Understanding IEEE 802.11ac VHT Wireless

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The most recent version of the IEEE's wireless local-area network (WLAN) standard, 802.11ac, uses the 5-GHz unlicensed band and multiple-input multiple-output (MIMO) to significantly boost data speeds while minimizing the interference inherent in the already crowded 2.4-GHz band. Chips are now available, and engineers are beginning to incorporate this new technology into products.

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Background

Developed by IEEE, the 802.11 WLAN standards are mainly used for local wireless communications in the 2.4- and 5-GHz unlicensed frequency bands. The 802.11 standards family has been adopted widely internationally and its popularity is helped by the WiFi Alliance, an industry association that promotes WLAN technology and certifies products conforming to 802.11 standards.

The standards consist of physical-layer (PHY) and media access control (MAC) protocols. Since 802.11's first release, there have been major additions and amendments to the PHY, while the MAC's basic functions remain largely unchanged.

Many 802.11 standards have been developed to address various aspects of WLAN requirements. Hiert et al. summarizes them nicely.[1] WLAN devices often advertise their capabilities based on the implemented PHY version *(Table 1)*. The popular ones include 802.11b, 802.11a, 802.11g, and more recently 802.11n. The last significant release of 802.11 was IEEE 802.11-2009, which introduced 802.11n.[2]

TABLE 1: IEEE 802.11 PHY STANDARDS						
Release date	Standard	Band (GHz)	Bandwidth (MHz)	Modulation	Advanced antenna technologies	Maximum data rate
1997	802.11	2.4	20	DSSS, FHSS	N/A	2 Mbits/s
1999	802.11b	2.4	20	DSSS	N/A	11 Mbits/s
1999	802.11a	5	20	OFDM	N/A	54 Mbits/s
2003	802.11g	2.4	20	DSSS, OFDM	N/A	54 Mbits/s
2009	802.11n	2.4, 5	20, 40	OFDM	MIMO, up to four spatial streams	600 Mbits/s
2012 (expected)	802.11ad	60	2160	SC, OFDM	Beamforming	6.76 Gbits/s
2013 (expected)	802.11ac	5	40, 80, 160	OFDM	MIMO, MU-MIMO, up to eight spatial streams	6.93 Gbits/s

Due to the increasing backhaul (e.g., xDSL, fibre) speed and emergence of new applications that demand high data rates, such as High Definition (HD) content streaming and instant file transfers, IEEE launched 802.11ac and 802.11ad to significantly increase the maximum data rates beyond that offered by 802.11n.

Also known as Very High Throughput (VHT), 802.11ac is positioned as the successor to 802.11n, known as High Throughput (HT). Like previous evolutions within WLAN, 802.11ac is designed to be fully backward compatible with previous standards. Formed in 2008, the TGac 802.11ac task group started to develop 802.11ac, which will be an amendment to IEEE 802.11-2009. The standard is anticipated to be finalized by the end of 2012 with final 802.11 working group approval in 2013.[3]

802.11ac Usage Models

IEEE identified a number of applications that require gigabit throughput and subsequently defined six usage models *(Table 2)*.[4] This serves as the basis for the 802.11ac development. Among the usage models, digital homes are emphasized. Indeed, with the high data rates promised by 802.11ac, multiple high-bandwidth applications in a home environment can operate concurrently, such as HD video streaming, instant file transfer, and zero delay Internet browsing *(Fig. 1)*.

TABLE 2: 802.11AC USAGE MODELS

Category	#	Usage model
Wireless display	1a	Desktop storage and display
	1b	Projection to TV or projector in conference room (lightly compressed video)
	1c	In-room gaming (lightly compressed video)
	1d	Streaming from camcorder to display (lightly compressed video)
	1e	Broadcast TV field pickup
Distribution of HDTV	2a	Lightly compressed video streaming around the home
	2b	Compressed video streaming around the home
	2c	Intra-large-vehicle (e.g., airplane) applications
	2d	Wireless networking for office
	2e	Remote medical assistance
Rapid upload/download	3a	Rapid sync-n-go file transfer
	3b	Picture-by-picture viewing
	3c	Airplane docking
	3d	Movie content download to car
	3e	Police/surveillance car upload
Backhaul	4a	Multimedia mesh backhaul
	4b	Point-to-point backhaul
Outdoor campus/auditorium	5a	Video demos/telepresence in auditorium
	5b	Public safety mesh
Manufacturing floor	6a	Manufacturing floor automation

1. The 802.11ac applications in a digital home environment include connections between a broadband router, HDTV, laptops, video security, smart phones, projectors, and even electric vehicle charging.

