Keysight Technologies
Testing New-Generation WLAN 802.11ac

Application Note

Introduction

The first popular standards for wireless LAN (IEEE 802.11a and b) were designed primarily to serve the needs of a laptop PC in the home and office, and later to allow connectivity "on the road" in airports, hotels, Internet cafes, and shopping malls. Their main function was to provide a link to a wired broadband connection for Web browsing and email. Since the speed of the broadband connection was the limiting factor, a relatively low-speed wireless connection was sufficient—802.11a provided up to 54 Mb/s at 5 GHz, and 802.11b up to 11 Mb/s at 2.4 GHz, both in unlicensed spectrum bands. To minimize interference from other equipment, both used forms of spread-spectrum transmission and were heavily encoded. A later revision of the standard, 802.11g in 2003, consolidated use in the 2.4 GHz band but maintained the maximum data rate at 54 Mb/s. However, by the same time, new usage models with the need for higher throughput had been recognized: data sharing amongst connected devices in the home or small office and wireless printing as examples. A study project was set up which produced 802.11n in 2009. As well as improving the maximum single-channel data rate to over 100 Mb/s, this new standard introduced MIMO (multiple input, multiple output) sometimes referred to as spatial streaming, where up to 4 separate physical transmit and receive antennas carry independent data that is aggregated in the modulation/demodulation process.

Today, there are further usage models, summarized in Table 1, that require even higher data throughput to support today's "unwired office."

Table 1. New WLAN usage models.

Category	Usage model
Wireless Display	– Desktop storage and display – Projection to TV or projector in conference room or auditorium – In-room gaming – Streaming from camcorder to display – Professional HDTV outside broadcast pickup
Distribution of HDTV	– Video streaming around the home – Intra-large-vehicle applications (e.g. airplane, ferry) – Wireless networking for office – Remote medical assistance
Rapid upload/download	– Rapid file transfer/sync – Picture-by-picture viewing – Airplane docking (manifests, fuel, catering, . .) – Downloading movie content to mobile device – Police surveillance data transfer
Backhaul	– Multi-media mesh backhaul – Point-to-point backhaul
Outdoor campus/auditorium	– Video demo /tele-presence in auditorium – Public safety mesh (incident presence)
Manufacturing floor	– Automation

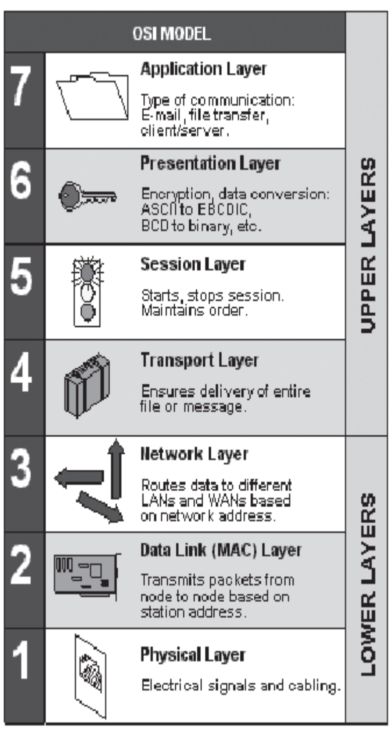


Figure 1. OSI 7-layer model

To cater for these, two IEEE project groups aimed at providing "Very High Throughput" (VHT) were set up. Working Group TGac aimed to specify 802.11ac as an extension of 802.11n, providing a minimum of 500 Mb/s single link and 1 Gb/s overall throughput, running in the 5 GHz band. Working Group TGad in partnership with the Wireless Gigabit Alliance (WiGig) jointly proposed 802.11ad, providing up to 7 Gbs throughput using approximately 2 GHz of spectrum at 60 GHz over a short range. (60 GHz transmission suffers from large attenuation through physical barriers.) Bearing in mind the number of existing devices, backward compatibility with existing standards using the same frequency range was a "must." The goal was for all the 802.11 series of standards to be backward compatible, and for 802.11ac and ad to be compatible at the Medium Access Control (MAC) or Data Link layer, and differ only in physical layer characteristics (see Figure 1). Devices could then have three radios: 2.4 GHz for general use, but which may suffer from interference, 5 GHz for more robust and higher speed applications, and 60 GHz for ultra-high-speed within a room – and support session switching amongst them. Both new standards are currently complete, and devices are on the market, with first-generation products being routers with 3x3 MIMO and laptops with 2x2 MIMO.

Because of the differences in physical layer attributes of the two Very High Throughput standards at 5 and 60 GHz, for the remainder of this application note, we will focus on 802.11ac.

Technical Differences From 802.11n

The 802.11ac physical layer is an extension of the existing 802.11n standard, and as already discussed, maintains backward compatibility with it. The following discussion highlights the changes. Table 2 shows the physical layer features of 802.11n, and Table 3 shows how this is extended for 802.11ac. The theoretical maximum data rate for 802.11n is 600 Mb/s using 40 MHz bandwidth with 4 spatial streams, though most consumer devices are limited to 2 streams. The theoretical 802.11ac maximum data rate is 6.93 Gb/s, using 160 MHz bandwidth, 8 spatial streams, MCS9 with 256QAM modulation, and short guard interval. A more practical maximum data rate for consumer devices might be 1.56 Gb/s which would require an 80 MHz channel with 4 spatial streams, MCS9, and normal guard interval.

