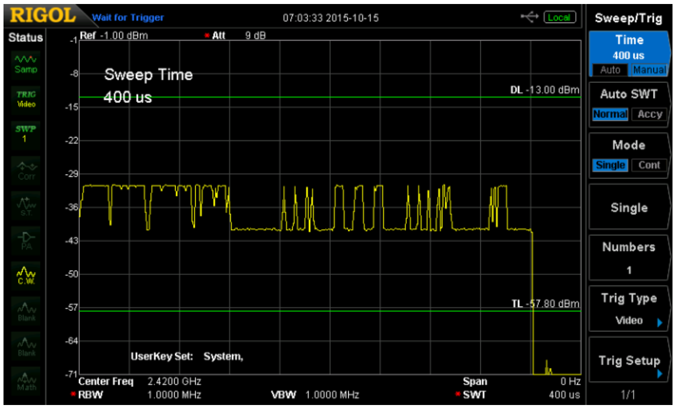


Figure 14: Example of high frequency emulation using dual instrument pulsing

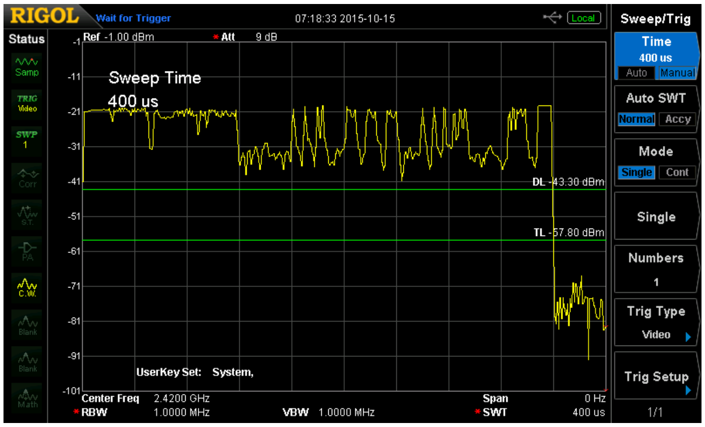
Additional modulation capabilities

More complex signals might utilize phase as well as amplitude to encode data. IQ or Quadrature modulation is a common example of this. To emulate IQ modulation signals upgrade to the DSG3030 generator. This generator has the same user interface and function set as the DSG800 with all of the options, but adds the capability to do IQ modulation as well. This includes an internal IQ generator as well as baseband outputs allowing you to create high bandwidth encoded signals on a 2.42 GHz carrier with precise amplitude control. To learn more about IQ emulation check out our app note. **Figure 15** shows IQ emulation of the signal with the arbitrary wave driving only the I or Q data input. In this way we use it like simple high bandwidth amplitude modulation. If you actually encoded the data as true IQ signals it would be impossible to view the data on a standard spectrum analyzer because all the phase data between I and Q is ignored by the instrument.

All of these separate methods provide interference and noise in the signal that can cause problems for our test device. The transceiver demonstrated difficulty synchronizing with its control signal when other similar signals were present, but was largely able to maintain a stable connection once made due to the spread spectrum techniques that moved the signal to other carrier frequencies in the band. In addition to interference, rudimentary control of the remote device would be possible with deeper examination of the data encoding being used and clearer high bandwidth captures of the modulation. The DSG800 series and companion products used here provide uncompromised capabilities for interference and emulation testing of 2.4 GHz transceiver systems at an unprecedented value.

Device Integration in the IoT Design Cycle

One of the challenges IoT engineers face is integrating multi-node networks. A system’s nodes may include sensors, actuators, or indicators communicating over a wireless link. The emulation and modulation requirements described in this application note are core to this process. Rigol products are specifically designed to meet the needs of engineers in IoT development.



Ref -1.00 dBm Att 9 dB

Center Freq 2.4200 GHz Span 0 Hz

RBW 1.0000 MHz VBW 1.0000 MHz SWT 400 us

Figure 15: Example of emulation and interference signals using IQ on the DSG3030

modulation	Approximate bandwidth	Pros	Cons
Sweep	50 Hz	Convenient amplitude and frequency control	Slow update speed
AM	100 kHz	Complete amplitude control	Limited data rates
FM	100 kHz	Control variation over multiple frequencies	Limited data rates
Phase Mod	100 kHz	Complete phase control	Limited data rates
Pulse Mod	100 MHz	High speed and 70 dB difference between 2 states	No fine amplitude control; on or off

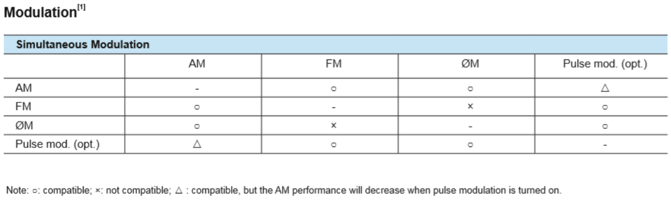
Figure 16: DSG800 Modulation Capabilities Table

Appendix: Modulation Capabilities of the DSG800 Series Signal Source

The DSG800 can natively implement AM, FM, and Phase modulation. There are also options available for pulse and pulse train modulation. For amplitude, frequency, or phase modulation the instrument can internally generate a modulation shape of sinusoidal or square. Sine modulation can be set from 10 Hz to 100 kHz while square modulation can be set from 10 Hz to 20 kHz. Any of these modulations can also be defined from the external input. This is what we will do with our waveform generator. The bandwidth of the external modulation input is also 100 kHz.

Pulse modulation is higher bandwidth but does not enable fine amplitude control. It is a binary on/off pulse. When the pulse input or internally generated pulse value is high, then the RF output is on, otherwise it is off. The DSG800 provides >70 Db difference between the 2 states. The 10-90% risetime for the pulse modulation is typically 10 ns providing significantly more bandwidth than the other modulation formats. We can also utilize the sweeping function of the DSG800 as a type of modulation. Earlier we used a list sweep with one step at a high level value and the others low to create a pulse event. The minimum time for a sweep step is about 20 msec, but the flexibility to create other shapes and use the sweep function in conjunction with other modulations provides some powerful versatility for testing overall system stability. Sweeps can also be triggered externally.

Some modulations can be used together. Here is the table that explains those capabilities:



Modulation[1]

Simultaneous Modulation				
	AM	FM	ØM	Pulse mod. (opt.)
AM	-	○	○	△
FM	○	-	×	○
ØM	○	×	-	○
Pulse mod. (opt.)	△	○	○	-

Note: ○: compatible; ×: not compatible; △ : compatible, but the AM performance will decrease when pulse modulation is turned on.

Another important note here is that AM, FM, and Phase share one external input, so they can not simultaneously modulate from separate external input values. Pulse has a separate input so pulse and one other modulation can use separate external signals. Additionally, sweep can be used with any combination of these modulations. When considering which modulation or capability to use consult the table in **Figure 16**.

Find more information online

DSG800 Family RF Signal Sources Information page

DSG3000 Family RF Signal Sources Information page

DSA800 Family Spectrum Analyzers Information page

DG1000Z Family Waveform Generators Information page

For more information on our waveform generators or other products please go to **rigolna.com** or contact us directly at ***applications@rigoltech.com*** or call us toll free at **877-4-RIGOL-1.**

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