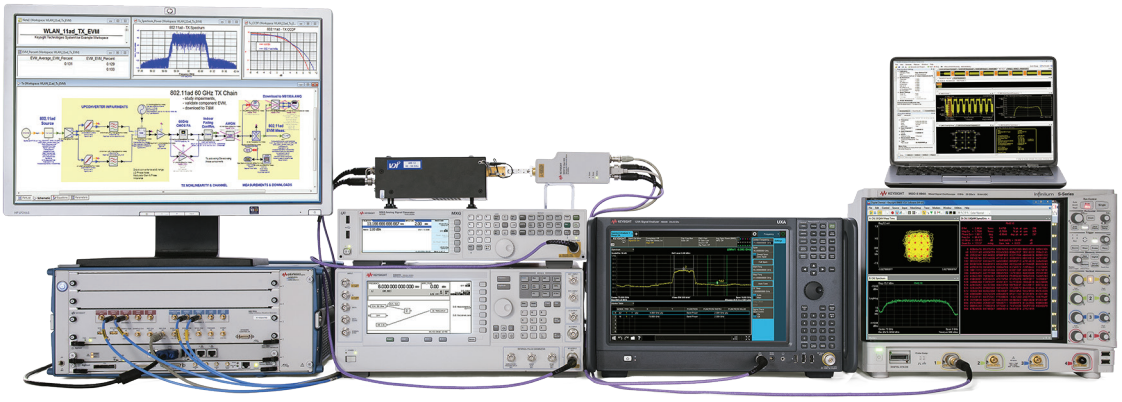
Keysight Technologies
802.11ad Waveform Generation & Analysis Testbed, Reference Solution

Solution Brochure



KEYSIGHT TECHNOLOGIES

Flexible and Comprehensive Solution for Generation and Analysis of 802.11ad Signals

Introduction

Early standards for wireless LAN - IEEE 802.11a and b - were designed to link a wired broadband connection to PC for web browsing and email in the home or office. 802.11b supported up to 11 Mb/s at 2.4 GHz while 802.11a supported up to 54 Mb/s at 5 GHz, both in unlicensed spectrum. A later revision, 802.11g, consolidated the two standards in the 2.4 GHz band but maintained the maximum data rate at 54 Mb/s. It was soon recognized that new usage models with data sharing amongst connected devices required more bandwidth than the original standards could support. 802.11n was introduced to provide up to 600 Mb/s and utilized new techniques like MIMO. IEEE project groups researched ways to provide very high throughput (VHT) to meet ever increasing bandwidth requirements for applications such as wireless display, distribution of HDTV and rapid upload/download of files. The 802.11ac specification added support for up to a theoretical 6.93 Gb/s using 160 MHz of bandwidth, 8 spatial streams, and 256QAM, although the practical data rate for consumer devices was typically 1.56 Gb/s using 80 MHz of bandwidth and 4 spatial streams.

The 802.11ad offers up to 6.75 Gb/s of throughput using approximately 2 GHz of spectrum in the unlicensed 60 GHz band and maintains backward compatibility with legacy 802.11 devices. The 802.11ad standard adds significant capability, but also presents new test challenges for engineers developing and designing to this standard.

802.11ad Generation and Analysis Test Challenges

Component and system design and test at 60 GHz is an established, well understood science. Tools for mmWave circuit design and simulation, network analysis, signal analysis and power measurement have been used for a number of years in applications such as short-range radar and military communications. However, the new commercial 60 GHz applications require much wider modulation bandwidth, and hence different test solutions are needed.

Creating and analyzing signals with 2 GHz of bandwidth at mmWave frequencies, which is many times greater than other wireless communication systems, is one of the biggest challenges. There is often a need for testing the IF and baseband sections of a device or system, so a flexible test system architecture is desired. Additionally, capturing IQ samples for demodulation is needed to compute metrics like EVM to assess in-channel performance, and traditional swept-tuned analysis is needed to measure out of channel and out of band harmonic and spurious performance.

802.11ad Waveform Generation and Analysis Testbed Reference Solution

To help address these test challenges, the 802.11ad waveform generation and analysis testbed, reference solution provides a combination of hardware, software, and measurement expertise, the essential components of a flexible 802.11ad generation and analysis test platform. The reference solution enables engineers and researchers to generate and analyze 802.11ad signals at baseband, IF, RF, and mmWave frequencies.

The reference solution includes the 81199A Wideband Waveform Center software from Keysight Technologies, Inc. for creating and analyzing waveforms with two pieces of hardware – a precision AWG and a vector signal generator with wideband I/Q inputs. The combination of hardware and software enables generation of wideband test signals with up to 2 GHz of modulation bandwidth at frequencies up to 44 GHz to support a wide range of possible IF frequencies. Frequency coverage in V-Band is obtained through the use of an upconverter. A wide bandwidth oscilloscope performs signal demodulation at IF frequencies by digitizing the signals and passing them to the software for analysis. A downconverter can be used to translate 60 GHz signals into an IF usable by an oscilloscope.

