APPLICATION NOTE

# Addressing WiFi Measurement Challenges with Multi-channel Test Instrument

## Evolution of WiFi Technologies

WiFi has been the dominant wireless technology in the world and its success rests on a solid foundation established over the last 20 years. WiFi technologies have been evolved with fast pace while providing continuity with full backwards compatibility.

As the first wireless access technology that used unlicensed spectrum, WiFi technologies have gone through several generations to meet the increasing requirements in data throughput and performance expectations in terms of speed, latency, reliability, etc.

IEEE 802.11n, labelled as WiFi 4 by WiFi Alliance, was the first standard with MIMO support, which improved network throughput over the legacy SISO standards 802.11a/b/g significantly.

802.11ac, labelled as WiFi 5 by WiFi Alliance, provides WLAN service on 5 GHz frequency band. The enhancements over 802.11n mainly included wider RF bandwidth (up to 160 MHz), more MIMO spatial streams (up to eight), downlink multi-user MIMO (up to four clients), and high order modulation (up to 256-QAM).

The latest generation of Wi-Fi based on IEEE 802.11ax, brings higher speed and capacity, lower latency, and more advanced traffic management targeting better user experiences in the demanding environments, such as airport, stadium, and so on. It will work in both 2.4 GHz and 5 GHz frequency bands with device labelled as WiFi 6, and new opened 6 GHz frequency band approved by FCC in Unite States with device labelled as WiFi 6E. It introduces better power-control methods to avoid interference with neighboring networks, orthogonal frequency-division multiple access (OFDMA) for multi-user access, higher order modulation up to 1024-QAM, and up-link MU-MIMO(Multi-User MIMO) to further increase throughput.

The key PHY enhancements for 802.11be would include:

- 240 MHz & 320 MHz bandwidths and more efficient utilization of non-contiguous spectrum
- OFDMA with up to 4096QAM
- One STA using more than one RU (Resource Unit)
- Up to 16 spatial streams and MIMO enhancements
- Asynchronous Multi-band/multi-channel/multi-link aggregation and operation

WiFi is never standing still despite its success. Now standard group in IEEE 802 has started working on the next generation system 802.11be called EHT (Extremely High Throughput), which arms to build on the current and emerging WLAN technologies by providing further improvements of aggregate throughput and reduced latency.

The summary of WiFi PHY Technologies is listed as below.

**WLAN Standards**

| Standard | Frequency (GHz) | Bandwidth (MHz) | Modulation | Max Data Rate |
|---|---|---|---|---|
| 802.11b | 2.4 | 22 | DSSS | 11 Mbps |
| 802.11a | 5 | 20 | OFDM | 54 Mbps |
| 802.11g | 2.4 | 20 | OFDM | 54 Mbps |
| 802.11n (WiFi 4) | 2.4, 5 | 20, 40 | MIMO-OFDM 64QAM | 600 Mbps |
| 802.11ac (WiFi 5) | 5 | 20,40,80,160 | MIMO-OFDM 256QAM | 7 Gbps |
| 802.11ax (Wi-Fi 6/6E) | 2.4, 5, 6 | 20,40,80,160 | MU-MIMO OFDMA 1024QAM | 10 Gbps |
| 802.11be (EHT, under definition) | 2.4, 5, 6 | 20,40,80,160, 240, 320 | MU-MIMO OFDMA 4096QAM | 30 Gbps |

Although the maximum data rates are provided in the table, capacity is the key performance metric for Wi-Fi 6 instead of theoretical peak rate, and some other specifications are also very critical, such as latency, coverage, power consumption and so on.

## Challenges for WiFi Test and Measurements

WiFi targets to deliver both high performance and cost effectiveness to enable a wide range of new, disruptive business models and monetization opportunities. The combination of high performance and equipment affordability has played a major role in establishing the ubiquity and dominance of Wi-Fi. Even the advanced technologies bring more values, the marginal cost of adding Wi-Fi to a device or an AP continues to decrease. To meet this objective, the adequate and cost-effective test solution is critical to address new challenges which keep coming with fast technological evolution and increase demands. Let's look at the challenges caused by technologies and test cost.

