RF mmWave Test Complexity, a Growing Concern for 5G Front-End-Modules

mmWave RF IC test: technical, cost, and time-to-market challenges

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Although the explosive growth of wireless applications and communications systems in recent years has made available spectrum scarce, the rollout of 5G networks will dramatically improve bandwidth availability, particularly with the advent of more hardware that takes advantage of high-frequency millimeter wave (mmWave) technology.

While the use of mmWave frequencies for backhaul E band (71-76 GHz and 81-86 GHz) in 3G and 4G cellular infrastructure applications is nothing new, 5G networks are now driving mmWave frequencies (24 GHz, 28 GHz, 39 GHz, 47 GHz and beyond) to the access side of the network.

For example, a recent forecast predicts there will be 1.9 billion subscriptions for enhanced mobile broadband on 5G networks by 2024.[1] A significant portion of these networks will also carry mmWave signals.

This presents wireless operators and their suppliers with major economic and technical challenges. Because mmWave frequencies have shorter effective ranges, the move to build out 5G networks will require higher volumes of base stations, small-cell and consumer premises equipment than those used in previous networks. Now in early stages, this deployment is quickly gaining momentum, and it is driving increasingly urgent concerns about how to adequately and economically test the mmWave ICs used in the diverse architectures of the RF front-end-modules (FEMs) in this equipment.

This paper explores the 5G mmWave FEM RF IC testing challenges and solutions needed in the marketplace today, including those provided by GLOBALFOUNDRIES (GF®), which leverage the company's extensive portfolio of semiconductor technologies, in-house test expertise and decades of experience with high-speed RF technologies.

[1] *Ericsson Mobility Report, June 2019. A 5G subscription is counted as such when associated with a device that supports New Radio (NR), as specified in 3GPP Release 15, and is connected to a 5G-enabled network*

5G Network Design Considerations

5G is the fifth and latest generation of cellular technology. It promises reduced transmission costs per bit, exponentially faster network speeds, far greater network capacity, increased responsiveness due to lower latency, and greatly expanded connectivity.

3GPP, the organization developing mobile broadband technical standards, defined the first full set of 5G standards in 3GPP Release 15, which covers the specifications for mmWave based 5G New Radio (NR) up to 52 GHz. 3GPP Release 16, now under development, will define the spectra and specifications for bands up to 116 GHz.

Clearly, the 5G future is mmWave and that means important new considerations must be taken into account. One consideration, as previously mentioned, is that because mmWave signals are more subject to atmospheric attenuation than are the sub-6 GHz bands used by 2G/3G/4G wireless technologies, the resultant network infrastructure density is making the 5G mmWave buildout a high-growth area for semiconductor foundries and product companies, with a corresponding need to test those ICs at speed.

Another consideration is that mmWave base station radios use phased array antennas to focus energy towards each user via beamforming (see Figure 1). These systems can use from 16 to 256 or more antenna elements, while taking advantage of the smaller-sized antennas used at mmWave frequencies.

Figure 1: Illustration showing phased array antenna

The key challenge in any mmWave system is how to minimize parasitics between the antenna and the low-noise amplifier (LNA) on the receiver side, and the power amplifier (PA) on the transmitter side. It's not enough to just design, build and test system performance at the wafer level; mmWave chip design houses and die suppliers must also ensure that the specifications are met at the antenna (specifically, that they are met over-the-air).

The architecture of a mmWave phased array base station radio, shown in Figure 2, can be implemented by various chip-partitioning strategies. The dashed lines in the figure show two different options:

- Optimize the performance of the front-end-module (FEM). The optimized FEM approach can also use a hybrid PA to maximize the transmitter power and efficiency.
- Integrate the FEM and transceiver and minimize the overall power budget.

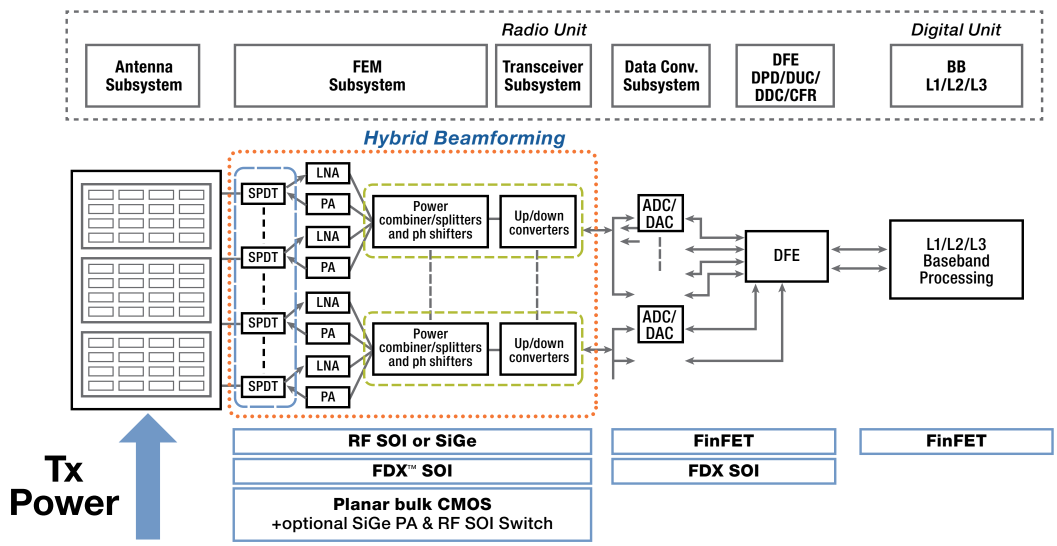


Figure 2: mmWave phased array base station radio architecture

IC technology providers need to work closely with equipment manufacturers to help them select the architectural approach best suited for their requirements:

- The optimized FEM approach can be addressed with a 45 nm partially depleted SOI platform optimized for mmWave FEM applications. It offers the unique capability to design chips with P_{sat} of up to 23 dBm at >40% efficiency.

  In this approach, chip designers can also choose to leverage high-performance SiGe technology for a hybrid PA to meet the required effective isotropic radiated power (EIRP) levels with a smaller number of antenna elements, and for higher efficiency on the transmitter side.

- The integrated FEM and transceiver approach can be addressed by a 22nm fully depleted SOI platform with the ability to boost performance and reduce standby power through back gate biasing. It is an ideal technology to fully integrate a 5G mmWave radio solution (including PAs, LNAs, switches, transceivers and even data converters) at optimum power efficiency and performance levels.

Table 1 shows the key performance metrics of these GF solutions at 28 GHz.

Table 1: Key performance metrics for mmWave-optimized GF solutions

GF solution	Performance	Power	Integration	Comments
High-performance (HP) SiGe	>23 dBm P_{sat}	High power amplifier (PA) efficiency	Optimized for discrete PA	Ideal for infrastructure power amplifier
45RFSOI	>20 dBm P_{sat}, high Rx sensitivity	High PA efficiency	Optimized for integrated FEM	Low-loss passives for reducing on-chip mmWave interconnect loss
22FDX®	Up to 20 dBm P_{sat}, high RX sensitivity	High PA efficiency	Optimized for integrated FEM and transceiver	Ideal for low-power PLL, data converters and logic

A New Testing Paradigm for mmWave ICs

Verifying mmWave RF product performance has been an industry challenge since the first E-band transceivers were introduced in the early 2000s, although significant progress has been made since then. Sophisticated rack-and-stack RF test and measurement equipment can excel at characterizing/debugging initial engineering samples, while low-volume RF production testing can be accomplished with additional programing and handling equipment.

Today, however, as 5G comes to market and as infrastructure hardware proliferates, keeping costs low while simultaneously delivering high production volumes of the mmWave ICs needed to meet the burgeoning demand for infrastructure equipment have become first-order priorities.

For example, mmWave 5G FEMs require production verification of such parameters as phase shift differential and noise margin compare. Product owners must make sure that the current mmWave test systems used to verify these characteristics are not sub-optimal TAE and bench equipment assemblies challenged to meet the required throughput and cost-efficiency targets.

In moving from 6 GHz to mmWave frequencies, RF test developers realized that cabling, bench equipment, board design/simulation practices and calibration procedures needed to be reexamined. Commercially viable mmWave RF manufacturing tester options need to evolve beyond costly integrated subsystems consisting of many instruments connected with cumbersome cabling and requiring complex calibration.

To address this industry shortcoming, GF developed an RF test platform known as Tester-on-Board, or ToB (see Figure 3).

Figure 3: GF's integrated, flexible ToB platform, which the company uses to provide fast, economic and comprehensive turnkey 5G mmWave testing support.

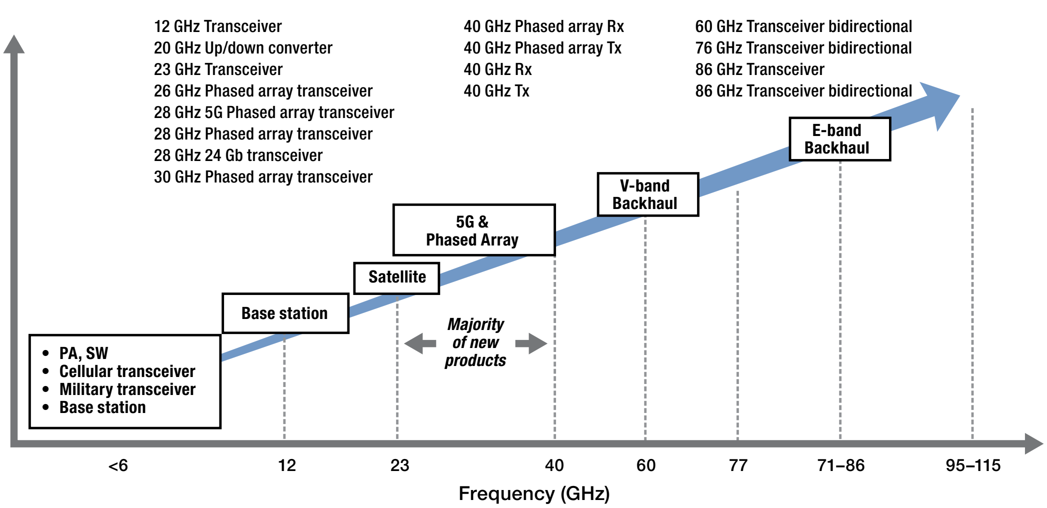
RF test houses, guided by requirements from their customers, are now or soon will be assessing purchase of various 5G RF mmWave-frequency-capable ATE production testers. Several criteria need to be considered when making this decision, and cost coupled with time-to-market are the two dominant factors. For example, initial test platform capital investment, payback schedule and operating cost all will influence the hourly production rate.