Figure 1 below shows a conceptual arrangement of the software and hardware elements and Figure 2 shows a combination of Keysight hardware and software for the 802.11ad generation and analysis testbed.

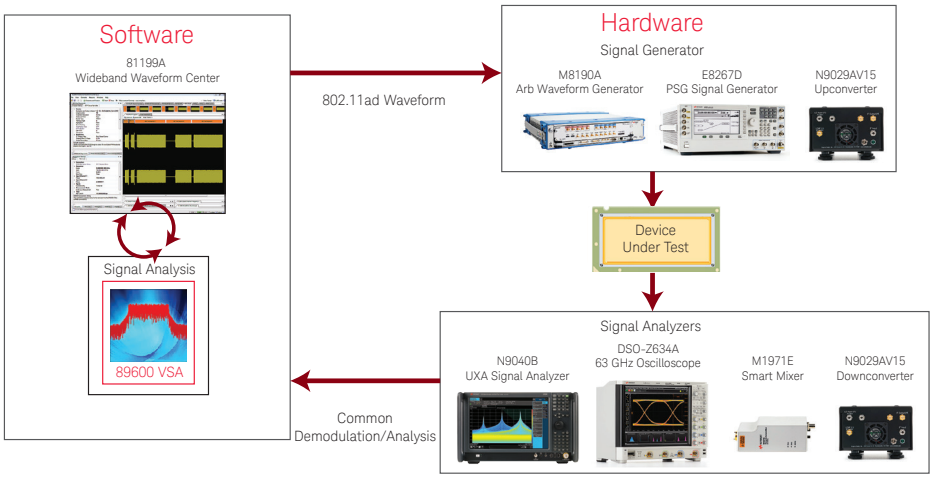


Figure 1. The 802.11ad testbed provides combinations of hardware and software, giving the researcher flexibility to explore 802.11ad technologies at different device measurement planes.

