



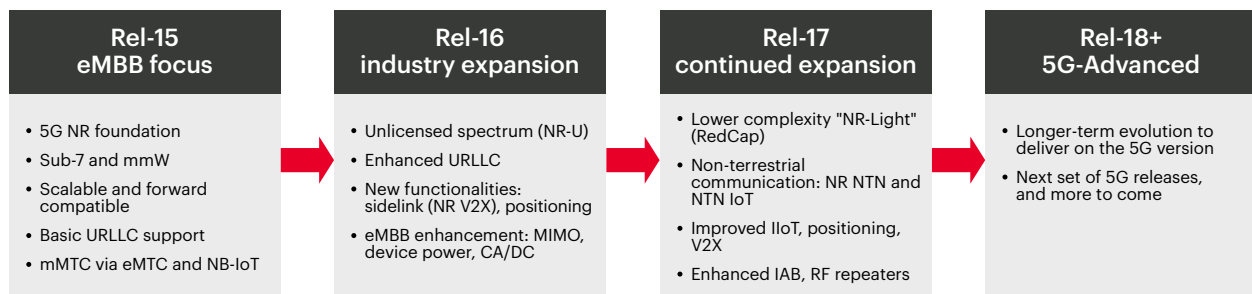
Accelerate 5G Testing

5G manufacturing test considerations

Technology Evolution

The promise of 5G is faster and more reliable communications. To enable mobile broadband communications, 5G uses existing and new technologies to achieve extreme data throughputs. The introduction of these technologies leads to new testing demands, including operation in more frequency bands, wider channel bandwidths, and complex multi-antenna configurations.

With the standalone version (Release 15.2.0) of 5G New Radio (NR) approved by the 3rd generation partnership project (3GPP) in December 2017, the cellular ecosystem is evolving from research to product development and early production. The follow-up releases of 5G NR specifications (Release 16 and 17) continue to expand 5G NR features to cover more and more industries and applications.



To address these challenges cost effectively, test engineers need access to future-proof test instruments that support the latest 3GPP standards. Those instruments should offer best-in-class radio-frequency (RF) performance in a flexible and scalable solution that addresses future needs. This white paper covers the impact of the 3GPP evolution on testing and solutions available to help you scale to production quickly.

Global Spectrum Requirements

The 5G NR standard specifies two frequency ranges (FR) — sub-7 GHz (FR1) and millimeter-wave (mmWave) bands (FR2). Table 1 shows the definition of frequency ranges. All 5G devices and test instruments need to support FR1, FR2, or both.

Table 1. Definition of frequency ranges in the 3GPP standard

Frequency range designation	Corresponding frequency range
FR1	450 MHz – 7.125 GHz
FR2	24.25 – 71.0 GHz

FR2 mmWave operating bands have wider channel bandwidths, up to 1.2 GHz contiguous or 1.6 GHz noncontiguous when aggregating multiple component carriers. This additional spectrum is essential for enabling 5G's promise of extreme data rates of 20 Gbps in the downlink and 10 Gbps in the uplink. However, mmWave frequencies with wider bandwidths also expose signal propagation issues, such as excess path loss, delay spread, and blockage, resulting in a poor radio link.

To overcome these propagation issues, 5G NR uses multi-antenna techniques, such as phased-array antennas, to increase directivity and gain. The mmWave components are compact and highly integrated with no place to probe, requiring radiated tests, also known as over-the-air (OTA) tests. Table 2 illustrates the 5G NR conformance test for user equipment (UE) and base stations (gNB). FR2 requires only radiated tests.

Table 2. 3GPP technical specification for 5G NR test

Device	Minimum requirements	Conformance Tests		Notes
UE	TS 38.101	Conducted tests	TS 38.521-1	FR1
		Radiated tests	TS 38.521-2	FR2
		Conducted / radiated	TS 38.521-3	Interworking operation
gNB	TS 38.104	Conducted tests	TS 38.141-1	FR1
		Radiated tests	TS 38.141-2	FR1 and FR2

Millimeter-wave test challenges

Using mmWave frequencies and wide signal bandwidths poses challenges related to path loss and signal propagation. Figure 1 shows the 5G NR FR2 measurement setup for the transmitter, receiver, and RF component. Both transmitter and receiver tests require radiated testing. Component tests can be either conducted or radiated, depending on the device under test (DUT).