Table 2. IEEE 802.11n key specifications

Feature	Mandatory	Optional
Transmission method	OFDM	
Channel bandwidth	20 MHz	40 MHz
FFT size	64	128
Data subcarriers/ pilots	52/4	108/6
Subcarrier spacing	312.5 kHz	
OFDM symbol duration	4 µs (800 ns guard interval)	3.6 µs with short guard interval
Modulation types	BPSK, QPSK, 16QAM, 64QAM	
Forward error correction	Binary convolutional coding (BCC)	Low density parity check (LDPC)
Coding rates	1/2, 2/3, 3/4, 5/6	
MCS supported	0 to 7, 0 to 15 for access points	8 to 76, 16 to 76 for access points
Spatial streams and MIMO	1, 2 for access points direct mapping	3 or 4 streams Tx beamforming, STBC
Operating mode/ PPDU format	Legacy/non-HT (802.11a/b/g) Mixed/HT-mixed (802.11a/b/g/n)	Greenfield/HT-Greenfield (802.11n only)

Table 3. IEEE 802.11ac key specifications

Feature	Mandatory	Optional
Channel bandwidth	20 MHz, 40 MHz, 80 MHz	160 MHz, 80+80 MHz
FFT size	64, 128, 256	512
Data subcarriers/ pilots	52/4, 108/6, 234/8	468/16
Modulation types	BPSK, QPSK, 16QAM, 64QAM	256QAM
MCS supported	0 to 7	8 and 9
Spatial streams and MIMO	1	2 to 8 Tx beamforming, STBC BPSK, QPSK, 16QAM, 64QAM Multi-user MIMO (MU-MIMO)
Operating mode/ PPDU format	Very high throughput/VHT	

Technical Differences From 802.11n

The new wider mandatory channel bandwidths are shown in Figure 2 for the U.S. region, along with possible placements of the non-contiguous 80+80 MHz channels specified in the standard. Note that due to the need to avoid operation in channels that may interfere with weather radars, in certain locations there may only be one available 160 MHz channel. While 160 MHz and 80+80 MHz modes are both included as optional features in the 802.11ac standard, the first devices available – wireless routers and dongles – have settled on 3x3 and 2x2 spatial streams respectively.

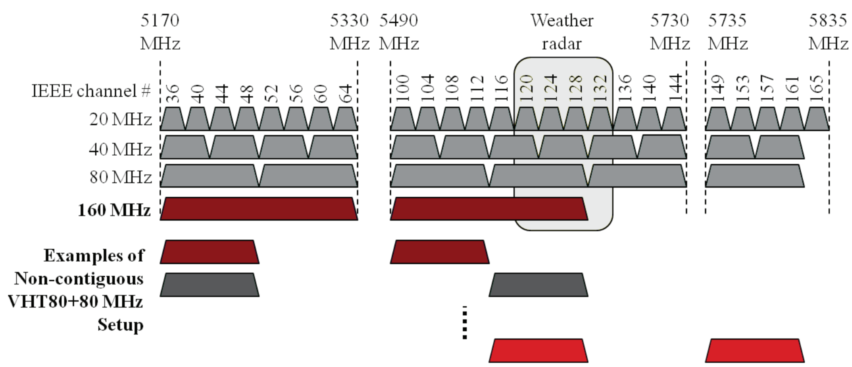


Figure 2. IEEE 802.11ac frequency allocation for the US region

For 20 and 40 MHz channels, the number of subcarriers and pilots and their positions are the same as in 802.11n. New values are defined in 802.11ac for 80 MHz channels, and a 160 or 80+80 MHz channel is defined in the same way as two 80 MHz channels.

Within the frame structure, the preamble and training fields make it possible for the receiver to auto-detect the physical layer standard being used. 802.11n and 802.11ac preamble frames are shown in Figure 3. The first 4 fields in both preambles are intended to be received by non-HT and non-VHT stations for backwards compatibility. The initial Legacy Short and Long Training Fields (L-STF and L-LTF) and signal field (L-SIG) are similar to the same fields in 802.11a/b/g, while the difference in the 4th field (symbols 6 and 7) identifies the frame as either 802.11n or 802.11ac.

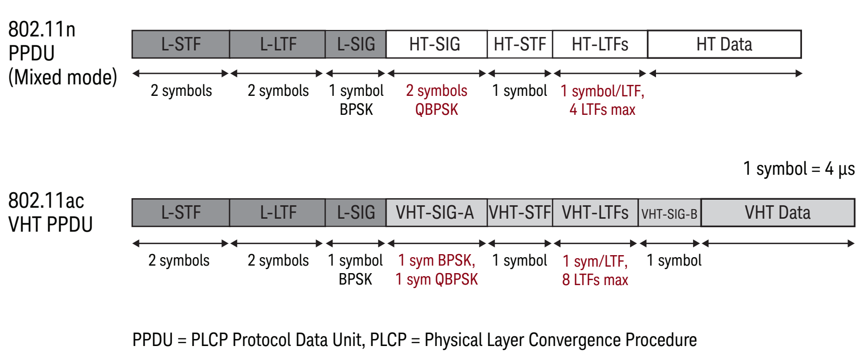


Figure 3. Comparison of 802.11n and 802.11ac frame formats

Technical Differences From 802.11n

Examining the VHT preamble in more detail, for channels wider than 20 MHz, the legacy fields are duplicated over each 20 MHz sub-band with appropriate phase rotation. Subcarriers are rotated by 90 or 180 degrees in certain sub-bands in order to reduce the peak-to-average power ratio (PAPR). To signal VHT transmission and enable auto-detection, the first symbol of the VHT-SIG-A is BPSK, while the second symbol is BPSK with 90 degrees rotation (QBPSK). This differs from the HT-SIG for 802.11n where both symbols use QBPSK modulation. The VHT-SIG-A field contains the information required to interpret VHT packets—bandwidth, number of streams, guard interval, coding, MCS and beamforming.

The remaining fields in the preamble are intended only for VHT devices. The VHT-STF is used to improve automatic gain control estimation in Multiple Input Multiple Output (MIMO) transmission. Next there are the long training sequences that provide a means for the receiver to estimate the MIMO channel between the transmit and receive antennas. There may be 1, 2, 4, 6 or 8 VHT-LTFs depending on the total number of space-time streams. The mapping matrix for 1, 2 or 4 VHT-LTFs is the same as in 802.11n, with new ones added for 6 or 8 VHT-LTFs. VHT-SIG-B field describes the length of the data and the modulation and coding scheme (MCS) for single or multi-user modes.