Also, 802.11ac offers the potential for major benefits in power efficiency due to the ability to transfer data much more quickly. 802.11ac chips are expected to be much more power efficient than ones based on previous standards. This is a critical requirement for battery-powered devices such as mobile phones, allowing users to leave their WLAN on with very little penalty on power consumption. New applications and scenarios will be possible, such as cellular IP data offloading.

802.11ac Performance Goals

To support new applications and future-proof devices, TGac defines three main performance and functional requirements for 802.11ac: system performance, backward compatibility, and coexistence.[5]

First, 802.11ac shall achieve a maximum single-station throughput and multi-station aggregate throughput of more than 500 Mbits/s and 1 Gbit/s, respectively. This is measured at the MAC data service access point (SAP), with no more than 80 MHz of channel bandwidth in the 5-GHz band. As the data rate requirement is at MAC rather than PHY, it implies that MAC efficiency must be addressed, not just an improvement to the PHY data rate.

Second, the 802.11ac amendment shall provide backward compatibility with 802.11a and 802.11n devices operating in the 5-GHz frequency band. To ensure backwards compatibility and co-existence, 802.11ac reuses 802.11n technical specifications where possible.

For example, 802.11ac uses the same PHY modulation in orthogonal frequency division multiplexing (OFDM) and maintains the same coding and interleaving architecture of 11n. To meet the performance goals, though, some modifications and new 11ac features are necessary *(Table 3)*.

TABLE 3: KEY FEATURES OF 802.11AC

Operation frequency	5-GHz unlicensed band only
Bandwidth	20, 40, and 80 MHz 160 and 80+80 MHz (optional)
Modulation schemes	BPSK, QPSK, 16QAM, 64QAM 256QAM (optional)
Forward error correction coding	Convolutional or LDPC (optional) with a coding rate of 1/2, 2/3, 3/4, or 5/6
MIMO	Space time coding, single-user MIMO, multi-user MIMO (all optional)
Spatial streams	Up to eight (optional)
Beamforming	Respond to transmit beamforming sounding (optional)
Aggregated MPDU (A-MPDU)	1,048,575 octets (65,535 octets in 802.11n)
Guard interval	Normal guard interval Short guard interval (optional)

The mandatory PHY parameters for 802.11ac devices are 80-MHz bandwidth, 64-state quadrature amplitude modulation (64QAM) 5/6, and one spatial stream. With this configuration, the data rate is 293 Mbits/s. But for a device with all optional parameters (160 MHz, 256QAM 5/6, and eight spatial streams), a data rate of 6.93 Gbits/s can be achieved.

The Physical Layer Convergence Protocol (PLCP) defines a PLCP Protocol Data Unit (PPDU) format *(Fig. 2)*. To ensure backward compatibility, specific non-VHT fields that can be received by 802.11a and 802.11n devices are defined.

2. In the VHT PPDU Format, the first three fields are the same and backwards compatible with 802.11n and 802.11a. The remaining fields are 802.11ac specific.

The first four fields of the preamble are intended to be received by non-VHT stations. The first three fields are the same fields as in 802.11n, and the fourth field identifies the fame as either 802.11n or 802.11ac. The remaining fields in the preamble are intended only for VHT devices.

VHT-STF is used to improve automatic gain control (AGC) estimation in MIMO transmission. VHT-LTFs are the long training sequences for MIMO channel estimation for the receiver. VHT-SIG-B provides the information of the data length and the modulation and coding scheme (MCS) for single-user or multi-user modes.