But buyers also need to be aware if tester features can expand to address evolving measurement requirements, such as increases in the linearity, voltage dynamic range or signal bandwidth of 5G mmWave ICs, without incurring additional cost or delays from the ATE provider in bringing up the required capability. In such a fast-moving marketplace, it's essential to have test platforms with the flexibility to address all aspects (full-frequency RF through digital) of FEM phased array drivers/receivers, analog and digital transceiver subsystems.

Today, systems like GF's ToB are urgently needed to address issues such as the mmWave range's higher signal bandwidth, which requires a correspondingly higher instantaneous analog bandwidth test capability (see Figure 4). That capability is needed so that complex modulation schemes can be measured, and so that accurate phase measurement between antenna ports can be carried out, for phased array multi-RF channel designs of 16, 32, 64 or more antenna elements.

In addition, mmWave ICs bring entirely new challenges to the test environment. One is the need for closer proximity of cooling systems and test hardware to the handler/probe environment, because of higher dBm power losses at mmWave frequencies. Also, the testing of modules with an integrated antenna in a production environment requires completely new thinking, because in some cases, only over-the-air communications between the tester and the DUT is possible.

Figure 4: Some of the mmWave test programs available from GF.



Turnkey and Packaging Support

RF turnkey service experience can provide significant value to clients. Some examples include:

- One-stop shopping and accountability for managing post-fab services.
- Reduced test cost by control of the hardware, firmware and software to optimize test time.
- Straightforward and predictable cycle times for RF test development and implementation to reduce time-to-market.
- Established procedures to take a client's test specification and create a flexible program that supports both initial product characterization, to validate design robustness, and then optimize to provide cost-effective production testing.

Turnkey services can be varied to align with clients' specific requirements (see Figure 5). Some clients only need bumped wafers to feed into their managed downstream assembly setup. Others need a more comprehensive set of services, in which the turnkey supplier provides yielded, tested, packaged multichip RF modules for a fuller RF turnkey embodiment. Across all these options, the turnkey provider manages product flow and is accountable for all product quality.

Clients often ask for packaging support to accompany test services. A flexible engagement model may be considered that provides clients with detailed package design, thermal and electrical modeling, or simply enable what the client has designed. Partnerships with leading packaging suppliers help ensure that package design and manufacturing are executed with precision and predictability.

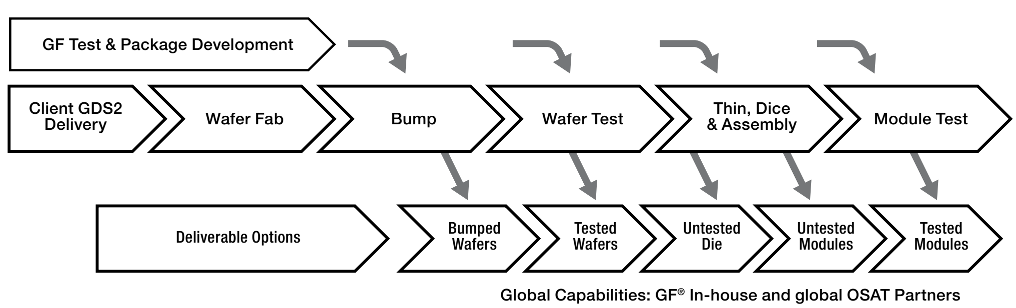


Figure 5: GF offers a varied array of turnkey services to align with clients' specific requirements.

Full turnkey support can also include reliable qualification services. For example, 5G base station providers need to know that their system components can endure harsh environmental conditions. Reliability stress services validate silicon and package operational effectiveness over time. These reliability tests can include but are not limited to HTOL, ELFR, HAST and CPI. Any issues that might be discovered get attention from the teams that developed or designed the underlying silicon and package technology.

Conclusion

The buildout of 5G infrastructure and client-premises equipment will require a proliferation of new hardware, and suppliers of 5G infrastructure equipment will depend heavily on their supply chains to deliver the necessary quantities.

GF supports its 5G clients with a range of differentiated turnkey testing and packaging services as mentioned in this paper, in addition to wafer fabrication. These include one-stop accountability for validated hardware; reduced test-development time and rapid mmWave production testing; and cost savings from GF's ability to reduce test time through control of the test program, firmware and hardware.

With GF, clients do not need to invest in mmWave RF test development and post-fab supply chain management; instead, they can put their resources into bringing 5G infrastructure hardware to life.

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