### Technological evolution

1. Wider bandwidth. Increasing the bandwidth is one of the ways to increase the throughput. The bandwidth of WiFi has been increased from 20 MHz in legacy standard in 802.11a to 160 MHz in WiFi 5 and WiFi 6 and will get increased further to 320 MHz in 802.11be. So, the test instruments need to be able to support at least 320 MHz bandwidth for new standard.
2. Higher order modulation. Another way to increase the throughput and spectrum efficiency is to use higher order modulation, especially when frequency resource is limited. In 802.11ax, the highest modulation is 1024QAM compared 256QAM in 802.11ac, while 4096QAM has been adopted in 802.11be when transmission channel quality is high. High order modulation would require the transmitter with high EVM performance for receiver to demodulate the signal correctly. For example, the required EVM for 4096QAM would be lower than -38dB to guarantee receiver to demodulate and decode the signal correctly , then the requirement for EVM floor of test equipment would be nearly -48dB, which brings higher requirements for the key specs of the test instruments, such as noise floor, phase noise, etc.
3. MIMO. MIMO is also an effective way for higher throughput by using space diversity. The maximal number of spatial streams is up to 8 in WiFi 6 and very likely will be increased to 16 in 802.11be. The number of channels of the instruments should be increased correspondingly for MIMO test, which would also require higher port-density and increase the test cost a lot.
4. Multi-user technologies. With Wi-Fi 5, the access point could talk to multiple devices at the same time by DL MU-MIMO, but those devices couldn't respond at the same time. Wi-Fi 6 has an improved version with multi-user technologies by both DL and UL MU-MIMO and OFDMA. For MU-MIMO, multiple users' data will be sent out by different antennas which can be separated in space. For OFDMA, a wireless channel is divided into several subchannels in frequency so that multiple users could send the data on one OFDM symbol. A reliable tool is needed for flexible signal configurations to cover all possible scenarios for multi-user support.
5. More frequency bands. Wi-Fi is deployed in 2.4 GHz and 5 GHz unlicensed frequency bands initially and has used both bands efficiently for nearly 20 years. The 6 GHz band just became available for unlicensed access in the US and EU, maybe as well as in other countries soon. So, the test instruments would also need to expand the frequency coverage for the new 6 GHz band. Also, FCC has issued proposed rules for shared use of 6 GHz band to ensure WiFi coexist with the incumbents besides the spectral mask of emission. For example, Automated Frequency Coordination (AFC) is a system that automatically determines and provides lists of which frequencies are available for use by access points operating in the 5.925 - 6.425 GHz and 6.525 - 6.875 GHz bands; Operation in the 6.425 - 6.525 GHz and 6.875 - 7.125 GHz bands is limited to indoor locations. So entire 6 GHz band will not necessarily be available to WLAN. Specifications and measurements would be developed carefully to make full use of 6 GHz band correctly.

## Cost reduction for test in design and verification test (DVT) and manufacturing

Cost reduction in device tests is always a key objective for the vendors and it could come from multiple aspects. Test speed or throughput improvements and cost-down of test system are the two important factors.

- Throughput of product line depends on each station's measurement speed and reliability, also system configuration time, etc.
- Cost of test system includes the costs for both hardware platform and test software.

Theoretically, newer technologies with high performance requirements will increase the test cost with higher performance test instruments, including higher frequency range, wider bandwidth and higher specifications. Also test time could increase linearly with number of channels under test basically.

We have to find some innovation ways to make the test affordable. For example, use multi-channel transceiver architecture in the instrument for parallel test for lower cost and higher speed, apply sequencing in test plan for faster test schedule, and so on.

# Keysight Solution for Wireless Device Test

## Introduction and features

Keysight S8780A Wireless Device Solution includes multi-channel transceivers and measurement software targeting wireless device test for DVT and manufacturing. It was developed to cover measurement requirements for latest technologies, such as 802.11be, 5G NR FR1, Bluetooth 5.1, etc. and it is especially effective to increase the throughput by testing multiple DUT in parallel for manufacturing. The key features include:

- 32 channels fully loaded with up to 4 transceivers in one chassis and the number of transceivers is configurable
- Connect once to all DUT antennas with 8 full-duplex ports for each transceiver (i.e., VSG and VSA), and all ports support all bands
- Calibrate up to 4 DUT antennas simultaneously with signal broadcasting
- Up to 7.3 GHz to cover all 802.11 frequency bands and scalable bandwidth up to 800 MHz. The bandwidth can be upgraded later when ready to test 802.11be without removing unit from lab, bench or production line.
- Execute test plans quickly with sequencing
- Support all wireless formats (WLAN, BT, cellular) without additional hardware

Figure 1 shows the ports of a fully loaded S8780A, testing multiple DUT with up to 32 ports. There are 4 independent transceivers in a chassis with 8 ports for each transceiver. The signal from each port will be tested by internal switching. Then much greater number of devices can be calibrated and verified by once connection compared with legacy instruments.

