Z Series

APPLICATION NOTES

Testing Power Amplifiers for 802.11ax

LITEPOINT

TESTING POWER AMPLIFIERS FOR 802.11AX

802.11ax Goals

The first Wi-Fi standards were used primarily to provide low data rate wireless connectivity for web browsing and email. Over time, new 802.11 wireless protocols offered higher data rates for new applications such as wireless networked computing and video streaming. The upcoming 802.11ax standard takes Wi-Fi another step forward by enhancing wireless connectivity for more consistent and reliable high throughput Wi-Fi in dense user environments. A familiar target application for 802.11ax is the crowded hot-spot in a busy airport or stadium where an overloaded access point delivers terrible user experience. 802.11ax promises to support 10X more users over the same unlicensed spectrum, increase average throughput per user by 4X, and improve outdoor and multi-path signal robustness [1].

802.11ax versus 802.11ac

The 802.11ac standard, which was initially released in November, 2011 has achieved solid market adoption. According to IDC, second quarter 2016 data shows that 802.11ac-based devices made up 77% of revenue for enterprise access points and 51% of revenue for consumer access points. 802.11ac was the first Wi-Fi standard to achieve Gbit/s data rates via instantaneous bandwidths up to 160 MHz, MIMO channels up to 8, and higher density modulation constellations up to 256 QAM. Unfortunately, these promised 802.11ac data rates were often achievable only in benign wireless environments. 802.11ax builds upon 802.11ac to improve spectral efficiency in real-world wireless environments using a number of technologies leveraged from 4G LTE cellular.

Table 1 compares the physical layer parameters of 802.11ac and 802.11ax. Unlike 802.11ac which operates only in the 5 GHz band, 802.11ax operates in both 2.4 GHz and 5 GHz unlicensed bands. One of the most significant innovations of 802.11ax is the change to OFDMA (Orthogonal Frequency Division Multiple Access). OFDMA is a multi-user version of OFDM where the Wi-Fi channel bandwidth is divided amongst multiple users who simultaneously share smaller subchannels called resource units (RU). 802.11ax adds uplink (UL) MU-MIMO where access points trigger multiple clients to send data simultaneously using beamforming and spatial division multiplexing. The 4X longer symbol lengths in 802.11ax improve signal robustness within outdoor and multipath environments. The longer symbol lengths cause subcarrier spacing to be 4X narrower. Another challenging new 802.11ax specification is the increase in modulation density from 256 QAM to 1024 QAM. In addition to these physical layer enhancements, there are other MAC layer innovations for spectral efficiency within 802.11ax including improved traffic flow and channel access, and enhanced power saving techniques.

	802.11ac	**802.11ax**
Operating Bands	5 GHz	2.4 & 5 GHz
Technology	OFDM	OFDMA
MU-MIMO	DL MU-MIMO	DL / UL MU-MIMO
Subcarrier Spacing	312.5 kHz	78.125 kHz
Symbol + Guard Interval Length	3.2 μs + 0.4/0.8 μs GI	12.8 μs + 0.8/1.6/3.2 μs GI
Modulation	256 QAM	1024 QAM
Maximum Users	Up to 4 users	Up to 8 users
Spatial Streams	Up to 8 streams	Up to 8 streams
Bandwidth	20, 40, 80, 80+80 and 160 MHz	20, 40, 80, 80+80 and 160 MHz

Table 1: 802.11ac versus 802.11ax Physical Layer Differences

Power Amplifiers for 802.11ax

The power amplifier (PA) is a critical component within a Wi-Fi transmitter circuit because PA performance affects wireless coverage area, data rate capacity, and battery life. The goal for any transmitter PA is to generate sufficient linear RF output power while using as little DC power as possible. Mobile devices and wireless access points typically transmit between 100 mW (+20 dBm) and 1 W (+30 dBm) of RF output power. PA non-linear distortion often dominates the system-level Wi-Fi transmitter performance because the PA is typically operated in its gain compression region to improve DC power efficiency. Achieving and demonstrating target PA performance becomes more challenging for 802.11ax due to the following physical layer changes: (1) increased PA linearity requirements for 1024 QAM, (2) in-band emission requirements for OFDMA, and (3) measurement errors due to test equipment sensitivity to narrower subcarrier spacing.

