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HARNESSING THE POWER OF 5G

MOUSER ELECTRONICS

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FOREWORD

Shaping the 5G World

By Rodney Hsing Qorvo
Director of Global Distribution

Qorvo is at the center of this revolution, with high-performance solutions that address the complexity of transitioning to 5G.

For more than three decades, Qorvo has been innovating, researching, and developing cutting-edge technologies that shape the world around us. Our RF expertise and advanced technologies play crucial roles in enabling our increasingly connected world.

The next era of connectivity is 5G, or fifth generation mobile, which will dramatically improve the bandwidth, capacity, and reliability of mobile broadband. 5G adds Fixed Wireless Access (FWA), enhanced Mobile Broadband (eMBB), Ultra-Reliable Low-Latency Communication (URLCC), and Massive Machine Type Communication (mMTC).

5G isn't just about faster upload and download speeds. It supports low-latency applications such as autonomous driving, vehicle-to-everything (V2X) communication, and Virtual Reality/Augmented Reality (VR/AR). 5G will open the door to many new applications, and help revitalize industries like agriculture, manufacturing, healthcare, entertainment, automotive, and smart energy.

Qorvo is at the center of this revolution, with high-performance solutions that address the complexity of transitioning to 5G. We're enabling global 5G base station deployments today and helping to develop the 5G mobile devices of tomorrow. Browse our diverse product portfolio and educational resources at qorvo.com/innovation/5g.

Qorvo has participated in nearly every 5G infrastructure field trial with its base station products and introduced the industry's first 5G RF front-end module for smartphones, which earned the GTI Award for Innovative Breakthrough in Mobile Technology. In addition, our RF products have been chosen by leading global smartphone manufacturers for their 5G demonstration handsets.

We are helping to define 5G standards as a voting member of 3GPP, and are collaborating with network operators, base station manufacturers, smartphone manufacturers, and chipset providers on their 5G programs.

At Qorvo, we see the amazing potential of 5G to bring the world around us ever closer, and we are working every day to make that fully connected world a reality.

How Carrier Networks Will Enable **5G**

By Qorvo

Active Antenna Systems, beamforming, beam steering, Fixed Wireless Access (FWA): the transition to 5G is bringing new terminology and technologies to life in the commercial space. At its heart, 5G begins with the carrier network and how it enables these next-generation technologies. This blog post explains some of the key RF communication technologies that will enable 5G base stations and networks.

This blog is an excerpt from Chapter 4 of our e-book, 5G RF For Dummies®.

5G Begins with the Carrier Network

5G networks must handle many functions that require different Active Antenna Systems (AAS) to meet the challenges of enhanced Mobile Broadband (eMBB), massive Machine-Type Communications (mMTC), and ultra Reliable Low-Latency Communications (uRLLC).

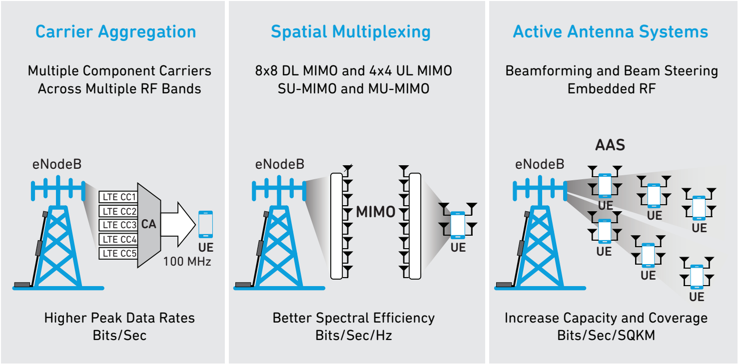
One of the first major applications will be Active Antenna Systems (AAS) in the millimeter wave (mmWave) bands, providing Fixed Wireless Access (FWA). FWA provides an initial stepping stone toward 5G in the mmWave bands. Carriers and infrastructure manufacturers alike have been conducting trials and plan to offer this service as a more scalable and economical way to deliver broadband. Although this service is for nomadic and fixed users, it is being designed with true mobility in mind. This allows carriers to get their feet wet in new mmWave technologies—such as phased array antennas and hybrid beamforming—that will be the basis of mobile 5G.

A very recent twist in 3GPP standards definition—the addition of an accelerated path, called non-Standalone (NSA) 5G—as a cost-effective way to bring early 5G benefits to market without the expense of building out the 5G network core needed for standalone (SA) 5G. NSA accomplishes this by using an existing 4G 3GPP band as an LTE anchor in the Control Plane.

AAS/FD-MIMO

The Active Antenna Systems (AAS) is an advanced base station platform with optimized cost, structure, and performance. 4G Release 12 enhancements significantly impacted how enhanced NodeB (eNodeB) radios are designed. Release 12 items included new combinations of carrier aggregation, spatial multiplexing enhancements with downlink MIMO (multiple input/multiple output), and RF requirements needed in AAS. This first figure summarizes portions of the Release 12 items with respective features and benefits.

Evolution of LTE Advanced eNodeB Radio Antennas



Evolution of LTE Advanced eNodeB Radio Antennas

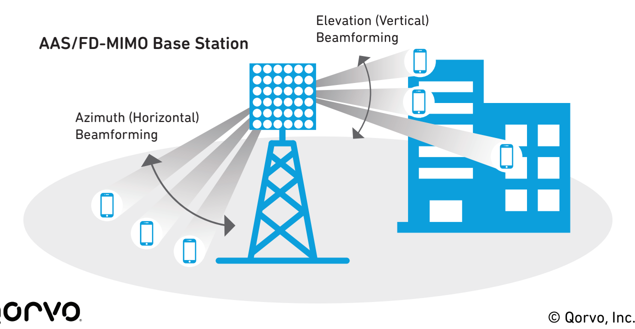
MIMO technology uses multiple antennas installed at both the source (transmitter) and destination (receiver), to improve capacity and efficiency. As shown in the previous figure, more antennas equals more data stream layers. This results in a bigger data pipe to a single user or multiple data pipes to separate users, also known as multi-user (MU) MIMO.

Massive MIMO takes MIMO to the next level. Today's MIMO deployments typically consist of up to eight antennas on the base station and one or two antennas on the receiver. This allows the base station to simultaneously transmit eight streams to eight different users or double down and send two streams to four users. Massive MIMO scales to dozens or hundreds—theoretically thousands—of antennas, providing capabilities and benefits that include the following:

- Vastly improved capacity and reliability
- Higher data rates and lower latency
- Better connections (especially with the challenging higher frequencies to be used for 5G)
- Less intercell interference
- Greater efficiency and better signal coverage enabled by beamforming

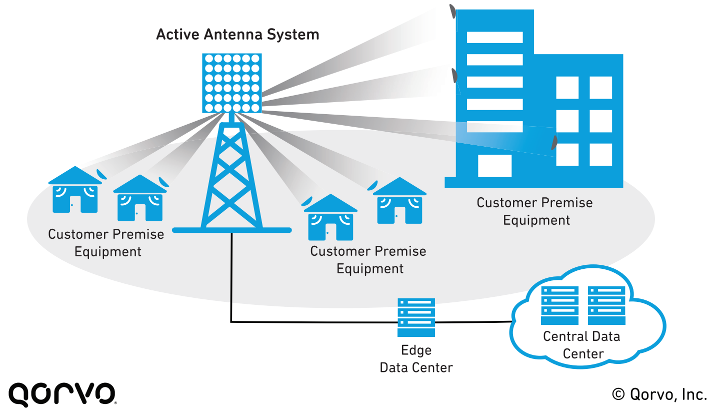
The next figure illustrates how an AAS/full-dimension (FD) MIMO base station can direct beams in both the horizontal and vertical directions. This operation dynamically points the antenna pattern on a per-user basis, providing a better link and higher capacity to that user. In turn, this allows him to offload his traffic and free the radio resources more quickly, which can then be used by others, resulting in a net increase in aggregate capacity for the entire cell.

Antenna Beam Forming



The next figure below illustrates how AAS uses beam steering to provide end-to-end Fixed Wireless Access (FWA) connectivity to Customer Premise Equipment (CPE) located in commercial buildings and residential homes.

5G End-to-End Fixed Wireless Access (FWA) Networking Using Beam Stearing



One of the obvious advantages of 5G FWA is its ability to support very high peak data rates without requiring dedicated fixed facilities for each individual user. To enable higher peak data rates and greater system capacity, FWA radios will make use of new higher frequency bands from 24GHz up to 42GHz and potentially even higher.

Using larger antenna arrays provides additional beamforming to overcome more severe propagation challenges encountered at mmWave frequency ranges. These arrays can have hundreds of elements but due to the short wavelength are extremely compact. For example, a 64-element antenna array at 30GHz is only 40mm x 40mm. Large arrays provide very focused beams that can be redirected in less than a micro-second. In addition, the large phased array can act as a single array or as multiple independent subarrays with unique beams directed to service multiple user terminals simultaneously on the same frequency resource. The following figure shows a block diagram of the 2x2 RF front-end modules in the per-antenna RF subsystem of an AAS antenna array that comprises an AAS cell tower.

Go in Depth

Learn more about 5G FWA systems:

- 5 Things to Consider When Designing FWA Systems
- 5G Fixed Wireless Access Array and RF Front-End Trade-Offs (Microwave Journal, Feb. 2018)
- Delivering 5G mmWave Fixed Wireless Access (EDN, Sept. 2017)

5 Things to Consider When Designing Fixed Wireless Access (FWA) Systems

By David Schnaufer, Technical Marketing Communications Manager, Qorvo

One of the earliest uses of 5G will be fixed wireless access (FWA), which promises to deliver gigabit internet speeds. FWA can be delivered to homes, apartments, and businesses in a fraction of the time and cost of traditional cable/fiber installations. As with any technological advance, FWA brings new design hurdles and technology decisions. Let's dig into five things to consider when designing FWA systems:

- The choice of frequency spectrum: millimeter wave (mmWave) or sub-6GHz
- Achieving higher data rates with antenna arrays
- All-digital or hybrid beamforming
- Power amplifier (PA) technology choices: silicon germanium (SiGe) or gallium nitride (GaN)
- Choosing components from today's RF front-end (RFFE) product portfolios

#1 Spectrum choice: mmWave or sub-6GHz

The first decision is whether to use mmWave or sub-6GHz frequencies for FWA:

- **mmWave**. These higher frequencies offer a large amount of contiguous spectrum available at low cost. mmWave supports component carriers up to 400MHz wide and enables gigabit data rates. The challenge is path loss due to obstacles like vegetation, buildings, and interference. However, don't assume FWA is useful only in clear line-of-sight settings between the base station and the home—FWA can actually perform very well in both urban and suburban settings. It's true that vegetation and interference are challenging, but these can be overcome with antenna arrays that provide high gain.