MIMO Re-visited

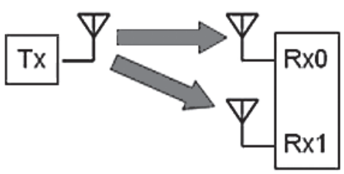
In the legacy WLAN standards, there was only one stream of data between the access point and a device. MIMO transmission was first introduced in 802.11n, and included new requirements where the access point and device communicate using two or more completely separate transmit/receive chains and take advantage of cross-coupling between them. The primary goal was to increase the data rate that a single user could expect from their wireless connection.

In the specifications, the terms “input” and “output” refer to the medium between the transmitters and receivers, including the RF components of both—known as the “channel.” Thus an access point with two transmitters provides two inputs to the channel—the “MI” part, and a device with two receive chains takes two outputs from the channel—the “MO” part. This is true only if the data transmitted and received is independent, and is not just a copy of the same data, as explained below and shown in Figure 4.

SISO

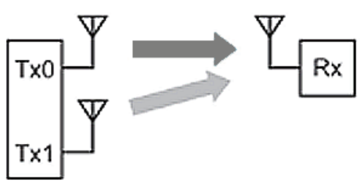
Single Input Single Output (SISO) is the standard transmission mode in most systems, and the objective of any more complex system is capacity or data rate gain measured with respect to SISO.

SIMO



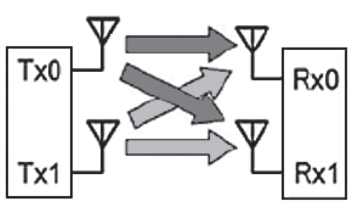
Single Input Multiple Output or Receive Diversity—a single transmitter, and therefore a single data stream, feeds two receiver chains. Aids received data integrity, especially where signal to noise ratio is poor. There is no gain in data capacity except any benefit that comes from better error ratio and consequent reduced retransmission.

MISO



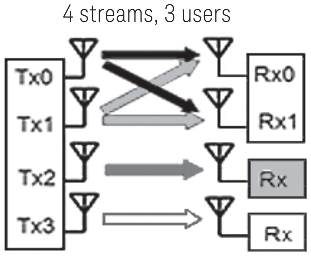
Multiple Input Single Output is a transmit diversity technique. Space Time Block Coding, where the transmitters send the same data but at different times, may be used to improve signal robustness.

MIMO (2X2)



True Multiple Input Multiple Output, shown here with two transmitters and two receivers with independent data content, is also known as spatial multiplexing. Each receiver sees the output of the channel, which is a combination of the outputs from the transmitters. Using channel estimation techniques, the receivers use matrix mathematics to separate the two data streams and demodulate the data. In ideal conditions, with maximum de-correlation between the streams, data capacity is doubled, though there is a premium to be paid in a better signal to noise ratio requirement than for SISO.

Multi-user MIMO
4 streams, 3 users



Typical 802.11n consumer devices support up to two spatial streams rather than the maximum four specified in the standard. 802.11ac extends this to a maximum of eight streams. New in 802.11ac is the concept of multi-user MIMO (MU-MIMO). As opposed to “normal” (i.e. single-user) MIMO, which improves data throughput to an individual device, MU-MIMO is designed to re-use resources to improve network efficiency, though the data rate to any individual device is unchanged. MU-MIMO in 802.11ac allows transmission to up to 4 users simultaneously, with up to 4 streams per user, with a maximum of 8 streams combined, in each timeslot.

Figure 4. Transmission modes

Beamforming

Beamforming is a technique in which the transmitter uses knowledge of the MIMO channel to generate a steering matrix that focuses resources in the direction of the target device (Figure 5). It enables a dramatic improvement in WLAN 802.11n and 802.11ac performance in terms of reliability, range and coverage.

Figure 5. Simplified, beamforming focuses resources towards particular devices

Test Requirements

The high volumes for WLAN devices call for strict attention to manufacturing costs, and the use of innovative design techniques to maximize repeatability and minimize cost of test. This leads to the need for exhaustive testing during the design and pre-production stages of development, and optimized production test for both components and complete devices.

The 802.11ac standard includes the transmitter and receiver tests shown in Table 4. These are similar to the tests for 802.11n, with some new definitions and specification limits added to cover the new features in 802.11ac. To get the latest test specifications, download the current version of 802.11ac from **www.ieee802.org**, and see section 20.3.20 for transmitter specifications and section 22.3.18 for receiver specifications. In addition to these tests, designs will need to pass conformance tests and additional functional tests to verify performance and prove interoperability.

Table 4. Transmitter and Receiver Tests

Transmitter Tests	Receiver Tests
Transmitter power	
Transmit spectrum mask	Minimum input level sensitivity
Spectral Flatness	Adjacent channel rejection
Transmit center frequency tolerance	Non-adjacent channel rejection
Packet alignment	Receiver maximum input level
Symbol clock frequency tolerance	Clear channel assessment (CCA) sensitivity
Modulation accuracy	
Transmit center frequency leakage	
Transmitter constellation error (EVM)	

Design and Test Challenges

EVM is critical

Some of the new features in the 802.11ac standard result in new challenges in design and test. One of these is the use of 256QAM modulation, which requires better error vector magnitude (EVM) or constellation error in the transmitter and receiver. EVM problems may be caused by imperfections in the IQ modulator, phase noise or error in the LO, or amplifier nonlinearity. Vector signal analysis is a valuable tool for measuring and identifying causes of poor EVM, and the Keysight 89600 VSA software provides detailed analysis of 802.11ac signals, with support for all bandwidths and modulation types and up to 8x8 MIMO.