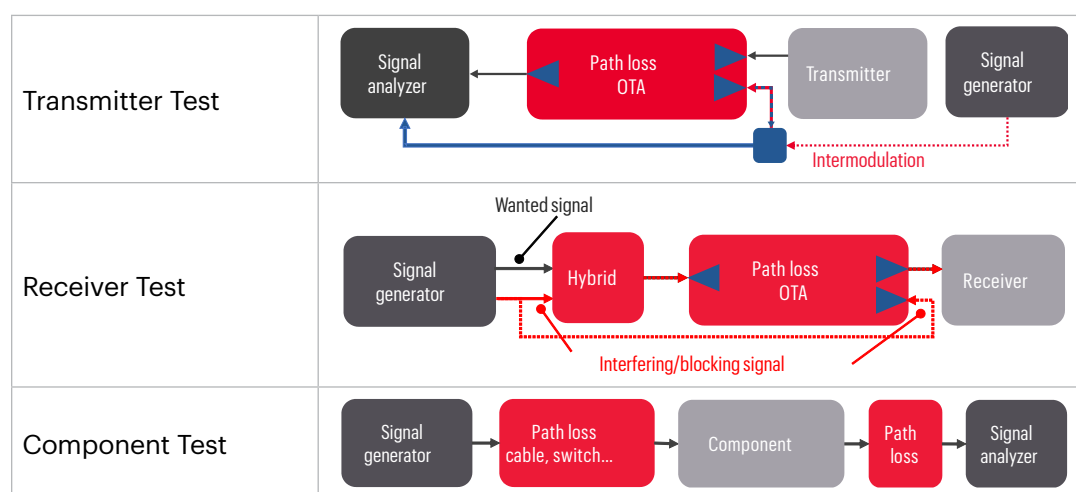


Figure 1. Measurement setup for transmitter and receiver radiated tests and component tests

Path loss

At mmWave frequencies, the excess path loss between instruments and DUTs results in a lower signal-to-noise ratio (SNR) for signal analysis. The low SNR causes the transmitter measurements to deliver poor error vector magnitude (EVM) and adjacent channel power ratio (ACPR) performance, which does not represent the DUT's actual performance, as shown in Figure 2.

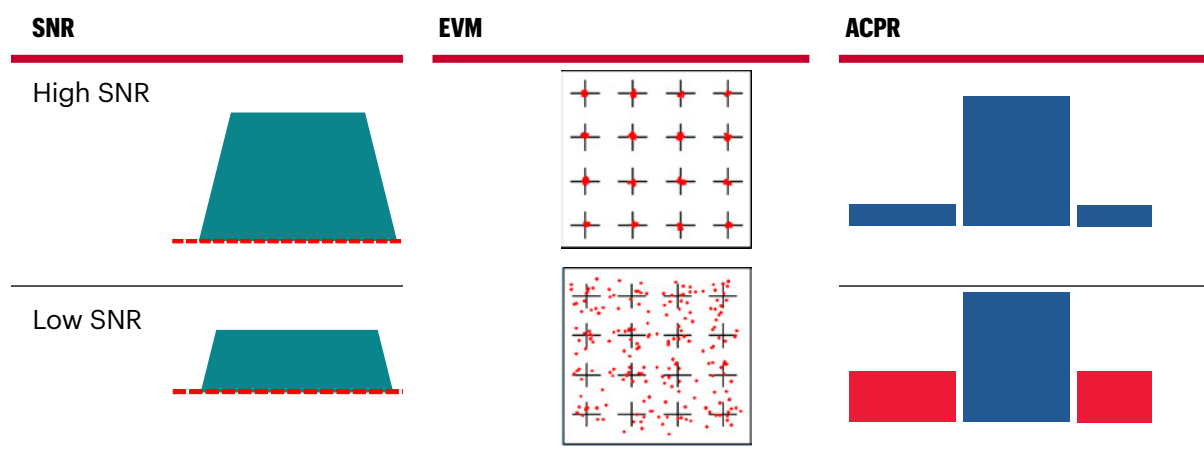


Figure 2. SNR's impact on transmitter measurements

For receiver and component tests, signal generators need higher-output power levels with less distortion to compensate for the excess path loss.