- **Sub-6 GHz.** This lower-frequency spectrum helps overcome the problems caused by obstructions, but at a cost. Only 100MHz of contiguous spectrum is available, so data rates are lower.

Efficient use of frequency range (sub-6GHz or mmWave) is critical to scaling deployments. The choice for any situation will depend on balancing the goals of speed and coverage.

#2 Achieving higher data rates with antenna arrays

An FWA system will also need to employ active antenna systems (AAS) and massive MIMO (multiple input/multiple output) to deliver gigabit service.

- **AAS** provides many directional antenna beams. These beams are redirected in less than a microsecond, enabling beamforming that offsets the greater path loss associated with high frequencies.
- **Massive MIMO** uses arrays of dozens, hundreds, or even thousands of antennas, allowing simultaneous transmission of single or many data streams to each user. The results are improved capacity, reliability, high data rates, and low latency. Beamforming also enables less inter-cell interference and better signal coverage.

Learn more about AAS and massive MIMO included in this eBook.

#3 All-digital or hybrid beamforming

A third element to consider is the type of beamforming to employ—all-digital or hybrid.

All-digital approach

The most obvious choice in mmWave base station applications is to upgrade the current platform. You could explore extending all-digital beamforming massive MIMO platforms used for sub-6GHz frequencies, but this isn't a plug-and-play solution

An all-digital approach faces these design constraints:

- **Power consumption.** Digital beamforming uses many low-resolution analog-to-digital converters (ADC). But ADCs with a high sampling frequency and a standard number of effective bits of resolution can consume a large amount of power.

This power consumption can become the bottleneck of the receiver. A large AAS with massive bandwidth presents a huge challenge for an all-digital beamforming solution. Essentially, the power consumption will limit the design.

- **The need for two-dimensional scanning in dense urban environments.** The required scanning range depends on the deployment scenario, as shown in the figure below. In a dense urban landscape, wide scan ranges are needed in both azimuth (~120°) and elevation (~90°). For suburban deployments, a fixed or limited scan range (< 20°) in the elevation plane may be enough. A suburban deployment requires limited scan range or half as many active channels to achieve the same effective isotropic radiated power (EIRP), which reduces power and cost.

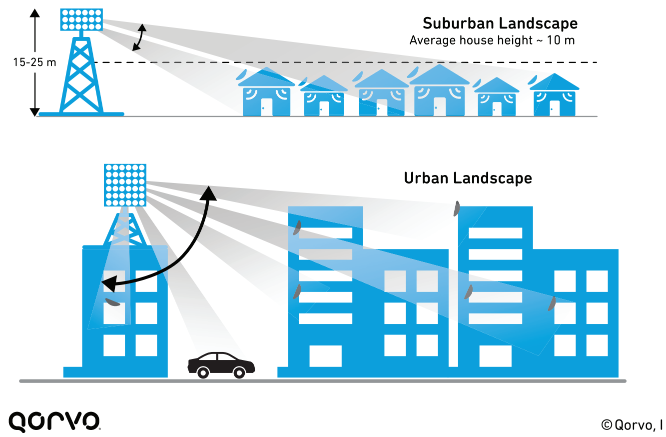
Remember: An array's size is dependent on:

- The scanning range (azimuth and elevation)
- Desired EIRP

EIRP is the product of:

- The number of active channels
- Conducted transmit power of each channel
- Beamforming gain (array factor)
- Intrinsic antenna element gain

FWA Array Complexity Depends on the Scanning Range Needed for the Deployment Scenario

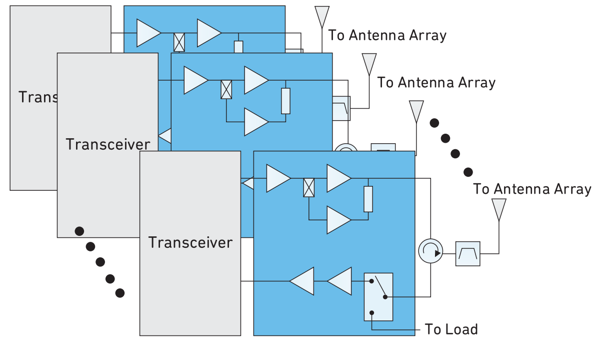


To achieve the target EIRP of 75dBm and beamforming gain, an all-digital solution using today's technology would need 16 transceivers. This would equal a total power consumption of 440W. But for outdoor passive-cooled, tower-top electronics, it's challenging to thermally manage more than 300W from the RF subsystem. We need new technological solutions.

Efficient GaN Doherty PAs with digital predistortion (DPD) may provide the required margin, but these devices are still in development for mmWave applications. But it won't be long before we see an all-digital beamforming solution. Several developments will make it a reality:

- Next-generation digital-to-analog and analog-to-digital converters that save power
- Advances in mmWave CMOS transceivers
- Increased levels of small-signal integration

Integrated FEM with GaN Doherty PA and Switch-LNA

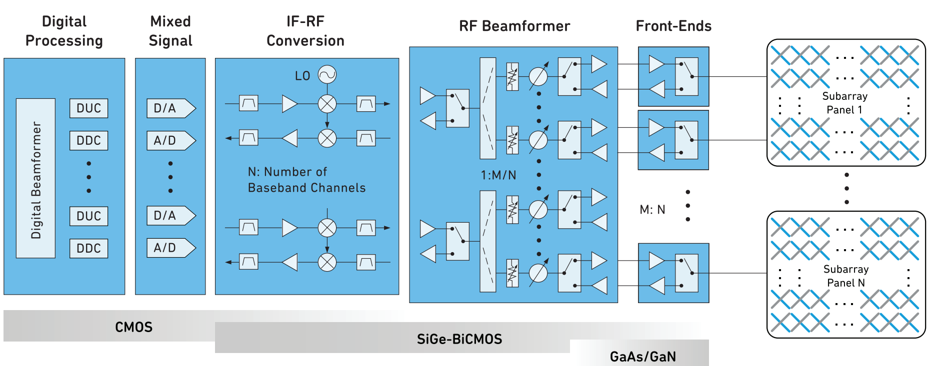


Hybrid approach

An alternative is hybrid beamforming, where the precoding and combining are done in both baseband and RF front-end module (FEM) areas. By reducing the total number of RF chains and analog-to-digital and digital-to-analog converters, hybrid beamforming achieves similar performance to digital beamforming while saving power and reducing complexity.

Another advantage of the hybrid approach is the ability to meet both a suburban fixed or limited scan range (<20º) and dense urban deployments with wide scan ranges in both azimuth (~120°) and elevation (~90°).

Hybrid Beamforming Active Antenna Systems (ASS) Block Diagram



The bottom line: All-digital and hybrid approaches both have advantages and disadvantages. We believe the hybrid approach is more appealing and doable today, but new products on the horizon could make the all-digital approach equally appealing in the future.

#4 PA technology choices: SiGe or GaN

The technology you choose for the FWA front end depends on the EIRP, antenna gain and noise figure (NF) needs of the system. All are functions of beamforming gain, which is a function of the array size. Today, you can choose between a SiGe or GaN front end to achieve your desired system needs.

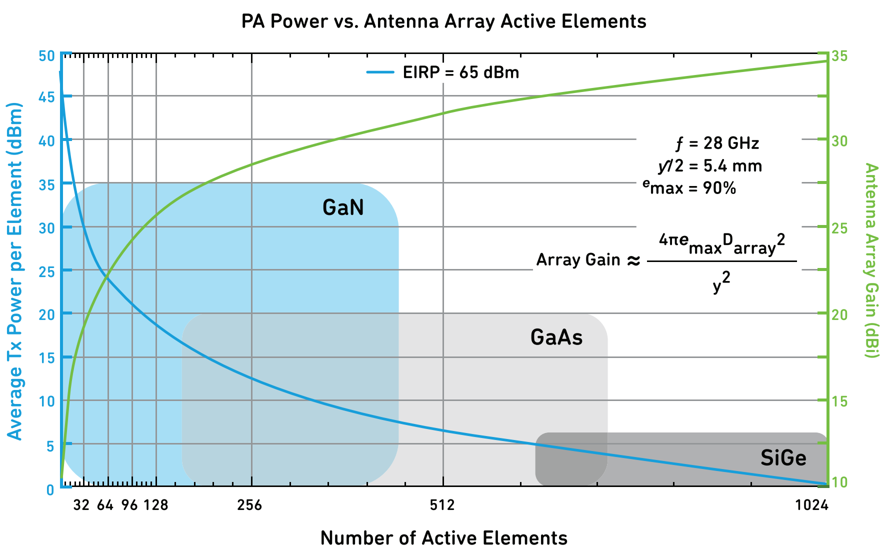
In the U.S., the Federal Communications Commission (FCC) has set high EIRP limits for 28GHz and 39GHz spectrum, as shown in the following table.

FCC Power Limits for 28GHz & 39GHz Bands

Equipment Class	Power (EIRP)
Base Station	75 dBm/100 MHz
Mobile Station	43 dBm
Transportable Station	55 dBm

To achieve 75dBm EIRP with a uniform rectangular array, the PA power output required per channel reduces as the number of elements increases (i.e., the beamforming gain increases). As shown in the below figure, as the array size gets very large (>512 active elements), the output power per element becomes small enough to use a SiGe PA, which could then be integrated into the core beamformer RFIC.

