Facing 5G NR Test Challenges

White Paper

By Peter McNeil

Pasternack
17792 Fitch, Irvine, CA 92614
sales@pasternack.com | pasternack.com
Toll-free: 866-PASTERNACK (866-727-8376)

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Abstract

5G wireless communications technology has been the topic of much debate, theorizing, and predictions over the past several years. One of the only sure considerations in these early 5G discussions was that testing hardware to meet 5G goals was going to present substantial challenges. With initial 5G trials and deployments now using the official 3GPP standard (Release 15), design laboratories and conformance test facilities are now facing the struggle to deliver user equipment (UE), fixed-wireless access (FWA), and customer premise equipment (CPE) verified to meet this standard, and also to anticipate advances in 5G technology, the 3GPP standard, and corresponding test requirements.

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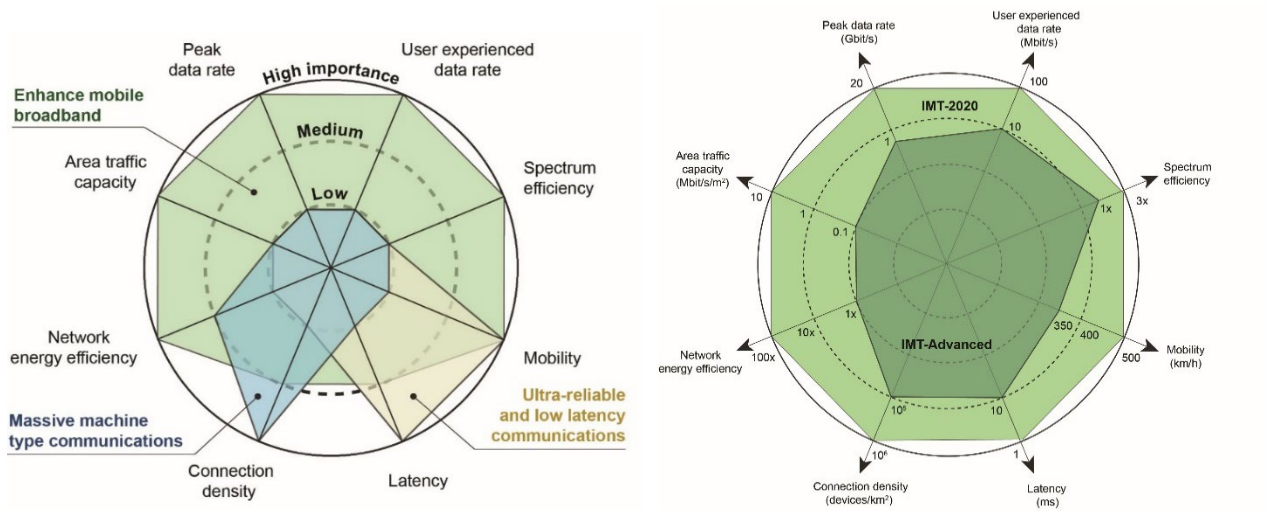
1: Introduction

It has been nearly 5 years since the ITU released ITU-R M.2083-0, with a roadmap to release IMT-2020 to address the anticipated future of 5G performance that would greatly eclipse that of IMT-Advanced and then-planned 4G technology [1.1, 1.2, 1.3, 1.4, 1.5]. In 2017, 3GPP rushed to release a preliminary version of their 5G standard (Release 15), so telecommunications companies would begin developing hardware and deploying 5G infrastructure according to their guidelines instead. The result was the new radio (NR) standard for 5G that includes a non-standalone (NSA) millimeter-wave spectrum capability and additional sub-6 GHz cellular bands. Release 15 has provided enhanced mobile broadband (eMBB) specifications, with future updates to Release 16 and a Release 17 to provide more definition of massive machine-type communications (mMMC) and ultra-reliable low-latency communications (URLLC).


The importance of key capabilities in different usage scenarios

Enhancement of key capabilities from IMT-Advanced to IMT-2020

IMT-2020 set a high bar for future telecommunications performance that will likely require substantial changes to every aspect of the telecommunications infrastructure. [1.1]

3GPP Release 15 has provided standards that support higher capacity, greater network efficiency, higher peak data rates, higher user experienced data rates, greater spectrum efficiency, and greater mobility. The result has been telecommunications base-station transceivers (BST) and UE hardware that operates at higher frequencies, handles greater carrier aggregation (CA), supports higher MIMO layers for UE/BST, offers greater bandwidth per channel, leverages more efficient access methods, and can use more complex modulation schemes (See Table 1).

