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Performance and Integration for 5G Massive MIMO

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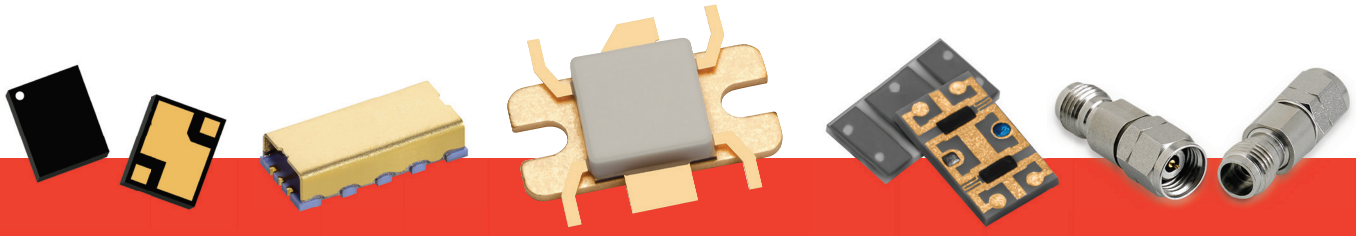

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Introduction

Performance and Integration for 5G Massive MIMO

We are well into the era of 5G. The deployment of 5G infrastructure and user equipment is pervasive and we can all recite the 5G vision of enhanced mobile broadband (EMBB), massive machine-type communications (mMTC) and ultra-reliable low latency communication (URLLC) by heart. While we can have a long discussion about the short-term trajectory of the 5G market, the longer-term prospects still look good. In Ericsson's most recent Mobility Report, they estimate that there will be 4.6 billion 5G subscribers by 2028, accounting for slightly more than half of all mobile subscriptions. To accommodate all these users, some market research firms are forecasting more than 30 billion 5G-enabled devices will be sold by 2028.

This is the opportunity for the core *Microwave Journal* reader and that opportunity is large. However, 5G networks and devices are enabling a whole host of new services and including that revenue creates an even larger opportunity that is being forecast to be between $700 billion and nearly $2 trillion by 2030. However, this opportunity does not exist without developments in devices, systems and networks. The challenges that the industry is facing and the solutions that are being developed at each step of the supply chain to enable the 5G future form the basis for this eBook.

The first entry dives into the 5G market, with a focus on base stations. It provides a good summary and forecast of the trends, drivers, ecosystem, technology shares and market segmentations for PAs in base station applications. The second entry describes integrating DAS networks to improve 5G coverage and article three provides and discusses the benefits of transitioning to a 5G standalone (SA) network. The fourth article gives a good overview of the importance of power amplifiers in 5G architectures and the challenges and advantages of integrating functions into PA modules. The final article discusses the benefits of Open RAN, a standardized approach to radio access network hardware and software disaggregation and how front-end reference designs can enable massive MIMO, which has become an essential. building block of the 5G future.

We hope that this eBook gives you a good overview of how device and network architecture evolution is enabling the 5G opportunity. The enormous 5G market potential will only come to fruition through the efforts of companies at every point in the supply chain. The teams at RFMW and Qorvo continue to provide innovation and enable breakthroughs to ensure that 5G will succeed in its vision. We thank them for sponsoring this eBook so that we can offer it to our readers for free.

Eric Higham, *Microwave Journal,* Technical Editor

Innovation and Pricing Pressures Drive 5G Base Station Power Amplifier Trends

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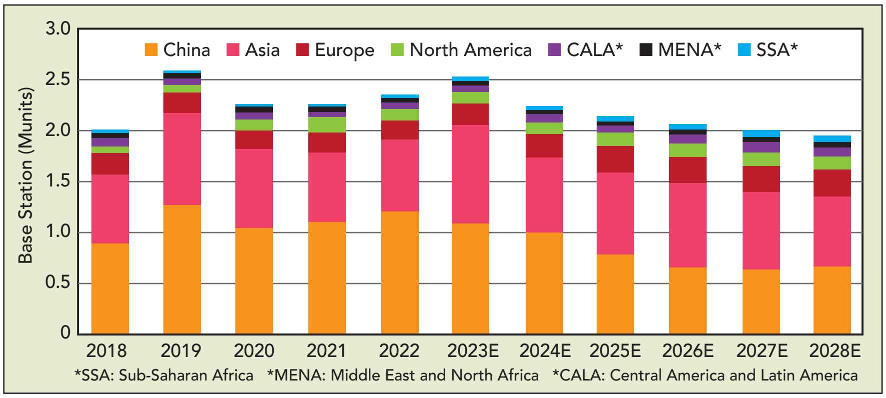
To keep up with the exponential growth of mobile traffic globally, mobile network operators (MNOs) are massively deploying 5G networks. At the same time, they are shutting down their 3G and 2G services to free up the cell site spectrum for 4G and 5G. Globally, 5G is being deployed at two different paces, with China supporting half of the base transceiver station (BTS) market while the rest of Asia, Europe, the U.S. and late 5G entrant India dominate the balance of the market. ***Figure 1*** shows our latest base station forecast by region.

We estimate that 5G comprises more than 70 percent of the investment from the MNOs. MNOs are expected to continue investing massively in 5G in the upcoming years and this will continue to expand the 5G footprint. The first wave of investment mainly focused on 5G Non-Standalone (NSA), involving only new radios, to ensure a fast time to market and a smooth cohabitation with 4G. The second wave is now focusing on the baseband and core networks, where evolution is critical to provide 5G Standalone (SA) that enables new use cases and levers for monetization. There are big expectations for RAN and RF front-end (RFFE) market opportunities in 2023, primarily due to an ambitious launch of 5G networks in India. The question becomes; will it last over the next few years?

MARKET DRIVERS COME OUT OF MNO REQUIREMENTS

5G is bringing massive network capacity improvements by using new spectrum in the sub-6 GHz frequency band while reusing legacy 4G bands. 5G architectures leverage traditional remote radio heads (RRHs) and active antenna systems (AAS). The use of massive MIMO (mMIMO) is a crucial technology to improve AAS spectral efficiency and throughput. Mainstream mMIMO systems use 32 or 64 streams and this has a huge impact on the number of RF lines compared to legacy RRHs that typically had 2 to 8 TRx. Although the mMIMO architecture is much more efficient than an RRH architecture in terms of gigabits per kilowatt, AAS consumes much more power than legacy RRH. With the increase in mMIMO penetration, the trend toward higher-power radio units (RUs) with transmit power above 300 W is becoming the norm.

