WHITE PAPER

Mastering 5G Manufacturing

Beyond Conformance: Winning the 5G Race at Scale

5G is moving fast. Participants across the mobile ecosystem are eager to capture the new revenue streams from 5G business models. Device makers and network equipment manufacturers (NEMs) are moving full-speed ahead towards commercialization.

In their path stands the manufacturing challenge: a paradigm shift in focus from conformance test, where priorities revolve around test coverage, to manufacturing test, where cost of test and test times determine profitability and first-to-market status. The industry needs to take 5G through the manufacturing workflow from new product introduction (NPI) to high-volume manufacturing (HVM) as fast as possible. Device makers and NEMs need to overcome new manufacturing test challenges not faced in 4G - more frequency bands, millimeter-wave (mmWave) frequencies, and wider bandwidths.

5G new radio (NR) incorporates massive multiple input multiple output (MIMO) radio technology and mmWave frequencies. Taking 5G devices and base stations (gNBs) through the testing workflow for these technologies is not easy. Device and gNB manufacturers need to overcome significant challenges while coping with tremendous pressure on time to market and the cost of test. Challenges include the support of more frequency bands from sub-6 GHz to mmWave, greater channel bandwidths, and the move to over-the-air (OTA) test methods.

Device and network infrastructure manufacturers must master the complexities of 5G to innovate, transform, and win in 5G quickly. To be first to market, they must accelerate the delivery of secure, reliable, and cost-effective 5G solutions.

Key topics covered in this paper:

- 5G moves beyond conformance
- Techniques to reduce test time, complexity, and cost
- Redesigning for mmWave test

KEYSIGHT TECHNOLOGIES

5G Moves Beyond Conformance

Handset manufacturers and mobile network operators are eager to reap the economic benefits from 5G. Deployments are accelerating and will increase exponentially over the next few years. Performing 5G measurements quickly and reliably is critical for device manufacturers and NEMs. This is best accomplished with standardized platforms that can adapt and change to accommodate the latest standards and test methodologies for 5G.

Device and gNB manufacturers require future-proof test platforms that will remain relevant for the next 5 to 10 years.

Cellular standards evolution

To maximize time to market and optimize the cost of test, manufacturing engineers must perform a subset of the conformance tests laid out in the 3rd Generation Partnership Project (3GPP) specifications. Many test requirements, especially for mmWave frequencies, are still work in progress. This scenario requires device and gNB manufacturers to deploy flexible and scalable test systems in their manufacturing environments, so they can adapt to changing test specifications.