PA EVM for 1024 QAM

Error Vector Magnitude (EVM) is a comprehensive and widely used technique for Wi-Fi PA testing [2-3]. EVM is a measurement used to quantify the performance of a digital communication channel, and provides a measure of the deviation of captured encoded data symbols from their ideal locations within the I/Q constellation. The root mean square EVM is a comprehensive measurement that is degraded by any imperfection in the RF signal or device. For a Wi-Fi transmitter design, the PA must achieve an acceptable EVM contribution over its operating range of output power levels and channel frequencies. Because 802.11ax includes 1024 QAM constellations with a -35 dB system-level EVM specification limit, the PA linearity and corresponding EVM contribution requirements are more stringent than earlier 802.11 standards. Whereas the EVM contribution limit for an 802.11ac PA was around -40 dB, the target EVM contribution limit for an 802.11ax PA is around -46 dB [4].

Figure 2 shows PA test data using an 802.11ax-80 MHz (HE80) 1024 QAM waveform at all five HE80 Wi-Fi channel frequencies. As the PA output power level increases into its gain compression region, non-linear distortion occurs and causes the increase in EVM. This EVM power sweep test identifies the usable linear power region for the PA, which is critical for Wi-Fi transmitter design considerations. Note that this particular PA can achieve approximately -46 dB EVM up to a maximum of +15 dBm output power at most Wi-Fi channel frequencies. PA linear output power can likely be increased further using linearization techniques such as digital pre-distortion within an 802.11ax chipset or test environment [5].