This rising concern about energy consumption is a serious challenge for MNOs. This is becoming increasingly problematic as energy prices are rising and sustainability is becoming important for consumers, politicians and investors. Various sources estimate that BTS energy consumption is between 20 and 40 percent of an operator's OPEX, representing one of the highest contribu-



▲ **Fig. 1 Macro/Micro regional BTS forecast. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.**

tors to that expense. Addressing this energy issue is critical because MNOs cannot deal with increasing OPEX on one hand and increasing CAPEX to support expensive 5G hardware deployment on the other.

To address the energy issue, original equipment manufacturers (OEMs) are focusing on power amplifiers (PAs). These devices consume the most power in the radio and drive high transmit power levels but they suffer from limited efficiency. Huawei was the first to trade the low-cost laterally-diffused metal-oxide semiconductor (LDMOS) power transistor technology for the better power-added efficiency of GaN technology solutions. With the increasing need to optimize power consumption, the transition toward GaN-based RUs is accelerating. The supply chain has adapted accordingly to support the growing demand for GaN devices. Our market share forecast for the various PA technologies is shown in ***Figure 2***.

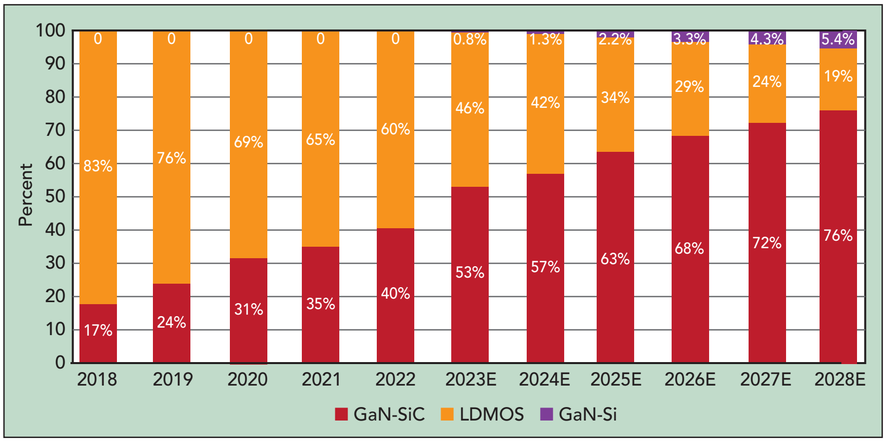


Fig. 2 Forecast of final PA technology in BTS RAN. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.

The most significant example of the growing importance of GaN in BTS applications is probably NXP, a key historical LDMOS player. In 2020, they opened a 6-in. GaN fab in the U.S., showing the strategic need to internalize GaN production and to compete with other long-time GaN manufacturers in the BTS market. Sumitomo Electric Device Innovation (SEDI) and NXP, the top two GaN players in this market are seeing increasing competition from Qorvo and Wolfspeed in the U.S. and a few growing players in China, such as Dynax, Bowei and WaTech Electronics.

With the ongoing trade conflict between the U.S. and China, the supply chain tends to be polarized. This is a tough challenge for Chinese players, system and device makers, as well as foundries, because it turns the Chinese ecosystem against the rest of the world. China has been forced to accelerate the development of a local supply chain and with massive support from the government, more companies are emerging in the RFFE field.

The second important lever to improve energy efficiency is artificial intelligence (AI), which is set to play a critical role in dynamic power management. AI is expected to power significant breakthroughs in the telecommunication field as it is now used by many manufacturers to reduce energy consumption. To make the best use of this new feature, PAs will have to support dynamic control of the threshold voltage for low or high traffic modes, optimizing the power consumption as a function of the traffic. To perform smoothly, AI also requires a very low latency network to control traffic and power management in real-time.

With the RAN market expected to peak in 2023, the telecom industry is now looking for new growth drivers. While MNOs are looking toward 5G SA and monetizing their 5G networks, OEMs are getting ready for the second phase of deployment involving sub-6 GHz small cells and mmWave RUs. Thanks to the massive amounts of bandwidth available, potential 5G mmWave use cases are numerous, but as of today, the technology has had difficulty penetrating the market outside the U.S. and Japan. The growth has been slow because the industry is focusing on C-Band mMIMO deployment and the need for mmWave in consumer devices remains to be proven. The mmWave ecosystem is counting on fixed wireless access applications emerging as a killer use case to encourage MNOs to deploy this technology. In the same way, the opportunity for sub-6 GHz small cells remains limited as the cost of installation, which requires fiber at each access point, and the cost of the radios is still too high.

Nevertheless, there is a lot of activity around mmWave and sub-6 GHz small cells from both established RF component makers and emerging companies. For mmWave communication, the industry has chosen to use a hybrid architecture, combining digital and analog beamforming. This architecture requires beamforming integrated circuits (BFICs) integrating four to 32 complete RF chains. These RF chains contain PAs, LNAs, filters, switches and phase shifters and several technology platforms are suitable for these functions. The first BFICs were designed using SiGe or CMOS, but we now see several players turning to RF-SOI for its scalability and good performance. Tier 1 OEMs like Samsung, which has an important mmWave footprint in the U.S., are using in-house designed BFICs.

5G MARKET STATUS

After the RAN market slowed down in 2021 due to COVID restrictions and a tight supply chain, it regained strength in 2022, with more than 2.3 million BTS deployed. In 2023, we expect to see a peak of 2.5 million BTS, with 35 percent of those BTS using mMIMO AAS. The penetration rate of this type of architecture has continuously increased since the beginning of the 5G era. The demand for infrastructure hardware is mainly supported by operators in India deploying 5G networks with lofty ambitions and a sustained rollout in China. India is a new and important market for 5G and the country has chosen to turn toward the Western supply chain, with Nokia and Ericsson as the main suppliers.

The growth in the RAN market is mainly supported by the five big established players: Huawei, Ericsson, Nokia, ZTE and Samsung. These suppliers are trying to consolidate their leading positions by innovating in their RAN portfolio to optimize system size and power efficiency. Huawei and ZTE increased their market share thanks to massive deployments in China and Samsung is capitalizing on its early adoption of virtual RAN (v-RAN) and open RAN (O-RAN) strategies.

Nevertheless, O-RAN and network virtualization represent a major opportunity for other players, such as NEC and Fujitsu, or even smaller players, like Mavenir or Airspan. Companies like Samsung and NEC are showing their ambitions to capture an important part of this market, which is expected to reach up to 25 percent of the annual RAN market by 2025. The small cell and mmWave markets also present an exciting opportunity for small players and newcomers.