Tradeoffs Between the Number of Antenna Array Elements and RFFE Process Technology



As you can see from the table below, a SiGe PA can achieve 65dBm EIRP using 1024 active channels. However, by using GaN technology for the front end, the same EIRP can be achieved with 16x fewer channels.

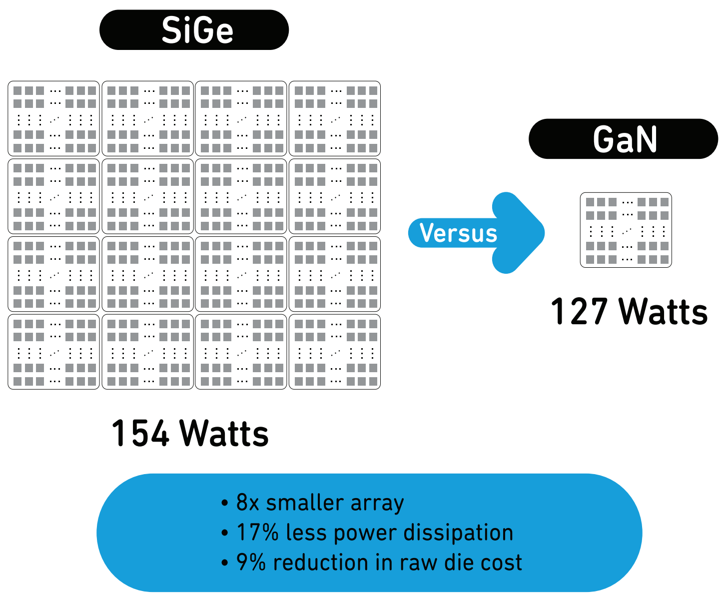
Assumptions and Total Dissipated Power for SiGe versus GaN FWA Front End

	SiGe	GaN	Units
Average Output Power/Channel	0	18	dBm
Power Dissipation/Channel	150	840	mW
Antenna Element Gain	5	5	dBi
Number of Active Channels	1024	128	Channels
EIRP	65	65	dBm
Total Pdiss	154	127	W

A GaN FWA front end provides other benefits:

- **Lower total power dissipation.** To ensure an accurate comparison, the GaN power dissipation includes an extra 19.2 watts, to account for the 128 beamformer branches needed to feed the front ends. As shown in the following figure, at the target EIRP of 65dBm, GaN provides a lower total power dissipation (127Pdiss) than SiGe. This is better for tower-mounted system designs.

Comparing an All-SiGe FWA System to a Combination of SiGe Beamforming with GaN Front Ends



- **Better reliability.** GaN is more reliable than SiGe, with >107 hours MTTF at 200°C junction temperature. SiGe's junction temperature limit is around 130°C.
- **Reduced size and complexity.** GaN's high power capabilities reduces array elements and size, which simplifies assembly and reduces overall system size.

The takeaway: In wireless infrastructure applications, reliability is imperative because equipment must last for at least 10 years. For FWA, GaN is a better choice than SiGe for reliability, cost, lower power dissipation, and array size.

#5 Choosing from today's RF technology

The last consideration is selecting product solutions that are being used in real-world applications. Several RF companies are positioned to support the development of sub-6GHz and cmWave/mmWave FWA infrastructure. Qorvo, for instance, is already supplying products for many Tier 1 and Tier 2 supplier field trials. Across the RF industry, examples of products for FWA include:

- Sub-6GHz products: Dual-channel switch/LNA modules and integrated Doherty PA modules
- cmWave/mmWave: Integrated transmit and receive modules

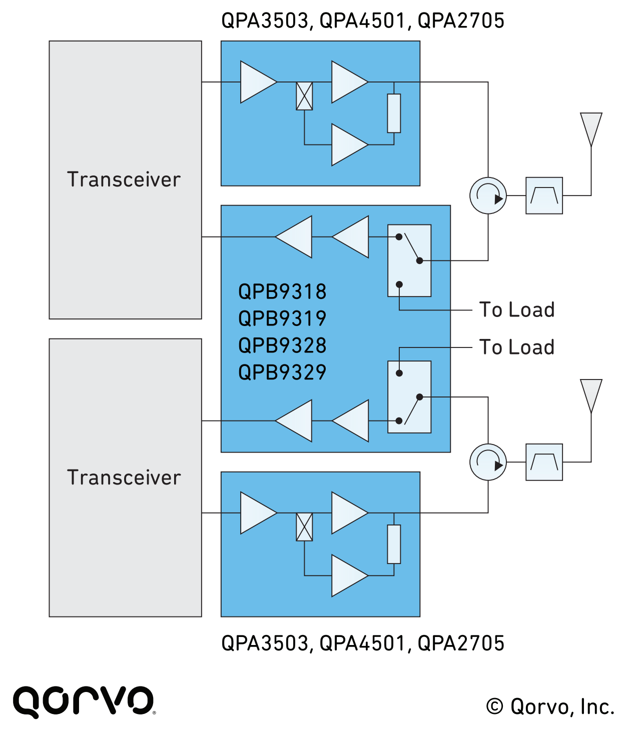
Additionally, in the 5G infrastructure space, several things are a must:

- Integration
- Meeting passive cooling requirements at high temperatures

To support these trends, Qorvo has created integrated transmit and receive modules for cmWave/mmWave, as well as integrated GaN FEMs. These integrated modules include a PA, switch and LNA, and have high gain to drive the core beamformer RFICs. To meet the infrastructure passive-cooling specification, we use GaN-on-SiC to support the higher junction temperature.

For more information on Qorvo solutions for FWA, click on the images below or visit our 5G Infrastructure page, where you'll find product details and interactive block diagrams.

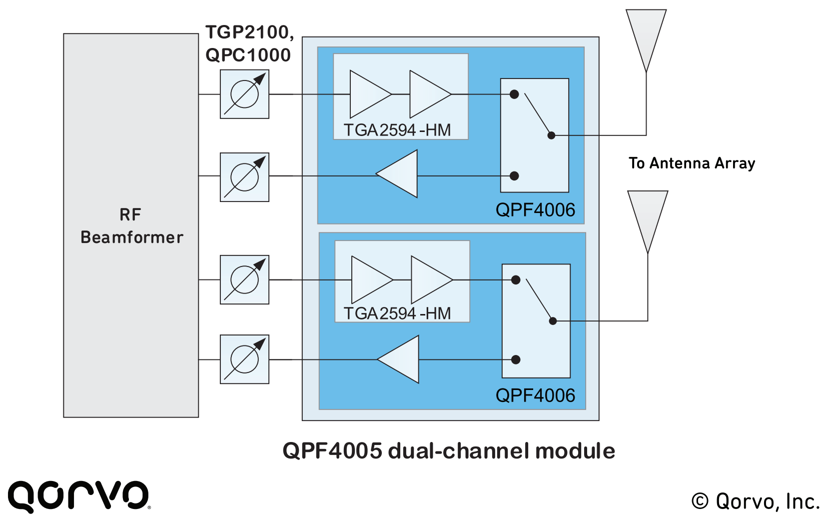
Qorvo FWA Solutions: Sub-6GHz Massive MIMO GaN Front Ends



Learn more about these products:

- QPA3503, QPA4501, QPA2705
- QPB9318, QPB9319, QPB9328, QPB9329

Qorvo FWA Solutions: mmWave Massive GaN Front Ends



Learn more about these products:

- TGP2100, QPC1000
- TGA2594-HM
- QPF4005
- QPF4006

FWA is approaching—fast

FWA implementation has begun, and full commercialization is approaching rapidly. Today, we believe hybrid beamforming is the best approach. Additionally, GaN, along with SiGe core beamforming, meets FCC EIRP targets of 75dBm/100MHz base station targets. This approach also minimizes cost, complexity, size, and power dissipation.

For more information on application-specific components, visit Qorvo's 5G Infrastructure solutions online. For technical guidance and applications support, please visit our Technical Support information.

EEJournal Chalk Talk
5G mmWave Front-End Technology

By Bror Peterson, Wireless Systems Architect, Qorvo

The RF section of 5G system brings a host of engineering challenges. When we are designing for 5G, we need to step up our game, and that means taking advantage of the latest high-performance, wide-bandgap materials like Gallium Nitride. In this episode of Chalk Talk, Amelia Dalton chats with Bror Peterson of Qorvo about the issues designers face in RF design for 5G, and some unique solutions Qorvo brings to the table.

Watch Video: mouser.com/qorvo-5g-solutions/#Video-2

5G Enters an Arena All Its Own: AT&T to Bring 5G to AT&T Stadium

By Paul Golata, Mouser Electronics

Taking center stage in 2019 at billionaire Jerry Jones's AT&T Stadium isn't simply the world-famous Dallas Cowboys football team or Country Music Hall of Famer Garth Brooks with his bigger-than-life concert. It's the arrival of 5G—the fifth generation of mobile network and wireless system connectivity.

Since Ancient Greece and the time of the Roman Coliseum, stadiums have been a gathering place for thousands of spectators hungry for entertainment. Now, 5G technology is taking the stadium experience to the next level.

In 2009, Jerry Jones opened the most ambitious technological stadium in the world, providing seating for approximately 80,000 spectators. In 2013, AT&T—a global leader in telecommunications, media, entertainment, and technology—purchased the naming rights for the stadium at a price of between $17 and $19 million per year. Originally founded by Alexander Graham Bell, the inventor of the telephone in 1880, AT&T is the world's largest telecommunications company. They provide premium content, direct-to-consumer distribution, and high-speed networks to people and businesses. AT&T is making significant investments to become the premier integrated media and communications company.

AT&T recently announced that they are introducing standards-based mobile 5G services. But, they did not stop there. They stepped up and announced that they plan to be the first US carrier to light up 5G at one of the most iconic venues in the country—AT&T Stadium in Arlington, Texas, a location just about 20km down the road from Mouser Electronics.