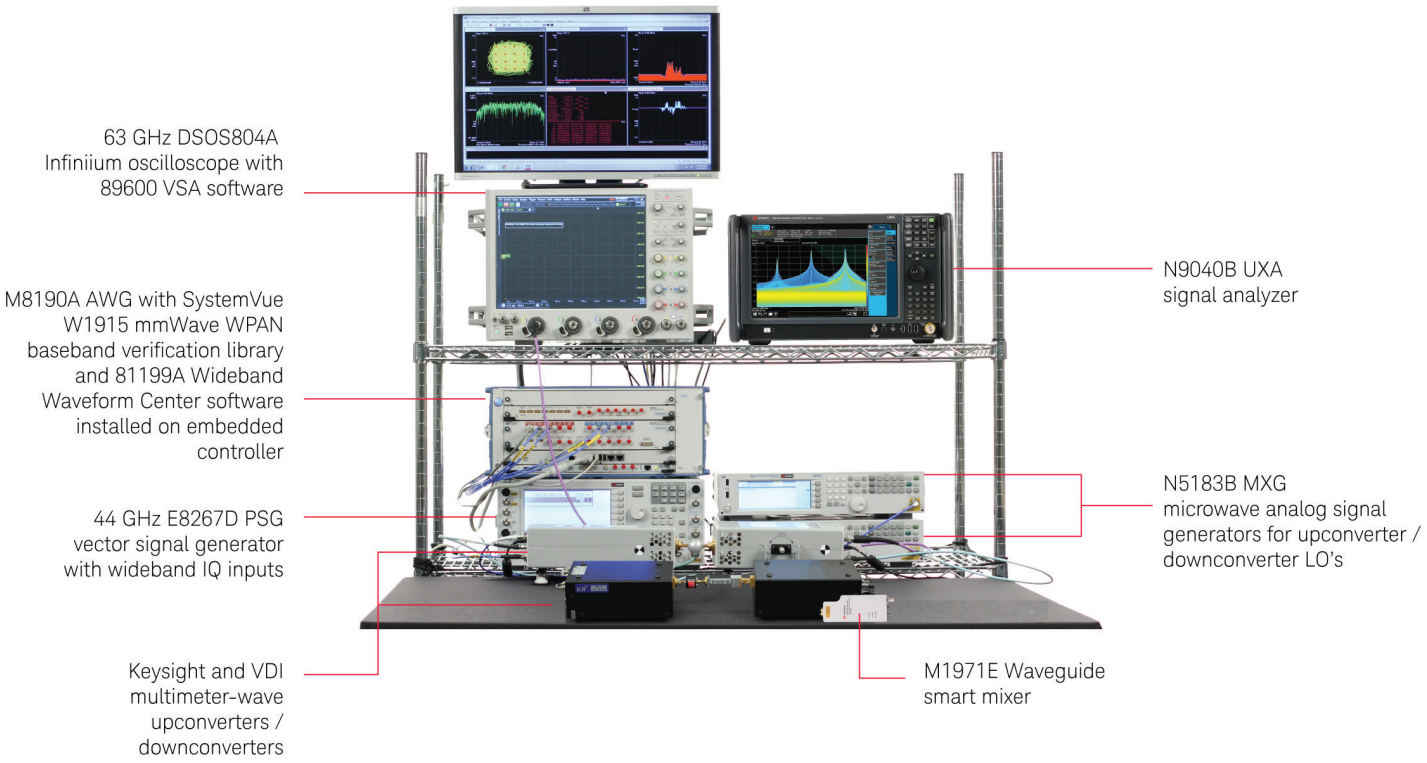


Figure 2. This combination of hardware and software provides a considerable amount of flexibility and capability for determining 802.11ad system performance.

Features	Benefits
802.11ad waveforms	Generate and analyze 802.11ad waveforms with custom configurations for thorough evaluation of device performance & characteristics to gain insight and reduce risk
Scalable modulation bandwidths and frequency bands	Provides flexibility to adapt to next generation technologies, like 5G and reduce risk of locking in today and choosing the wrong path
Supports many topologies for transmitter / receiver testing (IQ, IF, RF, uWave, mm-Wave)	Evaluate performance at various stages along Tx and Rx chains and gain insight to debug issues

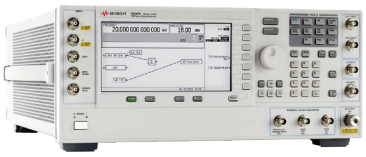
Reference Solution Configuration

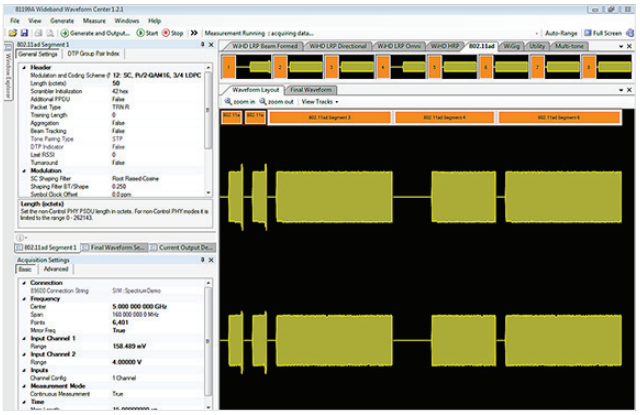
Signal creation configuration

The testbed signal generation hardware includes the M8190A AXIe AWG installed in an AXIe chassis that also contains an embedded controller. The 81199A software runs on the embedded controller, which creates waveforms that are loaded in the AWG installed in the same chassis. The 2-channel precision AWG can operate with 14-bit resolution at up to 8 GSa/s or 12-bit resolution up to 12 GSa/s. It offers 5 GHz of analog bandwidth and 2 GSa of memory per channel.

As part of the reference solution, the AWG is used to drive a PSG vector signal generator equipped with wideband differential external I/Q inputs (option 016). The wideband inputs can produce modulation bandwidths of up to 2 GHz on carrier signals up to 44 GHz. Depending on your application and performance requirements, a choice of upconverters is available to generate signals in V-Band. The Keysight N5152A offers a frequency range of 57 to 66 GHz, and Virginia Diodes, Inc. has a number of different upconverters available in V-Band (50 to 75 GHz), E-Band (60 - 90 GHz), and beyond. MXG or PSG microwave analog signal generators provide the LOs for the millimeter-wave upconverters.

The creation of 802.11ad waveforms is controlled by the 81199A software, which provides fully coded and modulated PHY signal generation. The software provides a library of individually-configurable waveform segments. Assembling a desired signal is a simple matter of dragging and dropping waveform segments and then assigning essential attributes to them. Before downloading to the arbitrary waveform generator at an appropriate sample rate, you can also add Additive White Gaussian Noise (AWGN) and other impairments.





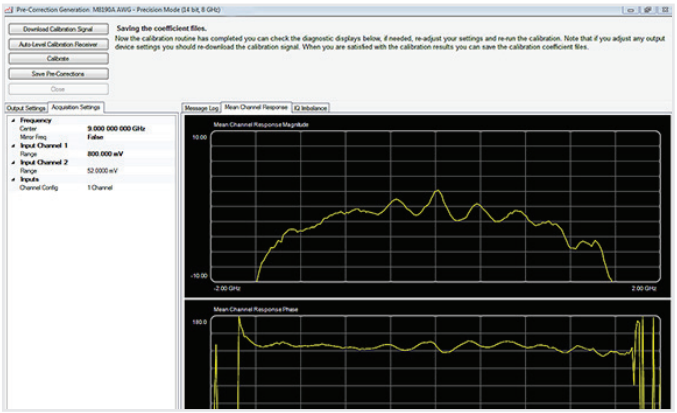
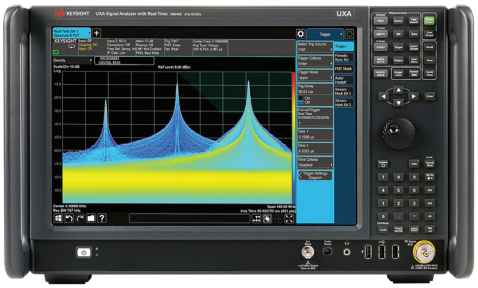


Figure 3. M8190A AXIe AWG, E8267D PSG, and 81199A Wideband Waveform Center software. The Wideband Waveform Center images show a simple sequence of different 802.11ad packets and the channel response used for calibration.

