Keysight Technologies
Solutions for WLAN 802.11ac Manufacturing Test

Application Note

Testing 802.11ac Client and Infrastructure Devices Using a Fast, Flexible and Cost-Effective Calibration and Non–Signaling Verification Solution

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Overview

The number of wireless devices on the market these days is exploding and, as a result, so too has the number of users—many of whom now carry multiple wireless devices (e.g., cell phone, laptop or tablet). More and more, these devices are providing functionality beyond the ability to just make calls or surf the Internet. That trend, along with today's countless other media-rich applications, is pushing current bandwidth availability to its limit and driving the need for wireless technologies capable of increasing bandwidth capacity.

One such technology, 802.11ac, promises to deliver the higher data rates necessary to meet consumers ever increasing data demands. Unlike other standards being rolled out, it achieves this relatively cheaply by leveraging the same 5-GHz technologies that are now well established with 802.11n. With the standard's mandatory set of features, a very high throughput of greater than 1 Gbps can be achieved. When its optional features are implemented, peak data rates up to 6 Gbps can be supported. 802.11ac achieves these data rates by building on 802.11n with four key enhancements:

- – Wider channels: 40- and 80-MHz channels are mandatory, with optional support for a contiguous 160-MHz channel and non-contiguous 80+80-MHz channels.
- – Higher-order modulation: 256QAM (optional).
- – Multiple Input Multiple Output (MIMO) support with up to 8 spatial streams and antennas, although only 1 is mandatory.
- – Support for multi-user MIMO to increase downlink transmission efficiency.

802.11ac's ability to achieve such high data rates using these enhancements, coupled with its cost-effectiveness, are key reasons why it is expected to supplant 802.11n in the coming years.

Problem

Successfully building out the 802.11ac ecosystem requires both client and infrastructure devices. Fortunately, producing these devices does not add any new types of tests. As with other well established 802.11 standard test plans, manufacturers must test the transmitter for channel power, spectral mask, and Error Vector Magnitude (EVM)/modulation accuracy or relative constellation error, and the receiver for sensitivity and maximum input level. MIMO testing may also be required. MIMO processing is usually integrated into the chipset DSP, but it remains dependent on the relative performance of each antenna/amplifier chain, and consequently, needs to be well characterized—at least by the chipset supplier during R&D.

In addition to these standard tests, 802.11ac poses a number of new challenges in terms of modulation performance. While 802.11ac supports the BPSK, QPSK, 16QAM and 64QAM used in 802.11n, it also introduces 256QAM, which can be used only in the new wider 80-MHz or 160-MHz channels. The 256QAM enables a faster data rate and better spectral efficiency in good link conditions, but demands better receiver and transmitter performance to handle noise and interference. That's because the receiver needs to be able to differentiate between many more, more tightly packed constellation points than for 16 or 64QAM. Verifying the better EVM performance that's needed to support this higher-order modulation requires higher quality measurement equipment.

Solution

With the number of 802.11ac devices expected to reach the market by 2015 topping 500 million, device manufacturers require a cost-effective and efficient solution for appropriately testing client and infrastructure devices. Besides the transmitter and receiver testing, which are similar to that required for 802.11n, 802.11ac also introduces some new requirements: wider RF bandwidth up to 160 MHz, higher modulation up to 256QAM and higher order MIMO. Consequently, the solution must be able to support the new testing requirements. It also must be flexible enough to support future changes to the 802.11ac standard.

One test solution that meets the criteria is the Keysight Technologies Inc.'s E6640A EXM Wireless Test Set, which is designed for calibration and non-signaling verification of all cellular devices, as well as WLAN through 802.11ac. The solution delivers the speed, accuracy and port density needed to ramp up rapidly and optimize full-volume manufacturing, while also being scalable to meet production needs. It supports all of the new tests required for the 802.11ac specification, without the need for additional equipment.

Achieving Faster Test with Sequence-Based Test Modes

The EXM enables both non-signaling and sequence-based testing, as well as testing via Single Acquisition Multiple Measurement (SAMM) technology, through its highly flexible sequencer capability (Figure 1). SAMM enables the EXM to make several measurements on the same captured device-under-test (DUT) data burst, without having to make any major changes to chipset test modes. With its sequencer capability, the EXM can facilitate faster testing with current WiFi chipsets and their test modes, while also allowing for future advances in chipset test modes.