Figure 1. Increase Throughput by Testing Multiple DUT in Parallel with S8780A

802.11be is the new generation of WiFi technologies and the standard is still under definition but some key enhancements for PHY have been defined. When equipped with the software applications for WLAN waveform generation and measurements with Keysight's industry-proven measurement algorithms used across most platforms, S8780A will fully support 802.11be device measurements and the results for transmitter test are shown in Figure 2, including test requirements defined in the specs.

- Transmit power
- Transmit spectral mask
- Spectral flatness
- Transmit center frequency and symbol clock frequency tolerance
- Modulation accuracy (EVM)

(a) Summary for RF characteristics

(b) Spectrum Emission Mask (SEM)

Figure 2. Measurement Results for 802.11be

By running sequencer, the transmitter calibration and RF performance measurements can be implemented quickly, which helps achieve high throughput for product line.

## Test cases with multi-channel test instrument

Let's look at some test cases for WiFi device supported by multi-channel of S8780A.

### Case 1: Calibrate and verify multiple clients for manufacturing

The WiFi client can be a mobile phone or a laptop, etc. Usually, 2x2 MIMO is used. For manufacturing test, MIMO performance is not tested, and test instruments are used just to calibrate and verify each individual transmitter and receiver. By using S8780A, we can calibrate and verify up to 4 clients per transceiver by using broadcasting on 4 ports and internal switching, as shown in Figure 3. So up to 16 clients can be tested by one chassis without needing to change connections.

For transmitter test, using internal switching through 8 ports, measurements for each transmitter will implemented by WLAN X-Series measurement application and the measurements would include Transmit power, Transmit spectrum mask, EVM, etc.

For receiver test, WLAN signal sent out by VSG is broadcasted through 4 ports, then on the other 4 ports through internal switching. Received power on the device can be calibrated first and sensitivity test will be implemented.

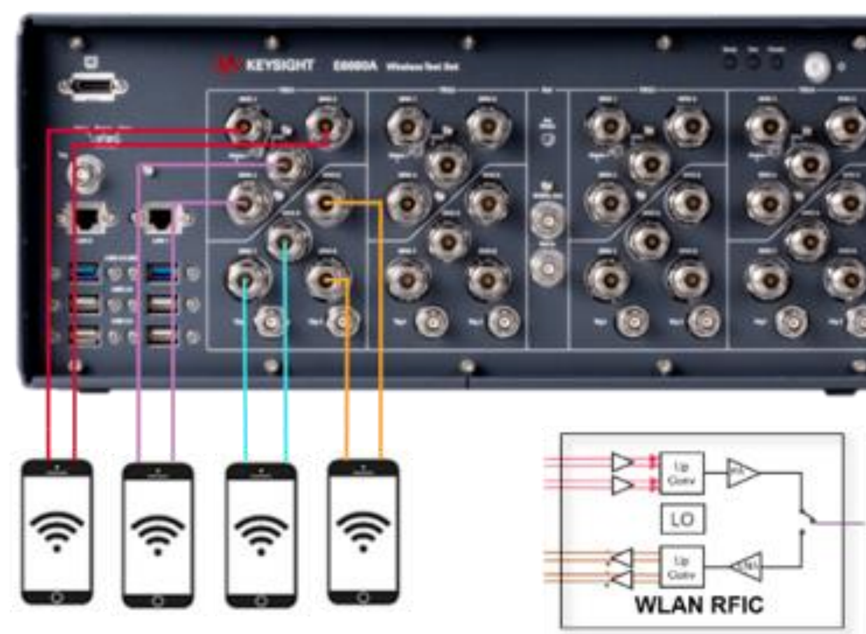


Figure 3. Calibrate and Verify Multiple Clients

### Case 2: Calibrate and verify multiple Access Points for manufacturing

Similar to the case for Client manufacturing, the DUT is changed to Access Point (AP), and usually 4x4 MIMO is used for an AP and up to 8x8 MIMO for a few advanced ones. By using S8780A, we can calibrate and verify up to 2 APs with 4x4 MIMO per transceiver by using broadcasting on 4 ports and internal switching. So up to 8 APs can be tested by one chassis with 4 transceivers.