Power amplifier needs to be designed for linearity and efficiency

Improving amplifier linearity and power efficiency are other challenges in multi-format handsets. New techniques have been introduced to improve the linearity and decrease the power consumption of the power amplifier, Linearity is improved using digital pre-distortion (DPD), where the input is adjusted to give a flat output, and envelope tracking (ET) improves the power efficiency of the amplifier by allowing the amplifier's drain bias to track the magnitude of the input signal envelope. ET offers significant advantages in terms of improved battery life and RF PA performance, along with reduced heat dissipation.

Designing an ET PA is challenging since it has to be treated as a 3-terminal active device. It requires a low noise, high bandwidth power supply, and designing and optimizing a shaping curve or table (which determines characteristics of the ET system). (Figure 6).

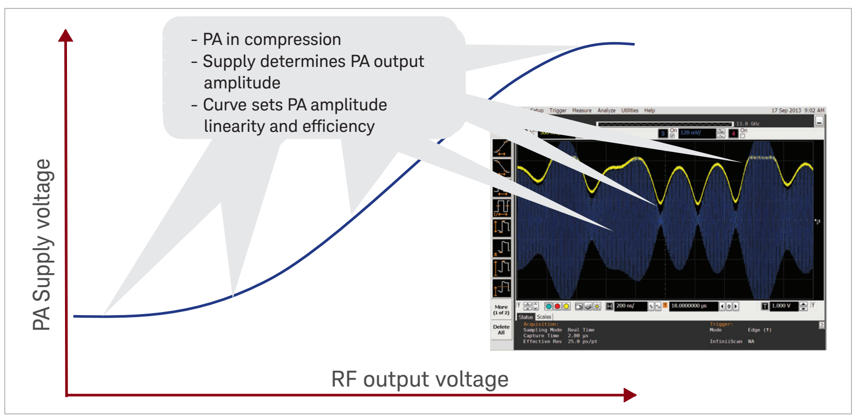


Figure 6. Designing an envelope curve

Keysight offers multiple solutions for the flexibility, accuracy and continuity needed to effectively evaluate ET components and ET-based radio designs. They include simulation environments, signal generators and analyzers, signal generation and analysis software, LXI bench instruments, and PXI modular instruments, which can be to provide today's designers with a solution for ET system test—from R&D to design verification and into production.

For the modeling portion of the flow, SystemVue electronic-system level design software or Advanced Design System (ADS) software can be utilized. During characterization, the Nonlinear Vector Network Analyzer (NVNA) is used to measure the nonlinear behavior of the PA. That information can then be used to create X-parameter* models. ADS can also be used to simulate and generate X-parameter models. Swept frequency and pulse power measurements are performed using the PNA-X microwave network analyzer and N6705B DC power analyzer with N6781A Source/Measurement Unit (SMU). Next, the shaping table is designed using custom methods or X-parameters.

Design and Test Challenges

Power amplifier needs to be designed for linearity and efficiency *continued*

The RF and envelope signal is created (with the shaping table applied to the signal) using N7614B Signal Studio software for PA test, the vector signal generator MXG/EXG/ESG and 33522B/33622A Trueform arbitrary waveform generator. Finally, the signal's PAE, ACLR and receiver band performance is measured and the result analyzed using the X-Series signal analyzer, Infiniium 9000A oscilloscope,and N7614B Signal Studio or 89600 VSA software.

An example setup is shown in Figure 7. For details, please see Keysight Application Note 5992-0137EN

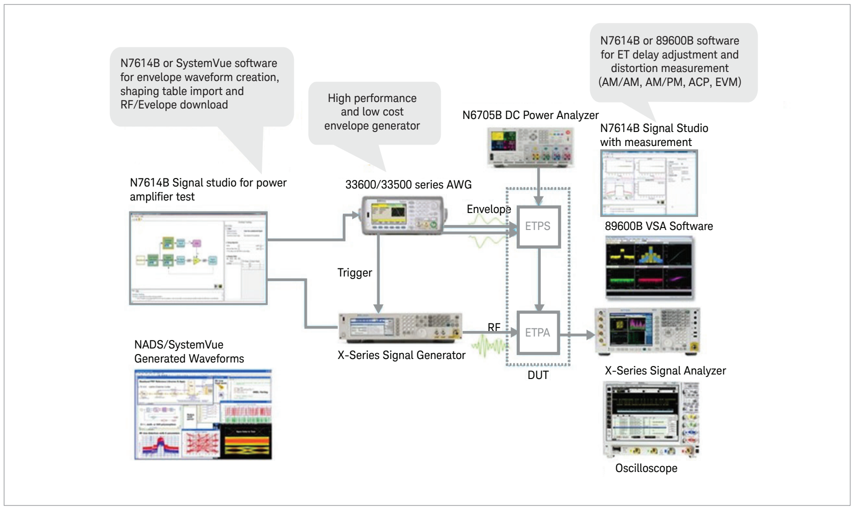


Figure 7 Shown here is a typical PA test solution configuration with support for ET. It includes waveform generation software, a signal generator for the RF signal, an arbitrary waveform generator for the envelope signal, a DC power supply, and a signal analyzer for spectrum and distortion measurement.

Figure 8 shows an example of DPD using an 80 MHz 802.11ac signal. The original stimulus signal is shown in green, while the blue trace shows the output of the power amplifier without DPD and the red trace shows the results with DPD.