Table 1:

5G Parameters/Features	FR1*	FR2**
	Sub-6 GHz (low-band and mid-band)	Millimeter-wave (high-band)
Frequency Range	0.45 GHz to 6.0 GHz	24.25 GHz to 52.60 GHz
Subcarrier Spacing	15, 30, and 60 kHz	60, 120, and 240 kHz
Bandwidth	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, and 100 MHz	50, 100, 200, 400 MHz
Duplex Mode	FDD and TDD	TDD only
Antenna Complexity	2T2R, 4T4R, 8T8R, 16T16R, 32T32R, and 64T/64R	2T2R, 4T4R, 8T8R, 16T16R, 32T32R, and 64T/64R
MIMO Layers UE	DL:8T8R and UL: 4T4R	DL:2T2R and UL: 2T2R
MIMO Method	spatial multiplexing	beamforming
Carrier Aggregation	32 max (LTE), 16 max (R15)	16 max
Modulation	pi/2-BPSK, QPSK, 16QAM, 64QAM, and 256QAM	pi/2-BPSK, QPSK, 16QAM, and 64QAM
Channel Coding	LDPC Codes (Data), Polar Codes (Control)	
Access	DL: CP-OFDM UL: CP-OFDM and DFT-s-OFDM	
Radio Frame Duration	10 ms	
Subframe Duration	1 ms	
Spectrum Occupancy	from 90% (LTE) to 98% of channel bandwidth	to 98% of channel bandwidth
Dynamic Analog Beamforming	not support (LTE), supported (R15)	supported
Digital Beamforming	to 8 layers (LTE), to 12 layers (R15)	to 12 layers

* Frequency band below 7.225 GHz
** Frequency band above 24.250 GHz

Another result of 3GPP Release 15 was the release of conformance and performance testing recommendations and requirements (TR 38.810).. Unlike previous generations of cellular technology, 5G NR standards introduced not only millimeter-wave frequency bands, but the requirement for sub-6 GHz and millimeter-wave communications to operate simultaneously (5G NR NSA).

With the mainstreaming of beamforming/beamsteering, CA, and multi-input multi-output (MIMO) technology, BST and UE hardware is no longer a single radio with tuning/filtering technology and a mix of antennas/wideband antenna. Telecommunications hardware has evolved to be an array of antenna elements with transmit/receive modules (TRMs) driving each element, or a sub-array of elements. More complex digital processing is also required to successfully implement beamforming, CA, and MIMO, which leads to extremely integrated active antenna systems/advanced antenna systems (AAS) which now resemble the active electronically scanned array (AESA) technology used in military radar.

The inclusion of AAS, CA, and beamforming/MIMO technologies has led to an infinite number of potential test scenarios, and made both prototype testing and conformance testing much more challenging for engineers and test facility staff. So, there has recently been a substantial amount of research and investment into finding methods to reduce testing complexity and cost.

This whitepaper aims to discuss 5G hardware RF test challenges and to highlight several current developments in research and test component selection that move toward mitigating the challenges.

2: Intrinsic Millimeter-Wave Test Challenges

Until 3GPP Release 15, the highest frequency of cellular telecommunications reached only a few gigahertz. Though there are wireless networking standards (WiFi IEEE 802.11.ac) that operate between 5 GHz and 6 GHz, these systems were specifically designed for short range (tens of meters) networking communications. With the introduction of FR2 millimeter-wave frequencies, cellular technology moved in a single iteration to a technology node with a very different makeup than that of commercial telecommunications technology [2.1].

The Difference between Sub-6 GHz Telecommunications & Millimeter-Wave Design & Production

In the past, the telecommunications industry has mainly relied on the vast ecosystem of vendors and manufacturing infrastructure to produce large volumes of hardware for relatively low unit cost. Microwave/millimeter-wave hardware manufacturers and suppliers have organized around a different model, one that has cateredprimarily to applications in military/defense, aerospace, space, weather, and scientific research, rather than telecom. These providers have typically produced small volumes of highly custom components designed to meet stringent criteria specific to the application being served. The design, manufacturing, and testing mechanisms for products that operate in the tens of gigahertz have traditionally not responded rapidly to commercial influence and are instead largely structured to respond to long project windows.

Some of the reasons for this is that designing products that overcome the intrinsic challenges of millimeter-wave operation requires niche design expertise, familiarity with the nuances of computer-aided design (CAD) tools in the millimeter-wave spectrum, substantial computing power for simulations, lossy interconnect, high cost test and measurement equipment, extremely precise and repeatable manufacturing capability, and well-trained technicians capable of performing exacting inspections, quality control, and tuning procedures. Therefore, millimeter-wave products tend to be produced in small batches and at a high cost per unit. In order to reliably mass produce millimeter-wave telecommunications hardware, a new approach is necessary, but this new approach must address the intrinsic physical complexity of millimeter-wave signals and hardware.