In addition, connectorless radiated testing signal routing to OTA chambers requires longer cables (typically 2 to 4 meters) and switch matrixes, which introduce about 5 to 10 dB higher insertion loss.

Phase noise

5G NR adopts the orthogonal frequency-division multiplexing (OFDM) modulation scheme. OFDM uses many closely spaced orthogonal subcarrier signals, each with its own modulation scheme, to transmit data in parallel. During frequency conversion with a poor phase noise local oscillator of a signal analyzer or a signal generator, the subcarrier with phase noise spreads into other subcarriers as interference. The interference degrades measurement accuracy. For a higher-order modulation scheme (for example, 256QAM), the symbols are closer and the test requirement of EVM performance is higher.

Two microscopic electronic effects influence the phase noise performance: thermal noise from passive devices, which is broad and flat (the green line), as shown in Figure 3, and flicker noise from active devices, which is a $1/f$ shape (the purple line). The flicker noise, also known as pink noise, is 20 dB per decade. If you increase frequency by 10 times, the phase noise increases by 20 dB. This is why the phase noise performance of a mmWave test instrument is often a key factor in determining how well it fits an application.

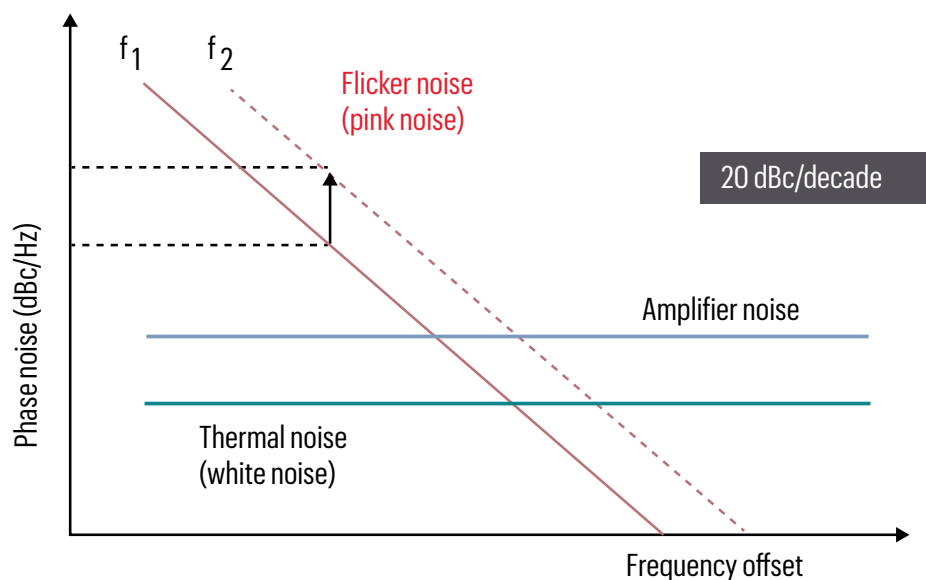


Figure 3. Phase noise profile with thermal noise and flicker noise

Test strategies

To overcome excess path loss and make accurate measurements, high-performance signal generators and signal analyzers must ensure that the errors are not from test instruments. Integrating design verification test (DVT) systems for 5G requires many high-performance test instruments and complicated system integration. The test system integration and test costs create higher barriers from R&D to volume production. To successfully and cost-effectively scale 5G R&D DVT to production requires a new solution with the combined advantages of performance, trusted measurement applications, scalability, and flexibility.

A banded solution is a common approach to high-volume production tests. A 7.125-GHz vector signal analyzer (VSA) and a vector signal generator (VSG) are essential for FR1 in-band RF test cases. The VSA and VSG can be an intermediate frequency (IF) signal analyzer and signal generator, coupled with an external mmWave transceiver for FR2 in-band tests. Figure 4 shows a banded solution for FR2 to reduce the insertion loss using a remote mmWave transceiver head to cover FR2. Move the head as close as possible to the antenna to shorten the mmWave signal routing. This approach is less costly than using a high-performance microwave VSA and VSG. However, you need to calibrate the external path and channel response. The next section covers extension calibration.