When using the EXM for 802.11ac manufacturing test, the DUT must first be set up to transmit a known pattern. The EXM then has to be set up to capture that pattern and make the appropriate measurements. To minimize test time, the DUT and EXM may be set up simultaneously, which injects a bit of parallelism into the process.

Achieving Faster Test with Sequence-Based Test Modes (continued)

Several things are required to generate a powerful, fast sequence. The overall sequence, as shown in Figure 2, is a combination of acquisitions (red bars) and measurement or analysis steps (blue bars). The engineer must be able to define what and when he/she wants to capture data, and what measurements will be made. Key to rapidly optimizing your testing is the ability to set up parameters quickly and easily, compare measurements to real-world results, and quickly make adjustments as needed.

An EXM 'sequence' can be comprised of up to hundreds of separate acquisitions (for each frequency and expected signal level, trigger conditions are programmed). Figure 2 shows two such acquisitions. Within each acquisition, a number of 'measurement steps' can be defined that will normally be programmed to match the programmed output from the DUT using its sequence mode. Each measurement step can be set up to process and return one or more measurement results from the data acquired in that time period. In the figure, there are six measurement steps on the data from acquisition 1. The EXM sequence is constructed to match the sequence programmed in the DUT, and both are initiated together to capture the desired result.
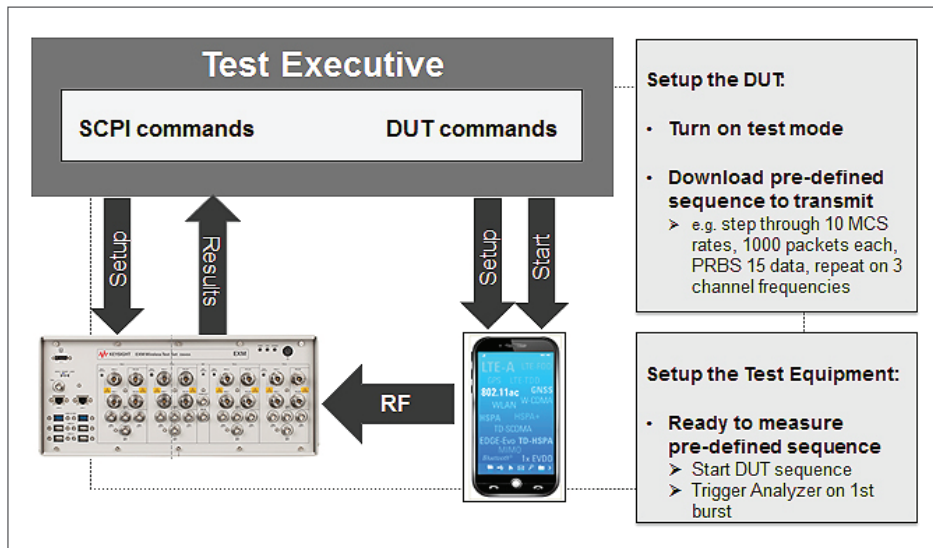

Figure 1. The basic operation of the EXM solution in sequencer mode operation is shown here
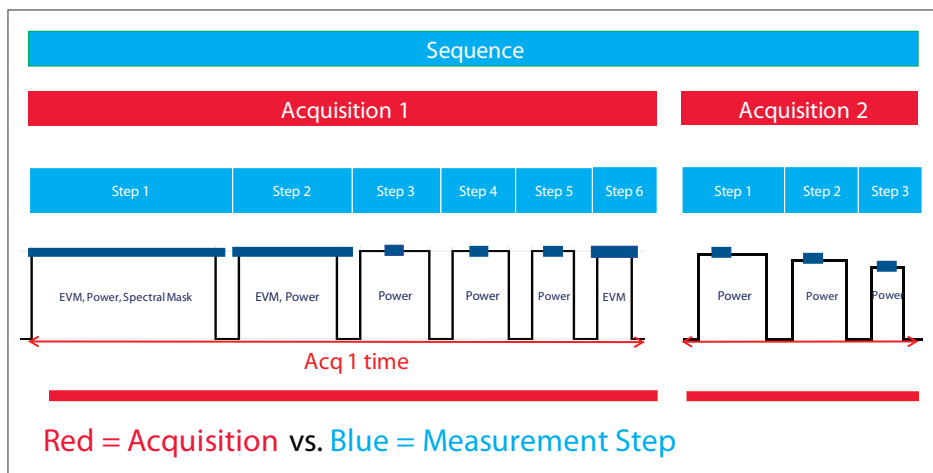