The RF component market is directly benefiting from the mMIMO penetration. We estimated the RFFE market at $3.3 billion in 2022 and this opportunity is forecast to exceed $4.2 billion in 2023, including sub-6 GHz small cells and mmWave RUs. In terms of volume, the RFFE market represented almost 1.2 billion RF components in 2022 and it will account for almost 1.5 billion components in 2023. The market is expected to keep growing in volume over the next five years as mMIMO becomes increasingly dominant.

THE BTS PA

In the RFFE market, the final stage PAs attract most of the attention because these devices account for 45 percent of the overall market, split between LDMOS and GaN-SiC technology platforms. GaN-SiC devices are emerging as winners in this market, but the cost of the technology remains an issue when compared to LDMOS. Under pressure from OEMs and with the GaN-SiC process constantly improving, the technology cost is slowly decreasing. Chip makers are refining their value propositions by proposing multi-chip PA modules, along with integrating more amplification stages and power management features. This offering is well accepted by OEMs as it saves manufacturing and testing time, leading to benefits for manufacturers and system OEMs. From the technology standpoint, PA modules are becoming more complex and diversified; they are monolithic or multi-chip and sometimes combine several technology platforms inside a module. LDMOS is becoming a supporting technology as it provides easy impedance matching when used as a driver, for example. Finally, GaN-on-silicon, expected to bridge the cost/performance gap between LDMOS and GaN-SiC, is likely to enter the market in 2023 for mid-band mMIMO AAS, driven by Infineon. A snapshot of the RF final PA supply chain and market share for all technologies used in RAN applications is shown in ***Figure 3***. ***Figure 4*** shows our estimate for the share of device technology and the evolution toward integrated modules for the final PA stage in RAN applications.

A wide variety of semiconductor technologies are used in the RAN RFFE, not only for the final PA but also

Fig. 3 2022 RF final PA supply chain and market share. ***Source:*** **RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.**

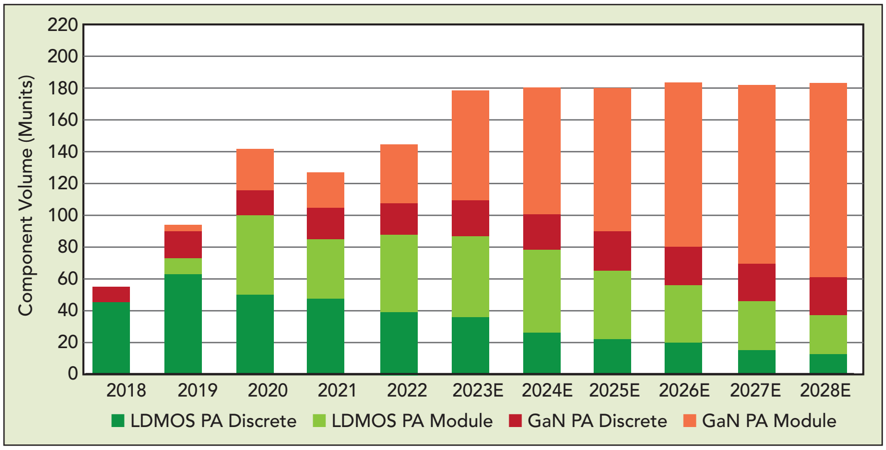


Fig. 4 RAN PA technology and integration forecast. ***Source:*** **RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.**

for drivers, switches and filters. The diversity in terms of power levels, frequency and architecture among systems creates a need for complementary solutions to adequately address the demand. This results in a complex technological ecosystem. The industry's recent technological disruption caused by 5G has created a fragmented market with many players involved. A few players, like NXP, Qorvo, SEDI and Analog Devices, stand out in this market with large market shares. NXP is the uncontested leader with a 35 percent share of the overall RFFE component market. With the expected market growth in the next several years, we will likely see other players generating significant revenue in BTS applications.

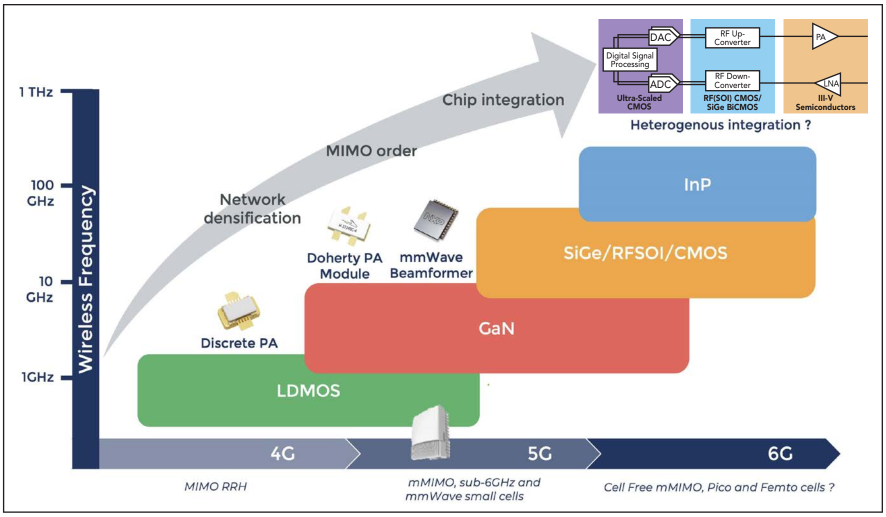


Fig. 5 A 6G technology roadmap. *Source:* RF for Radio Access Network (RAN) 2023 report, Yole Intelligence, 2023.

CONCLUSION AND PERSPECTIVES

Innovation continues for 5G and the next generation of wireless networks, but price pressure from the MNOs is becoming more challenging for OEMs and chip makers. Fragmented spectrum assets, coupled with an increasing number of available frequency bands are compelling operators to push to combine several bands inside a radio. In response, leading chip makers are designing PAs with very large bandwidths that also support higher transmit powers.