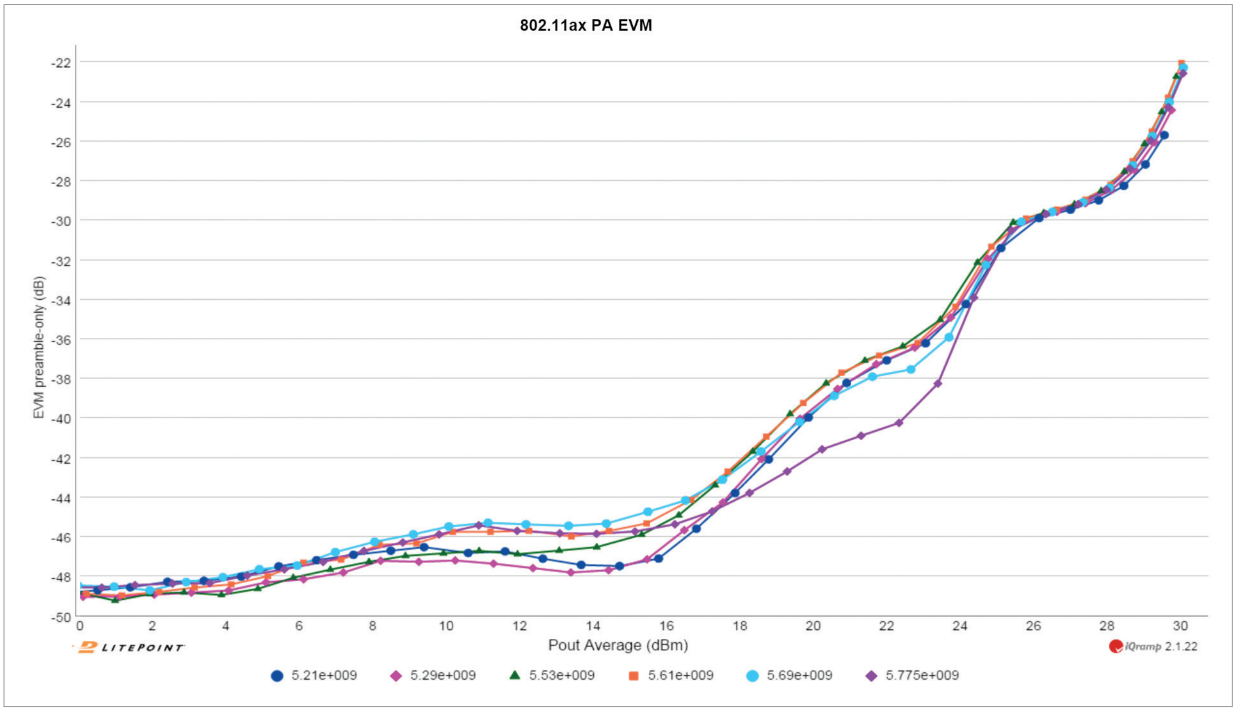


Figure 2: PA EVM versus Output Power

OFDMA & In-Band Emission Testing

Within a dense multi-user environment, an 802.11ax Wi-Fi channel can be shared amongst multiple OFDMA users by dividing the Wi-Fi channel into smaller dedicated subchannels. Similar to LTE's resource block concept, 802.11ax divides the Wi-Fi channel bandwidth (20, 40, 80 or 160 MHz) into resource units (RU), with the smallest RU being 26 subcarriers (2.03 MHz wide). Figure 3 illustrates channel division into multiple RUs with various allowable RU sizes in number of subcarriers per RU.

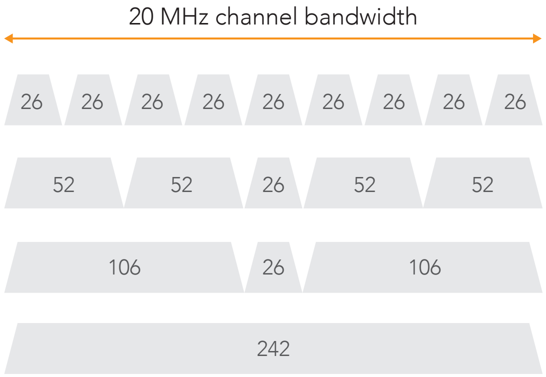


Figure 3: Example of dividing a Wi-Fi channel into multiple RUs for Multi-User OFDMA

Number of RUs within a Wi-Fi Channel				
RU size	**20 MHz**	**40 MHz**	**80 MHz**	**160 MHz**
26 subcarrier	9	18	37	74
52 subcarrier	4	8	16	32
106 subcarrier	2	4	8	16
242 subcarrier	1	2	4	8
484 subcarrier	N/A	1	2	4
996 subcarrier	N/A	N/A	1	2
1992 subcarrier	N/A	N/A	N/A	1

OFDMA does impact PA transmit performance and PA test requirements. In a multiple-user OFDMA environment, each client station (STA) transmits within a portion of the Wi-Fi channel and runs the risk of interference with other STAs transmitting on adjacent RUs within that same channel. Because client STAs are transmitting from different locations, each client STA may adjust its transmit power to balance the signal across the combined Wi-Fi channel received at the access point. This requires much more power adjustment range by the mobile STA, affecting the design, calibration and testing of the mobile PA for use within a client STA device. For example, there will likely be requirements for in-band emission testing similar to the LTE test shown in figure 4. As another example, there may be requirements for increased range and linearity of the PA's Power Detect (Pdet) output.