Physical Design & Manufacturing Challenges Associated with Millimeter-Wave Technology

There are several physical phenomena that become more significant at higher frequencies. There are also a variety of features of RF components and interconnect that are correlated to the size of the operating wavelength. For instance, RF losses increase as a function of frequency, as factors like skin effect and frequency-dependent conductivity and loss of materials become more prevalent in the millimeter-wave spectrum. Also, transmission lines, such as coaxial cables and microstrip/stripline dimensions must be proportionally smaller to accommodate shorter wavelength signals, which further increases the loss of the signal path between, and within, RF components.

There are also manufacturing challenges associated with consistently producing small precision components. For example, the center conductor of an N-type coaxial connector with a maximum rated frequency of 18 GHz is 3.04 mm in diameter, where a 1.85mm coaxial connector good to 70 GHz is only 0.803 mm in diameter. As the loss is much higher for microstrip/stripline and coaxial interconnect, waveguide interconnect is often used at frequencies beyond 6 GHz.

Table 2:

Characteristic	Coaxial	Waveguide	Stripline	Microstrip
Preferred Mode	TEM	TE10	TEM	Quasi-TEM
Other Modes	TM, TE	TM, TE	TM, TE	TM, TE
Dispersion	None	Medium	None	Low
Bandwidth	Broadband	Banded	Broadband	Broadband
Loss	Low	Lowest	High	High
Power Capacity	High	Highest	Low	Low
Physical Size	Large	Largest	Small	Smallest
Fabrication Ease	Medium	Medium	Easy PCB	Easy PCB
Component Integration	Connectorization	Waveguide Flange	Surface Mount	Surface Mount

At higher frequencies waveguide interconnect also becomes proportionally smaller and, therefore, more compact. However, waveguide interconnect is intrinsically banded and still large, heavy, and expensive compared to coaxial interconnect, which is why waveguide interconnect is predominantly used in high-precision and high-power testing while coaxial interconnect is still used for most broadband testing.

Other considerations at millimeter-wave, and with ultra-wide bandwidth applications, are group delay and phase delay. For dispersive media, such as waveguide and microstripline, the group delay and phase delay can be large enough to require special delay-mitigating components and other design and routing efforts to correct. This is a special concern for wideband AAS, as substantial group delay and phase delay can degrade the beamforming and MIMO performance of these systems.

Though vector network analyzers (VNAs) are typically used to characterize group delay variations by measuring the phase distortion, it may be advantageous in some setups to use spectrum analyzers (SAs) and signal generators (SGs). A SA/SG test setup for group delay may lead to a more simplified setup with faster measurement speed, which could benefit test scenarios with a large number of signal paths. Having separate control of a SG may also be helpful in some millimeter-wave test scenarios, as the power output of the SG could be made higher to compensate for the greater transmission losses at these frequencies. Skew matched coaxial assemblies may also help to mitigate the time delay (skew) between various signal paths. Skew matched cable assemblies could help in applications where it is critical to have various signal paths with matched phase, such as with beamforming antenna elements driven by a common signal source.