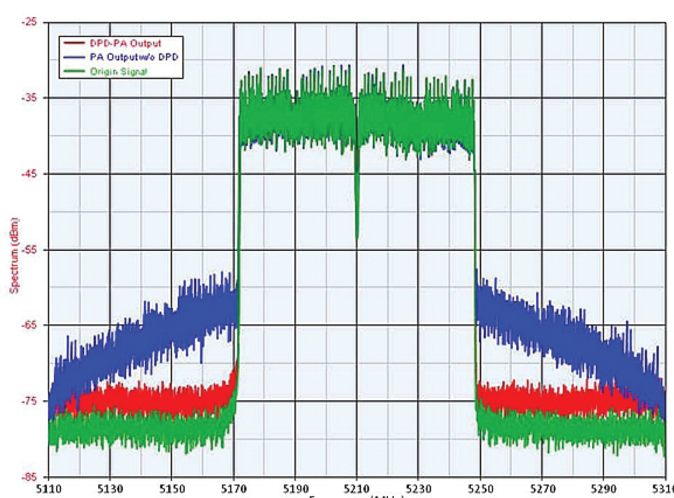


Figure 8 Example of DPD using 80 MHz 802.11ac signal

Design and Test Challenges

Wider Bandwidths

Amongst the more complex challenges for design and development is the generation and analysis of the wider bandwidth signals for 802.11ac. 80 and 160 MHz capabilities are needed to test components, transmitters, and receivers.

Receiver design is difficult because the device must be able to handle a wide variety of input-signal conditions, with signal levels ranging from transmitter and receiver in close proximity to maximum range, and with the potential for interference and varying signal level due to moving obstacles. Testing receivers requires instruments capable of producing the bandwidths and complex modulation techniques used in all the 802.11 variants.

For generating 80 MHz signals, many RF signal generators do not have a high enough sampling rate to support the typical minimum 2x oversampling ratio, which can result in images in the signal due to aliasing. However, with proper filtering and oversampling of the waveform file, it is possible to generate 80 MHz signals with good spectral characteristics and EVM using the Keysight N5172B EXG, N5182A MXG, or M9381A PXI vector signal generator.

The N5182B MXG signal generator provides 160 MHz bandwidth RF signals with excellent EVM performance. The PXI VSG is recommended for multi-channel tests such as MIMO or beamforming. Another solution is to use a wideband arbitrary waveform generator (AWG) such as the Keysight 81180A, M8190A, or M9330A to create the analog I/Q signals, and these can be applied to the external I/Q inputs in a vector signal generator such as the MXG, or E8267D PSG for upconversion to RF frequencies. It is also possible to create a 160 MHz signal by using 80+80 MHz mode to create the two 80 MHz segments in separate MXG signal generators and then combining the RF signals.

802.11ac waveforms can be created using the SystemVue W1917 WLAN Library, which provides a working baseband reference design for both transmit and receive signal processing paths. An open EDA implementation allows more intimate access and control of the inside of the block diagram for baseband developers. It also allows ideal or precisely-impaired signals of all bandwidths and modulation types to be downloaded to arbitrary waveform generators and signal generators, for RF verification. For dedicated, standalone waveform generation, N7617B Signal Studio for WLAN provides fully-coded waveform files with up to 160 MHz bandwidth for use with the EXG, MXG, PSG and PXI signal generators, as well as the N5106A PXB baseband generator and channel emulator. Signal Studio also supports 80+80 MHz mode using PXI or two EXGs, MXGs, or ESGs.

For signal analysis, signals up to 160 MHz bandwidth can be analyzed using the 89600 VSA software in combination with the N9030A PXA Signal Analyzer, multiple M9391A/M9393A PXI VSAs, M9703A Wideband AXIe multi-channel digitizer, or Infiniium or Infiniivisionoscilloscopes. The M9703A provides 8 synchronized channels with 12-bit resolution and is capable of capturing 802.11ac baseband IQ signals up to 800 MHz analysis bandwidth at full sampling rate. The AXI digitizer and oscilloscopes that can support bandwidths beyond 1 GHz are ideal in digital predistortion applications, which typically require measurement of signals that are 3 to 5 times the bandwidth of the signal being linearized.

Design and Test Challenges

MIMO and beamforming

Verifying MIMO and beamforming design is another difficult challenge. Both are functions of the device's design, so it will not change from one device to another. Manufacturing test will typically be limited to the individual receiver chains. Proving the design, however, is absolutely necessary. Multi-channel signal generation and analysis can be used to provide insight into the performance of MIMO and beamforming devices and assist in troubleshooting and design verification.

For testing receivers, MIMO signals can be created with both the SystemVue WLAN library and Signal Studio. Up to 8 PXI VSGs are easily integrated into the PXI chasis with precise synchronization to simulate MIMO or beamforming transmission. The effects of the fading channel can also be included in the waveform files to provide simulation of the signals at the receive antennas. The Keysight PXB can be used to emulate realtime fading conditions. For MIMO transmitter test, the 89600 VSA software can be used with an Infiniium or Infiniivision oscilloscope, or up to 8 PXI Vector Signal Generators to decode and display the multiple channels of time, frequency and modulation domain measurements simultaneously, as well as measure cross-channel performance to characterize complex MIMO and beamforming designs (Figure 9).

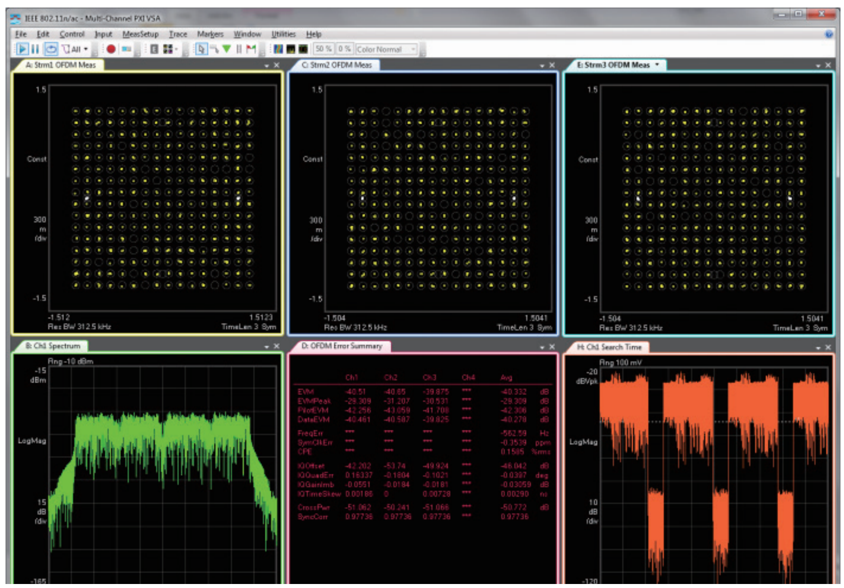


Figure 9 shows an example of modular products combined with 89600 VSA software for demodulation and analysis of up to 8 phase coherent channels simultaneously.