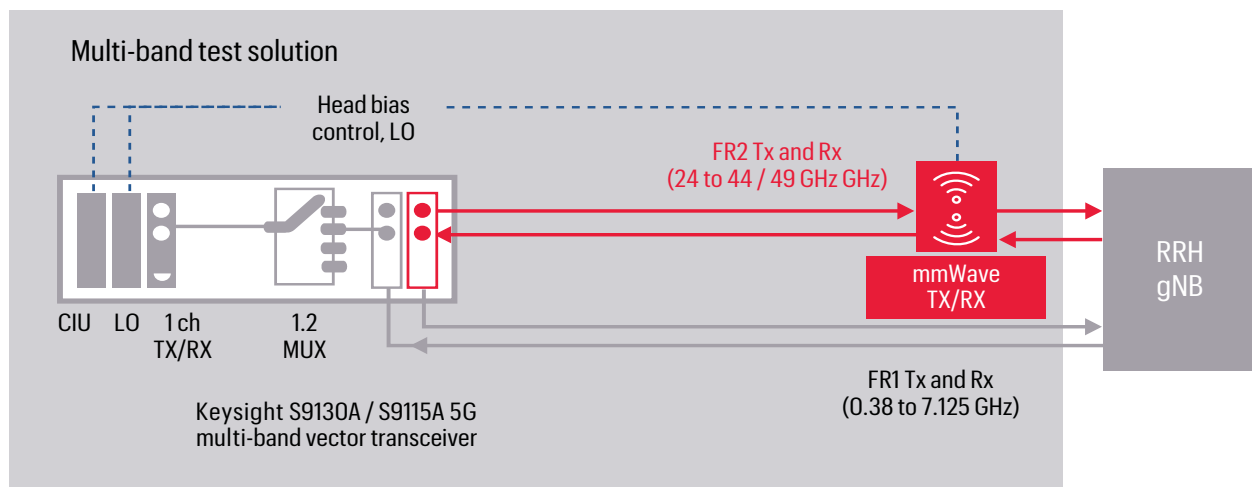


Figure 4. OTA test with remote mmWave transceiver head (in red) helps reduce insertion loss

The Keysight **S9130A** and **S9115A** 5G multiband vector transceiver are streamlined for automated, non-signaling test solution of 5G NR infrastructure equipment in FR1 (sub-7 GHz) and FR2 (24 to 44 / 49 GHz) spectrum bands. They support configurations with multiple measurement channels. Keysight offers system integration with coordinated assembly, installation, calibration, and service. Take the S9130A for example, it includes a Keysight M9415A / M9416A PXIe vector transceiver, a Keysight M1741A mmWave transceiver, a synthesizer module, and a control interface module.

- **M9415A / M9416A** PXIe Vector Transceiver
 - Covering frequency range from 380 MHz to 12 GHz, and 1.2 GHz bandwidth, M9415A and M9416A provides integrated vector signal generation and vector signal analysis capability in a compact PXIe form factor, with superior performance to address your evolving needs to test 5G FR1 devices. They are also used as an intermediate frequency for testing FR2 bands.

	M9415A	M9416A
Number of slots	3	4
Frequency range	380 MHz to 6, 8, or 12 GHz	
Bandwidth	400, 800, or 1200 MHz	
Source output level	+5 dBm standard; +20 dBm with option 1EA	
5G NR EVM, 200 MHz (256QAM), at 4 GHz, loopback to RF input	0.28% nominal	
802.11be EVM, 320 MHz, at 5.8 GHz, loopback to RF input	-47 dB nominal; >5 dB improvement via ncEVM optimization (requires F/W revision M.37.53 or above)	
MIMO (timing sync), VSA software or X-apps	Yes, available for WLAN test mode, requires option MMO	
Sequencing	No	Yes
Spectrum analysis	Yes	No