Signal analysis configuration

The test signals can be demodulated using an oscilloscope and the 81199A software. Keysight offers a wide portfolio of oscilloscopes with bandwidths up to 63 GHz. This enables digitizing 60 GHz signals directly, which offer extremely flat amplitude response and linear phase response. Alternatively, a lower bandwidth oscilloscope can be used with a downconverter to translate the 60 GHz signal into an IF suitable for that particular oscilloscope. There are several possibilities for downconverters, depending on your application and performance requirements:

- Keysight N1999A downconveter
  - Features a built-in attenuator & preamplifier
  - Frequency range from 57 to 66 GHz
  - Bandwidth: 2 GHz
- Keysight M1971E smart mixer
  - Enables swept-tuned measurements with a spectrum analyzer
  - Enables I/Q captures for demodulation measurements with an oscilloscope
  - Frequency range from 55 to 90 GHz
  - Bandwidth: > 2 GHz
- N9029AV12 and N9029AV15 VDI downconverters
  - Flexible LO/IF planning
  - Frequency range:
  -- V-Band: 50 to 75 GHz
  -- E-Band: 60 to 90 GHz
  - Bandwidth: ~9 GHz



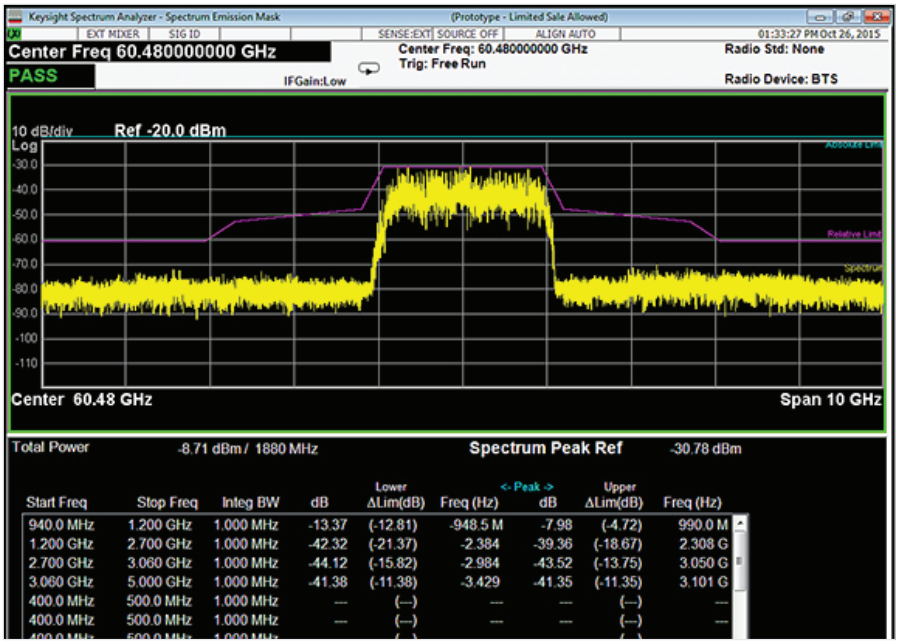


Figure 4. Wideband smart mixer, UXA signal analyzer, and S-Series oscilloscope. The spectrum trace shows an 802.11ad Spectral Emission Mask (SEM) measurement at 60.48 GHz using the M1971E smart mixer.