Figure 2. Shown here is an example of the EXM's WLAN sequencer

Throughput Optimization with Multi-Device Parallel Testing

The EXM provides a high-density test capability by offering up to four complete test sets in a single 4U, 19-inch rack package and is capable of 6-GHz frequency coverage and bandwidths up to 160 MHz. Each test set comprises a Keysight X-Series vector signal generator (VSG) and vector signal analyzer (VSA), and includes a flexible 4-port RF Input/Output (I/O) section that reduces the need and cost of complex external switching. The internal VSG and VSA can each be switched to any of these four ports, enabling connection of multiple devices with multiple antenna ports without the need for external switching. In fact, the EXM permits testing of up to 4 DUTs with fully asynchronous parallel testing, as well as, connection of up to 16 single-antenna, 8 dual-antenna, or 4 quadrant DUTs (Figures 3 and 4).

The EXM also natively supports ping-pong operation—a commonly deployed mode of operation for enhancing throughput efficiency (Figure 5). In ping-pong configuration, while one device is being tested using the tester's source and analyzer, a second device is connected and remains ready to be switched onto the active test port as soon as the first device finishes testing. This mode of operation eliminates the time it normally takes to connect and boot each device. Moreover, with the EXM's built-in RFIO switching ports, the process can be adopted without having to add external switching.

Figure 3. As shown here, the EXM permits the connection of up to 16 single-antenna DUTs

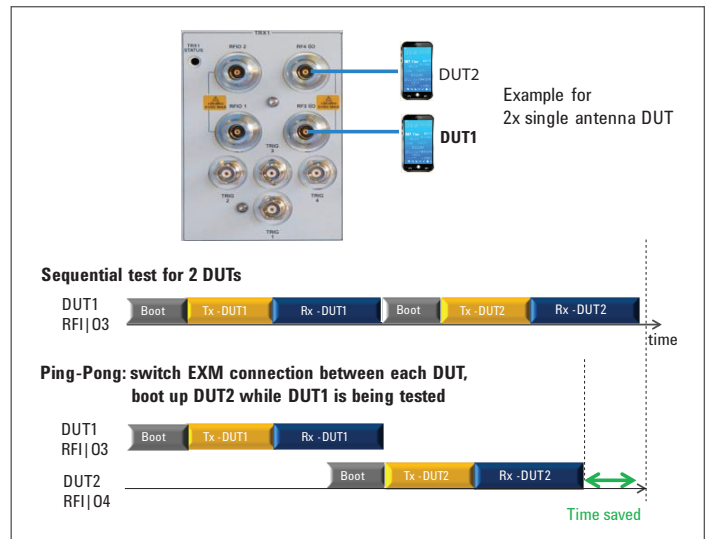Figure 4. The EXM also allows users to connect 8 dual-antenna DUTs

Figure 5. In this example with a single antenna DUT, DUT1 is shown connected to RFI|O3 and DUT 2 is shown connected to RFI|O4 port. The source/analyzer is switched internally in sequence between the ports to which the different DUTs are attached.

Improving Throughput Efficiency with Pipeline Operation

Pipeline operation describes a configuration whereby the transmitter of a 1st device is tested with the tester's analyzer, while the tester's source is used to test the receiver of a 2nd device. This approach is particularly well suited to WLAN testing, which is a Time Division Duplex (TDD) system, and is tested using control modes where only the Tx or the Rx is being tested. Maximum throughput gain is achieved when the Tx test time equals the Rx test time for the Device Under Test (DUT). At this point, the pipeline effectively halves the test time.