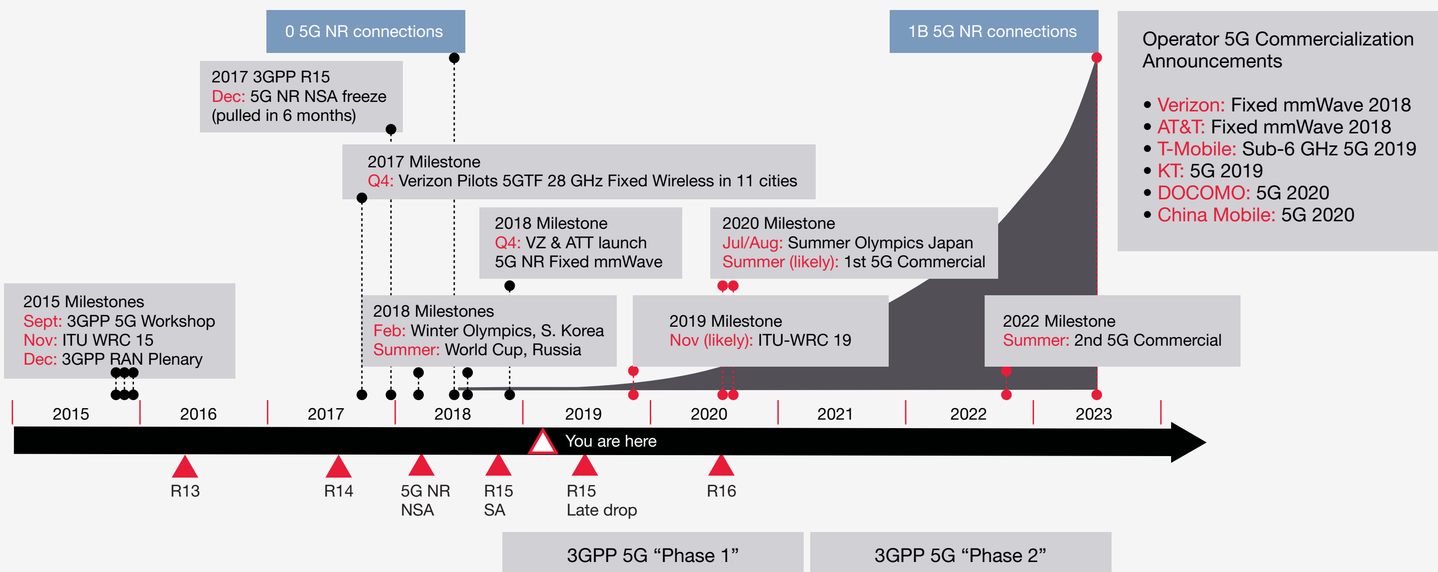


Figure 1. Key milestones and cardinal dates for 5G

5G standards continue to evolve. Approved in December 2017, Release-15 (Rel-15) address non-standalone (NSA) deployments which leverage the 4G long term evolution (LTE) network infrastructure. Standalone (SA) mode, which does not rely on an anchor in the LTE network, was approved in June 2018. Much development lies ahead for 5G — device and gNB manufacturers require future-proof test platforms that will remain relevant for the next 5 to 10 years.

The virtuous workflow cycle

A critical element for device makers and NEMs in their manufacturing test strategy for 5G is to leverage the work done and data gathered at each stage of the design-to-manufacturing workflow. The manufacturing phases include NPI, manufacturing, and the transition to HVM. Optimizing the transition from conformance to manufacturing is crucial to profitability, volume production, and time to market.

Design and validation

- Design simulation
- mmWave testbed
- Network and UE emulation

Conformance and acceptance

- Protocol
- RF/RRM
- Carrier acceptance

Manufacturing

- Calibration
- RF verification

Accelerating the workflow for time to market advantage

Protocol testing is a challenge of the past in the manufacturing environment. Non-signaling testing eliminates costly signaling overhead and increases throughput while maintaining test integrity. Adopting common test platform elements is essential for moving devices and network equipment through the workflow quickly. It also helps with controlling the cost of test for globalized operations.

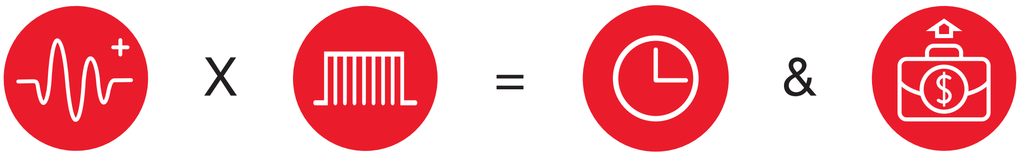
"Keysight's end-to-end 5G test solutions have accelerated the development and validation of our new 5G designs across the workflow, from early prototyping to design validation and manufacturing."

Woonhaing Hur

Vice president of System LSI Protocol Development at Samsung Electronic

Techniques to Reduce Test Time, Complexity, and Cost

Challenges: more frequency bands and wider bandwidths = more time and cost



Devices and gNBs need to support both legacy bands and new frequency bands. This increases design complexity and test times.

5G new radio (NR) covers a wide range of frequencies grouped into two categories — 410 MHz to 7.125 GHz (FR1), and 24.25 to 52.6 GHz (FR2). Devices can operate in multiple bands depending on the regions in which they are expected to be sold. FR1 bands range from 1 to 255 while FR2 bands range from 257 to 511.

Nine new bands are available for sub-6 GHz frequencies that are not part of the 4G long term evolution (LTE) specifications. They aim to increase coverage and capacity and address the lack of spectrum available at low frequencies for 5G services. The new mmWave bands are for high-throughput applications, made possible by wider bandwidths available in the mmWave spectrum.

Maximum channel bandwidth increases to 100 MHz for sub-6 GHz frequencies and 400 MHz for mmWave bands — with even higher bandwidth possible via carrier aggregation. Greater bandwidths and more frequency bands drive higher costs. Requirements for error vector magnitude (EVM), flatness, and dynamic range are more difficult to achieve. Existing test hardware is not capable of addressing such bandwidths. The number of test points increases. Test equipment and chambers are more expensive. These factors increase the cost of test.

Techniques to Reduce Test Time, Complexity, and Cost

- Challenges: more frequency bands and wider bandwidths
- New techniques: FPGA, multi-device testing, cloud data processing, and measurement consistency

Solutions: new techniques include FPGA processing, multi-device testing, cloud processing, and improved measurement consistency.