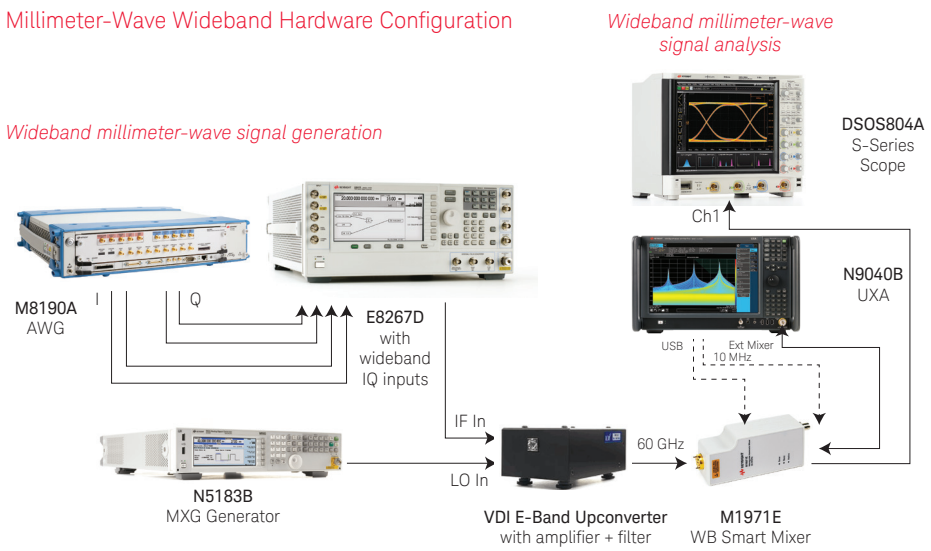


Figure 5. Example hardware configuration for wide bandwidth millimeter-wave signal generation and analysis.

Out-of-channel and out-of-band performance can be evaluated using traditional swept-tuned analysis. The measurement in Figure 4 was made using the Keysight M1971E Smart Mixer, converting a 60 GHz signal to IF measurable by an X-series signal analyzer.

A simple block diagram of an 802.11ad test configuration for wide bandwidth millimeter-wave signal generation and analysis is shown in Figure 5. The hardware configuration can be altered to address requirements at baseband, IF, or millimeter-wave. Figure 5 includes the AWG and PSG setup previously described with either the Keysight or Virginia Diodes upconverter used to upconvert the signal to the 60 GHz band. The MXG provides the LO for the millimeter-wave upconverter. Optional millimeter-wave amplifiers and filters are available depending on the application and performance requirements.

The M1971E wideband smart mixer is used for signal analysis from 55 to 90 GHz, when combined with an X-Series signal analyzer and oscilloscope. The smart mixer is connected to the output of the upconverter and the IF output is fed to the signal analyzer for swept-tuned measurements. The auxiliary IF output is fed into an oscilloscope for demodulation with the 81199A software.

Figure 6. Demodulation of a 802.11ad signal in the 60 GHz band using the Keysight upconverter and downconverter.

Figure 6 shows the demodulation analysis of a vector-corrected 802.11ad waveform at 60.48 GHz. The 81199A software was used to correct the channel response and the IQ imbalances in the system. As a result, the channel response is flat and the IQ impairment metrics exhibit nearly perfect balance.

This 60 GHz example configuration is one of many possible configurations. Other configurations can be created to address different frequencies, such as IF or baseband for testing at other test planes. A Keysight representative can recommend the best hardware configuration for your specific application requirements.

Table 1. General overview of source and analyzer configurations for different carrier frequencies and modulation bandwidths

Carrier Frequency	Modulation Bandwidth	Source Configuration	Analyzer Configuration
< 6 GHz	< 160 MHz	MXG	X-Series Analyzer[1]
< 44 GHz	< 1 GHz	AWG + PSG	X-Series Analyzer[1] + S-Series Oscilloscope
55 to 90 GHz	< 2 GHz	AWG + PSG + VDI Millimeter-Wave Upconverter	Wideband Smart Mixer + X-Series Analyzer[1] + S-Series Oscilloscope

1. X-Series analyzers come in range of frequencies and performance attributes. The UXA, PXA and EXA are available at 44 GHz.

Reference Solution Key Performance Characteristics

M8190A AXIe 12 GS/s arbitrary waveform generator
14-bit resolution up to 8 GSa/s or 12-bit resolution up to 12 GSa/s
Analog bandwidth 5 GHz (direct DAC out)
Up to 2 GSa arbitrary waveform memory per channel
E8267D PSG vector signal generator
100 kHz to 20, 31.8, or 44 GHz. Extendable to 60-90 GHz (and other frequency bands) with Keysight and VDI millimeter-wave upconverters
+ 14 dBm at 20 GHz (typical) + 13 dBm at 40 GHz (typical)
External I/Q inputs provide up to 2 GHz modulation bandwidth when used with M8190A AXIe AWG
N5183B MXG microwave analog signal generator for uW LO
9 kHz to 13, 20 31.8 or 40 GHz
+ 15 dBm output power at 20 GHz
-124 dBc/Hz phase noise at 10 GHz and 10 kHz offset
N5152A upconverter & N1999A downconverter
57 to 66 GHz frequency range
2 GHz bandwidth
N9029AV12/N9029AV15-UDC Millimeter-wave upconverter/downconverter
50 to 75 GHz frequency range (N9029AV15)
60 to 90 GHz frequency range (N9029V12)
~9 GHz bandwidth
M1971E Waveguide wideband smart mixer
55 to 90 GHz
27 dB maximum conversion loss
N9040B UXA signal analyzer
3 Hz to 8.4, 15.6, 26.5, 44, or 50 GHz
25 MHz (standard), 40, 255, 510 MHz or 1 GHz analysis bandwidth
+22 dBm third order intercept (TOI)
DSOS804A S-Series oscilloscope
8 GHz bandwidth with flat frequency response for high signal fidelity
20 GSa/s maximum sample rate
10-bit analog-to-digital converter (ADC) vertical resolution
DSOZ634A Infiniium oscilloscope
63 GHz bandwidth with flat frequency response for high signal fidelity
160 GSa/s maximum sample rate
8-bit analog-to-digital converter (ADC) vertical resolution

Hardware Elements

The combination of this test equipment provides waveform generation and analysis up to millimeter-wave frequencies with up to 2 GHz of modulation bandwidth. A Keysight representative can help to recommend the best hardware configuration based on the specific application needs.