AT&T Stadium—home to "America's Team," the Dallas Cowboys—hosts championship sporting events as well as some of the biggest music and entertainment shows in the world. It is where tens of thousands of people come to enjoy and share experiences that they can't get anywhere else. AT&T reported that customers consumed more than 155TB (155*1012 bytes) of mobile data—the equivalent of sending about 400 million selfies— while visiting AT&T Stadium in 2018.

Over the coming months, AT&T plans to integrate its 5G network into the stadium. 5G will provide high throughput and enhanced capacity coupled with low-power consumption and low latency (1-10ms). The introduction of the 5G network to AT&T stadium is expected to further enable Internet of Things (IoT) devices and enhance mobile broadband to provide new fan experiences at the venue.

AT&T believes this technology will ultimately lead to the realization of spectators being able to integrate their physical experiences with virtual augmentation. AT&T suggests that in the future fans may get the thrill of an up-close-and-personal view of the locker room victory celebrations through virtual reality (VR) glasses hooked up to smartphones. Another real possibility is for fans to watch an instant replay in crystal clear 360-degree video while waiting in line for the restroom or concessions.

Conclusion

5G is launching and will be entering into the mainstream of our lives. Its technological benefits will provide new ways to consume data and new ways for spectators and fans to engage with their favorite entertainment events. Whether it is with 100,000 people cheering on your local sports team or singing the choruses of every song from your favorite musical act, 5G will enable us to draw more intimately and experientially into the arena of life.

Getting to **5G**: Comparing 4G and 5G System Requirements

By Qorvo

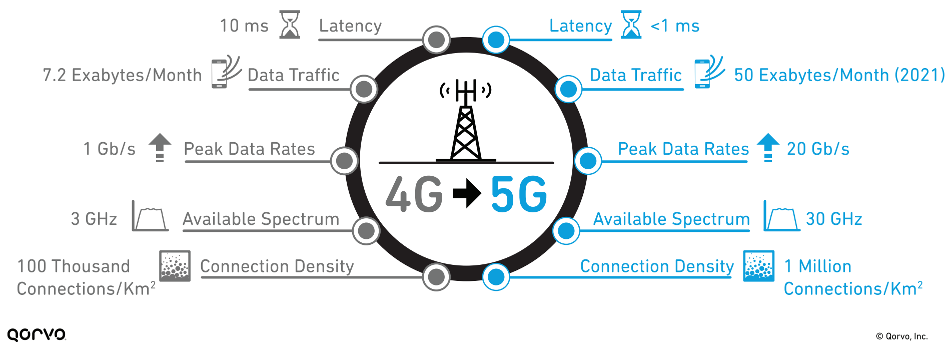
5G isn't just an incremental improvement over 4G—it's the next major evolution of mobile communication technology with performance improvements of several orders of magnitude over today's networks. 5G does not replace 4G, it simply enables a huge diversity of tasks that 4G cannot perform. 4G will continue to advance in parallel with 5G, as the network to support more routine tasks. 5G will enable services yet to be imagined, in a world where national economies are driven by sophisticated communications networks.

Let's explore what 5G technology is, compare some of the characteristics of 4G and 5G, and look at the path to 5G deployment.

This blog is an excerpt from Chapter 1 of our e-book, 5G RF For Dummies®.

What 5G Technology Is

- **Enhanced Mobile Broadband (eMBB)** requiring hundreds of megahertz (MHz) of channel bandwidth using new frequencies for mobile wireless—from 2.5 gigahertz (GHz) for 4G LTE Pro and 3.5GHz for 5G, to tens of gigahertz and beyond into the millimeter wave (mmWave) spectrum
- **Ultra efficient** for streaming data, taking full advantage of carrier aggregation (CA) and massive multiple input/multiple output (MIMO)
- **Fixed wireless,** giving more choices to get 20 gigabit per second (Gbps) connections to your home and business
- **Wireless infrastructure,** using beam steering and high-power gallium nitride (GaN), ideally suited to adaptive-array steerable antennas
- **Low latency** for real-time connections enabling autonomous vehicles and augmented reality/virtual reality (AR/VR)
- **Internet of Things (IoT)** connecting more than a trillion devices to the Internet in the next ten years with extremely low data rates, battery life greater than ten years, and the longest possible communication range



Comparing 4G and 5G

The figure above provides a comparison of the performance characteristics and technical specifications of 4G and 5G technology.

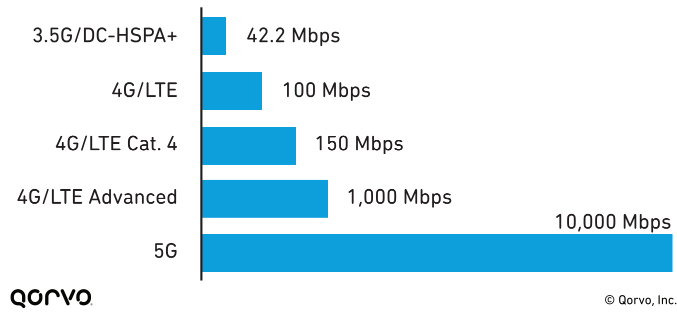
The following table summarizes the major differences between 4G and 5G technology.

	4G (Today, Before Further Developments)	5G
Latency	10ms	Less than 1ms
Peak data rates	1Gbps	20Gbps
Number of mobile connections	8 billion (2016)	11 billion (2021)
Channel bandwidth	20MHz 200kHz (for Cat-NB1 IoT)	100MHz below 6GHz 400MHz above 6GHz
Frequency band	600MHz to 5.925GHz	600MHz–mmWave (for example, 28GHz, 39GHz, and onward to 80GHz
Uplink waveform	Single-carrier frequency division multiple access (SC-FDMA)	Option for cyclic prefix orthogonal frequency-division multiplexing (CP-OFDM)
User Equipment (UE) transmitted power	+23 decibel-milliwatts (dBm) except 2.5GHz time-division duplexing (TDD) Band 41 where +26dBm, HPUE is allowed IoT has a lower power-class option at +20dBm	+26dBm for less than 6GHz 5G bands at and above 2.5GHz

Currently, use cases are being defined, new radio access technologies are being developed, and carrier field trials are being conducted. The [Third Generation Partnership Project (3GPP)] standards body is harmonizing and globalizing these new ideas into a unified specification.

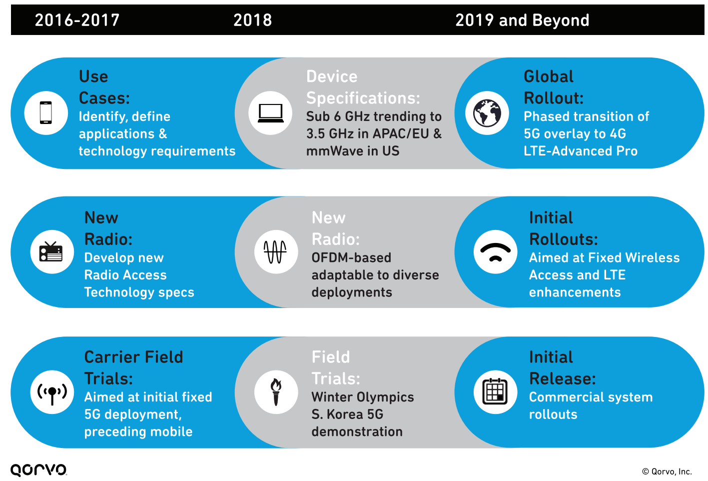
By adopting LTE Advanced (LTE-A), carriers are making considerable progress toward the speed goals for 5G (see graph below), but more work is required.

Downlink Speeds by Technical Generation



The Path to 5G Deployment

Enhancing the mobile wireless experience is a step-by-step pathway for carriers, requiring further expansion and development of 4G and moving toward LTE-A technologies. Carriers are currently in the midst of developing software-defined networks (SDNs), [heterogeneous networks (HetNets)], and low power networks. Finally, in 2019 and beyond, global 5G rollouts and initial commercial releases will begin (see figure to the below).



Want more details about what's to come with 5G? Download a copy of our latest e-book, 5G RF For Dummies®.

– Excerpted with permission from John Wiley & Sons, Inc., from 5G RF For Dummies.

Enabling **5G** and The Future of Robotics

By Barry Manz and Paul Golata, Mouser Electronics

The fifth generation of wireless technology will pave the way for a new generation of robots, free to exploit the vast computing and data storage resources of the cloud.

If robotics and cellular communications seem strange bedfellows, it's because the fifth generation of wireless, 5G, is the first to wirelessly address the needs of such applications rather than just increasing data rates and expanding coverage as previous generations did. This ambitious standard, called IMT-2020 by the International Telecommunications Union (ITU) that globally regulates them, will accomplish this by completely revolutionizing the way cellular networks are built, the devices they can connect with, the frequencies at which they operate, and the applications they serve.

The fifth generation of wireless technology will pave the way for a new generation of robots, some free to roam controlled via wireless rather than wired communications links and all exploiting the vast computing and data storage resources of the cloud. Armed with these capabilities, robots can be precisely controlled dynamically in near real time, and be connected to people and machines locally and globally. In short, 5G will fully enable applications such as the "factory of the future" and many, many others that were previously beyond the capabilities of both cellular and robotics technologies.

But Will They Still Need Us?

There are many predictions that robotics and artificial intelligence (AI) will come to rule the world, including some containing rather draconian prospects for the fate of humanity. The champions of robots believe they will complement people rather than replace them, and perform some functions that humans aren't very good at anyway. On the other side are some who believe that robots may take the place of humans in manufacturing and other industries, eliminating millions of jobs. Whether or not robots will ultimately look down their artificial noses at humans remains to be seen, but 5G is almost certain to let them function more efficiently and serve more applications than ever before.

Robots are already ubiquitous in manufacturing, of which the auto industry is perhaps the most obvious example. Other key applications examples include industrial and medical. The innovations within 5G will expand their capabilities so much further that it will be necessary to expand the definition of what a robot really is. So when autonomous vehicles finally hit the streets, they too will be robots, executing instructions from a vast array of sensors to make decisions and perform functions, presumably a lot more accurately, reliably, and faster than humans. Gyrocopters and other unmanned vehicles fit this category too.