Figure 4. Calibrate and Verify Multiple Access Points

## Case 3: Calibrate and verify multiple Access Point antennas for manufacturing

WiFi client usually has one antenna to cover all 3 bands, while for AP, different antennas are used for 3 bands respectively, for example, for the 4x4 AP in Figure 5, 4 antennas for 2.4 GHz band operation and another 4 antennas for 5 GHz and/or 6 GHz band and they can work simultaneously. In this 4x4 MIMO example, we can calibrate and verify up to 8 AP antennas per transceiver and don't need to change connections.

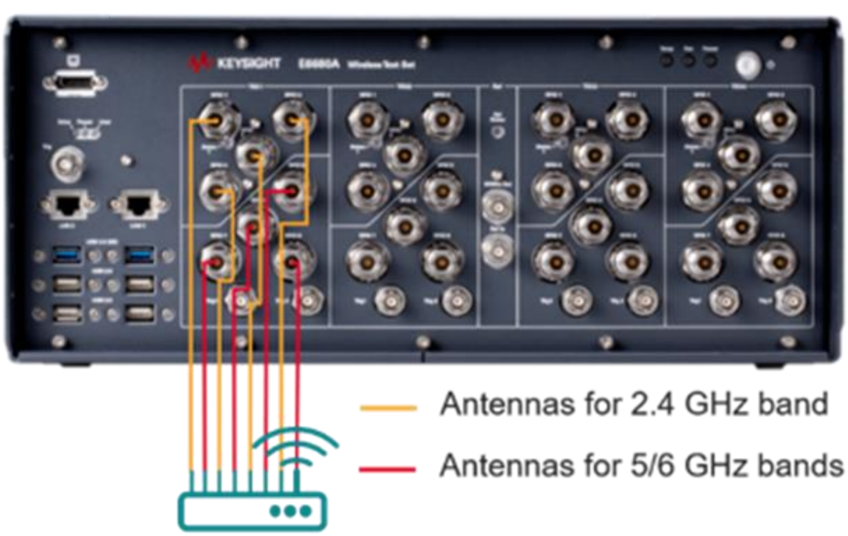


Figure 5 Calibrate and Verify Multiple Access Point Antennas

## Case 4: Verify performance for MIMO for AP design and verification

For MIMO performance verification, multiple channels are required to transmit and receive multiple spatial streams. The example shown in Figure 6 is for 4x4 AP MIMO test.