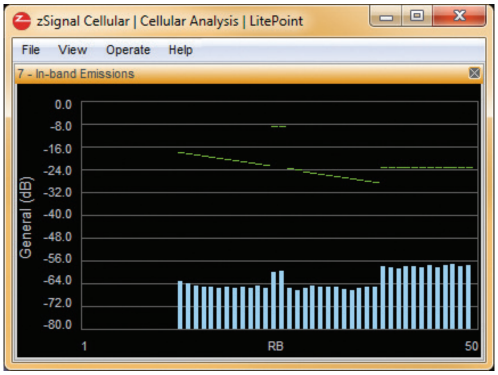


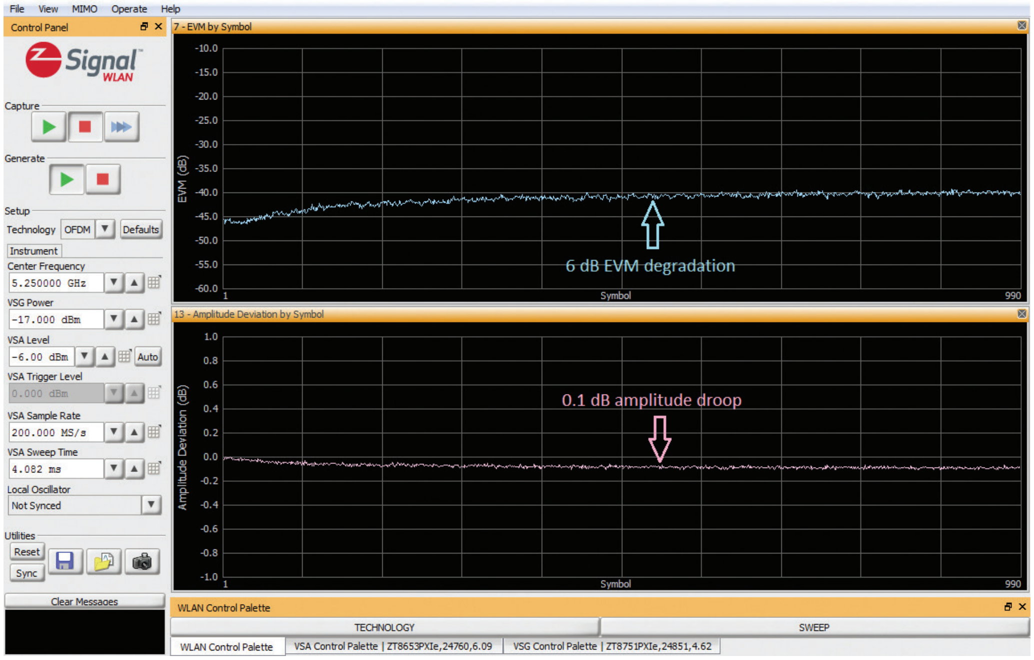
Figure 4: Example of In-band Emission Testing (Resource Blocks 1-12 occupied)

There is a similar impact of multiple-user OFDMA on the access point (AP) transmit PA. When transmitting to multiple client STAs located at various distances from the AP, the transmit power level for one RU can vary by up to 12 dB relative to other RUs within a Wi-Fi channel. This uneven distribution of RU power levels across the transmit channel may limit dynamic range. For example, the transmit PA within the AP may need up to 12 dB better linear power range to limit in-band distortion degrading EVM performance for the lower power RUs. Sophisticated test scenarios will be necessary to validate PA performance with uneven RU power levels across the channel.

Other PA Test Challenges for 802.11ax

With the lower EVM floor required for 802.11ax 1024 QAM, even small signal impairments can be impactful. Errors in the DC voltage supply to the PA can quickly degrade EVM when trying to achieve the necessary EVM floors for 802.11ax. Current and voltage transients caused by dynamic EVM operation are particularly challenging. For example, a 0.1 dB amplitude error in the preamble portion at the start of the Wi-Fi packet can limit EVM to approximately -40 dB. Test equipment setup where the DC supply voltage is sourced remotely over a few feet of cable exacerbates transient effects on the PA. Care must be taken to compensate for test equipment cabling to isolate the measurement to the dynamic performance of the actual PA and PA circuit.

Another condition that will be exacerbated by multiple-user OFDMA is the broader use of long packets. Because the channel bandwidth is shared amongst multiple users, there will be an increase in the use of long packets to maintain throughput for each user. Long packets often cause amplitude droop as the PA heats up over a few milliseconds of transmission. As shown in figure 5, a 0.1 dB droop in amplitude over a 4 ms packet degrades EVM from -46 dB to -40 dB. This EVM degradation is a result of the channel amplitude estimate being computed only on the preamble at the start of the packet.



Technology: OFDM
Center Frequency: 5.250000 GHz
VSG Power: -17.000 dBm
VSA Level: -6.00 dBm
VSA Trigger Level: 0.000 dBm
VSA Sample Rate: 200.000 MS/s
VSA Sweep Time: 4.082 ms
Local Oscillator: Not Synced

Figure 5: Effects of Amplitude Droop on Long Burst (4 ms) EVM

Digital pre-distortion (DPD) will likely be broadly deployed with the next-generation 802.11ax chipsets. Validating PA performance in the presence of DPD is necessary to quantify the PA linearization that can be achieved with DPD. 802.11ax OFDMA adds more variables to the application and effects of DPD. For example, the number of subcarriers populated in a multiple-user OFDMA singal can vary, affecting the signal bandwidth, peak-to-average power ratio (PAPR) and complementary cumulative distribution function (CCDF). These variables may affect the DPD linearization performance for a particular PA. Also, because OFDMA requires real-time power level adjustment, DPD needs to be affective over a broader range of PA output power levels. All of these additional DPD operating conditions and variables will need to be well tested and characterized for an 802.11ax PA.