To understand the synergy between 5G and robotics, there is no better example than healthcare, where robotics has immense potential. Not only will robots perform mundane functions such as transferring things from place to place in a hospital, aided by 5G communications and the cloud, but they will also enable telesurgery in which operations are orchestrated remotely by doctors and performed locally by robots. This was demonstrated for the first time back in 2001 when endocrine surgeon Jacques Marescaux (1948–) removed the gallbladder of a patient in Strasbourg, France while sitting at a console in New York City—a distance approximately 6,200km away—during an event appropriately called Operation Lindbergh.

Flip forward to about 2025 and imagine operating rooms in one hospital populated by robots and humans connected by 5G through the cloud to surgeons anywhere on Earth who orchestrate the surgical procedures. They could be aided by specialists in one or more locations who can lend their expertise, all in real time. Fantastic though this may seem, it's just the beginning: Using virtual reality (VR)—and the ever-present cloud—it should be possible to convert an imaging scan into a virtual, three-dimensional (3D) representation of a patient.

Using this "digital clone", the surgeon would then remotely orchestrate the operation on a virtualization of the patient while one or more robots perform the actual surgery. The doctor would have a tactile yet virtual "experience" as bones, tissue, and organs will all "feel" differently. The full measure of telesurgery won't be possible for perhaps a decade but will continue to advance in stages as 5G and robotics mature.

So Why Not Now?

Besides the fact that the robots and the entire "ecosystem" required to enable telesurgery and other next-generation robotic applications are still in their infancy, current 4G networks simply do not have the characteristics required to make them possible. That is, as they require virtually instantaneous response times, it will be essential to reduce a metric called latency to unprecedented levels. Latency is basically the time span between when input is initiated at one point in a communications link and when it returns with error-free input from another point. Low latency is vital for high reliability machine-centric communication for robotics of tomorrow.

Current 4G Long-Term Evolution (LTE) cellular networks have round-trip latency of about 50ms, but to enable applications like robotics the 5G standard recognizes that <1ms will be required, a colossal technical challenge. Other promised benefits of 5G, such as cloud computing and increasing data rates, are relatively "simple" when compared to reducing latency to such a minute level, as it faces the immutable laws of physics.

To understand this, consider that the speed of electromagnetic radiation in a vacuum is 3×10^8m/s. As the Earth's atmosphere is not a vacuum, this top speed is reduced ever so slightly due to atmospheric air. However, its propagation speed is dramatically reduced by further considerations, including the optical fibers, terrestrial and satellite communication links, and the electronics and interconnects through which a signal must pass. The upshot is that the shorter the physical distance between Point A and Point B, the lower latency time can be. This is how 5G intends to accomplish its goal of reducing this metric to <1ms.

5G will require the number of data centers that collectively form the cloud to be dramatically expanded geographically, as a data center in one location is likely to be too far away from most other locations to reduce latency time to acceptable levels. This expansion, combined with data rates greater than 1Gb/s and the use of new cellular frequencies—an order of magnitude higher than those presently employed—will be essential ingredients that allow distances ranging from 1–100km to be covered with <1ms latency.

The Factory, Reimagined

5G will play a crucial role in creating the factory of the future, another application in which <1ms latency is essential **(Figure 1).** In combination with the almost limitless processing and data storage available in the cloud, 5G communications will allow robots in next-generation manufacturing environments to do far more than they can today. Robots will be able to exchange large amounts of information between themselves and the factory workforce, revolutionizing the "shop floor" along with other 5G enabled devices such as wearables and technologies like augmented reality (AR).

Figure 1: Industrial robots are used for palletizing food products like bread and toast at a bakery in Germany. (Source: Mouser)

As robots will become mobile and able to interact with people, significant increases in production throughput should be achievable along with greater product quality and operator safety. To maintain very low latency throughout this reimagined factory, it will be necessary to rely heavily on edge computing within the network. Edge computing brings intelligence and functionality to the "edges" of a network where the actual applications reside, similar to what distributed computing achieved decades ago.

Robots on the Field

The "untethering" of robots via 5G and GPS-based geolocation will allow them to perform functions impossible today. For example, in agriculture, robots could wander through fields monitoring growing conditions and sending video and other sensor information back to a computer located virtually anywhere, or even perform activities such as spraying, pruning, and harvesting **(Figure 2).** A company called FFRobotics has developed what it calls a fresh-fruit robotics harvester that combines robotic controls with image processing software algorithms that allow it to find and distinguish between saleable and damaged produce as well as between fruit that is either not yet ripe or dead.

A technology called High-throughput Plant Phenotyping (HTPP) combines genetics, sensors, and robots that could be used to

Figure 2: Not the usual vision of a robot, but robotic nevertheless, this machine can traverse fields commanded by 5G. Images and other sensor data that are returned to a command point and potentially stored, distributed, and processed in the cloud can increase crop yields and efficiency. (Source: Mouser)

develop new crop varieties, as well as improved nutrient content and tolerance to environmental conditions. This would be accomplished using the sensors on robots to measure various characteristics and send their findings back to for analysis to scientists who could be located virtually anywhere. Other robots are being developed to plant and track seeds to improve the efficiency of farming and many other aspects of agriculture that people now perform. In the future, many are likely to be performed by remotely-controlled machines.

Qorvo: Enabling 5G Infrastructure

Qorvo is a leading global supplier of RF solutions with a diverse portfolio of solutions that "connect and protect,"communication applications such as radar, Wi-Fi customer premises equipment for home and work, high-speed connectivity in LTE and 5G base stations, cloud connectivity via data center communications and telecom transport, automotive connectivity, and other IoT, including smart home solutions. Qorvo's leading edge products include gallium arsenide (GaAs) and gallium nitride (GaN) power amplifiers (PAs), low-noise amplifiers (LNAs), switches, complementary metal–oxide–semiconductor (CMOS) system-on-a-chip solutions, premium bulk acoustic wave (BAW) and surface acoustic wave (SAW) filter solutions, and various multi-chip and hybrid assemblies.

Qorvo is leveraging their product capabilities across low frequencies up through millimeter wave to respond to the product demands of the next-generation 5G networks for sub-6GHz and millimeter wave solutions. A wide variety of products are embedded in ongoing 5G field trials, and Qorvo has multiple product development engagements with top OEMs to intersect network operators' timelines for deployment of 5G networks. Let's take a look at some of the specific technologies and products that are bringing 5G and the future of robotics into reality.

Integration Makes It Easy: QPF Front End Modules

Qorvo is a leader in 5G infrastructure front end modules (FEMs). FEMs are integrated radio frequency (RF) modules that contains amplifiers, filters, switches, and other components. The Qorvo QPF4001 GaN Monolithic Microwave Integrated Circuit (MMIC) FEM is a multi-function device module targeted for 28GHz (26–30GHz) phased array 5G base stations and terminals. It combines a low noise high linearity LNA, a low insertion-loss high-isolation transmit/receive (TR) switch, and a high gain, high efficiency multistage PA. Operating at a higher frequency Qorvo offers the QPF4005 Dual Channel FEM, which is a multifunction GaN MMIC module targeted for 39GHz (37–40.5GHz) phased array 5G base stations and terminals. It also combines a LNA, a low-insertion-loss high-isolation TR switch, and a high-gain high-efficiency multistage PA. Additionally, Qorvo QPF4006 39GHz (37–40.5GHz) GaN Transmit/Receive Module is targeted for 39GHz phased array 5G base stations and terminals. Like the others, it combines a low noise high linearity LNA, low-insertion-loss high-isolation TR switch, and a high-gain high-efficiency multistage PA.

Signal Boosting: QPL Ultra-Low Noise Flat Gain Amplifiers

Qorvo QPL9057 Low-Noise Amplifiers provide a flat 2.4dB gain over a wide bandwidth from 1.5–3.8GHz. These gain amplifiers provide 22.8dB gain, +32dBm OIP3 at a 50mA bias setting, and 0.54dB noise figure. The QPL9057 gain amplifiers require five external components to operate from a single positive supply as they are internally matched using a high-performance E-pHEMT process. Typical applications include mobile infrastructure, repeaters, Time Division Duplex (TDD) or Frequency Division Duplex (FDD) systems, LTE/WCDMA/CDMA/GSM, and general-purpose wireless.

Dual Channels, Different Frequencies: QPB Switch Low-Noise Amplifiers

Qorvo's QPB9329 4.4–5.0GHz Dual Channel Switch LNA Modules are highly integrated FEMs targeted for Time Division Duplex (TDD) base stations. These switch modules integrate a two-stage LNA and a high-power switch in a dual-channel configuration. Similarly, the Qorvo QPB9337 2.3–3.8GHz Dual Channel Switch LNA Modules are highly integrated front-end modules targeted for TDD base stations. Like the QPB9329, these LNA modules integrate a two-stage LNA and a high-power switch in a dual-channel configuration. The QPB9337 LNA modules can control the power down and bypass capabilities with the control pins on the module. These modules are designed for wireless infrastructure applications configured for TDD-based multiple-input and multiple-output (MIMO) architectures.

Flick of the Switch: QPC Absorptive High Isolation SOI Switches

Qorvo QPC silicon-on-insulator (SOI) RF Switches like the QPC6054 are specifically designed for cellular, 3G, LTE, and other high-performance communications. The devices have a surface mount design for ease-of-assembly and operate from 5MHz–6GHz. Developed using a high isolation symmetric topology, the QPC SOI RF Switches offer excellent linearity and power handling capability. The QPC6054 is a single-pole, single-throw (SPST) switch. The Qorvo QPC6324 Absorptive High Isolation Single Pole Double Throw (SPDT) Switch offers high isolation with excellent linearity and power handling capability. The QPC6324 switch finds its applications in a wide variety of 4G/5G wireless infrastructure applications.