Notes on Characterization Testing for 5G Devices & Components

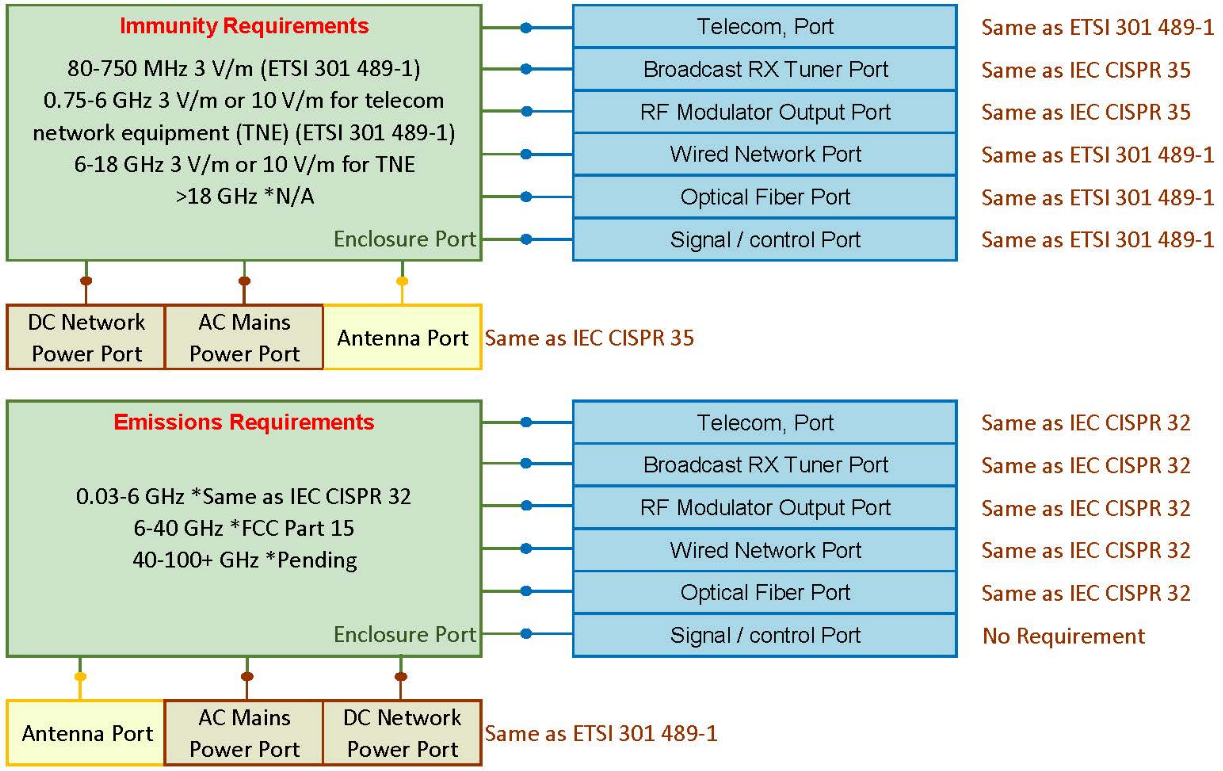
Characterizing RF devices, of which there is greater need for highly integrated components/devices for 5G applications, involves testing a device in a very precise manner over an extremely wide range of frequencies. In order to generate an accurate model for use with electronic CAD (ECAD) software for design and simulation purposes, a device/component usually must be tested a few times beyond its maximum operating frequency range and well below its minimum frequency of operation. That means that a device operating to 30 GHz must be tested to nearly, or even beyond in some cases, 100 GHz to generate an accurate enough model.

Therefore, the surge of demand for MMIC and SoC/SiPs for 5G is also raising the need for characterization testing to, and beyond, 100 GHz, which generally requires a variety of upconverters/downconverters, waveguide interconnect, and complex banded test setups. Broadband testing can be done to 110 GHz with precision 1 mm coaxial connectors, for which calibration standards and adapters are commercially available. Testing beyond 110 GHz requires iterative testing of devices/components over several waveguide bands and then de-embedding and stitching the data in order to create a model. There are now even smaller proprietary coaxial connectors that use innovative physical coupling methods, but these aren’t widely commercially available yet and are only compatible with specific instruments.

3: FR1 and FR2 Simultaneous Test Challenges

In addition to the challenges posed by millimeter-wave testing, testing multi-band (FR1 & FR2) systems may lead to testing sub-6 GHz and millimeter-wave frequencies and systems simultaneously. In the case of 5G NR NSA, where the millimeter-wave data communications require sub-6 GHz control plane signals to function, simultaneous multi-band testing is necessary [3.1, 3.2]. To account for electromagnetic compatibility (EMC) and conformance testing, multi-band testing is also needed to ensure that multi-band systems don’t create undue interference, as harmonics from lower frequencies could also reach into the millimeter-wave spectrum, and vice versa.

Current coexistence and EMC standards do not necessarily account for sub-6 GHz devices creating interference in the millimeter-wave spectrum. The ITU has released recommendations (ITU-T Series K Supplement 10) on methods for handling immunity and emissions tests for 5G devices. However, coexistence testing, along with conformance testing of 5G devices, is still progressing.



ITU-T Immunity and Emissions Test Recommendations for 5G [3.1]

Given the new number of frequency bands and operation modes (i.e. carrier aggregation), coexistence testing for 5G is significantly more complex compared to prior cellular technologies. There is now a much larger number of harmonic and spurious byproducts that could result from co-site interference from sub-6 GHz band and millimeter-wave 5G transmissions, and given the proximity of antennas in compact AAS, the resulting interference products could be substantial compared to low RX signal levels from high path loss millimeter-wave communications.

There is simulation software specifically designed to predict co-site interference and other coexistence issues that could help to mitigate these challenges. Along with future recommendations and innovative test approaches, testing for coexistence issues may become more straightforward and reliable. For sub-6 GHz bands, low PIM coaxial interconnect may help to reduce some of the distortion and possible interference byproducts that could reach millimeter-wave bands or other sub-6 GHz bands.

4: Multi-functional Device Testing

Beyond just FR1 and FR2 measurements, 5G UE will also contain a variety of other wireless technologies, including Bluetooth, WiFi (2.4 GHz, 5 GHz, and possibly WiGig at 60 GHz), NFC, and, potentially, a variety of wireless charging technologies. The resulting test landscape for complex UE means that immunity and emissions testing will become significantly more nuanced (See Table 2) [4.1].