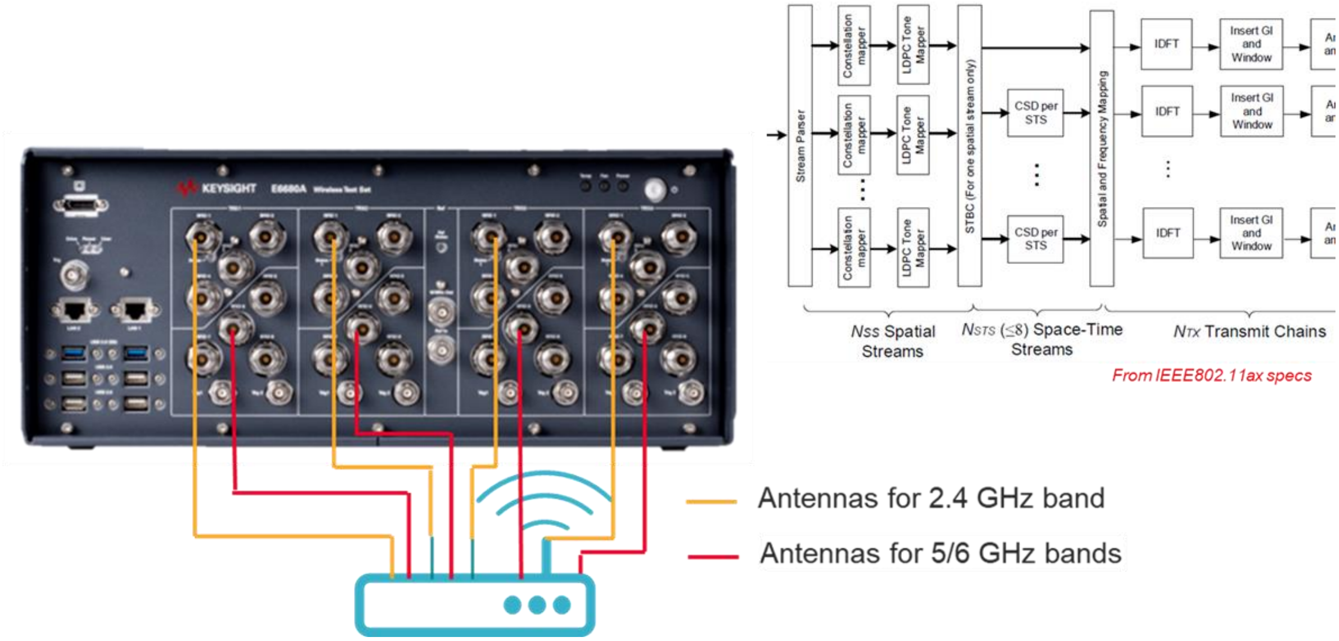


Figure 6. Verify RF Performance for MIMO

For Receiver test, the waveforms for 4 spatial streams are loaded to 4 VSGs respectively and sent out at RF with frequency coherency.

For transmitter test, 4 streams are received with frequency coherency and sent to X-apps for analysis, which will give measurement results for each stream, as shown in Figure 7.

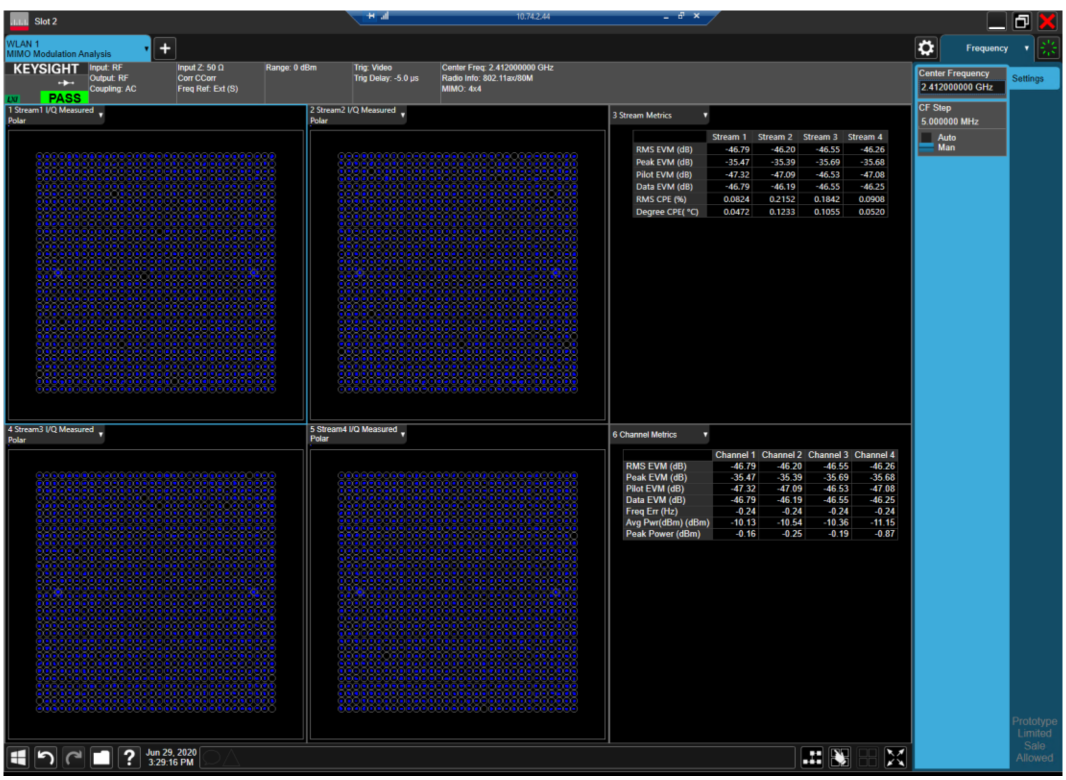


Figure 7. Measurement Results for MIMO

For different frequency bands, we can use different ports by internal switching and change the transceiver frequency of the instrument by command, then no connection change needed.