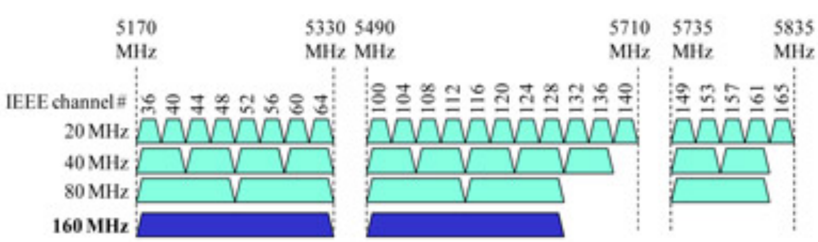
And third, the 802.11ac amendment shall provide mechanisms that ensure coexistence between 802.11ac and 802.11a/n devices. It should be noted that 802.11ac is only required to be backward compatible and co-exist with 802.11a and 802.11n since 802.11ac devices only operate in the 5-GHz band.

Manufacturing Test Challenges

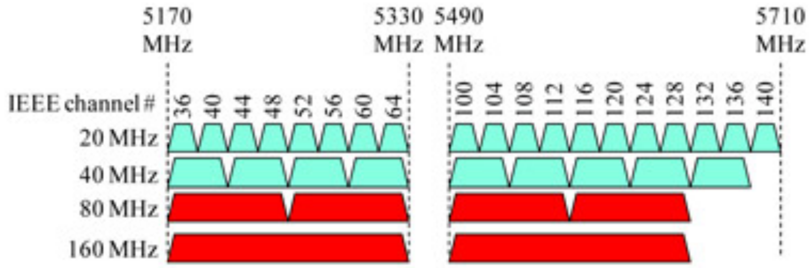
WLAN manufacturing test systems are widely installed in WLAN device factories around the world. The hardware platforms have been largely unchanged for a long time, and software upgrades were often sufficient to keep up with additional test requirements as the WLAN standard evolved. However, the new features of 802.11ac bring significant requirements to test systems, and many of the existing hardware platforms will have to be upgraded.

Three of the many changes in 802.11ac will lead to the most significant challenges for manufacturing test equipment: wide bandwidth, multiple spatial streams, and high-density modulation. In addition, speed of test is an important requirement for manufacturing.

802.11ac only operates in the 5-GHz unlicensed band. Compared to the 2.4-GHz band, 5 GHz provides wider bandwidth availability and less interference *(Fig. 3 and Fig. 4)*.[6] Therefore, the test equipment has to generate and analyze signals with 80-MHz wide instantaneous bandwidth or 160 MHz (optional) at up to 5.835 GHz in frequency.



3. In the United States, the smaller data channels in 802.11ac are 2.16 MHz wide. The wider channels are multiples of the smallest.



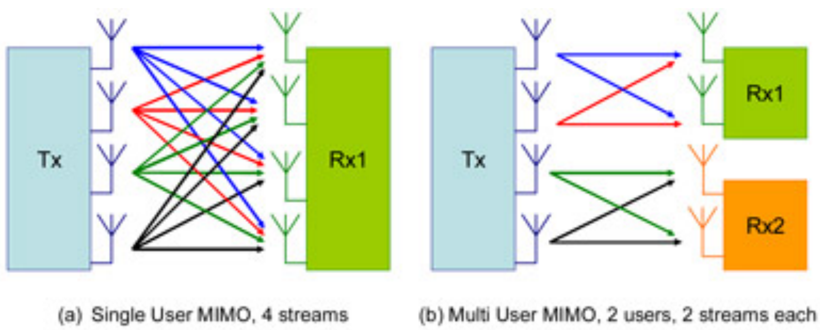
4. Data channels for 802.11ac in Europe are similar to the U.S. channels, but with different frequency assignments.

For transmitter tests, a single capture of the full signal bandwidth is required to carry out signal quality, frequency, power, and spectrum flatness measurements. The spectrum mask measurement requires the analysis of a much wider bandwidth (e.g., 240 MHz for 802.11ac). This can be implemented in a more economical way through the use of spectrum stitching, which captures multiple snapshots of the signal, "stitches" them in the frequency domain, and displays the full bandwidth.