Technology Type	Spectrum Availability	Application Scenarios	Coverage & Penetrability	Distance & Mobility	Infrastructure Readiness & Cost	UE Application Challenge
1: 5G Sub-6 GHz (stand alone)	Widely distributed from 450 MHz to 6 GHz	• High data rate • MaMi • 5G mmWave bands unavailable • Both urban and rural areas	Wide, Strong (<5 GHz) and Medium (>5 GHz)	Long/ medium, high	• High maturity for normal MU-MIMO applications, • PoC stage for MaMi BS • High cost for MaMi	• Large dimension of sub-6 GHz MaMi antennas • More hardware resources • High complexity and power consumption for MaMi
2: 5G mmWave (stand alone)	28/37/ 39 GHz (licensed)	• Very high data rate • 5G Sub-6 GHz bands unavailable • Beamforming required for interference reduction and security • More friendly with LoS environments.	Limited, weak	Limited, low	• PoC stage with demos • High complexity and high cost for mmWave components	• MmWave circuits and systems implementation and test challenges • Human body blockage issue • High cost
3: WiFi 2.4 GHz WiFi 5 GHz	2412-2484 MHz 5150-5835 MHz	• Mainly for indoor applications • Medium data rate for 802.11a/b/g/n/ac • High data rate for 802.11ac (WAVE 2) • 802.11ax	Indoor/ Outdoor, Strong (<5 GHz) and Medium (>5 GHz)	Long/ medium, low	• 802.11ac (WAVE 2) MU-MIMO routers available • Medium cost • 802.11ax silicon announced	• Co-design challenge and resource competition with cellular systems • High complexity and power consumption • Large antennas dimension due to high MIMO layers, e.g. 8 × 8 MIMO
4: WiFi 60 GHz (WiGig)	57-71 GHz4	• Point-to-point indoor communications • Very fast (802.11ad) • Extremely fast (802.11ay)	Indoor, weak	Limited, <10 m	• 802.11ad routers available • High cost • 802.11ay silicon PoC announced	• Co-design challenge and resource competition with 5G cellular mmWave • Similar technical bottlenecks as tech. type 2

5: 5G Sub- 6 GHz CA1	Wide and distributed, from 450 MHz to 6 GHz	• Very high data rate • Spectrum segments at Sub-6-GHz bands available	Wide, strong	Long, medium	• Similar to tech. type 1 • More hardware resources to enable CA • Very high cost	• Similar technical challenges as tech. type, with higher design complexity and hardware resources
6: 5G mmWave CA	28/37/ 39 GHz (licensed)	• Similar to 5G NR SA • Multiple spectrum segments available at 5G mmWave bands	Limited, weak	Limited, low	• Similar to tech. type 2 • More hardware resources to enable CA • Very high cost	• Similar technical challenges as tech. type 2, with higher design complexity and hardware resources
7: 5G Sub- 6 GHz & mmWave CA	450 MHz to 6 GHz, 28/37/ 39 GHz	• Very high data rate • Shared spectrum at Band 46 available	Limited, weak	Limited, low	• Based on readiness and maturity of tech. type 5 and 6 • More hardware resources and high complexity • Very high cost	• Based on similar challenges of tech. type 5 and 6, but with even higher design complexity and hardware resources
8: 5G Sub- 6 GHz LAA	450 MHz to 6 GHz, 5150-5835 MHz (unlicensed)	• Very high data rate • Shared spectrum at Band 46 available	Wide, strong/ medium	Long, medium	• Similar to tech. type 5 • More hardware resources and more complicate design to enable LAA • Very high cost	• Based on similar technical challenges as tech. type 3 & 5, with higher co-design (Cellular&WiFi) complexity and more hardware resources such as antennas and chipsets
9: 5G mmWave LAA	28/37/ 39 GHz, 57-71 GHz (unlicensed)	• Similar to 5G NR SA with much higher data rate • Shared spectrum at mmWave available	Limited, weak	Limited, low	• More advanced than tech. type 6 • More hardware resources and more complicate design to enable LAA • Very high cost	• Based on similar technical challenges as tech. type 4 & 6, with higher co-design (Cellular & WiFi) complexity and more hardware resources such as antennas and chipsets

10: 5G Super-CA	450 MHz to 6 GHz, 28/37/39 GHz, 5150-5835 MHz, 57-71 GHz (unlicensed)	• Extremely high data rate • Massive data transmission • Multi-task • Highest requirement for networks and infrastructure	Indoor, weak	Limited, low	• Most advanced tech. type • Depends on readiness and maturity of tech. type 1-9 • Most hardware resources and most complicated design • Highest cost	• Based on similar technical challenges as tech. type 5-9, with highest co-design (Cellular & WiFi) complexity and most hardware resources such as antennas and chipsets