For wide baseband analysis, the M9703A AXIe multichannel digitizer provides 8-synchronized channels with 12-bit resolution and optional, real-time, digital down-conversion (DDC) for tuning into the signal of interest. This solution is capable of capturing 802.11ac baseband IQ signals and provides up to 800 MHz analysis bandwidth at full sampling rate to address emerging wireless standards.

Design and Test Challenges

MIMO Design Validation

For manufacturing and design validation, Keysight's EXM supports up to 4x4 MIMO, and provides the multiple TRXs needed for simultaneous test of multiple channels. Each antenna in the DUT is connected to a separate TRX in the tester (Figure 10). This method quickly provides engineers with a full and complete set of metrics since each channel is captured in parallel.

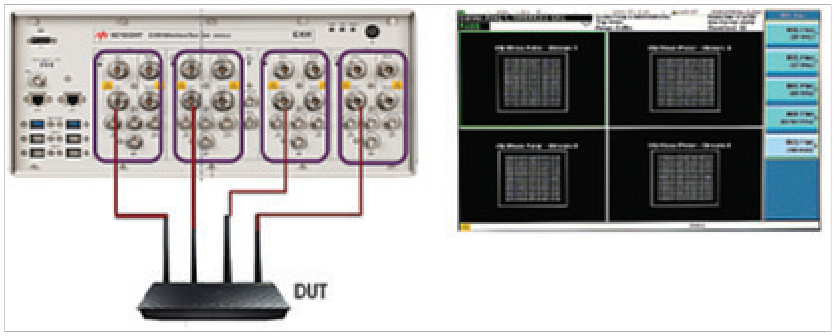


Figure 10. EXM configured for MIMO and beamforming test

IoT Sensors and Battery Drain

New types of sensors for the Internet of Things (IoT) include simple devices that are battery powered, transmit very little data, and are designed to have an unattended operating life of years. Designing and developing this type of device requires specific tools that can measure battery drain under three main conditions: "sleep mode", when the device is completely inactive; "idle mode", when the device is active but not transmitting; and "transmit mode", when it is sending data. Current consumption for these devices is random in nature, and ranges from nano-amps in sleep mode to milli-amps in idle and amps in transmit, over a very short time with with very steep rise and fall times.

Keysight's patented "Seamless Current Measurement" based on its N6780 Series Source Measurement Units (SMUs) let you visualize current drain from nano-amps to amps in one pass and one picture, unlocking insights to deliver exceptional battery life. (See Figure 11.)

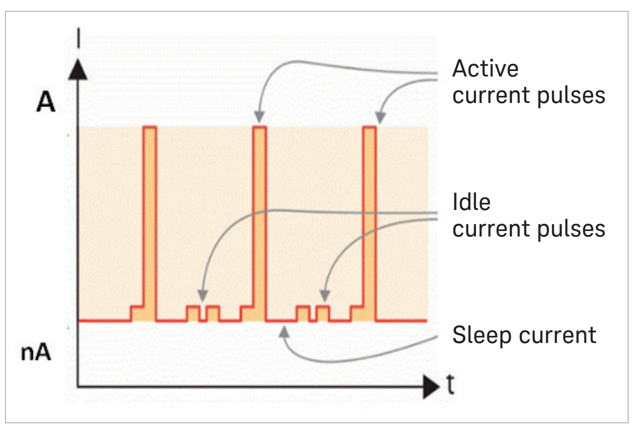


Figure 11. Current changes in a simple sensor device

Design and Test Challenges

WLAN Manufacturing Test

With an optimized design, high-volume, high-throughput manufacturing test should be fast and simple. Manufacturing test systems that incorporate multi-burst WLAN acquisition reduce test times to a few seconds, while providing all required transmitter and receiver test data you need to ensure your products consistently meet specifications.

Keysight's 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. 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.

An EXM 'sequence' can comprise up to hundreds of separate acquisitions (for each frequency and expected signal level, trigger conditions are programmed). 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.

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 connections can be switched, enabling connection of multiple devices with multiple antenna ports without the need for external switching. The EXM permits testing of multiple DUTs with fully asynchronous parallel testing, as well as connection of multiple-antenna devices. (Figure 12).

With its sequencer and multiple test capabilities, the EXM can facilitate faster testing in high volume applications, with current WiFi chipsets and their test modes, while also allowing for future advances in chipset test modes.

Figure 12. Example configuration of EXM with multiple antenna devices

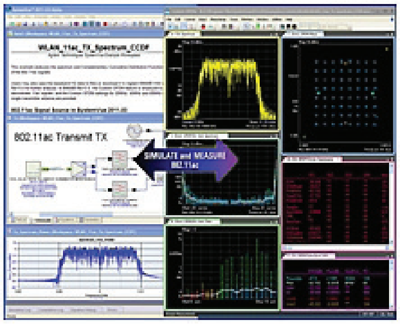
Conclusion

The continuing need for more speed and bandwidth of wireless LAN connections, and the increasing complexity of the standards to support it, bring major challenges for the test and measurement community. Comprehensive design and test capability is critical to the successful implementation of mass-market VHT WLAN products. System simulation tools, generation and analysis of the wider 80 and 160 MHz bandwidth signals, MIMO and 256QAM modulation for 802.11ac are key to testing components, transmitters and receivers. Close attention to design for manufacturing will help minimize cost of test and ensure that access points and clients meet consumers' price and performance expectations.