With the E6640A, the built-in RFIO switching ports enable pipeline operation to be adopted without additional external switching. In Figure 6, DUT1 is shown connected to RFI|O3, and DUT 2 is connected to the RFI|O4 port. This time the source and analyzer are switched internally between RFI|O3 and RFI|O4.
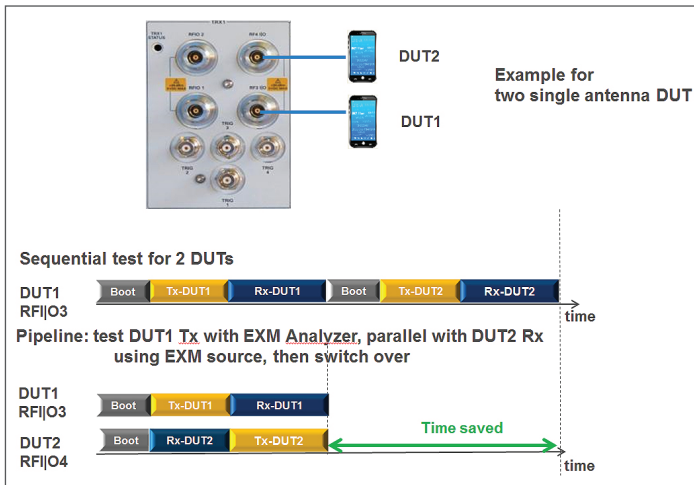

Figure 6. In this example with a single antenna DUT, DUT1 is shown connected to RFI|O3 and DUT 2 is shown connected to RFI|O4 port. The transmitter of DUT1 is being tested with the tester's analyzer. The tester's source is testing the receiver of DUT2.

MIMO Test

While 802.11ac's support for MIMO technology is critical to enabling higher data rates, its multiple antennas and data streams increase test complexity, which in turn makes testing MIMO devices quite challenging. Three techniques commonly used to verify MIMO performance include true MIMO, switched MIMO and composite MIMO (see the Table). With true MIMO, multiple analyzer/source pairs are used to simultaneously test all MIMO channels, while with switched MIMO, a shared analyzer/source pair is used to measure each channel in turn. The composite MIMO technique calculates a limited set of MIMO metrics using a combined channel capture of a specially coded set of waveforms.

	Test Coverage	True MIMO	Switched MIMO	Composite MIMO
Tx Test	Individual channel EVM	✔	✔	✔
	Combined EVM	✔	✔	✔
	Individual channel power	✔	✔	✔
	Total power (all channels)	✔	✔	✔
	Tx Frequency error	✔	✔	✔
	Channel cross power/isolation	✔	✔	✖
	Channel response	✔	✔	✖
	Individual Tx mask violation/margin	✔	✔	✔
	Combined channel mask margin	N/A	N/A	✔
RX Test	Individual RX channel PER (all channels active)	✔	✔	✖
	Individual RX channel PER (one channel active)	✔	✔	✔
	Combined RX channels PER	✔	✔	✔
	RX Isolation	✔	✔	✖
DUT Control			STBC off Scrambling off	Select channel on/off
				Training sequence Special reference waveform
HW/Cost		Multiple TRX	Switch integrated into TRX	External combiner
Speed		Fastest	Sequential stream capture	DUT control overhead

Table. This table compares the three techniques that can be used for MIMO measurements in production. The best test coverage is obtained using true MIMO, but it comes at the cost of more test hardware, as one TRX is required for each stream to be tested. Switched MIMO is less costly, but with the same test coverage. Composite MIMO covers many parameters, but cannot measure isolation between channels, and requires DUT control commands to measure any individual channel metrics.

To better deal with the complexity of MIMO, the EXM supports up to 4x4 true MIMO and up to 3x3 switched MIMO. In the case of true MIMO, frequently used in R&D, the EXM provides the multiple TRXs needed for simultaneous test of all MIMO channels. Each antenna in the DUT is connected to a separate TRX in the tester (Figure 7). This method quickly provides engineers with a full and complete set of MIMO metrics since each channel is captured in parallel.

MIMO Test (continued)