Source [4.1]

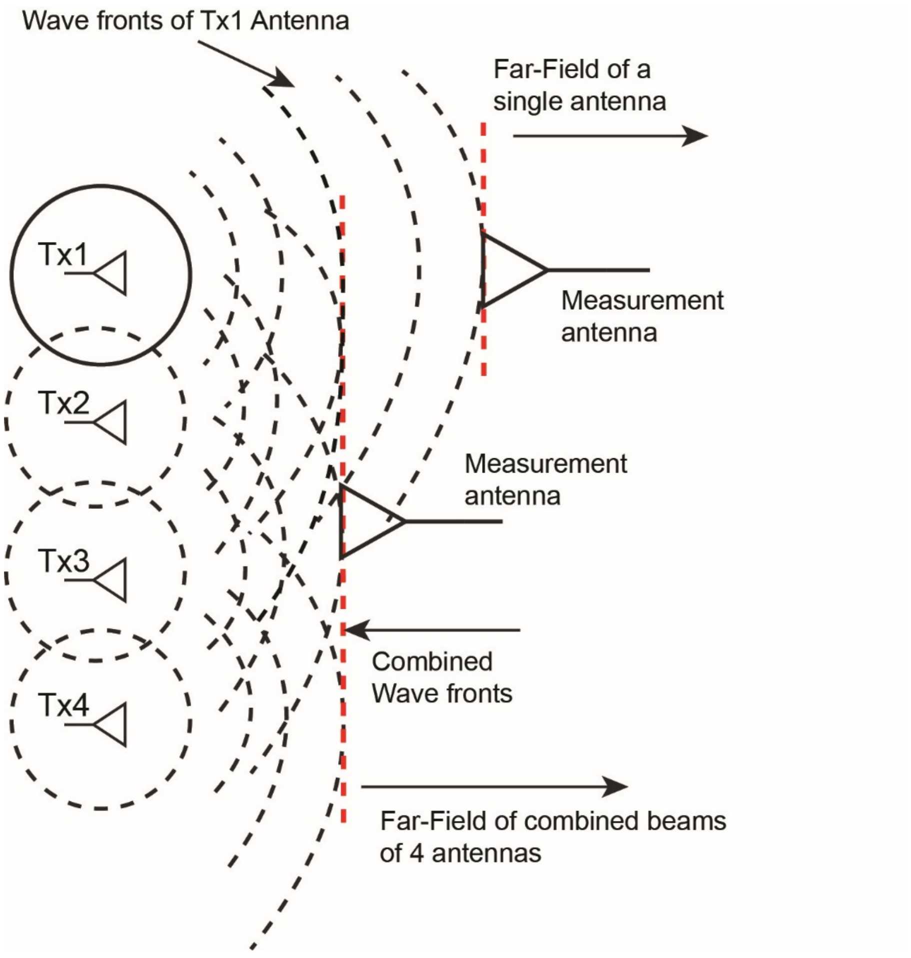
Currently, there is no standardized test approach for a 5G UE, and each individual wireless standard has their own compliance requirements. It may be that future versions of these standards will include additions or changes to the compliance sections to account for coexistence with new 5G operation, and it is also likely that future 5G conformance standards will have to take into account other wireless standards for better interoperability of future 5G UE.

5: High Density Testing of Active Antenna Systems

Several of the standards and conformance bodies, such as FCC, CISPR, and ETSI require that emissions amplitude is tested in an antenna's far field, when possible. The distance from the antenna at which the far field region begins is frequency dependent and proportional to wavelength. Hence, for sub-6 GHz frequencies, the far field region begins tens of centimeters to meters away from the antenna. For millimeter-wave frequencies, the far field may begin from centimeters to millimeters away from the antenna.

This factor combined with a much higher path loss for millimeter-wave frequencies means that the path loss for millimeter-wave signals may yield signal levels too low to measure in the far field of sub-6 GHz antennas. Higher gain antenna and low noise amplifiers may be used to increase the signal power from dual-band systems somewhat. However, higher gain antennas tend to be extremely directional and require precise positioning, potentially reducing repeatability. Low noise amplifiers do add some noise, and otherwise restrict the dynamic range of measurement at the high end to avoid saturation and desensitization.

In the United States, FCC Part 30: Upper Microwave Flexible Use Service dictates conformance standards, including power, bandwidth, effective isotropic radiated power (EIRP), emission limits based on power spectral density (PSD) for adjacent and spurious bands. An issue with the EIRP measurements as well as related measurements for total radiated power (TRP) is that the current methods assume the antenna is isotropically radiating. This assumption creates inaccurate measurements for AAS that use MIMO and beamforming technology.



The far field of MIMO/beamforming antenna arrays is different from traditional far field calculations for an antenna.