The next step for the 5G standard, 3GPP Release 18, is expected in the second calendar quarter of 2024, and will be considered the first release of 5G Advanced. This new standard will enhance 5G functionalities from the core network to RUs. Beyond 5G Advanced, the industry has begun 6G research, in parallel with many research and development initiatives around the globe. Some of the main challenges for 6G will be how to incorporate sub-THz and THz frequencies. Initial areas of interest are focusing on transmission in 100 to 300 GHz sub-THz bands. Activities in these and higher bands are likely to result in the development of new materials for semiconductors and antennas, novel packaging techniques and advanced semiconductor processes. InP and SiGe are considered potential elements to enable these higher frequency ranges being envisioned for 6G applications. With 5G mmWave applications struggling to find a market, the question of whether 6G will be beneficial if it requires even higher frequencies is legitimate. If 6G does have a path forward, compound semiconductors will play a big role in enabling that future. Our thoughts on a technology roadmap that takes us from 4G to 6G are shown in ***Figure 5***.■

Next-Generation DAS Technology Emerges to Serve 5G Needs

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Previous generations of cellular networks have relied on distributed antenna systems (DAS) to provide in-building coverage and to fill coverage gaps in complex structures. Though the same is true for emerging 5G systems and rollouts, there is a twist. Where previous generations of DAS antenna usually meant just covering new bands, 5G DAS also needs to support multi-antenna operation for advanced/active antenna system (AAS) beamforming and MIMO techniques that enable 5G. To support 5G speeds and coverage goals, new 5G DAS must also offer superior electrical performance. This is a challenge for network and antenna solutions.

5G REQUIREMENTS & CHALLENGES FOR NEXT-GENERATION DAS SOLUTIONS

Much of the cellular deployment and application discussion focuses on outdoor usage. We are familiar with mobile handset and automotive outdoor usage, but recent studies[1] show that over 80 percent of voice and data usage for handsets occurs indoors. This means that much of the demand for 5G services is likely to come from users located in buildings. While cellular network deployments will be able to provide outdoor coverage to users, it is unlikely that these networks will provide adequate coverage in mass transit systems, large venues, office spaces, warehouses and other indoor spaces. 5G will rely heavily on high frequency spectrum and the propagation characteristics of these signals mean they do not effectively penetrate buildings with concrete and low emissivity glass.

Traditional DAS Challenges

These new challenges are similar to traditional DAS challenges: how do we get cellular coverage into large, complex structures that are made up of a diverse mix of reflective and absorptive materials, along with odd geometries and layouts? With traditional cellular deployments, the link to the cellular services is often through an external antenna that connects to an existing cellular base station and tower. Alternatively, if the venue is large enough, it may have its own base station or use a nearby base station to route signals into the DAS.

Much of the design challenge is determining an appropriate layout for the DAS antenna, remote radio heads or nodes depending on the DAS architecture. Network designers must consider the use of RF cable runs, repeater antennas, fiber optic and Ethernet interconnections between the cellular network and the DAS. The DAS architecture must ensure adequate coverage with the desired frequency bands. As Wi-Fi has grown in popularity, DAS designers are facing the new challenge of offering multi-operator cellular services along with Wi-Fi services. The solution to these challenges typically involved upgrading the DAS hubs, antennas and interconnects to accommodate these new frequency bands while ensuring that DAS placement met customer expectations for service coverage. A typical indoor DAS network is shown in ***Figure 1***.

Emerging 5G DAS Challenges

5G currently uses three frequency ranges, with a variety of frequency bands within those ranges. GSMA defines these three 5G frequency ranges as low-band, with frequencies below 1 GHz, mid-band with frequencies from 1 to less than 7 GHz and high-band as frequencies above 7 GHz, but generally mmWave frequencies. The low-band frequencies generally exhibit the greatest range and coverage capability, but at limited data rates and capacity. Low-band networks are being deployed mostly in rural areas lacking good 4G coverage. These areas likely will not be significant for new DAS deployments. The mid-band range covers the frequency capability of most cellular handsets and this band is seeing the majority of current 5G activity. The mid-band frequency range is adjacent to other common wireless services, such as the 2.4 and 5 GHz ISM bands with services like Wi-Fi, Bluetooth, Zigbee and Matter. The high-band frequency ranges are in the mmWave spectrum where there is currently less activity and deployment effort. However, high-band services are likely to continue to be developed and deployed for the next several decades and future DAS deployments will increasingly need to account for services in these frequency ranges.

Beyond extending the frequency range to 7 GHz, or 7.125 GHz to accommodate Wi-Fi 6e, other capabilities differentiate 5G mid-band systems from legacy cellular technologies. Though 4G/LTE standards did introduce multi-antenna MIMO technologies, these are relatively simple arrangements of a handful of antennas, at most. In these cases, MIMO is generally used to achieve peak data rates for a single-user device. 5G standards introduced multi-antenna technologies to enhance coverage for several users in a given area, as well as beamforming technologies to enhance the gain of a given 5G antenna toward target user devices. For DAS to provide the same capabilities as 5G network antennas, they must become more complex and capable with multi-antenna technology.

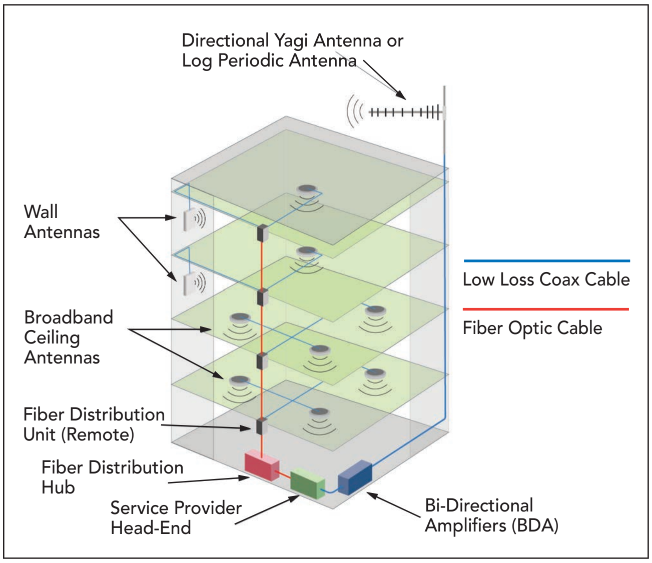
New 5G AAS technology enables much higher data rates and coverage in complex deployment scenarios, but this capability must be supported by the DAS distribution system and infrastructure. To do this, DAS interconnects must be able to support higher capacities, regardless of the 5G signal source. In addition, 5G DAS must support the legacy 4G/LTE cellular systems along with new 5G frequency bands and technologies.