In contrast to true MIMO, switched MIMO provides a much lower cost method for obtaining a full set of MIMO performance metrics using just a single EXM TRX. With any STBC and scrambling turned off, the EXM's built-in fast switching RFIO corrects the DUT antennas in turn to the analyzer and captures data sequentially from successive signal bursts. Keysight measurement software is then used to reconstruct the MIMO streams and perform measurements (Figure 8). The EXM's quad-core processor maximizes production throughput by bringing the speed penalty associated with sequentially capturing data from the MIMO streams down to a minimum.
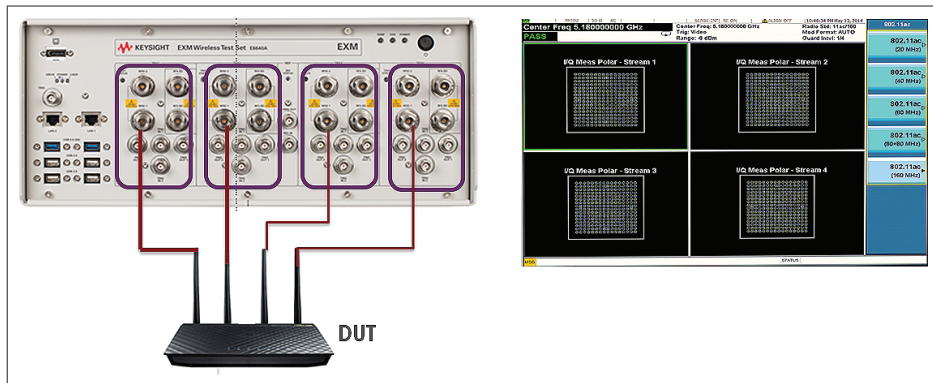
Figure 7. In the diagram on the left, the connection of the DUT for 4x4 true MIMO is shown
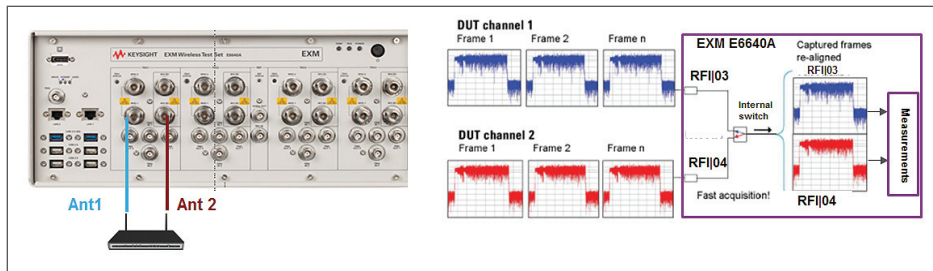

Figure 8. In the diagram on the left, the connection of the DUT for 2x2 switched MIMO is shown. In the example on the right, the first frame from antenna 1 is captured, followed by a later frame from antenna 2. The two streams are then reconstructed and each is processed using Keysight's measurement software. The software analyzes each stream in full, returning individual results on power, EVM and spectral mask, plus a cross power measurement.

Transmit Beamfoming

Beamforming is a technique in which the beamformer, or transmitter used in beamforming, utilizes the knowledge of the MIMO channel to generate a steering matrix that improves reception in the beamformee, or the receiver in beamforming (Figure 9). It enables a dramatic improvement in WLAN 802.11n and 802.11ac performance in terms of reliability, range and coverage.

There are two categories of beamforming based on the methods of getting channel knowledge.

– Category 1: Explicit Feedback
  Here, the beamformee makes a direct estimate of the channel from training symbols sent from the beamformer to the beamformee.
– Category 2: Implicit Feedback
  Here, the beamformer receives long training symbols transmitted by the beamformee. Implicit transmit beamforming is based on the assumption that the channel between the beamformer and beamformee is reciprocal.The beamformer obtains a reverse link channel estimate from a long training sequence in Acknowledgements (ACKs) and calculates the forward link H_{AB} channel information, as shown in Figure 10. It then applies channel compensation (and radio calibration) to the transmitted signal.

For this to work, the transmit chain radio performance needs to be calibrated to compensate for the transmit phase response. Implicit transmit beamforming calibration testing can be easily performed using EXM Option V9077B-KFP or V9077B-KTP.

A Wider Bandwidth, Higher-Order Modulation Test Solution

The 802.11ac standard specifies two ways to achieve the highest data rate: a single 160-MHz contiguous channel (in many geographies, only 2 or 3 such channels are available) or two non-contiguous 80-MHz channels (i.e., a 160-MHz non-contiguous channel). In the latter mode of operation, a special spectral mask is defined. Also note that the two 80-MHz channels used may have a number of different spacings.

Figure 11 illustrates some key 802.11ac transmitter measurements on a 160 MHz channel and 80+80 MHz channels. The EXM covers all higher-order modulation tests using its 160 MHz maximum capture and demodulation bandwidth. Channel power and modulation accuracy (EVM) measurements are required to be measured in up to a 160 MHz bandwidth. The 160 MHz capture bandwidth also enables rapid spectral mask testing.