For receiver tests, a full bandwidth signal waveform needs to be generated to stimulate the device under test (DUT). This enables receive sensitivity tests at different modes of operation.

MIMO is the use of multiple antennas at both the transmitter and receiver to improve communication performance through advanced digital signal processing. It takes advantage of the separate transmit/receive chains to either improve the link robustness or increase the data rate.

IEEE introduced MIMO to 802.11n and expands the capability to support up eight spatial streams and multi-user MIMO (MU-MIMO) in 802.11ac. As opposed to single-user MIMO, MU-MIMO allows a terminal to transmit/receive signals to and from multiple users in the same frequency band simultaneously *(Fig. 5)*.



5. The single-user version of MIMO uses four simultaneous streams to boost data speed. The multiuser version uses a pair of 2x2 streams for two users.

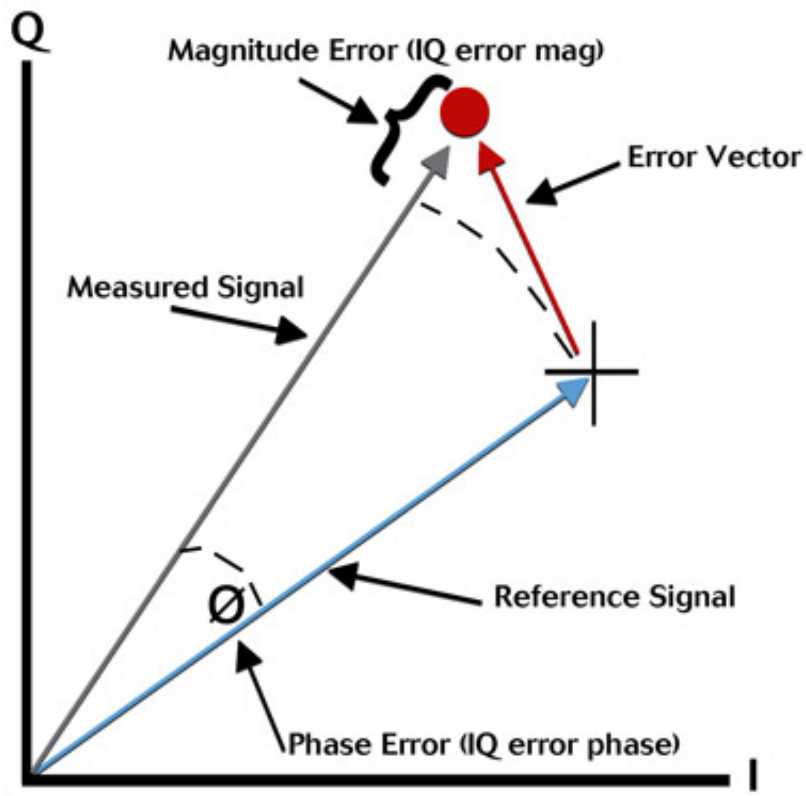
In the R&D environment, MIMO development would typically require the test equipment to perform encoding/decoding of multiple streams for different MIMO modes with multi-path channel emulation. In the manufacturing environment, however, the test focus shifts to RF components calibration and device quality assurance since the device design verification has already been completed in R&D. MIMO tests in manufacturing should also optimise for speed and cost.

One of the current practices is to test individual RF paths for MIMO transceivers. This is often carried out sequentially on each MIMO path through a switching matrix to further save the cost of test equipment since only one test transceiver channel is required. This approach can address the MIMO manufacturing requirements sufficiently and provide a good compromise between performance and cost.

802.11ac specifies a modulation scheme of up to 256QAM for the OFDM mode. 256QAM modulation is four times denser than 64QAM, which was the highest modulation scheme for previous WLAN standards. The required transmission signal quality for higher rate transmission is much more demanding than earlier WLAN modulation coding schemes. This requirement is the same regardless of the signal bandwidth.