- M1741A remote mmWave transceiver head
 - supports 5G NR FR2 bands across 24.25 to 43.5 GHz
 - mmWave transceiver's bias, control signals, and local oscillator provided by a micro-CIU and synthesizer module
- PXI chassis and software
 - includes chassis, control module, clock reference module, and all cabling
 - supports the latest **5G NR analysis** and **generation** software
 - switching and head control, saving external programming
 - unified application programming interface, coordinating all signal routing, calibration, and operation



Wider Channel Bandwidths

Enhanced mobile broadband is one of the use cases for 5G. It uses existing and new technologies, including wider channel bandwidths, carrier aggregation, a higher modulation density, and multiple antennas, to achieve the anticipated extreme data throughputs. The 5G NR maximum channel bandwidth is 400 MHz for FR2. For contiguous carrier aggregation (CA), the maximum aggregated channel bandwidth is up to 1.2 GHz. Table 3 shows the maximum channel and aggregated bandwidths of the new wireless standards.

Table 3. The bandwidth of the new wireless standards

Standard	Revision	Maximum channel bandwidth	Maximum aggregated channel bandwidth (contiguous)
3GPP 4G	LTE (R8)	20 MHz	NA
	LTE-A (R10)	20 MHz	100 MHz
	LTE-A Pro (R13–14)	20 MHz	640 MHz
3GPP 5G ¹	NR (R15) FR1	100 MHz	400 MHz
	NR (R15) FR2	400 MHz	1,200 MHz

¹ 3GPP TS 38.521-1/2 V15.0.0 UE conformance specification, radio transmission, and reception

To guarantee these bandwidths in devices, you need to test the components at even greater bandwidths. For example, to characterize the nonlinear performance of RF power amplifiers such as digital predistortion techniques, you would need a signal generator and signal analyzer with three to five times the channel bandwidth.

Test considerations

Both signal generators and signal analyzers offer internal calibration routines to correct amplitude and phase errors across the entire signal generation and analysis bandwidth. Although an OFDM receiver can perform equalization to correct frequency responses, the correction process still causes errors and reduces the signal's dynamic range.

For example, take the Keysight **M9415A** / **M9416A** VXT vector transceiver. The VXT integrates a 12-GHz VSG and a VSA in PXIe module. The VSG frequency response for amplitude error is less than ± 0.50 dB and 0.5 degrees for phase error across 400-MHz bandwidth. Use an external mmWave transceiver head to upconvert the VXT's signal to mmWave or downconvert a mmWave signal to an intermediate frequency for the VXT to analyze the signal. You'll need to correct the frequency responses of the external transceiver head. With this setup, the residual EVM performance for 5G FR2 400-MHz bandwidth can achieve < 1% for signal analysis and < 1.2% for signal generation.

Extend the reference plane to the DUT plane

Calibration ensures that the measurement system produces accurate results. Cables, components, switches, and mixers in the paths between the instruments and the DUT can degrade measurement accuracy or result in flatness errors. You must extend measurement accuracy from the signal generator's output or analyzer's input to the DUT's test port, as shown in Figure 5. You need to account for these errors before you make a measurement.