Keysight provides a broad portfolio of design and test solutions to give greater insight into device performance and provide greater confidence in your designs. Additional product information is available at www.keysight.com/find/802.11ac.

Design and Test Products

System simulation and verification software



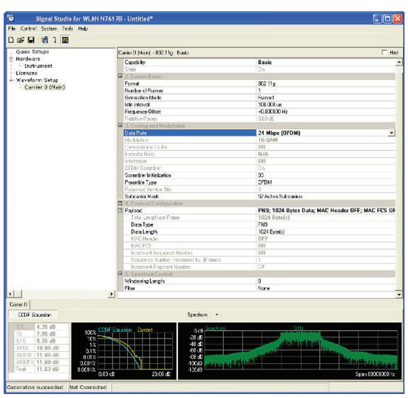
SystemVue W1917 WLAN Baseband Verification Library and W1716EP DPD Builder

The W1917EP WLAN Baseband Verification Library is a Layer 1 simulation reference library for Keysight SystemVue. The blockset, reference designs, and testbenches of the W1917 assist the design and verification of multi-format radios, by providing configurable physical layer waveforms for 802.11ac

Key features:

- Wider channel bandwidths (20, 40, 80, 160, and 80+80 MHz support for 11ac source)
- Aggregate MPDU (A-MPDU)
- All modulation types (BPSK, QPSK, 16QAM, 64QAM and 256QAM)
- SU-MIMO (Single-User MIMO) and MU-MIMO (Multi-User MIMO) up to 8 spatial streams
- BCC (Binary convolutional coder) and LDPC (low density parity check coder) channel coding
- Different spatial mapping schemes: Direct Mapping, Spatial Expansion and User Defined
- Provide EVM measurements compatible with Keysight VSA 89600 software
- Receiver baseband algorithm (synchronization, channel estimation and phase tracking, soft demapper and decoders)
- Provide WLAN TGac channel model
- Supported instruments
  - Arbitrary waveform generators: N8241A, M9330A, 81180, M8190A
  - Signal generators: MXG, PSG, PXI VSG
  - Signal analysis receivers: any instruments supported by 89600 VSA

Signal generation



N7617B Signal Studio for WLAN 802.11a/b/g/n/ac

Signal Studio offers a basic 802.11ac option (GFP) to provide partially coded, statistically correct waveforms for component testing, as well as an advanced 802.11ac option (TFP) to create fully coded waveforms for receiver testing.

Key features:

- Create 802.11ac signals with BCC or LDPC channel coding
- Supports all modulation and coding rates (MCS 0-9)
- Supports 20, 40, 80, and 160 MHz bandwidth signals with one signal generator (maximum bandwidth varies by instrument)
- Create 80+80 MHz signals using two signal generators and RF combining
- Supports single or multi-user MIMO (MU-MIMO) with flexible spatial stream configuration and space-time block coding for up to 4 streams/antennas
- Compatible instruments: N5172B EXG, N5182A/B MXG, E4438C ESG, or E8267D PSG signal generators and N5106A PXB baseband generator and channel emulator (MIMO not supported for PSG)

Design and Test Products

RF vector signal generators

N5172B EXG Vector Signal Generator [1]

Key features:

- 9 kHz to 6 GHz
- Up to 120 MHz RF modulation BW with internal baseband generator
- Up to 512 MSa baseband memory
- ~200 MHz BW using external I/Q inputs
- Built-in I/Q skew and channel corrections for improved EVM performance
- Simple synchronization of baseband generators in multiple EXGs for MIMO
- Option 012 provides LO in/out for phase coherency for MIMO

N5182B MXG Vector Signal Generator

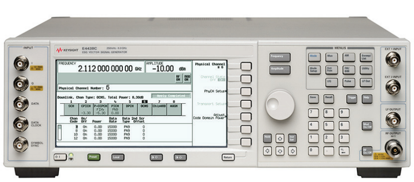
Key features:

- 9 kHz to 6 GHz
- Up to 160 MHz RF modulation BW with internal baseband generator
- Up to 1 GSa baseband memory
- ~200 MHz BW using external I/Q inputs
- Built-in I/Q skew and channel corrections for improved EVM performance
- Simple synchronization of baseband generators in multiple EXGs for MIMO
- Option 012 provides LO in/out for phase coherency for MIMO

N5182A MXG Vector Signal Generator

Key features:

- 100 kHz to 6 GHz
- 64 MSa baseband memory
- Up to 100 MHz RF modulation BW with internal baseband generator
- ~200 MHz BW using external I/Q inputs
- I/Q skew and channel flatness corrections for improved EVM performance
- Simple synchronization of baseband generators in multiple MXGs for MIMO
- Option 012 provides LO in/out for phase coherency for MIMO



E4438C ESG Vector Signal Generator

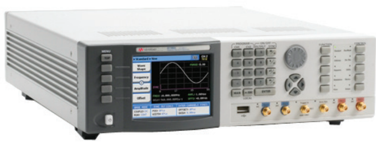
Key features:

- 250 kHz to 6 GHz
- 64 MSa baseband memory
- 80 MHz RF modulation BW with internal baseband generator
- ~200 MHz BW using external I/Q inputs

1. The EXG or MXG signal generators are recommended for 802.11ac instead of the ESG due to lower cost, better EVM performance for wideband signals, and simple configuration and synchronization for MIMO applications.