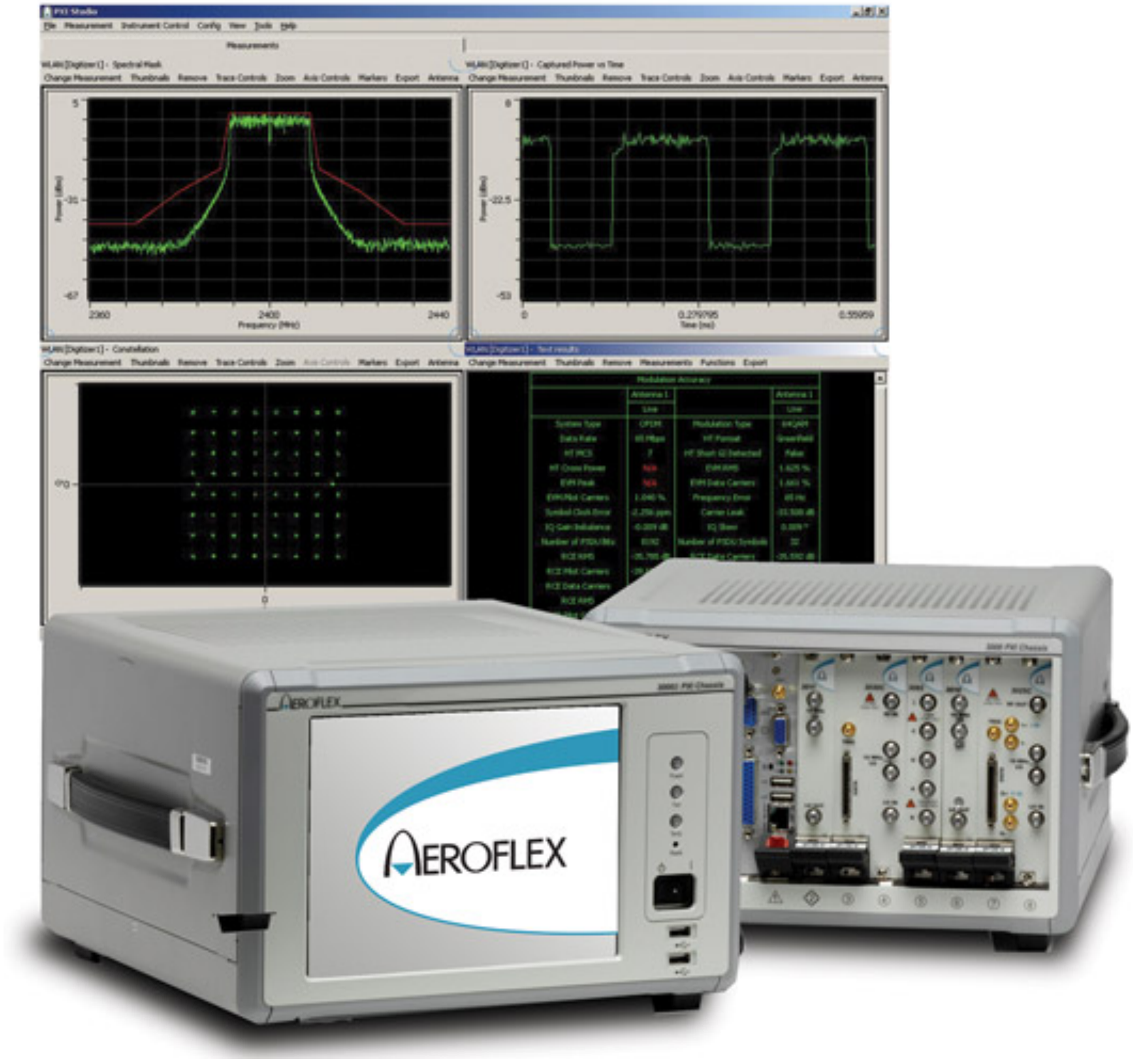
Phase, frequency, and magnitude errors affect the error vector magnitude (EVM) performance. High-order modulation, defining constellations with many points, means that different symbols may have very different signal amplitudes. Impairments that have a multiplicative effect on the signal, like nonlinearity and phase noise, become more prominent with high-order modulations.[7]

To accurately measure 802.11ac signals, the residual EVM of the test equipment must be significantly better than the lowest EVM requirement shownin Figure 6, such as –32 dB at 256QAM. Otherwise, production yield can be affected. The 802.11ac test equipment, then, must have much better performance on phase noise and linearity compared to those testing previous WLAN standards.