Figure 9. In simplistic terms, beamforming is a technique used to aim a signal directly at a target rather than broadcasting it to a wide area
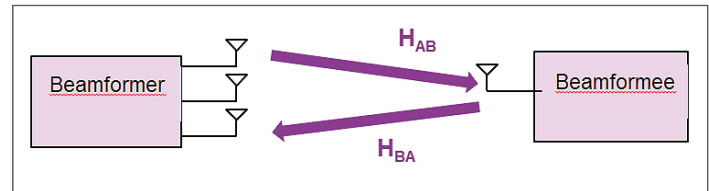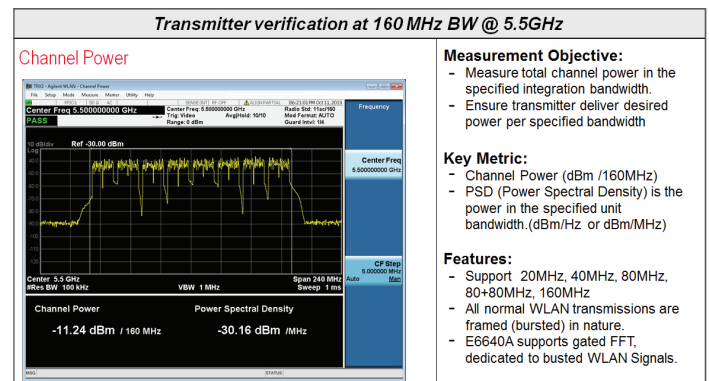

Figure 10. The implicit feedback method assumes that the channel between the beamformer and beamformee is identical in the uplink and downlink directions. Computation of correction matrices is required to eliminate any mismatch between the uplink and the downlink channels.

Figure 11. A channel power measurement using the EXM

A Wider Bandwidth, Higher-Order Modulation Test Solution (continued)

An adjusted spectral mask test is defined for the 80+80 MHz mode. The test effectively combines the mask for two 80-MHz signals, with a limit line of -25 dBr at the center point of the spectrum between the 80-MHz channels. As an example, Figure 12 shows two 80-MHz channels that are centered at 5210 and 5370 MHz, respectively, and are roughly 160 MHz apart. The spectral mask test would therefore, need to capture from 5090 to 5490 MHz, a total span of 400 MHz (Figure 13).

In addition, EXM can support measurements on 2x2 MIMO, non-contiguous 80+80 MHz signals. This advanced feature of 802.11ac increases data rate with spatial multiplexing and spectrum efficient usage. Figure 14 shows the constellation and EVM numerical results for 2 streams on 2 different frequency segments. EXM can also help customers verify devices for SISO implementation of 80+80 MHz. For more information on how to configure these measurements with the EXM, contact Keysight directly.

The EXM can also be used to test 802.11ac's 256QAM modulation (Figure 15). Since the constellation points are closer together in 256QAM, better EVM performance is needed in the transmitter and receiver to correctly identify the intended point in the constellation. The 802.11ac standard has a transmitter relative constellation error or EVM specification of -32 dB for 256QAM, compared to the -28 dB for 64QAM.

As compared to previous generation test sets, the EXM offers faster measurements, increased ARB and analyzer capture memory, increased number of sequencing steps, and the enhanced sequencing capabilities needed to meet the challenges of the fast moving wireless device market. In addition, a high-performance, quad-core controller ensures full performance, even when the EXM is equipped with four complete test sets.
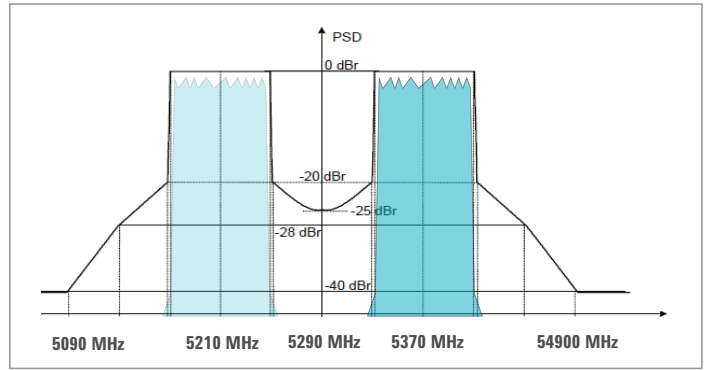