Fundamentally, DAS is entering a new era with 5G. Legacy 4G/LTE networks and services have evolved with mobile handsets as the focal point. The 5G vision addresses ultra-reliable low latency communications (URLLC), massive machine-type communications (mMTC) and enhanced mobile broadband (eMBB). These additional use cases and implicit capabilities broaden the focus to IoT devices and critical systems requiring reliability and low latency services. This repositioning envisions applications from real-time monitoring systems to autonomous mobile robots operating alongside human workers, customers and/or pedestrians.

Aside from massive MIMO (mMIMO) and beamforming, additional 5G technologies will impact how DAS are designed and deployed. While things like network slicing and network function virtualization are more of a consideration for 5G network operators, these features will influence the DAS requirements. New and emerging business cases will also influence DAS requirements as many large enterprises, government organizations and large campuses are considering 5G private networks alongside public 5G networks.

DAS EVOLVES TO ADDRESS 5G COVERAGE CHALLENGES

To address these challenges, the underlying infrastructure, interconnects and DAS antennas must evolve.



▲ **Fig. 1 Indoor DAS network architecture.**

Despite a large diversity of DAS solutions, more product solutions and availability are needed to maintain, upgrade and deploy new DAS installations.

Signal Source

The cellular network is an extension of the internet backbone. A mobile core in the cellular access network is the bridge between the radio access network (RAN) and the internet infrastructure. In 5G networks, that mobile core may be deployed at the edge and the mobile core and RAN may be co-located. A backhaul network connects the RAN to the base stations and then a remote radio unit (RRU) distributes wireless service from the base station to the user equipment. In these systems, the DAS may connect to the cellular network through an antenna, a base station or a small cell.

Using small cells to drive DAS is becoming a more common solution to support the throughput and capacity expected from 5G services. This solution requires multiplexing small cells from each service provider to the backhaul internet connection. Aggregating rapidly growing 5G traffic may strain transport capabilities and this may necessitate the installation of higher capacity transport networks. Worst case, this increases the DAS costs and complexity, but much of this 5G traffic may be replacing already existing traffic, resulting in little to no need for increased capacity. Small cell connections are likely to be the biggest growth sector as DAS seeks to enable 5G performance expectations and features. In response to a perceived need for in-building 5G services, small cell manufacturers are enhancing their DAS-like distribution systems. The result appears to be a convergence of small cell and DAS technology for in-building applications.

Signal Distribution

There are three main strategies for DAS signal distribution: passive, active and hybrid. Passive DAS uses a DAS head end connected to a signal source, which feeds a passive DAS network of antennas and other passive components. Common passive components in this arrangement include splitters, coaxial cable, coaxial adapters, tappers, combiners, dividers and couplers. Passive DAS systems rely on RF signal generation, so they are only as capable as the signal source. These systems have limitations in 5G installations and may be useful only for applications like the last stage of distribution in a hybrid DAS system. An active DAS system uses digital data transmitted over a fiber or Ethernet network to a master unit. The master unit converts the source data to digital signals for distribution to the active DAS antenna. Electronics in these units convert the data stream to RF or digital as needed. A hybrid DAS is similar to an active DAS, but the RF/digital conversion takes place in a separate unit that feeds several RRUs.

It is difficult to determine the mix of signal distribution techniques for 5G services. All methods will likely be necessary to accommodate various installation dynamics and cost considerations. To integrate DAS with 5G services, the antenna units or RRUs must support 5G multi-antenna or AAS technology. DAS antenna units must evolve from omnidirectional and directional antennas to arrays supporting MIMO and beamforming technologies. These technologies require much higher interconnect densities and signal distribution complexity than previous cellular technologies. To reduce costs and maintain small footprints, DAS systems will become more integrated and incorporate denser board-level technologies.

DAS antennas and distribution systems must support higher throughput and higher frequency signals and provide better performance than prior generations of cellular networks. Higher frequency 5G signals will experience higher transmission and RF component losses. Offsetting these losses may require higher transmit power, but this will create concerns about passive intermodulation distortion and other nonlinear characteristics. Degrading performance in these areas could reduce the signal-to-noise ratio, bit-error rates or packet-error rates. The active components in a DAS will need higher levels of linearity over a much wider bandwidth than with previous cellular generations. The RF-to-digital and digital-to-RF conversion electronics will require much higher conversion rates in response to the new 5G frequency bands. Conversion electronics in these bands are expensive and this may drastically increase the cost of active and hybrid DAS compared to passive DAS.

Future mmWave DAS

The previous discussion focuses primarily on sub-6 GHz 5G implementations. Incorporating mmWave 5G technologies into DAS systems presents a different set of challenges. mmWave 5G enables high throughput and much more targeted signal distribution. mmWave 5G is seeing some success in the fixed wireless broadband market where 5G wireless services are used to deliver home internet and other media services. Enterprise and in-building applications have been slow to emerge at these frequencies and it seems unlikely that millimeter DAS will be deployed in the short term. Enabling faster millimeter DAS adoption will require an ongoing evolution of RF and digital technologies, along with new building construction material and layout considerations.

CONCLUSION

The outcomes and exact steps along the way are never clear with any emerging technology. This is the same with DAS evolving to include 5G technologies. What is clear is that there is currently competition from small cell manufacturers, service providers and DAS installers. The lines are blurring between DAS and small cells when it comes to providing 5G services in venues, stadiums, arenas, mass transit systems, campuses and enterprise locations. Much more flexibility will be needed for DAS installers and service providers to develop methods of delivering 5G services in buildings, where most 5G services will be used.■

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Taking 5G to the Next Level with Standalone 5G

AT&T is architecting tomorrow's wireless network to connect people to greater possibility. As engineers, theydesign, build, test, refine and repeat to get more out of 5G's connection and developers can build and deploy the next generation of apps and services.

A key part of this evolution is the critical transition phase AT&T is entering in scaling from 5G Non-Standalone (NSA) to 5G Standalone (SA).

How does SA take 5G to the next level? Unlike 5G NSA that still relies on a 4G LTE core, 5G SA uses a dedicated 5G core that can unlock capabilities like faster upload speeds, ultra-low latency, ultra-high reliability and edge functions. This technology will be key to business opportunities like the next generation of connected cars.

AT&T has said that they plan to deploy SA 5G when the ecosystem is ready, and AT&T is charging forward to advance SA ecosystem readiness. Businesses and developers will be some of the first to take advantage of the new technologies 5G SA enables as we continue to move from research and development to their deployment.

UPLINK: WHERE CHALLENGE MEETS OPPORTUNITY

This new age of connectivity is not only about consuming more content but also generating more content than ever before. Demand for uplink capacity and speed continues to increase, about 30 percent a year in AT&T's mobility network.