Noise Reduction Techniques

The EVM error budget allocated to the PA for 802.11ax 1024 QAM requires greater understanding of all factors impairing signal fidelity. In order to achieve the -46 dB target EVM performance, any imparity can be impactful, including many that were not significant for other 802.11 Wi-Fi standards. Test equipment dynamic range becomes critical, and may further limit measureable PA performance. Test equipment noise reduction is a technique that is useful for diagnostic purposes to investigate various PA impairments, even those below the test equipment noise floor. Comparing the non-corrected EVM of figure 3 and the corrected EVM of figure 6 illustrates the advantages of test equipment noise reduction when trying to test a PA for the target -46 dB EVM.

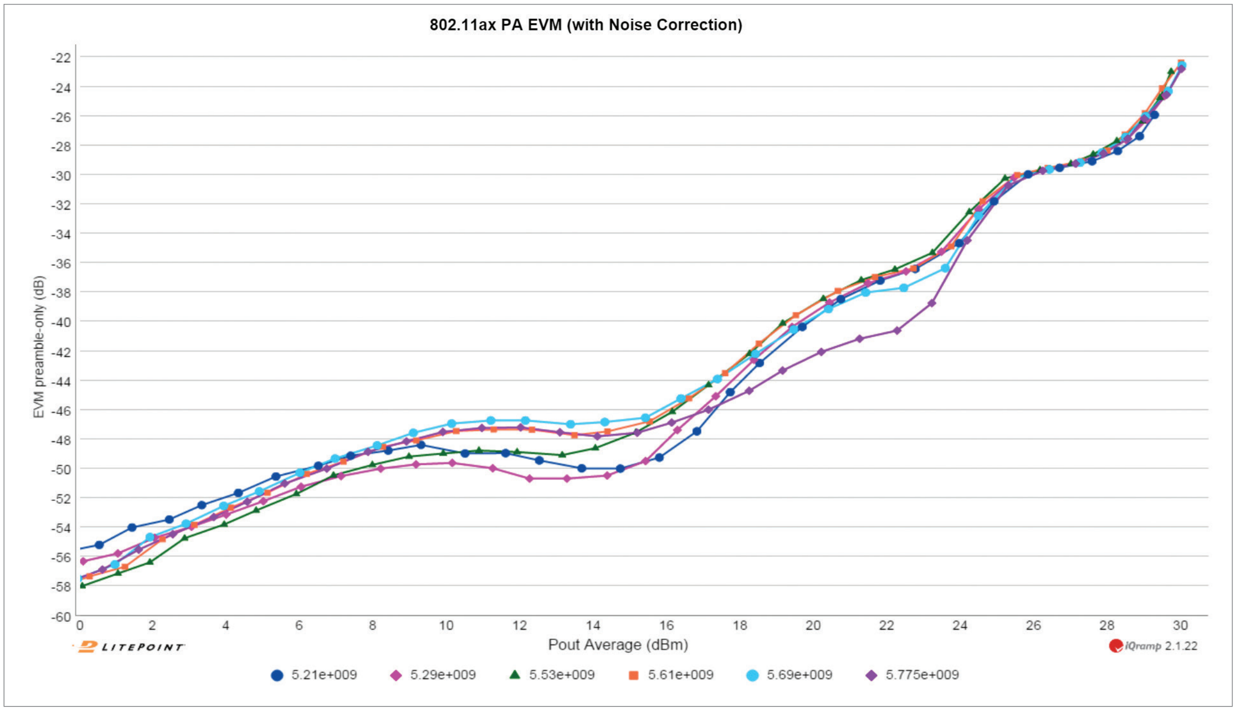


Figure 6: PA EVM versus Output Power with Noise Correction enabled

802.11ax PA Test Equipment

For previous generations of 802.11 Wi-Fi, PA test results were not as susceptible to minor test system errors. Correlation and golden-DUT testing may have been adequate in some test scenarios. Going forward, in order to demonstrate the requisite EVM performance for 802.11ax 1024 QAM, all test system error sources must be minimized. The entire integrated test system must be optimized to mimic the real world operating conditions and performance of the PA.