Figure 12. In this example, two 80 MHz channels are shown 160 MHz apart
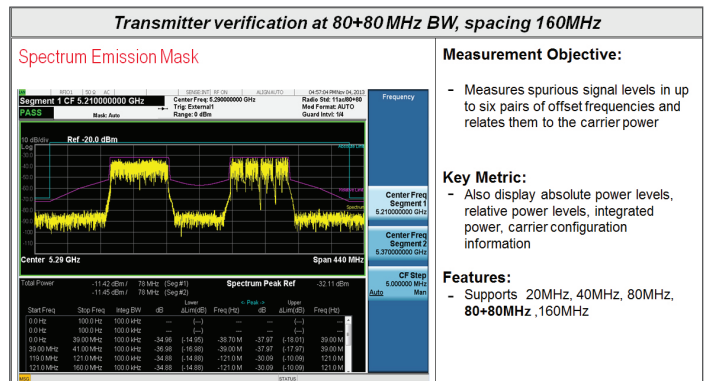

Figure 13. To conduct the 802.11ac spectral mask test on the channels in Figure 6, data is captured from 5090 to 5490 MHz
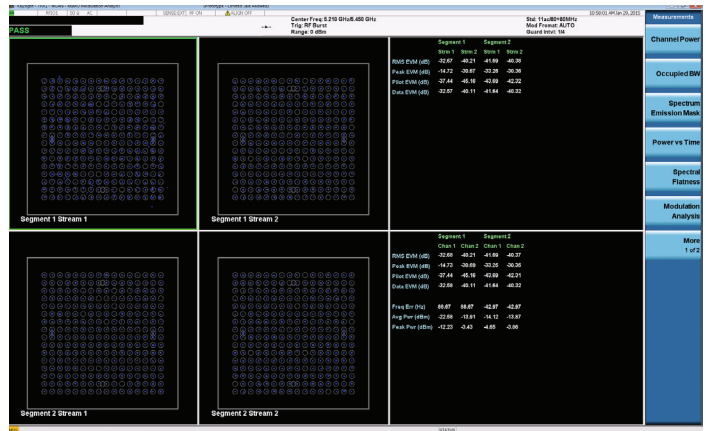

Figure 14. Shown here are the constellation and EVM numerical results for frequency segment 1, stream 1; frequency segment 1, stream 2; frequency segment 2, stream 1; and frequency segment 2, stream 2.
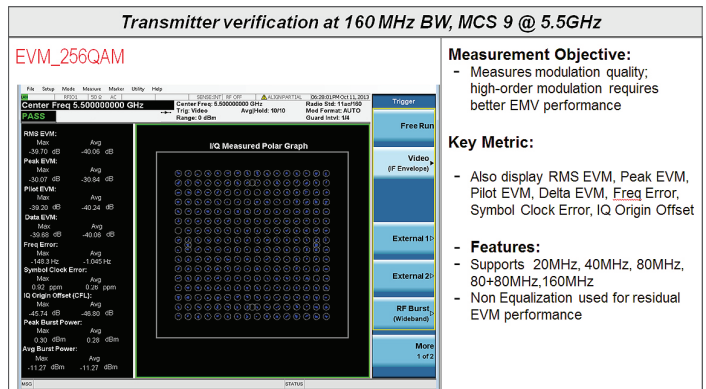

Figure 15. An EVM 256 QAM measurement using the EXM

Summary of Results

The emerging 802.11ac standard offers the high-data throughput that today's consumers demand; however, it also creates a number of test challenges for 802.11ac manufacturers producing client and infrastructure devices. Luckily, the EXM test set is well equipped to address all new 802.11ac test requirements in the production process, without the need for additional equipment. Its flexibility and capabilities enable testing that is both fast and cost-effective, providing a key differentiating factor for manufacturers working in the highly dynamic and competitive wireless device marketplace.

For more information, refer to the E6640A EXM wireless test set flyer, configuration guide and data sheet at **www.keysight.com/find/E6640A**. Or, download the application note, Solutions for LTE-Advanced Manufacturing Test, at **www.keysight.com/find/LTE-A**.

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