	Description
	Accelerated measurements help test engineers start closer to the finish line. PXIe's high-speed data handling capability and deep measurement expertise built into hardware-based FPGA measurements yield significant reductions in test times. This capability translates into increased test speed across power and frequency ranges for multiple channels and radio formats in base station testing.
	Testing more devices at once accelerates test times for device manufacturers. With Keysight's EXM 5G Multi-Device Test Solution, device manufacturers can test up to 32 devices using multi-port adapter technology. Advanced test sequencing and single-acquisition multiple measurements (SAMM) also help maximize throughput and yield.
	Cloud data processing can help test throughput reach extremely high levels. In a typical approach, the test equipment acquires the test data and calculates the measurements sequentially. In a cloud-based approach, the computing workload is in the cloud. Critical calculations now run in parallel on faster cloud-based servers. The test architecture is more efficient, increasing measurement throughput. It also increases test asset utilization and flexibility, enabling manufacturers to repurpose test stations.
	Using the same measurement algorithms across the workflow from conformance to manufacturing and beyond helps to reduce development time. Engineers have higher confidence in their measurement results. Traceability back to design accelerates resolution when issues do occur.

Redesigning for mmWave Test

Prior to 5G, commercial communications mostly resided at low frequencies. Most testing was performed via conducted methods. Attracted by the spectrum availability in mmWave frequency bands, the industry is shifting to higher frequencies. The move to mmWave frequencies requires UE and base station designers to use different architectures like phased array antennas. These architectures cannot support conducted connections, forcing test verification to happen over the air. Higher frequencies combined with OTA testing result in much more path loss than previous test methods.

mmWave radiated testing is entirely new to cellular manufacturing and presents significant challenges for device makers and NEMs.

Increased loss compromises signal quality

mmWave radiated testing is entirely new to cellular manufacturing and presents significant challenges for device makers and NEMs. Switch matrices and long cables incur high losses. Air absorption, high insertion loss, and fragile and expensive connectors reduce dynamic range and impact measurement quality.

It is imperative to accurately compensate for path loss with system calibration, and by reducing the distance between the DUT and the OTA chamber. Remote heads allow for long cables at low frequency and power to reduce insertion loss drastically while improving phase linearity and connector robustness. The added gain in the remote heads also improves dynamic range.

Figure 2 highlights how a remote mmWave transceiver head reduces insertion loss in an OTA test setup.