As noted throughout this paper, 802.11ax requires additional functionality and performance within the test equipment used for design validation, characterization and testing of power amplifiers. Within the RF instruments, the noise floor, phase noise, intermodulation distortion, and in-band spurious signals must be optimized to avoid degradation of the loopback residual EVM floor. Note that the 4X narrower subcarrier spacing of 802.11ax magnifies the phase noise error contribution of the test equipment. In addition, the other instruments must be selected and integrated to deliver the correct performance and functionality as to not impair the measured PA performance. This includes the DC power supplies, analog and digital instruments.

Figure 7 shows a block diagram of a typical test setup for PA testing using the LitePoint zSeries-PA/FEM test solution, including:

- z8653 6 GHz Vector Signal Analyzer (VSA), 1 GHz analysis bandwidth
- z8751 6 GHz Vector Signal Generator (VSG), 500 MHz modulation bandwidth
- z8801 8 GHz Local Oscillator Synthesizer (qty. 2), Low Phase Noise option for VSA and VSG
- z5211 200MS/s Arbitrary Waveform Generator
- z471 Source Measure Unit (SMU) including cabling with transient compensation circuitry
- PXIe chassis & host computer

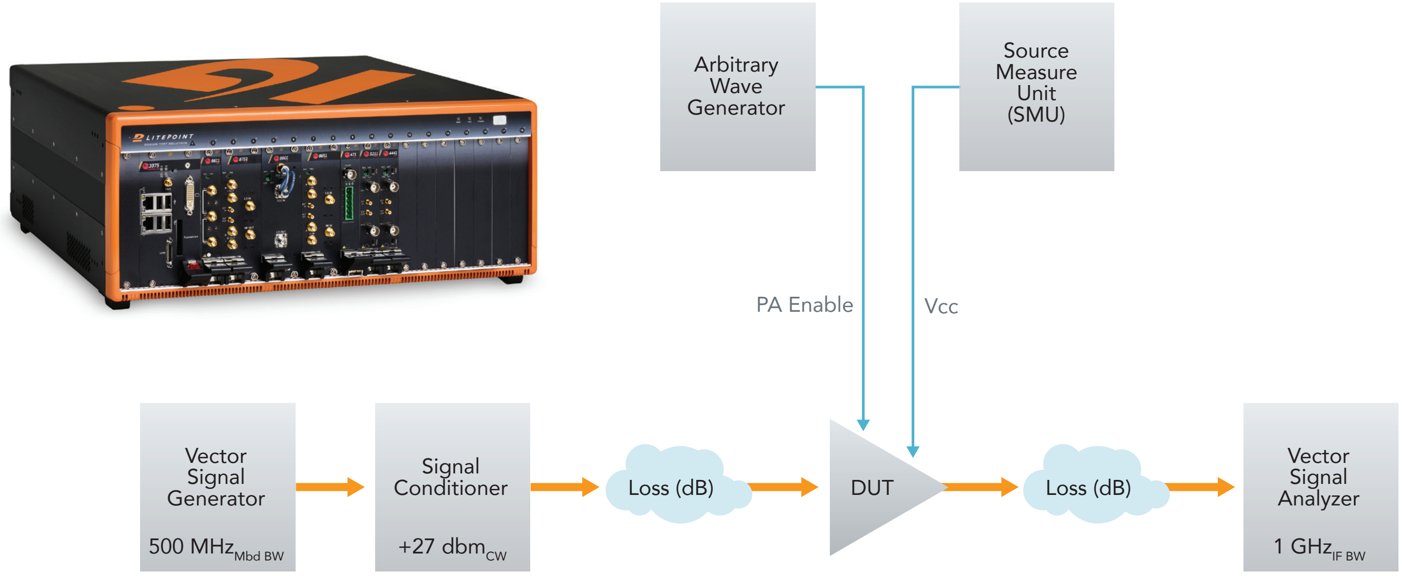


Figure 7: Test equipment block diagram for PA testing

The zSeries-PA/FEM Test Solution shown in figure 7 is comprised of a 6 GHz VSG/VSA combination with measurement bandwidths up to 1 GHz MHz [6-7]. In addition to wide measurement bandwidth that is useful for digital pre-distortion testing, the zSeries test solution provides the low noise and distortion necessary for characterization and testing of 802.11ax devices. The zSeries test solution provides an exceptional loop-back residual EVM floor better than -50 dB for 80MHz 802.11ax (preamble-only equalization). Other instruments are completely integrated to provide a comprehensive out-of-the-box solution with the functionality and performance necessary for 802.11ax PA testing.

The zSignal™ software toolkit provides test applications that automatically sweep a range of test parameters including RF power, supply voltage, modulation, temperature, channel frequency, pulse width, duty cycle, and other sweep parameters. Comprehensive measurements are rapidly collected for these sweeps including EVM, Dynamic EVM, ACLR, Spectral Mask, PAE, Icc, IMD, Psat, Pdet, Gain, and many others. The measurement datalog