M8190A AXIe 12 GS/s arbitrary waveform generator

www.keysight.com/find/m8190a

The M8190A AWG is used to drive an E8267D PSG vector signal generator equipped with wideband external I/Q inputs (option 016) to produce modulation bandwidths of up to 2 GHz on carrier signals up to 44 GHz. The M8190A is a 2-channel precision AWG that can operate with 14-bit resolution at up to 8 GSa/s or 12-bit resolution up to 12 GSa/s. It has 5 GHz of analog bandwidth and 2 GSa of memory per channel.

E8267D PSG vector signal generator

www.keysight.com/find/e8267d

The E8267D PSG vector signal generator provides wide-band signal generation to 44 GHz The PSG includes wideband differential external I/Q inputs for modulation bandwidths up to 2 GHz. For signal generation above 44 GHz, upconverters are available from Keysight (58 to 64 GHz with N5152A) and N9029AV12 Virginia Diodes Inc. (60 to 90 GHz). MXG microwave analog signal generators (N5183B) are used to provide the LOs for the millimeter-wave upconverters.

N5183B MXG microwave analog signal generator

www.keysight.com/find/n5183b

N5183B MXG microwave analog signal generators are used to provide LOs for the millimeter-wave upconverters and downconverters.

N5152A upconverter & N1999A downconverter

Contact Keysight for details.

The N5152A upconverter and N1999A downconverter were designed specifically for use with 802.11ad systems. Both the upconverter and downconverter use a 5 GHz IF. The upconverter has an output power of up to +5 dBm and also includes filters to produce an image free output. The downconverter uses a preamp to enable low level signals for analysis. An attenuator is included to optimize system performance.

N9029AV12-UDC/N9029AV15-UDC Millimeter-wave upconverter/ downconverter

www.keysight.com/find/SA_mmwave

The N9029AV15 & N9029AV12 millimeter-wave signal analyzer frequency extension modules, offered by VDI, Inc., cover the V-Band (50 to 75 GHz) and E-Band (60 to 90 GHz) respectively. The standard units are downconverters, and with option UDC, a single unit can be configured via jumpers to be either an upconverter or downconverter. This enables upconverting IF signals from a PSG to millimeter-wave or downconverting millimeter-wave signals to IF for analysis with an oscilloscope or signal analyzer.

Hardware Elements (continued)

M1971E Waveguide harmonic smart mixer

www.keysight.com/find/smartmixer

The M1971E wideband smart mixer is combined with an X-Series signal analyzer, such as an N9040B UXA signal analyzer, and DSOS804A S-series oscilloscope for wideband signal analysis from 60 to 90 GHz. The M1971E 55, 60 to 90 GHz waveguide harmonic mixer is an un-preselected mixer for wideband millimeter-wave signal analysis of more than 2 GHz with X-Series signal analyzers.

N9040B UXA signal analyzer

www.keysight.com/find/n9040b

A Keysight N9040B UXA signal analyzer is used for spectrum and demodulation analysis. The UXA signal analyzer, a high-performance member of the X-Series, provides frequency coverage up to 50 GHz, and ensures present and future flexibility through optional measurement capabilities and hardware expandability. A PXA may also be used, depending on application requirements.

DSOS804A Oscilloscope

www.keysight.com/find/oscilloscopes

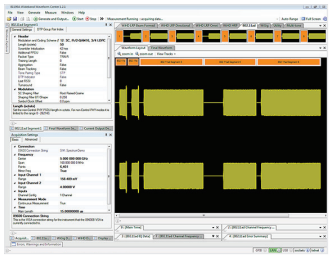
An Infiniium S-Series high-definition oscilloscope is used to perform wideband demodulation analysis when paired with the N9040B UXA signal analyzer used as a wideband downconverter and the M1971E wavegude harmonic smart mixer. A 10-bit ADC, low-noise front end, correction filters, vertical scaling support down to 2 mV/division, and a precise time base produce high-fidelity measurements. In addition, its advanced frame and broad range of capability enable the S-Series oscilloscopes to tackle a wide range of test needs.

Software Elements

The combination of this signal generation and analysis software provides waveform generation and analysis of 802.11ad waveforms with the hardware configuration listed above.