Moreover, for millimeter-wave beamforming antennas, the effective far field region of a MIMO/beamforming antenna is different than the respective far field region of each antenna element [5.1]. Meaning, to measure MIMO/beamforming antennas in their far field, accurate predictions of the far field region are necessary to select the correct measurement antenna and avoid unnecessary loss and error. Also, being non-isotropic, measuring spherically around the antenna to determine the EIRP and TRP might be necessary, or at least provide more accurate measurements for radiated power. The quiet zone for measurement antennas at these frequencies is very small, which would lead to the need for high precision positioning systems and a very long measurement time delayed by both the positioner time and measurement time.

To address these challenges, there has been a substantial amount of research into using a variety of modified test arrangements. These include simple-sectored multi-probe anechoic chambers (SS-MPAC)/MPAC, virtual probe MPAC, compact antenna test range (CATR) using a reflector, midfield (MF) testing, and other testing methods using complex near-field (NF) to far field (NF2FF) approximations [5.2, 5.3, 5.4, 5.5, 5.6, 5.7, 5.8, 5.9]. Each approach presents trade-offs for test accuracy, repeatability, complexity, cost, time, size, and other performance features. Without definitive testing standards yet in place, these methods are currently being explored for feasibility and for the future of 5G testing.

6: Testing Complex Assemblies, MMICs, and Systems-on-Chip (SoCs)/Systems-in-Package (SiPs)

With the small sizes of most RF components and devices and the need to reduce interconnect losses, it is more likely that telecom will look to integration and digitization to minimize the cost and complexity of 5G FR2 technology. This would result in complex assemblies built with integrated or compact filters, attenuators, amplifiers, oscillators, phase shifters, power combiners/splitters, interconnect, mixers, circulators/isolators, and other RF components and devices. Many AAS manufacturers are likely to integrate as many of these components as possible using current or partially augmented low-cost and high-volume production methods, such as silicon semiconductor fabrication. Hence, digitizing RF functions is becoming increasingly important and more commonly employed. This is similar to the trend seen in the military/defense and aerospace industries, with AESA radar being fabricated from compact modular components comprised of monolithic microwave integrated circuits (MMICs) and earlier generations of cellular technology.

Though higher levels of integration will lead to more compact, energy-efficient, and cost-effective telecommunications hardware, it will also result in more complex testing scenarios. It is likely that future 5G hardware will not have the ease and familiarity of coaxial or waveguide interconnect between test equipment and the device under test (DUT).

Many of today's millimeter-wave components are assembled in packages with coaxial or waveguide interconnect, which readily mates to the coaxial/waveguide ports of test equipment and calibration standards. Greater levels of integration mean that many RF components will be incorporated into a single complex assembly, or MMIC, where testing the components will need to be done using a custom test interface and/or probe testers at the chip-level or wafer-level. Much of this testing will also need to be multi-domain, where power, digital, analog, and RF testing occur simultaneously to determine device performance and functionality [6.1].