For 8x8 MIMO test, two chassis are needed to support up to 8 spatial streams.

## Case 5: Verify blocking performance of device with MIMO for AP design and verification

For blocking test for receiver, a separate signal generator is needed to generate blocking or interference signal, which would be WLAN, Bluetooth™, LTE, 5G NR, Zigbee…

For 2x2 AP DVT case shown in Figure 8, two channels are used for MIMO signal generation, and third transceiver is used for blocking signal generation by loading corresponding waveforms into the memory of the VSG. So, no external blocking signal generator is needed. The power level and frequency for blocking signal can be set according to test conditions while the connections don't need to be changed during the test.

The blocking signals for 2.4 GHz band and 5 GHz band could be different. This can be done by just switching waveforms for different blocking signals.

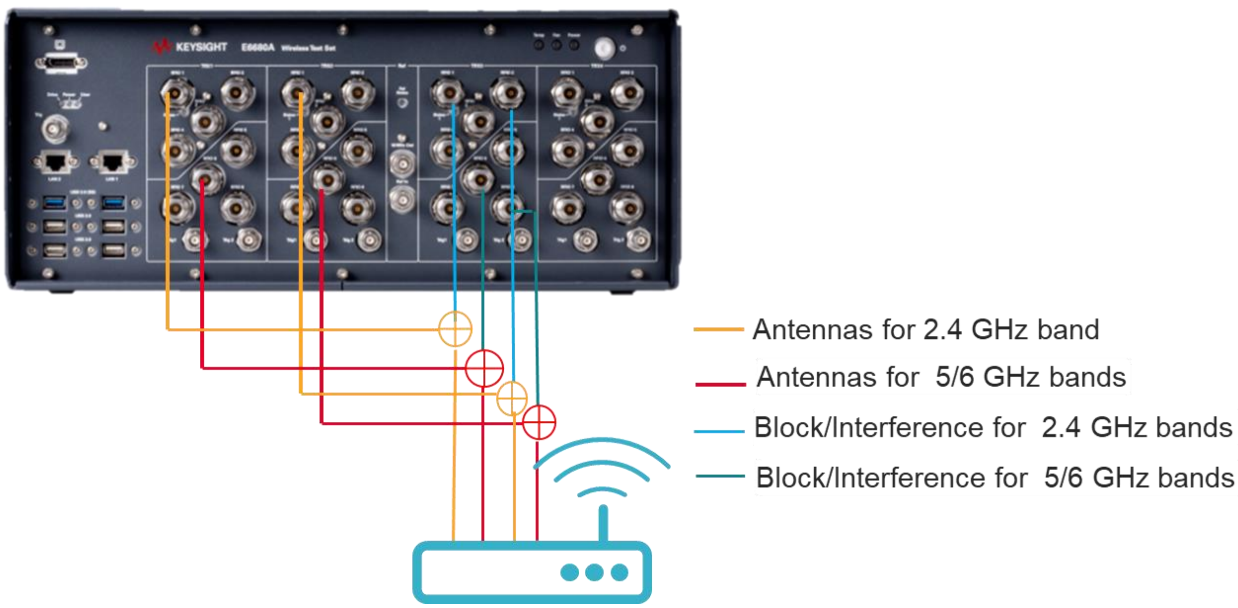


Figure 8. Verify blocking performance of device with MIMO

Similar hardware configuration can also be used for adjacent channel selectivity test for receiver.

## Conclusion

With the evolution of WiFi technologies, new challenges are keeping coming for test and measurement, such as more frequency bands, wider bandwidth, high modulation accuracy, more spatial streams, etc. Keysight is tracking the development of the new technologies closely and keeps the test solutions updated. Keysight new multi-channel Transceiver S8780A is ready to address all these challenges faced by WiFi device vendors with high efficiency and flexibility.