Whether you are uploading large files, on a video call with family, live streaming, cloud gaming or using extended reality applications, the network is facing surging upstream traffic demands it never has before.

Just a few weeks ago, AT&T completed the first 5G SA Uplink 2-carrier aggregation data call in the U.S. CA means they are combining or "aggregating" different frequency bands to give you more bandwidth and capacity. For you, this means faster uplink transmission speeds. Think of this as adding more lanes in the network traffic highway.

No one in the U.S market has successfully aggregated two carriers in 5G SA uplink – until now.

The test was conducted in AT&T labs with Nokia's 5G AirScale portfolio and MediaTek's 5G M80 mobile test platform. AT&T aggregated their low-band n5 and our mid-band n77 spectrum. Compared to the low-band n5 alone, a 100 percent increase was seen in uplink throughput by aggregating the low-band n5 with 40 MHz of the mid-band n77. Taking it a step further, they achieved a 250 percent increase aggregating 100 MHz of n77, achieving upload speeds of over 70 Mbps on n5 with 40 MHz of n77 and over 120 Mbps on n5 with 100 MHz of n77.

While carrier aggregation is like adding more traffic lanes in the highway, adding another vehicle to carry traffic is another way we are managing surging uplink demand. This is being done via a two-layer uplink MIMO on time-division duplex (TDD) in the mid-band n77. MIMO combines signals and data streams from multiple antennas ("vehicles") to improve signal quality and data rates. This feature will not only improve uplink throughput but also enhance cell capacity and spectrum efficiency.

NETWORK DESIGN AND DEVICE READINESS GO HAND IN HAND

Although AT&T continues to make progress in enhancing uplink coverage, they haven't forgotten about the downlink. Enhanced downlink and uplink carrier aggregation capabilities work together to bring the 5G SA performance today's technologies need.

Last fall, AT&T completed a 5G SA four component carrier downlink call by combining two frequency-division duplex (FDD) carriers and two TDD carriers. These capabilities enable AT&T devices to aggregate our mid-band n77 in the C-Band and 3.45 GHz spectrum ranges. Compared with low-band and mmWave spectrum, mid-band n77 provides a good balance between coverage and speed. This follows the 5G SA three component carrier downlink feature that we introduced last year to 2022 AT&T Flagship devices which combines one FDD carrier and two TDD carriers.

In the coming months, AT&T will also enable 5G New Radio Dual Connectivity (NR-DC), aggregating the low and mid-band spectrum with the high-band mmWave spectrum on 5G SA. AT&T labs have achieved 5G NR-DC downlink throughput speeds of up to 5.3Gbps and uplink throughput speeds of up to 670 Mbps. This technology will help provide high speed mobile broadband for both downlink and uplink in stadiums, airports and other high density venues.

The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to provide differentiated experiences. Here are some features that are on the horizon for 5G SA:

- Specialized Network Services –network slicing, precision location, private routing, etc. – for tailored network solutions to meet specific user requirements
- Non-terrestrial network solutions to supplement coverage in remote locations
- Reduced capability 5G (RedCap) for a new generation of 5G capable wearables, industrial IoT or wireless sensors and other small form factor consumer devices.

AT&T is dedicated to being the best connectivity provider. The 5G SA ecosystem is rapidly evolving, with new technologies and capabilities being introduced to set the foundation for next generation applications and services.■

Power Amplifier Modules and Their Role in 5G Design

Shawn Gibb, Senior Product Line Manager
5G Base Station Products

5G is one of the most important and powerful technologies ever to reach the market in the field of wireless communications. Offering significant improvements in data rates, latency and capacity as compared to 4G, 5G is poised to be a truly transformative technology in the industry and the world.

Yet, these radical performance improvements generate increased strain on and tighter requirements for the underlying radio frequency (RF) hardware. One of the most instrumental pieces of RF hardware is the power amplifier (PA), a device whose importance has only increased with the proliferation of 5G. To help ease the challenges of designing RF PAs for 5G, power amplifier modules (PAMs) have become an important tool in recent years.

In this post, we'll talk about PAs, their role in 5G, and how Qorvo leverages PAMs to help support the 5G infrastructure of the future.

WHAT IS A PA?

When working with RF signals, especially at the higher frequency bands of 5G, voltage levels can be extremely low. This is a challenge because the electromagnetic (EM) signal becomes more susceptible at lower amplitudes to the effects of system-level noise (i.e., signal-to-noise ratio decreases). On top of this, lower-voltage signals generally lack the strength necessary to drive downstream circuitry or antennas.

To address these challenges, engineers use PAs. An RF PA is a circuit block that serves to increase the amplitude, power output, or drive capacity of an RF signal. Generally, RF PAs live near the system antennas to provide a transmitting antenna with a high-power signal.

With a PA, the goal is to boost the signal while maintaining a high level of fidelity from input to output. For these reasons, linearity, efficiency and output power are important specifications for a PA.

PA DESIGN CHALLENGES

Historically, PAs and their surrounding circuitry were designed using discrete components on a board. While this approach has served the industry for many years, the efficacy of this approach is coming into question as several nontrivial design challenges emerge.

One of these challenges is being able to balance the tradeoffs among area, cost, performance and power consumption. Generally, these specifications tend to conflict with one another, and designers must know how to optimize their circuits to balance the tradeoffs in an optimal way for their given application. Balancing these tradeoffs is increasingly difficult when using discrete components as considerations like part selection, component interoperability, and layout impact performance.

This is further confounded when moving to 5G, where systems need to cover wider bandwidths and higher frequency ranges. Today's systems require an average instantaneous bandwidth of up to 400 MHz while operating at frequencies up to 4 GHz. The challenge is now maintaining the aforementioned system tradeoffs while also providing performance over this frequency band.

SOLUTIONS WITH A PAM

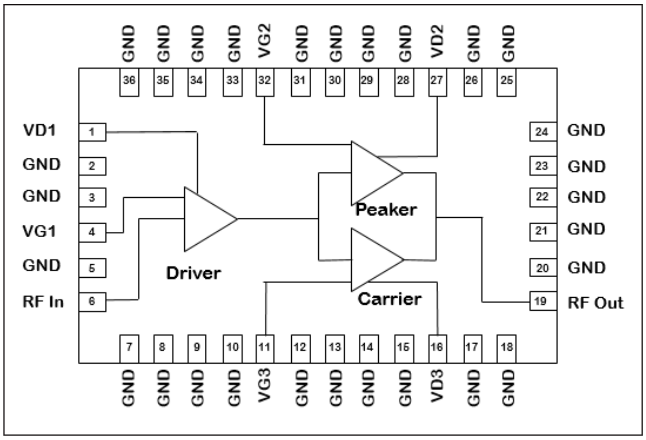
To address these challenges, Qorvo has turned to PAMs.