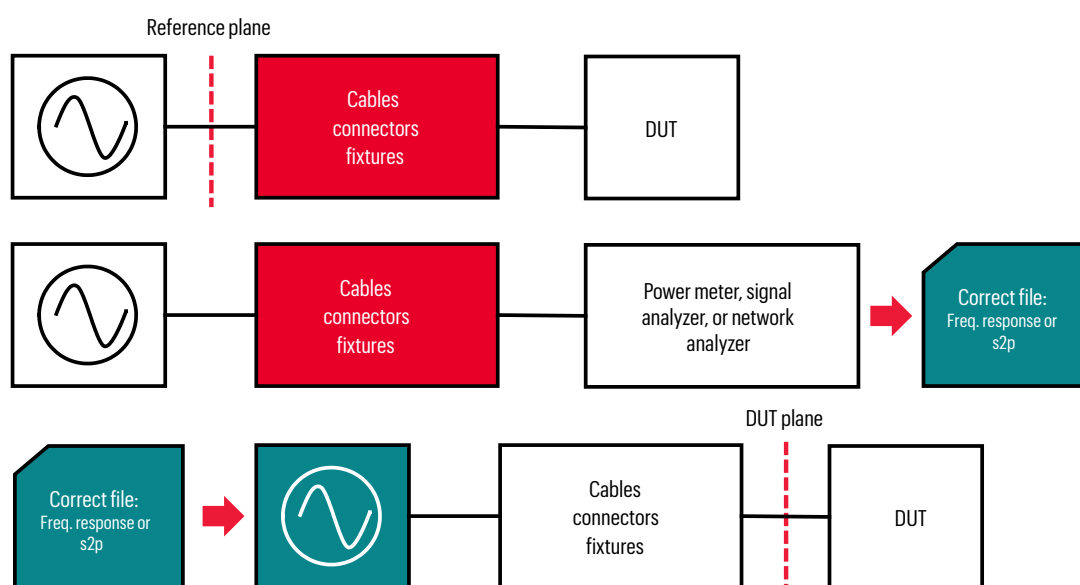


Figure 5. Signal generator correction setups

Measure the frequency response at the test fixture, cables, connectors, and mixers to obtain a corrected filter. A VSA and VSG, or a vector network analyzer, can measure the channel response. However, the correction comes at the price of SNR degradation. The SNR is critical to making accurate measurements at mmWave frequencies, such as EVM and ACPR.

Test Setup for 5G Mass Production

The introduction of the evolving 3GPP standard leads to new test challenges, including global spectrum requirements, wider channel bandwidths, and higher measurement performance. Addressing these challenges for mass production requires future-proof test instruments that support the latest 3GPP standards and offer superior RF performance in a flexible and scalable platform. Test engineers need to ensure that their test platforms offer the following:

- flexibility designed to scale to various frequency bands, bandwidths requirements, and evolving standards
- measurement accuracy that meets technical test requirements
- consistent and repeatable measurement results across the development cycle

Modular instruments can make implementation easier

High-volume device test in manufacturing benefits from the use of PXI modular instruments programmed for automatic measurement sequences where adjusts stimulus signals and measures results through software. With a greater number of stimulus and measurement channels, modular instruments allow you to test multiple devices simultaneously. Measurement data from multiple channels or devices can be quickly transferred and synchronized through a single, high-speed modular backplane, resulting in shorter test times and lower manufacturing test costs.

Space and power requirements for multiple modular instruments are much lower than the equivalent benchtop instrument configuration. Modular multichannel test systems do not carry redundant, multiple displays and power supplies, making modular instruments easier to accommodate in a production environment.

A compact modular design, such as the Keysight M9410A VXT, allows multiple transceiver modules in a single chassis for multichannel or multisite tests in the design verification and production phase, as shown in Figure 6. The modules are timing-synchronized through a PXI backplane bus and a precise frequency reference module. You can integrate other PXI modules, such as source / measure unit, digital input / output, and RF switching modules, in the chassis.



Figure 6. Multiple M9410A VXT modules in a single 18-slot chassis

Multisite systems test strategy in volume production

To test multi-antenna devices effectively, you must perform highly synchronized, multichannel signal generation and analysis. Accurate triggering among the instruments helps ensure that all measurements start at precisely the right time. To simplify your test synchronization for high channel count, consider a modular system that enables integration of multiple instruments into a multichannel test system.

The 5G manufacturing test is different from the R&D design verification test. The purpose of the manufacturing test is not to find design flaws, but rather to build a fast but thorough test that confirms DUTs pass specific post-manufacturing tests. A signal analyzer measures one antenna port at a time for transmitter tests.

Summary

The evolution to 5G technology introduces challenges and requirements that demand test instruments with sophisticated capabilities and performance. Implementing DVT systems for 5G requires multiple high-performance test instruments and complex system integration. The test requirements and complexity lead to high test costs across R&D and volume production.

The S9130A and S9115A 5G multiband vector transceivers offer users the flexibility, performance, compact size, and efficiency they need to address these complex test requirements. Their versatility helps speed the transition from design validation to a lean manufacturing environment.

Keysight Technologies' 5G NR solutions offer smart tools to address these challenges, from R&D to volume production. Visit the Keysight [5G NR solution](#) to stay up to date on emerging standards, techniques, and best practices. Download tutorials, application notes, case studies, and more.

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