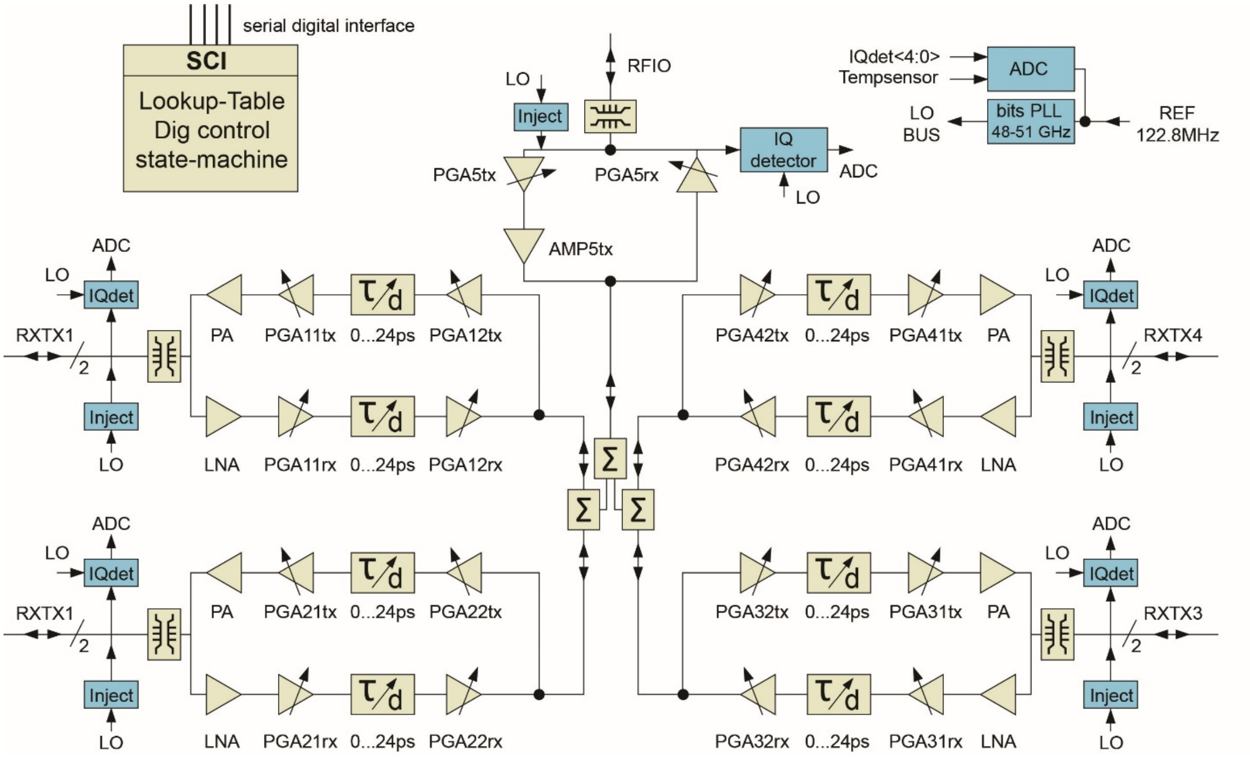
Even higher levels of integration, which are necessary for UE equipment that fits in the popular form factors and operates for an adequate duration with modern rechargeable batteries, is resulting in development of complex Systems-on-Chips (SoCs)/Systems-in-Packages (SiPs). These SoCs/SiPs are beginning to include a mix of domains and technologies in a single package, that is often only accessible for testing on the wafer or through the final package leads. These SoCs/SiPs are often operating with extremely high-speed digital signals, millimeter-wave signals, stringent power supplies, and highly sensitive analog signals.

In many cases, it is likely that this type of testing will be done at the wafer level to accommodate technologies such as wafer level chip scale packaging (WLCSP) and to enable modern integrated 5G systems [6.2]. A necessary component that would enable this trend is the modeling and characterization of the probing system as part of the test system, and how the behavior of the probing system varies over a wide range of conditions (including millimeter-wave frequency-dependent behavior). This type of simulation and modeling is necessary to embed the probe system and predict its impact on system performance. The interfacing between the probe card and test equipment for dense millimeter-wave test is often customized to the chip and complex system. Hence, this simulation and testing must be done for each chip and probe system.

7: Test Systems Evolve With 5G Challenges

Test systems with the capability of precision testing each of these domains are becoming necessary instead of convenient. There has been a rise of modular test systems, as well as turn-key and multi-function test equipment that is able to perform several types of tests. There are even emerging 5G test systems that use software-defined radios (SDRs), general purpose processors, and other readily available and low cost, configurable hardware.

In order to reduce test times, many researchers are exploring RFICs, antenna processors, and other complex SoCs/SiPs for 5G technology with integrated in-system (in-situ) self-test and self-calibration circuitry [7.1, 7.2, 7.3, 7.4]. The built-in-self-test (BST) circuitry is generally designed to aid with semiconductor fabrication and production testing, but is currently being researched to take direct measurements of other on-chip hardware, including RF hardware. Future BTS technology may be used to perform some aspects of production testing. However, characterization and conformance testing will likely require external test equipment and procedures to ensure repeatable test results that can provide 1:1 performance measurements using standardized methods.



An example RFIC architecture that features built-in test equipment that measures the RF output. Source [7.2]

8: Conclusion

Though much of the test landscape for current and future 5G UE and BST hardware is still nebulous, there are a few predictions that can be made. The inclusion of millimeter-wave frequencies and the simultaneous testing of sub-6 GHz and millimeter-wave bands will lead to greater test complexity and a variety of design/prototyping and conformance test challenges. The use of CA, MIMO, and beamforming technologies will lead to a much higher numbers of antennas and radio ports that need to be tested and, in the case of conformance testing, make OTA the only viable option. Greater integration of RF, digital, analog, and power components is also inevitable to reduce the size, weight, cost, and power consumption of complex AAS, which will ultimately transition much RF testing to probe stations. RF test equipment and systems will also need to evolve to better accommodate variable test requirements, a process that is already underway.

Lastly, telecom OEMs face the challenge of finding suppliers that can fulfill their many urgent requirements, to avoid the long lead times that are typical of RF and millimeter-wave component manufacturers and could lead to substantial delays and extended time-to-market for critical 5G hardware. That is why Pasternack has engineered a distribution system to provide same-day shipping for more than 40,000 RF and millimeter-wave products along with in-house, expert technical support to meet the immediate needs of the telecom industry for the next generation.

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