output is a standard CSV file ready for review with a statistical analysis and plotting tool, all without ever having to write a single line of code. The zSignal™ software also includes the intuitive real-time graphical user interface shown in figure 8 that is useful for manual operation, diagnostics, or test debugging. Comprehensive software drivers ease of automation for customized applications.

In combination with the zSignal™ software, the zSeries-PA/FEM test set offers a complete solution for 802.11 testing covering all aspects of the WLAN standards including:

- All Wi-Fi standards: 802.11 a/b/g/j/n/p/ac/af/ah/ax
- All Modulation Bandwidths: 160 MHz, 80 MHz, 40 MHz & 20 MHz
- All Modulation Coding Schemes (MCS) and Bit Rates: BPSK to 1024 QAM
- All Channel Frequencies: 2.4 GHz and 5 GHz bands
- MIMO Streams: X2 to X8
- Advanced testing including Noise Reduction, Digital Pre-Distortion and Envelope Tracking

Technology: OFDM

Center Frequency: 5.210000 GHz

VSG Power: -10.000 dBm

VSA Level: -9.00 dBm

VSA Trigger Level: 0.000 dBm

VSA Sample Rate: 240.000 MS/s

VSA Sweep Time: 282.596 µs

Local Oscillator: Not Synced

Center 5.21000 GHz, Span 195.00000 MHz, RBW 100.00000 kHz

2 - Frame Summary

Name	Value
Packet Type	802.11ax
BW	80 MHz
Rate	600.40 Mbps (1024-QAM Rate 5/6)
Symbols	17
Tones	1024
PSDU Length	Decode Disabled
PSDU CRC	Decode Disabled

3 - Measurement Summary

Name	Result
EVM (dB)	-53.41 (0.21 %)
Pilot EVM (dB)	-53.81 (0.20 %)
Data EVM (dB)	-53.41 (0.21 %)
Tx Freq Error (Hz)	1.15 (0.0002 ppm)
Phase Error(deg)	0.088
Sym Clock Error (ppm)	0.000
Center Freq Leakage (dB)	-79.9
I/Q Gain Mismatch (dB)	0.000
I/Q Phase Mismatch (deg)	-0.014
I/Q Delay Mismatch (ps)	1
Peak Power (dBm)	0.4
Average Power (dBm)	-9.89
PAR (dB)	10.3
Result Length (Sym)	17

Figure 8: zSignal™ WLAN 802.11ax Test Software GUI

Conclusion

This paper examines the demands that the new 802.11ax Wi-Fi standard places upon the design validation, characterization and testing of power amplifiers (PA). With the EVM contribution of the PA limited for 802.11ax to at most -46 dB, greater linearity and dynamic range requirements are needed for the PA and the RF test equipment. This paper defines a number of requirements and techniques for 802.11ax PA testing. The zSeries-PA/FEM test equipment and zSignal™ software provide a complete solution for qualifying PA performance for operation within an 802.11ax transmitter design.

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