Conclusion

It's important to keep in mind that 5G won't simply transform robotics overnight, as many of the applications and technologies to achieve it are today either embryonic, in development, or just on the drawing board. Rather, 5G should be viewed as the beginning of a new era in telecommunications that fully enables robotics and many other applications for the first time. In addition, mobile robots are also a long way from being a mature technology. It will likely take years before they are massively deployed in applications ranging from manufacturing and production to agriculture, search and rescue operations, wide-ranging search and rescue operations, and many others.

5G will require enormous levels of innovation in every aspect of the network, from the development of millimeter-wave communications systems to software-defined and virtual network architectures, and new wireless access methods that make it possible for many robots to operate in a small area without interfering with each other. Looming above it all is latency, which researchers must find a way to reduce to virtual insignificance.

Qorvo Ships 100 Million RF Devices for **5G** Wireless Infrastructure

By Qorvo

Operators are quickly migrating to 5G using existing spectrum with new front-end radio solutions for massive MIMO base stations

BARCELONA, SPAIN–February 27, 2019–Qorvo® (Nasdaq: QRVO), a leading provider of innovative RF solutions that connect the world, today announced that it has shipped over 100 million 5G wireless infrastructure components since January 2018. Qorvo's broad 5G portfolio includes solutions for both the receive and transmit RF front end, enabling customers to utilize beamforming with massive multiple-in/multiple-out (MIMO) base stations to achieve higher data capacity, wider coverage, and indoor penetration using sub-6GHz frequencies.

New 5G networks feature lower latency and higher data capacity which will enable virtual reality/augmented reality, connected cars, and new smart home and IoT applications.

The installation of new 5G networks utilizing massive MIMO architectures have created demand for new products supporting higher frequencies and increased integration. Qorvo's broad portfolio of 5G solutions include dual-channel low noise amplifiers (LNAs) integrated with high-power-handling switches, high linearity transmit pre-drivers, and final stage power amplifiers (PAs). Qorvo's GaN-based PAs for all sub-6Gz 5G bands feature fully integrated Doherty solutions that support the higher frequency, small size, weight, power consumption, and thermal management requirements for 5G equipment.

Roger Hall, general manager, Qorvo High Performance Solutions, said, "Qorvo is enabling mobile operators to enhance their existing network capacity and transition to 5G with minimal effort. Our technology leadership with massive MIMO based on beamforming is revolutionizing the base station market and accelerating the path to 5G."

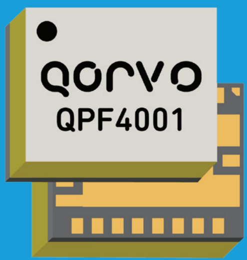
Qorvo's gallium nitride (GaN) technology delivers industry-leading performance, efficiency, and power. This enables transmission of multiple data streams with greater capacity, supporting quick and cost-effective implementation of 5G networks.

New Qorvo products that are available now to wireless infrastructure customers include the QPB9337 Dual-Channel Switch LNA module, the QPL9057 Ultra-Low NF LNA, and the QPA3503 Doherty Power Amplifier module.

Qorvo accelerates the path to 5G by helping to define 5G standards as a delegate to 3GPP, and through close collaboration with wireless infrastructure manufacturers, network operators, chipset providers, and smartphone manufacturers. Qorvo has helped conduct dozens of 5G field trials, and Qorvo's 28GHz products supported the Samsung® 5G MIMO demo at the 2018 Winter Olympics.

Qorvo is at the forefront of Solving RF Complexity™ and discussed its industry-leading portfolio of advanced RF front end solutions and pre-5G and 5G wireless infrastructure at Mobile World Congress 2019, February 25-28, in Barcelona. For more information, go to qorvo.com/5G.

QPF4001 GaN MMIC Front End Module



Key Features:

- Tx linear power: 23dBm with 8% PAE
- Rx 18dB gain, 3.5dB NF including switch
- Single channel FEM in 4x5mm laminate package

mouser.com/qorvo-qpf4001-front-end-module

QPL9057 Ultra Low Noise Flat Gain Amplifier

Key Features:

- 0.55dB NF at 3.5GHz
- >20dB gain across wide bandwidth
- 32 dBm OIP3 at 50mA IDD

mouser.com/qorvo-qpl9057-flat-gain-amplifiers

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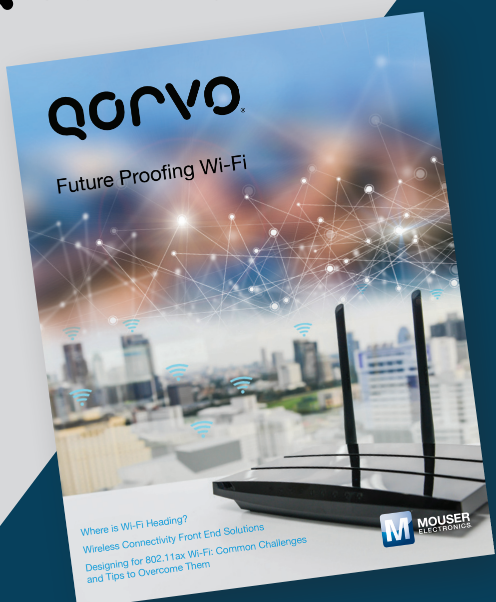
qorvo

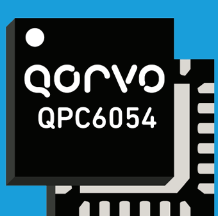


Overcome Wireless Design Challenges for Wi-Fi

Take a deeper dive into the modules, interference concerns, new 802.11ax standards, plus other useful design information.

www.mouser.com/news/qorvo-ebook/mobile/index.html

QPC6054 Absorptive High Isolation SOI SP5T Switch



Key Features:

- High isolation (RFX-RFX): 44dB up to 6GHz
- Fast switching: 150ns 50% control to 10/90% RF
- Operating temp -40 to +105C; 59dBm OIP3

mouser.com/qorvo-qpc-soi-rf-switches

QPC6324 Absorptive High Isolation SOI SPDT Switch

Key Features:

- High isolation (RFX-RFX): 50dB up to 6GHz
- Fast switching: 180ns 50% control to 10/90% RF
- Operating temp -40 to +110C; 60dBm OIP3

mouser.com/qorvo-qpc6324-spdt-switch

Realizing **5G** Sub-6GHz Massive MIMO Using GaN

By David Schnaufer, Bror Peterson, Qorvo

Gallium-nitride technology figures to play a significant role in sub-6GHz 5G applications to help achieve goals like higher data rates.

By 2021, it's estimated that more people will have mobile phones (5.5 billion) than running water (5.3 billion). Bandwidth-hungry video will further increase the demands on mobile networks, accounting for 78% of mobile traffic.[1] 5G networks using massive multiple-input, multiple-output (MIMO) technology will be key to supporting this growth. It's expected that 5G mobile connections will grow from just 5 million in 2019 to nearly 600 million by 2023, according to Strategy Analytics.[2]

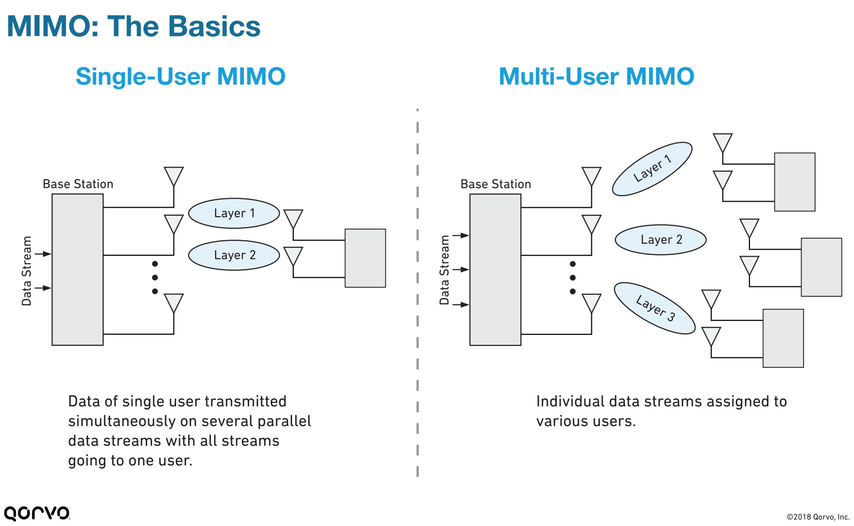


Figure 1: Single-user MIMO systems were used for 3G, while 4G adopted multi-user MIMO system technology.

Each generation of wireless technology has used advances in antenna technology to help improve network speeds. 3G employed single-user MIMO, which leverages multiple simultaneous data streams to transmit data from the base station to a single user. Multi-user MIMO is a dominant technology in 4G systems—it assigns different data streams to different users, providing significant capacity and performance advantages over 3G **(Figure 1)**. 5G will introduce massive MIMO, further increasing capacity and delivering data rates up to 20Gb/s **(Figure 2)**.

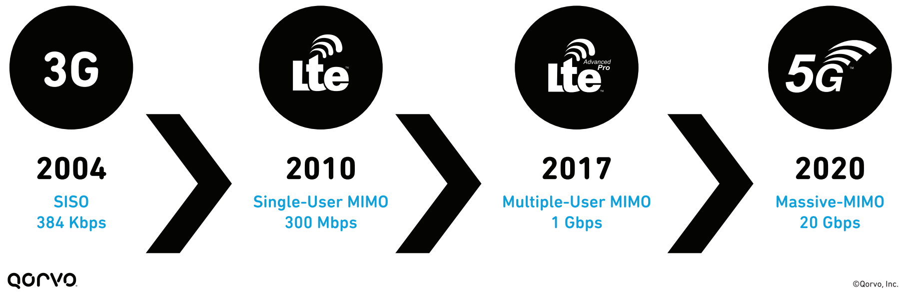


Figure 2: The evolution of MIMO in wireless technology generations will ultimately lead to the use of massive MIMO for 5G.

5G Massive MIMO Explained

The 5G mantra is to increase network capacity and data rates while minimizing operator expenses. Users also increasingly expect wireless data services to deliver wireline quality.