81199A Wideband Waveform Center software

www.keysight.com/find/81199a



The 81199A Wideband Waveform Center software provides fully coded and modulated PHY signal generation and analysis capability. A number of different 802.11ad packets can be uniquely configured and then sequenced together for playback for testing a receiver with different packet structures. Parameters that can be adjusted include:

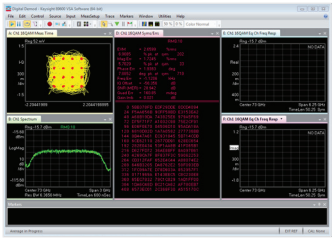
- Modulation Coding Schemes (MCS) 0 through 31
- Packet length
- Scrambler initialization
- Packet type
- Training length
- Payload data type
- Interpacket gap length

The software automatically demodulates the 802.11ad signal and determines the MCS type. Analysis measurements for thorough characterization of device performance and troubleshooting of unexpected problems include:

- Constellation diagram
- Error summary with EVM and IQ impairment metrics
- EVM vs spectrum and time for single carrier modulation or EVM vs symbol or subcarrier for OFDM
- Channel estimation
- Carrier tracking
- Phase error
- Decoded data

89601B 89600 VSA Software

www.keysight.com/find/89600



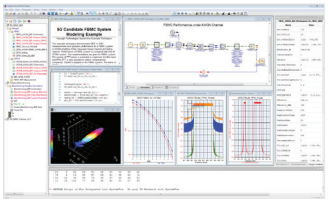
The 89600 VSA software is a comprehensive set of tools for demodulation and vector signal analysis. These tools enable you to explore virtually every facet of a signal and optimize your most advanced designs. As you assess the tradeoffs, the 89600 VSA helps you see through the complexity.

Software Elements (continued)

W1915EP SystemVue mmWave WPAN baseband verification library

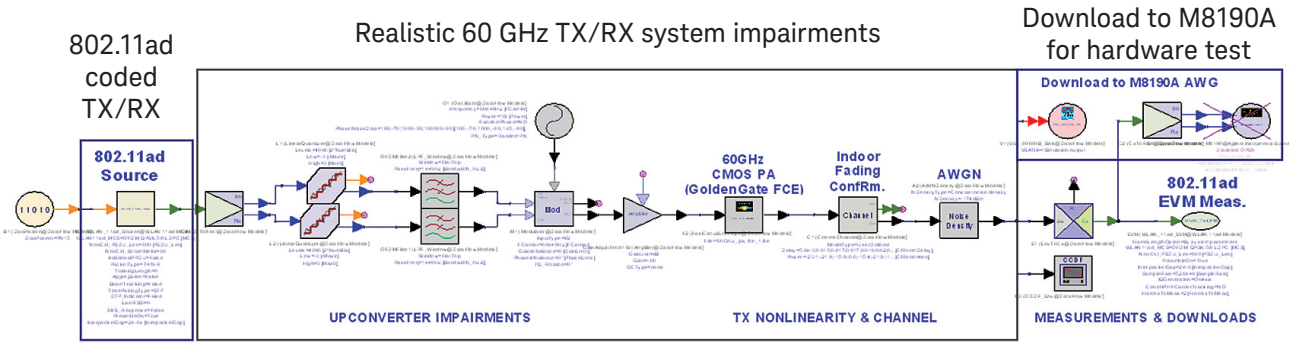
www.keysight.com/find/systemvue

SystemVue is a system-level communications design environment that brings together physical layer baseband algorithmic modelling, accurate RF modelling, standards-based reference IP, and direct interaction with test equipment. It is used early in the R&D lifecycle by system architects, and follows both the RF and Baseband design paths into implementation, providing continuity for cross-domain verification.



The W1915 mmWave WPAN Baseband Verification Library is a SystemVue add-on library that provides configurable IP references for 802.11ad and 802.15.3c wireless communications physical layers operating at 60 GHz. It is used by designers to verify baseband algorithms, system performance with faded and precisely impaired channels, and various RF components. Because of the difficulty in making 60 GHz components and measurements, SystemVue simulations are able to assist in these key ways:

- Validation of early RFIC and MMIC designs in Keysight GoldenGate and ADS, prior to taping out a wafer.
- Economical system-level validation and high-fidelity early pre-compliance using simulations, so that final hardware compliance testing can be performed more quickly, with greater confidence.
- Generation of consistent test vectors for simulation vs. hardware testing, using a direct download to the Keysight M8190A AWG and measurement using the 81199A Wideband Waveform Center software. The W1915 library is interoperable with the 81199A and 89600 VSA applications.



BB source
- Test vector generation
- Coding
- Std pre-compliance
- Algorithms
- MIMO/beamforming

Upconverter
- Quantizer (12 b vs. 16 b)
- Filtering
- Gain/phase imbalance
- Phase noise
- Nonlinearities
- Frequency response

60 GHz PA
- Ideal PA model
- X-parameters
- FCE from Golden Gate
- (with memory effects)
- Live ADS/GG co-sim

Channel
- Noise, fading
- Multipath
- Interferers

Receiver
- Downconversion
- Noise and filtering
- Clock recovery and EQ
- ADC and jitter
- Nonlinearities
- Spurs

Recommended Reference Solution Base Configuration

This Reference Solution is flexible and scalable. Buy what you need today and add more capabilities as your 802.11ad measurement requirements evolve.