Design and Test Products

Arbitrary waveform generators (AWG)



81180A 4.2 GSa/s Arbitrary Waveform Generator

Key features:

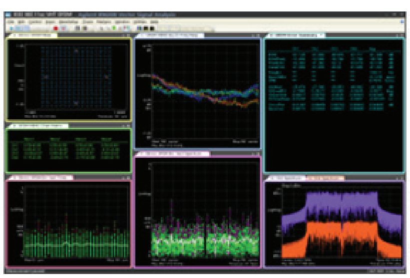
- 12-bit resolution
- Variable sample rate from 10 MSa/s to 4.2 GSa/s
- 1 or 2 channels, coupled and phase coherent or uncoupled
- 1 GHz modulation bandwidth per channel (2 GHz IQ modulation)
- 1.5 GHz carrier frequency
- Up to 64 MSa memory per channel
- Advanced sequencing capabilities
- Over 64 dBc spurious-free dynamic range
- Harmonic distortion less than –56 dBc

M8190A 12 GSa/s Arbitrary Waveform Generator

Key features:

- 14-bit resolution up to 8 GSa/s
- 12-bit resolution up to 12 GSa/s
- Variable sample rate from 125 MSa/s to 8/12 GSa/s
- Spurious-free-dynamic range (SFDR) up to 80 dBc typical
- Harmonic distortion (HD) less than –72 dBc typical
- Up to 2 GSa arbitrary waveform memory per channel with advanced sequencing
- Analog bandwidth 5 GHz (direct DAC out)

Signal analysis



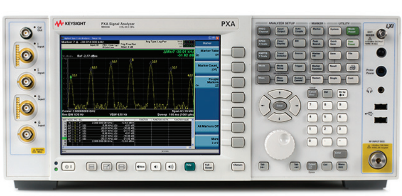
89600 Vector Signal Analysis Software

Option BHJ 802.11ac Modulation Analysis

Key features:

- Supports all channel bandwidths and modulation types
- Supports up to 4 spatial streams with auto or manual detection
- Provides measurements of EVM, OFDM errors, IQ parameters, single channel and cross-channel power
- MIMO measurements include EVM per stream, channel frequency response, channel matrix, and condition number
- Displays OFDM data burst information and VHT-SIG information Flexible display for optimal viewing of MIMO results

Supports a variety of hardware configurations for the performance, bandwidth, and number of channels you need, including PXA, MXA and EXA signal analyzers and 80000 and 90000 series Infiniium oscilloscopes.



N9030A PXA Signal Analyzer
N9020A MXA Signal Analyzer
N9010A EXA Signal Analyzer

Key features:

- Frequency coverage up to 26.5 GHz (MXA/EXA) or 50 GHz (PXA)
- Up to 40 MHz demodulation bandwidth (MXA/EXA)
- Up to 160 MHz demodulation bandwidth (PXA)
- Range of performance to meet your test requirements and budget
- Supports over 25 measurement applications as well as 89600 VSA

Design and Test Products

Signal analysis continued

PXI Multi-Channel Vector Signal Generators

Key features:

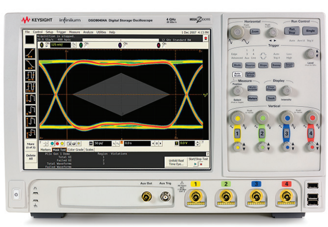
- Frequency coverage from 1 MHz to 3 GHz or 6 GHz
- 10 us switching speed with an exclusive baseband tuning technology innovation
- RF modulation bandwidth up to 160 MHz (± 0.3 dB flatness)
- Better than ± 0.4 dB absolute amplitude accuracy

PXI Multi-Channel Vector Signal Analyzers

Key features:

- 1 MHz to 3 or 6 GHz
- 40, 100 or 160 MHz analysis BW
- 157 dBm displayed average noise level (DANL)
- -119 dBc/Hz Phase noise @ 1 GHz, 10 kHz offset

Synchronize up to 8 phase coherent channels for MIMO and beamforming applications



Infiniium and Infiniivision oscilloscopes

Key features:

- 1 GHz or wider bandwidth
- 4 channels
- Range of bandwidths, maximum sampling rates, and memory depth availablle

8-channel AXI Multi-Channel Digitizer/Wideband Digital Receiver

Key features:

- 8-channels of DC to 2 GHz input freq, 12-bit resolution
- 1up to 3.2 GS/s sampling rate
- Multi-mode processing synchronization for up > 100 phase coherent channels
- On-board FPGAs for custom processing or OTS wideband real-time DDC

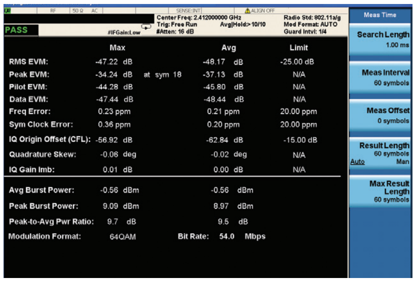
E6640A EXM Wireless Test Set

Key features:

- Up to four TRX channels per EXM, with up to 6 GHz bandwidth on each TRX
- Two full-duplex and two half-duplex or four full-duplex ports per TRX
- Customizable to connect up to 32 DUTs with multi-port adapter (MPA) technology
- Independent source and analyzer on each TRX allows efficient use of test resources

Design and Test Products

Signal analysis continued



N9077A WLAN 802.11a/b/g/n/ac Measurement Software Application for the EXM

Key features:

- Designed for high-volume, high-throughput manufacturing environments
- Eliminates measurement switching and reconfiguration for disparate bursts
- Perform large volumes of tests quickly and efficiently, while maintaining the flexibility required to calibrate, exercise, and characterize WLAN products.
- Using SCPI commands, WLAN list sequence makes a single acquisition of up to 45 WLAN bursts acquisition

Multi-channel tests for MIMO and beamforming

Multiple PXI Vector Signal Generators and PXI Vector Signal Analyzers can be configured into the PXI chassis and provide time-synchronized or phase coherent channels to address evolving wireless standards to validate critical WLAN multi-antenna techniques such as 8x8 spatial multiplexing MIMO and beamforming. In addition, the up to 160 MHz of signal generation and analysis bandwidth address the wider bandwidth needed for 802.11ac applications. The PXI solutions provide multi-channel configuration and calibration tools enabling engineers to accelerate test set up and gain deeper insight into their complex WLAN designs. See **www.keysight.com/find/PXI-MIMO** for more information.

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