A PAM is an electronic component that integrates the discrete components in a PA, and its surrounding circuitry, into a single packaged solution. For example, in the application of a 5G base station, a PAM might integrate the driver amplifier and final stage amplifier into a single package as opposed to implementing them as discrete circuit blocks. By integrating the entire PA system onto a single module, we can achieve many important results (***Figure 1***).

First, PAMs make the design of RF systems, such as base stations, significantly easier than the discrete option. Instead of selecting components and designing a discrete circuit, designers can instead select a module that fits their needs and implement it within their system as a whole.

Beyond this, PAMs can offer improved performance and area when compared to non-module solutions. By integrating the components, layout concerns, such as parasitics, can be minimized, resulting in higher performance and efficiency. Qorvo PAMs also address considerations like impedance matching for the designer, ensuring that maximum performance is attainable.

Lastly, this integration allows for smaller systems on average, saving weight and area for users in their final system design.



▲ **Fig. 1** **The Qorvo QPA4501 PAM incorporates a Doherty final stage for high power and efficiency.**

QORVO'S PAM EXPERTISE

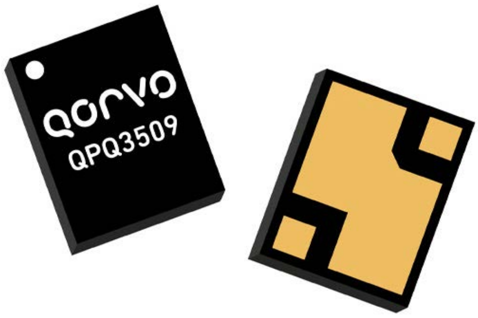
Qorvo offers the industry's largest, most innovative GaN-on-SiC portfolio to help users realize superior efficiency and operational bandwidth. The GaN-on-SiC products deliver high power density, reduced size, excellent gain, high reliability and process maturity. Qorvo recognizes the importance of PAMs in the future of 5G system designs and is working to bring industry-leading solutions to the market. Qorvo's PAMs aim to offer a balance of power, efficiency, size and cost while making the design as easy as possible for the users.■

About the Author

Shawn Gibb

Senior Product Line Manager for 5G Base Station Products

Shawn has been working on GaN technology for more than 25 years and understands the capabilities and challenges of this technology. As the Product Manager for our GaN Base Station products, he works in tandem with customers and our renowned team of GaN experts to develop state-of-the-art products that will shape the future of wireless communications.



Open RAN's Promising Future for 5G Design

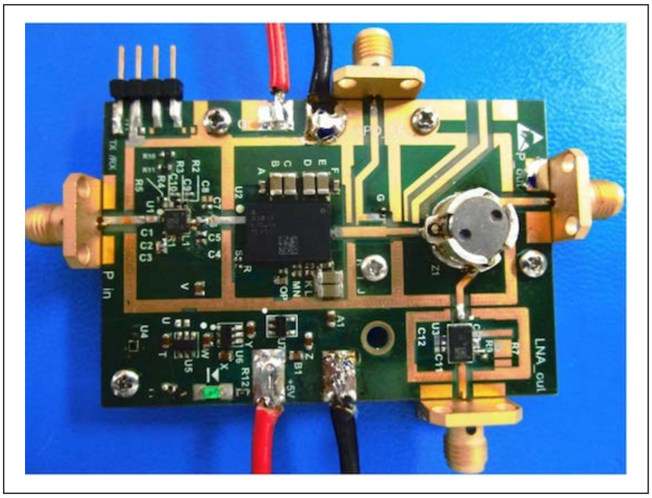
Qorvo

Say the term "5G" and consumers often think about getting the most out of their smartphones or tablets, setting up a personal Wi-Fi hotspot, watching video on demand in an airport, or making video calls to their family on the other side of the country. Electronic engineers and designers may think that way too, but they must also consider the demands that 5G systems and infrastructure put on their work. Over the years, key players in the telecommunication industry have created an ecosystem that forces service providers like AT&T, T-Mobile and others to be locked with specific equipment vendors into various system configurations.

Open RAN (Open Radio Access Networks) is a standardized approach to RAN hardware and software disaggregation. Open RAN will foster network vendor competition and innovation. It is a methodology to open up these systems for manufacturers to be able to service these networks. Open RAN offers greater flexibility and choice in designing and implementing 5G products.

Traditionally, the radio access network components were tightly integrated and controlled by a single vendor, limiting the options for product designers. By using the Open RAN methodology, designers can leverage a more open and standardized architecture, allowing them to mix and match components from several vendors. This flexibility enables designers to select the hardware and software solutions that work best for them, leading to improved product performance, innovation, and cost-effectiveness.

In the marketplace, Open RAN can promote increased competition benefiting both designers and consumers. By breaking down the traditional vendor lock-in and promoting interoperability, Open RAN encourages the participation of multiple vendors and start-ups. This more competitive landscape can lead to technological advancement reaching the market faster. As a result, designers can access a wider range of cutting-edge technologies, and consumers can take advantage of more diverse and innovative 5G products that cater to their specific needs.

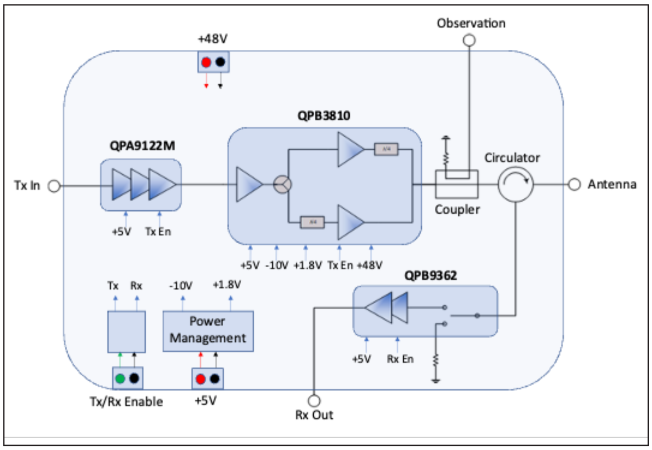


Reference Design Board: 8 Watt mMIMO 3.4-3.8 GHz RF Front End.