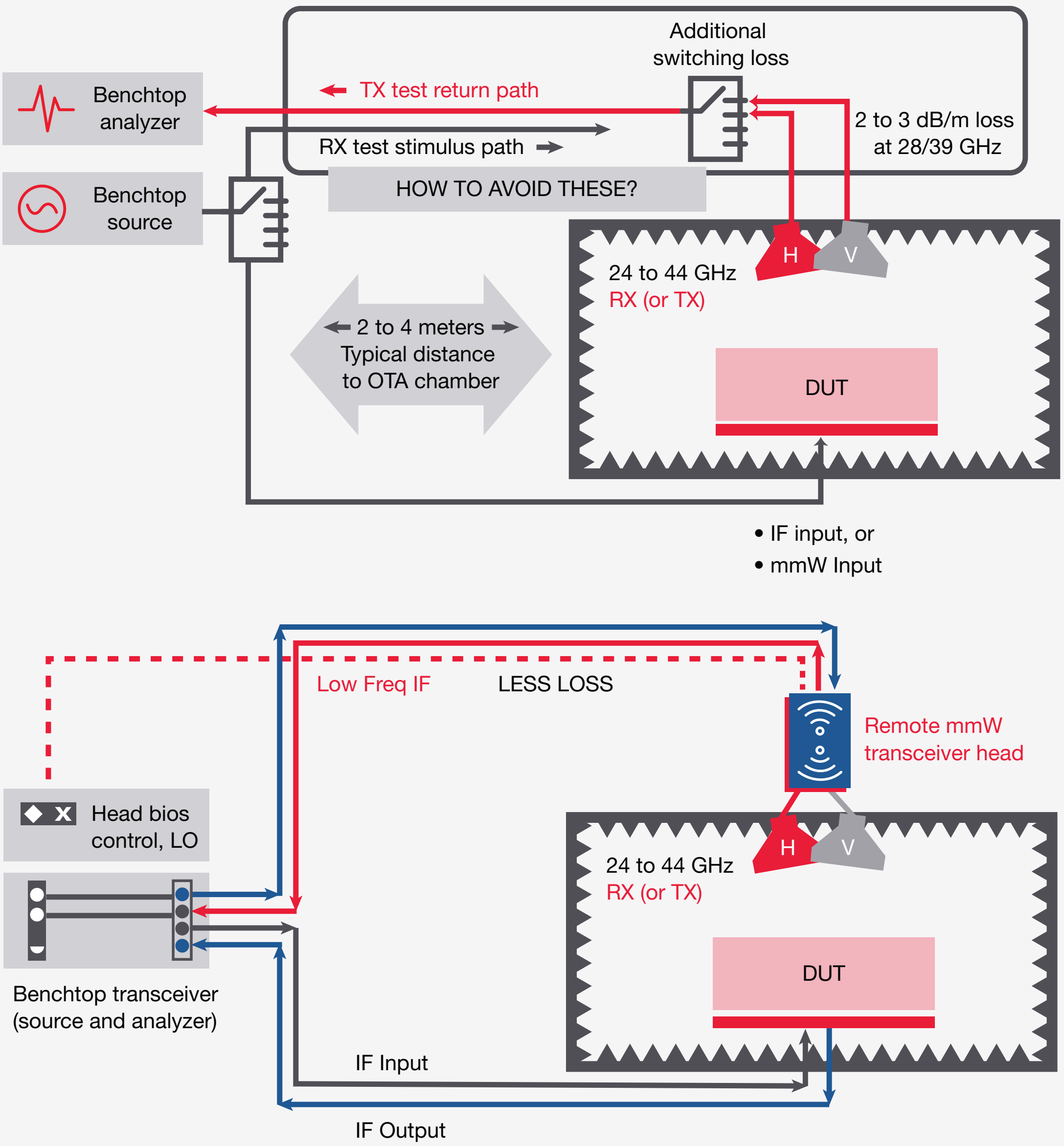


Figure 2. OTA test setups with and without a remote head

Floor space constraints for low cost of test

Without multi-port testing and high-density test systems, test equipment footprint will increase significantly in 5G. Higher performance requirements and the need for more test equipment and OTA chambers place new demands on the production floor. These factors impact the cost of test because contract manufacturers typically charge by the square foot. A larger test equipment footprint means higher real estate costs, or a reduction in production capacity.

Scalable test equipment provides major speed and space savings for device manufacturing. Testing multiple devices at the same time helps offset the increased test equipment footprint, while also accelerating time to market. Cloud processing can further speed processes, resulting in a high volume, high density device test system for HVM.

In addition to multi-device testing, 5G increasingly uses multi-port designs and multi-element MIMO arrays on both UEs and base station installations. Multi-channel scalable test equipment is critical to base station testing. It helps NEMs contain the test equipment footprint and the cost of test. Equipment scalability is essential to transition from testing 4- to 8-port 4G devices to 5G with 16, 32, 64, and 128 channels.

Be First at 5G Through Efficient Conformance to Manufacturing Transition

Device manufacturers and NEMs must surmount the challenges coming from 5G NR, MIMO, and mmWave frequencies to achieve success in 5G. Aggressive deployment targets for 5G networks globally are having a ripple effect throughout the mobile ecosystem. Device and base station manufacturers must effectively manage a drastic shift in focus from maximizing test case coverage to minimizing the cost of test and accelerating time to market.

With continuous standard evolution, flexibility in manufacturing test operations is critical. Measurement consistency is important to reduce test development efforts and foster collaboration among teams across the workflow.

More RF bands, band combinations, and wider channel bandwidths mean longer test times and higher costs because of the higher number of test points. Current instruments on device and base station manufacturers' production floors cannot handle such frequencies or bandwidths. They must deploy scalable solutions to minimize the number of test assets necessary to serve all bands, bandwidths, and test points.

Using frequencies in the mmWave spectrum also brings significant disruption to device makers and NEMs' manufacturing test operations. They must successfully manage the transition of their test operations from conducted to OTA test methods and overcome path loss. Floor space is also a major concern. Innovative solutions are required to contain test equipment footprint and lower the cost of test.

For more information on how Keysight's solutions can help you address your 5G manufacturing test challenges, visit the following webpages:

- For device manufacturing, click here.
- For base station and sub-assemblies manufacturing, click here.
- For Keysight's 5G solutions, click here.