6. Vectors represent the amplitude and phase of the carrier to illustrate EVM. The reference standard signal is compared to the measured signal. An error vector and phase error provide the EVM measurement. The error magnitude is expressed in dB compared to the vector amplitude.

An Aeroflex WLAN test solution based on the PXI 3000 series offers excellent residual EVM performance, which easily meets the 802.11ac requirement *(Figure 7)*. These numbers reflect residual EVM from both the transmitter and receiver *(Table 5)*. They also don't use any equalization, which would artificially produce lower measurements.



7. The Aeroflex PXI 3000 series test set is designed to speed and simplify tests and measurements related to certifying products under the 802.11ac standard.

TABLE 5: AEROFLEX PXI 3000 SERIES TYPICAL RESIDUAL EVM/RCE PERFORMANCE FOR WLAN

Input power	2.412 GHz			5.81 GHz				
	20 MHz		40 MHz	20 MHz	40 MHz	20 MHz	40 MHz	80 MHz
	802.11b	802.11g/n	802.11n	802.11a/n	802.11n	802.11ac		
–10 dBm	0.2%/ –51 dB	0.3%/ –49 dB	0.4%/ –47 dB	0.5%/ –45 dB	0.4%/ –46 dB	0.5%/ –45 dB	0.6%/ –44 dB	0.7%/ –42 dB
–20 dBm	0.3%/ –49 dB	0.4%/ –47 dB	0.5%/ –45 dB	0.6%/ –44 dB	0.5%/ –45 dB	0.6%/ –44 dB	0.6%/ –44 dB	0.7%/ –42 dB
–30 dBm	0.4%/ –47 dB	0.6%/ –44 dB	0.8%/ –41 dB	0.6%/ –44 dB	0.7%/ –42 dB	0.6%/ –44 dB	0.8%/ –41 dB	1.2%/ –38 dB

*Results include both receiver and transmitter residual EVM/RCE; no equalization.

Two of the most important metrics for manufacturing are production test speed and yield. While 802.11ac is now an additional test requirement, it is important for WLAN to maintain an acceptably low price point for manufacturing and its popularity in consumer devices.

The price point of 802.11ac must be similar to those of previous WLAN standards. Therefore, 802.11ac test equipment must calibrate and verify devices and components at high speed while maintaining accuracy and reliability to achieve good production yield *(Table 6)*.

TABLE 6: 802.11 MEASUREMENT TIME WITH PXI 3000		
Channel bandwidth	MCS	EVM measurement time (ms)
20 MHz	0	5.82
	1	5.83
	3	5.82
	5	5.83
	8	5.83
40 MHz	0	11.45
	1	11.39
	3	11.35
	5	11.42
	8	11.39
80 MHz	0	24.21
	1	24.04
	3	23.99
	5	23.95
	8	23.92

*Measurement time includes capture, transfer, and analysis; each measurement analyzes 16 symbols; results are averaged over 25 iterations.

Conclusion

IEEE's latest WLAN standardization effort increases data rate by a factor of six through the use of wider bandwidth, a higher number of spatial streams, and advanced digital modulation techniques. It is positioned as the evolution of 802.11n and expected to become mainstream by 2015 with approximately 1 billion global shipments.[8] This presents some major challenges for device test and measurement, in particular for manufacturing test.

Four main test challenges have been identified in the manufacturing environment for 802.11ac: wide bandwidth, MIMO, high-density modulation, and speed of test. The Wi-Fi Alliance testing and certification system is expected to be in place by mid-2013 so new end products can be officially interoperable.

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