QORVO'S NEWEST OPEN RAN 5G SUPPORT

Qorvo's most recent offering to promote Open RAN methodology are the QPB3810, QPB9362 and QPA9122 included in a full RF front-end reference design for 5G mMIMO applications. The reference design pictured below, provides a complete solution for a RF front end (RFFE) for an 8W average output power mMIMO 5G application in band n78 (3.4-3.8 GHz). It provides a transmit and receive solution from the digital front end to the antenna filter in a compact layout, which can be directly implemented into an array.

The transmit chain features the QPA9122M as a wideband high linearity pre-driver and the QPB3810 as a highly efficient GaN final stage power amplifier module. The transmit chain also includes a directional coupler for DPD observation path as well as a circulator. For the re-



Block diagram of 8 Watt mMIMO 3.4 GHz RF Front End Reference Design Board.

ceive chain, the reference design includes the low noise QPB9362 switch LNA.

The QPB3810 is the first commercially released GaN based module with an integrated bias controller factory programmed to set the optimal bias points of the Doherty Power Amplifier Module (PAM). The QPB3810 is a 48V, 8 W average power PAM covering the 3.4 – 3.8 GHz band. The bias controller includes a temperature sensor allowing it to automatically adjust bias over temperature and includes an enable pin for fast TDD switching. The QPB3810 is available in a compact 12 mm x 8 mm SMT package, offering a much smaller footprint than traditional discrete component solutions; and similar to Qorvo's other PAM products which require minimal external circuitry.

Also being released: Qorvo's QPB9362. This receive module is targeted for 5G wireless infrastructure applications configured for TDD-based mMIMO architectures. Its switch LNA module integrates an LNA with a high-power handling switch which can be used as a failsafe path to termination when a radio is in transmitting mode. The QPB9362 provides 34.5 dB of gain with 1.1 dB typical noise figure over the entire operating frequency band in the receiving mode and LNA power down mode is available via a transmit/receive control pin on the module. It is packaged in a RoHS-compliant, compact 5 mm x 3 mm LGA package.

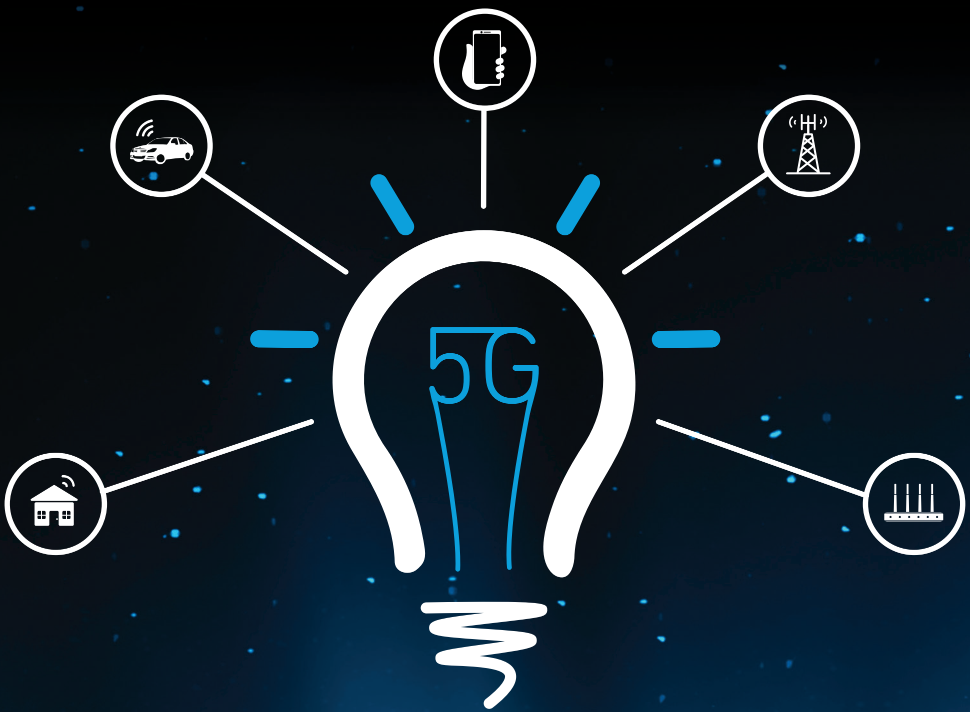
FASTER DEVELOPMENT PLUS SECURITY

Open RAN clearly enables rapid deployment and scalability for 5G networks, benefiting both designers and consumers. The open and standardized interfaces allow for easier integration and interoperability of network components, simplifying the deployment process. This streamlined approach accelerates the time-to-market for electronic product designers, enabling them to introduce innovative 5G products more quickly. Consumers, on the other hand, benefit from faster network expansion and improved coverage, leading to enhanced connectivity and a better user experience.

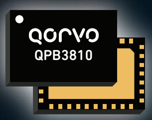
Open RAN promotes greater security and resilience for 5G products and networks. With a closed network architecture, vulnerabilities or flaws in a single vendor's equipment can potentially compromise the entire network. In contrast, Open RAN's multi-vendor approach reduces the impact of security breaches, as components from different vendors can be independently assessed and updated. This enhanced security framework reassures electronic product designers and consumers, providing them with more confidence in the reliability and integrity of their 5G products and networks.■

Your Smart Partners in RF

Powering the Industry's 5G Solutions



Compact PA Module Delivers High PAE at 8W



The QPB3810 is a compact, 50Ω, fully integrated two-stage Doherty® PAM with integrated bias controller designed for massive MIMO applications with 8W RMS at the device output covering frequency range from 3.4 to 3.8 GHz. Ideal for base stations and 5G mMIMO.

First BAW 280 MHz Band Pass Filter for 5G C-band

The QPQ3509 is an exceptionally high-performance BAW, 280 MHz bandpass filter in a compact 2.0x1.6 mm package for base station applications. Low insertion loss and high attenuation make it ideal for US 5G small cell and radio DOT systems.

Qorvo® is making 5G deployment a reality and supporting the growth of mobile data with a broad range of RF connectivity solutions. Qorvo offers an industry-leading portfolio of high-performance discrete RF components with the highest level of integration of multifunction building blocks targeted for 5G massive MIMO or TDD macro base stations.

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View our robust RF and power solutions portfolio at www.qorvo.com.

RFMW®

For more information and product samples, visit www.rfmw.com/qorvo.