5G massive MIMO will help operators achieve these goals. It will deliver high data rates to many users, helping to increase capacity. It will support real-time multimedia services without requiring much additional spectrum. In addition, massive MIMO will reduce energy consumption by targeting signals to individual users utilizing beamforming, a technique that focuses the signal from multiple antennas into a single strong beam.

Spatial Multiplexing and Massive-MIMO Benefits

Massive-MIMO technology uses large antenna arrays (typically comprising 64 dual-polarized, but at a minimum 16, array elements) to exploit spatial multiplexing **(Figure 3)**. Spatial multiplexing delivers multiple parallel streams of data within the same resource block. By expanding the total number of virtual channels, it increases capacity and data rates without additional towers and spectrum.

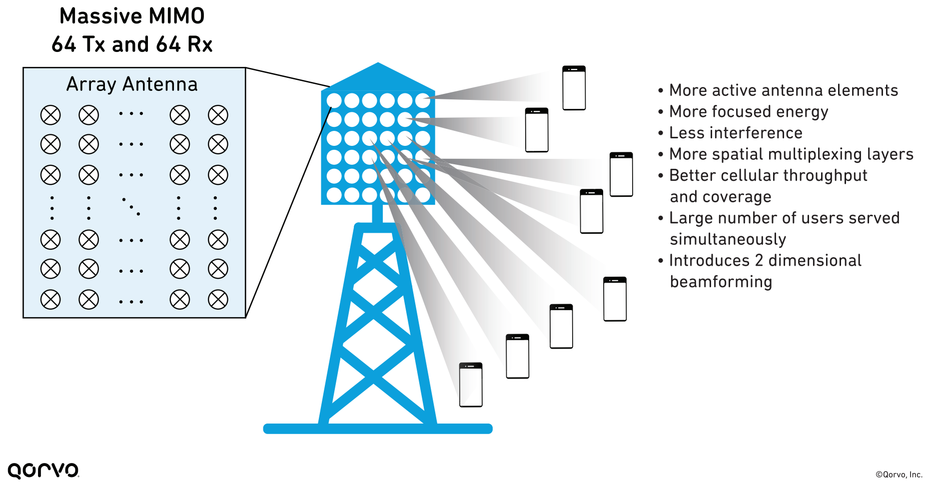


Figure 3: Various benefits are associated with massive MIMO, such as spatial multiplexing.

In spatial multiplexing, each spatial channel carries independent information **(Figure 4)**. If the environmental scattering is rich enough, many independent sub-channels are created in the same allocated bandwidth, thus achieving multiplexing gains with no additional cost in bandwidth or power. The multiplexing gain is also referred to as degrees of freedom in reference to the signal space constellation; in a massive-MIMO configuration, the degrees of freedom govern the overall capacity of the system.[3]

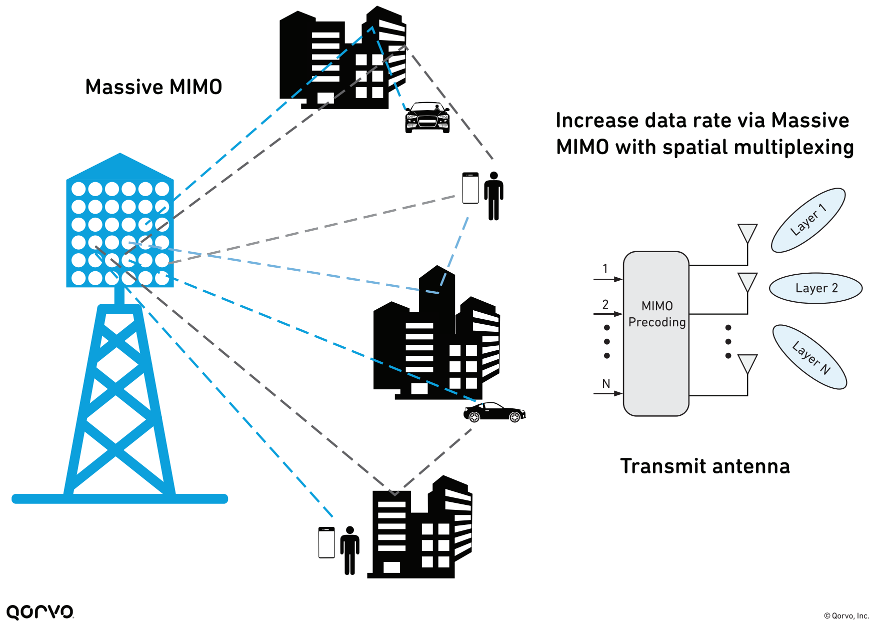


Figure 4: Each channel involved in spatial multiplexing with massive MIMO carries independent information.

With massive MIMO, multiple antennas focus the transmit and receive signals into smaller regions of space, bringing huge improvements in throughput and energy efficiency. The more data streams, the greater the data rate and more efficient use of radiated power. This approach also improves link reliability. The increase in antennas means more degrees of freedom that can be spent on spatial diversity. It improves selectivity in the transmit and receive data streams and enhances interference cancellation.

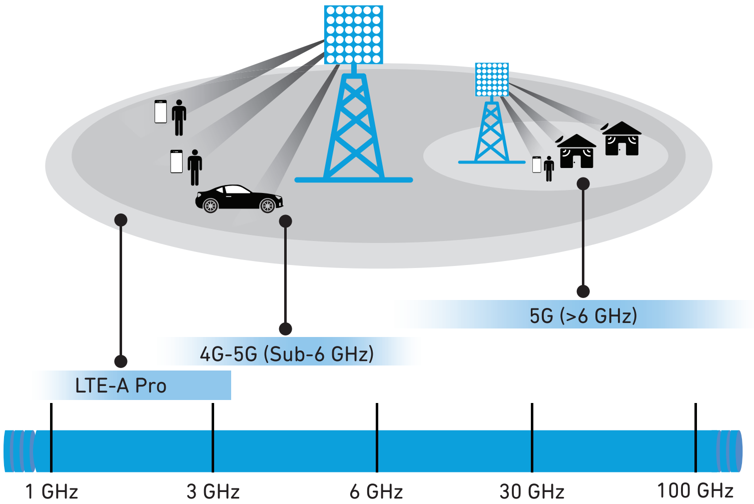
Massive MIMO will provide benefits, including:

- Preventing transmission in undesired directions, alleviating interference
- Decreasing latency, allowing for faster speeds and higher reliability
- Reducing fading and drops, boosting signal-to-noise-ratio (SNR)
- Increasing spectral efficiency and high reliability
- Greater energy efficiency

5G Massive MIMO and Sub-6GHz Deployment

It's clear that to achieve the 5G target of 20Gb/s data rates, it will be necessary to use millimeter-wave (mmWave) spectrum. However, several key challenges must be addressed before mmWave can truly be used for mobile communications.

While operators and original equipment manufacturers (OEMs) continue working to finalize mmWave technology, sub-6GHz will be the go-to 5G network technology in the near term. Sub-6GHz frequencies are suited for both rural and urban areas since the technology can deliver high data rates over long distances **(Figure 5)**. Operators are initially expected to deploy 5G in 3,300 to 4,200MHz and 4,400 to 5,000MHz frequency ranges, which will allow up to 100MHz channel bandwidths.



Standard	LTE-Advanced Pro	5G (Sub-6 GHz)	5G (>6 GHz)
Bandwidth*	Approx. 3x20 MHz	Approx. 3x100 MHz	Approx. 3x400 MHz
Downlink Speed*	1.2 Gbps	6.5 Gbps	18 Gpbs

*3 Carrier Aggregation and 80% downlink

Figure 5: Differences in coverage and capacity are distinct between 5G mmWave and sub-6GHz.

Sub-6GHz massive MIMO will solve interference problems by using a large number of antennas at the base station and will enable base stations to serve large numbers of users in urban areas. Massive MIMO also boosts peak, average, and cell-edge throughput, maximizing cost efficiency by providing the optimal balance between user coverage and capacity.

These technology advances do not come without system design challenges. Sub-6GHz massive-MIMO beamforming technology will drive demand for small, highly efficient, cost-effective power amplifiers (PAs) that can be used in massive-MIMO arrays. Also, because the 5G modulation schemes are becoming more complex (i.e., 256 QAM), wireless infrastructure PAs will need to be very efficient under the deep output-power back-off conditions (up to 8dB or more) that will be required to achieve the necessary linearity.

Making 5G Massive-MIMO Sub-6GHz a Reality Using GaN

High output power, linearity, and power-consumption requirements are pushing base-station and network OEMs to switch from using LDMOS technology for PAs to gallium nitride (GaN). GaN offers numerous advantages for 5G sub-6GHz massive-MIMO base-station applications:

- GaN performs well at 3.5GHz frequencies and above, while LDMOS is challenged at these high frequencies.
- GaN has high breakdown voltage, high current density, high transition frequency, low on-state resistance, and low parasitic capacitance. These properties translate into high output power, wide bandwidth, and high efficiency.
- GaN in a Doherty PA configuration attains average efficiencies of 50% to 60% with 100W output power, significantly reducing transmit power consumption.
- The high-power density of GaN PAs enables small form factors that require less printed-circuit-board (PCB) space.
- Using GaN in a Doherty PA configuration allows for the use of quad-flat no-leads (QFN) plastic packages rather than the expensive ceramic packages.
- GaN's efficiency at high frequency and over wide bandwidths means that massive-MIMO systems can be more compact. GaN reliably runs at higher operating temperatures, meaning it can use a smaller heat sink. This enables a more compact form factor.

Meeting Sub-6GHz RFFE Design Goals

Building the RF front end (RFFE) to support these new sub-6GHz 5G applications will be a challenge. The RFFE is critical to the system's power output, selectivity, and power consumption. The complexity and higher frequency range are driving the need for RFFE integration, size reductions, lower power consumption, high output power, wider bandwidth, improved linearity, and increased receiver sensitivity. In addition, there are tighter coupling requirements between the transceiver, RFFE, and antenna.