Note that other configurations may be available depending on specific application requirements. A Keysight representative can recommend the best hardware configuration based on the specific application requirements.

Model	Description
Hardware	
M8190A	**AXIe AWG**
M8190A-002	AWG – 2-channels
M8190A-02G (qty:2)	128 MSa to 2 GSa memory/Ch
M8190A-14B	14-bit resolution
M8190A-12G	12-bit resolution
M8190A-BU1	Bundle 1 (5-slot chassis and controller)
M8190A-DUC	Digital upconversion
M8190A- AMP	AC and DC amplifier
M8190A-811(x4)	Cable assembly
E8267D	**PSG Vector Signal Generator**
E8267D-544	Frequency range, 250 kHz to 44 GHz
E8267D-016	IQ differential inputs
E8267D-H18	Wideband modulation < 3.2 GHz
E8267D-UNY	Enhanced ultra-low phase noise
E8267D-602	Internal baseband generator
N9040B	**UXA X-Series Signal Analyzer**
N9040B-550	Frequency range, 250 kHz to 50 GHz
N9040B-B2x	Analysis bandwidth, 255 MHz
N9040B-H1G	Analysis bandwidth, 1 GHz
N9040B-P50	Preamplifier, 50 GHz
N5183B	**MXG X-Series Signal Generator (one needed as LO for each up/downconverter)**
N5183B-520	Frequency range, 9 kHz to 20 GHz
N5183B-UNY	Enhanced low phase noise
DSOS804A*	**S-Series High-definition Oscilloscope, 8 GHz**
DSOS000-400	Memory- 400 Mpts/ch
M1971E	**Waveguide Smart Mixer**
M1971E-003	Frequency range, 55 to 90 GHz

**Note: A high performance oscilloscope such as a DSAZ504A or DSAZ634A may also be used for high frequency wide bandwidth measurements (e.g. 2 GHz modulation bandwidth). Please consult with a Keysight representative for more information.*

Recommended Reference Solution Base Configuration - continued

Model	Description
Upconverters and downconverters	
N5152A	**Millimeter-wave upconverter**
N5152A-505	57 to 66 GHz upconverter (5 GHz IF)
N5152A-1E1	IF input step attenuator (useful if driving from DUT with no amplitude control)
N1999A	**Millimeter-wave downconverter**
N1999A-505	57 to 66 GHz downconverter
N9029AV15	**Millimeter-wave converter: V-band, 50 to 75 GHz**
N9029AV15-UDC	Upconverter capability*
N9029AV12	**Millimeter-wave converter: E-band, 60 to 90 GHz**
N9029AV12-UDC	Upconverter capability*
Millimeter-wave accessories	
N9029AV15-AMP	Amplifier, 55 to 67 GHz, 15 dB gain, WR15 waveguide
N9029AV15-BF1	Band pass filter, 57.24 to 59.40 GHz (802.11ad chan 1), WR15 waveguide
N9029AV15-BF2	Band pass filter, 59.40 to 61.56 GHz (802.11ad chan 2), WR15 waveguide
N9029AV15-BF3	Band pass filter, 61.56 to 63.72 GHz (802.11ad chan 3), WR15 waveguide
N9029AV15-BF4	Band pass filter, 63.72 to 65.88 GHz (802.11ad chan 4), WR15 waveguide
N9029AV15-BF5	Band pass filter, 57.24 to 65.88 GHz (802.11ad chan 1 – chan 4), WR15 waveguide
N9029AH15	V-Band horn antenna, 50 to 75 GHz
N9029AH12	E-Band horn antenna, 60 to 90 GHz
Software	
81199A	**Wideband Waveform Center**
81199A-001	Wideband Waveform Creator
81199A-002	Wideband Waveform Analyzer
81199A-IAD	Library for 802.11ad
81199A-DFP	Unencrypted waveform file export
89601B	**89600 VSA Software**
89601B-200	Basic vector signal analysis and hardware connectivity
W1461BP	**SystemVue Comms Architect (Recommended, optional)**
W1915BP	**SystemVue mmWave WPAN Baseband Verification Library (Recommended, optional)**
Recommended optional custom services	
PS-S10-100	Remote scheduled productivity assistance
PS-S20-100	Daily instrument and application consulting with customer equipment
PS-X10-100	Application specific technical assistance

**Note: the base N9029 series converters are configured as downconverters only. Option UDC enables the instrument to be used as either an upconverter or downconverter via selectable jumpers on the rear panel. Contact your local Keysight representative for more details.*

Published in USA, December 5, 2017
5992-1429EN
www.keysight.com