Some of the goals of the 5G sub-6GHz RFFE, and how GaN PAs can help achieve them, include:

- **Higher frequencies and increased bandwidth:** 5G uses higher frequencies than 4G and requires much wider component carrier bandwidths (up to 100MHz). GaN-on-silicon-carbide (GaN-on-SiC) Doherty PAs achieve wider bandwidths and higher power-added efficiencies (PAEs) than LDMOS at these frequencies. The higher efficiency, higher output impedance, and lower parasitic capacitance of GaN devices allow for easier wideband matching and scaling to very high output power.
- **High power efficiency at higher data rates:** GaN has soft compression characteristics, making it easier to pre-distort and linearize. Thus, it's easier to use in digital pre-distortion (DPD) high-efficiency applications. GaN is able to operate across multiple cellular bands, helping network operators deploy carrier aggregation to increase spectrum and create larger data pipes for increasing network capacity.
- **Minimizing system power consumption:** How do we meet the high data requirements of 5G? We will need more infrastructure, such as data centers, servers, and small cells. This means an overall increase in network power consumption, thus driving the need for system efficiency and overall power savings. Ultimately, the carriers demand more for less, which might seem difficult. But again, GaN can help provide the solution by offering high output power coupled with increased efficiency in base stations.

Figure 6 shows a high-level block diagram of an example sub-6GHz RFFE, which uses a Qorvo Doherty PA design to attain high efficiency.

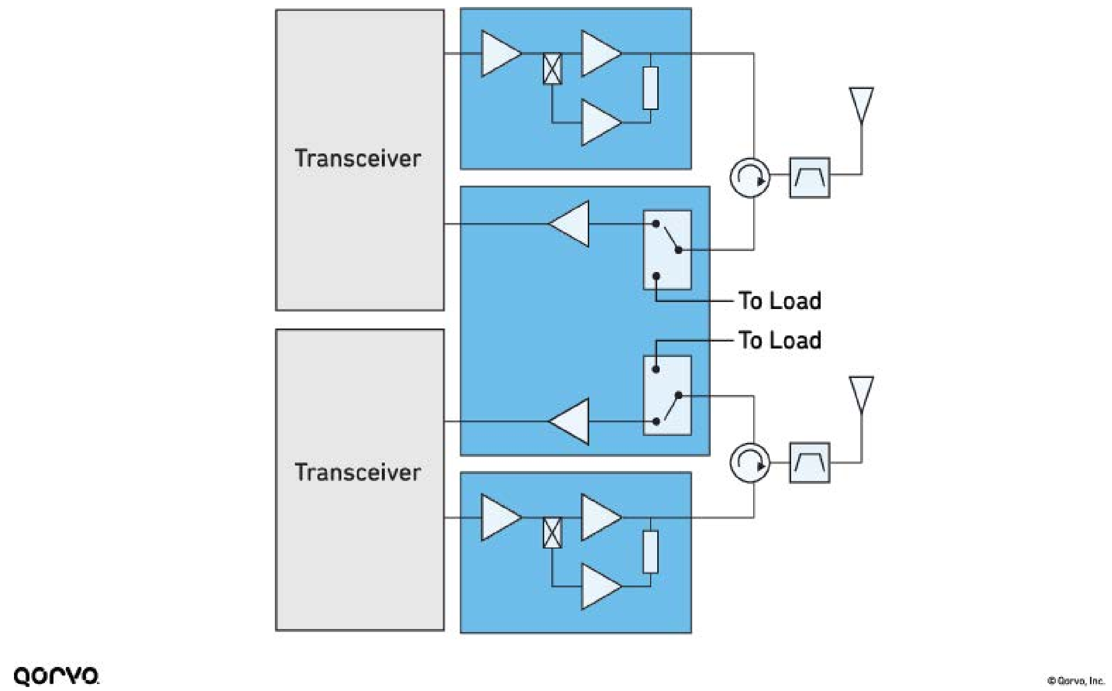


Figure 6: This sub-6GHz massive MIMO RFFE includes a Doherty PA.

GaN is becoming one of the go-to technologies for 5G. Qorvo has been manufacturing GaN for many years, and is able to quickly bring discrete and integrated modules to market. As shown in **Figure 7**, the company provides an array of products for greater design flexibility.

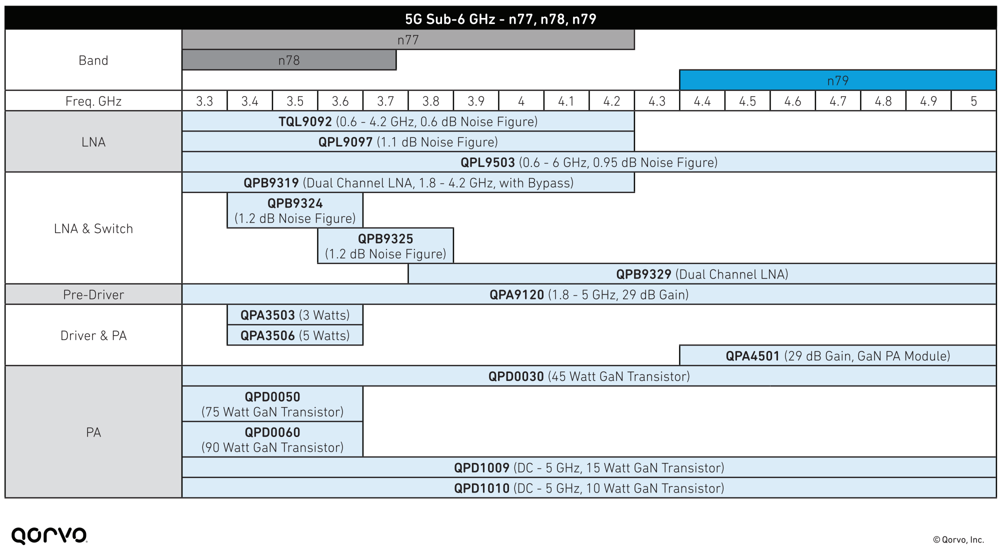


Figure 7: Qorvo offers an array of sub-6GHz products.

Conclusion

5G massive-MIMO sub-6GHz infrastructure designs are already being rolled out. This means the technology and system designs needed to address higher frequencies, higher power output, and lower power consumption must be available now to support global carrier build-out. Technologies such as GaN help carriers and base-station OEMs achieve their goals for 5G sub-6GHz and mmWave massive MIMO.

References:

1. *Cisco Systems, "Mobile Visual Networking Index (VNI) Forecast Projects 7-Fold Increase in Global Mobile Data Traffic from 2016-2021."*
2. *Strategy Analytics, "Strategy Analytics Forecasts Nearly 600 Million 5G Users by 2023."*
3. *Gaussianwaves.com, "MIMO – Diversity and Spatial Multiplexing."*

What's Best? 5G or Wi-Fi 6 (802.11ax)

Wi-Fi 6	5G
2.4GHz & 5GHz (Expected to extend into 6GHz & 60GHz in 2019)	600MHz to 6GHz (Expected to extend into 3.4-4.9GHz & 24.25-47GHz in 2019)
Commercial Computer Industry IEEE 802.11 Standard	Telephone Industry 3GPP Standard
License-Free Frequency Band (Router)	Subscription Service (SIM Card)
Indoor/outdoor networks (Internet, email, phone, security, energy management, home monitoring, etc.)	Indoor/outdoor networks (phone, chat, Internet, smart city, industry 4.0, agriculture, smart logistics, etc.)
Better coverage inside the home with mesh networking	Better coverage for home and office. 5G will use Wi-Fi, 3GPP, LTE-licensed & unlicensed bands

Visit **mou.sr/wifi6or5g** to learn more

5G RF Glossary

3rd Generation Partnership Project (3GPP)
3GPP is a collaboration between seven telecom standards setting associations. Originally convened to establish standards for 3G technology, the 3GPP is one of the primary groups working on new standards for 5G technology.

5G New Radio (NR)
Global air interface standard for 5G networks developed by the 3GPP. "Phase 1" was published in Release 15 with "Phase 2" coming in Release 16.

Beamforming
Technique by which base stations can identify the most efficient route to a user. Beamforming is used together with massive MIMO arrays to send individual data packets in a precisely coordinated pattern allowing many users and antenna to exchange more information while reducing interference for nearby users.

Cloud Radio Access Network (cRAN)
cRAN is a cloud computing-based architecture for radio access networks that supports existing and future wireless communication standards. The idea is that pooling resources in the cloud will create more efficient mobile networks by moving baseband processing from the device level to the cloud.

Critical Communications (CriC)
One of the three primary subsets of 5G use cases focused on applications that need immediate responsiveness with near zero latency. The amount of data may be small, but it must to be transmitted and received in as close to real time as possible. An example is medical surgery robotics.

Enhanced Mobile Broadband (eMBB)
One of the three primary subsets of 5G use cases offering faster data speeds and better coverage than previous wireless standards. Examples include augmented and virtual reality.

Latency
The time delay between a request for data or action and the response.

Massive Machine-Type Communication (mMTC)
One of the three primary subsets of 5G use cases specifically designed to handle vast amounts of data generated by various sensors networks and devices. The target for this use case is the Internet of Things.

Massive Multiple Input/Multiple Output (MIMO)
Wireless communication technology in which multiple antennas are used at the source and destination, and their functions (transmit/receive) are combined to reduce errors and optimize data speed.

mmWave
The band of spectrum between 30GHz and 300GHz. Also known as extremely high frequency (EHF).

Network Slicing
5G Network Slicing enables operators to build virtual networks tailored to specific application requirements. Each portion of the overall network receives optimized resources and network topology for a particular use case.

Small cell densification
Small cells are a type of base station that include femtocells, picocells, microcells, and metrocells. Small cells are low powered access devices with a typical coverage range of 10m to 300m. Placement of small cells every few hundred meters creates a dense and flexible network for a small but perhaps vital geographic area. Small cell densification will be critical to support the nMTC use case.

Tactile internet
The International Telecommunication Union (ITU) defines the Tactile Internet as an internet network that combines ultra low latency with extremely high availability, reliability, and security. It is projected to be the next evolution in the Internet of Things that will enable control of the IoT in real time and include more human to machine interface.

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