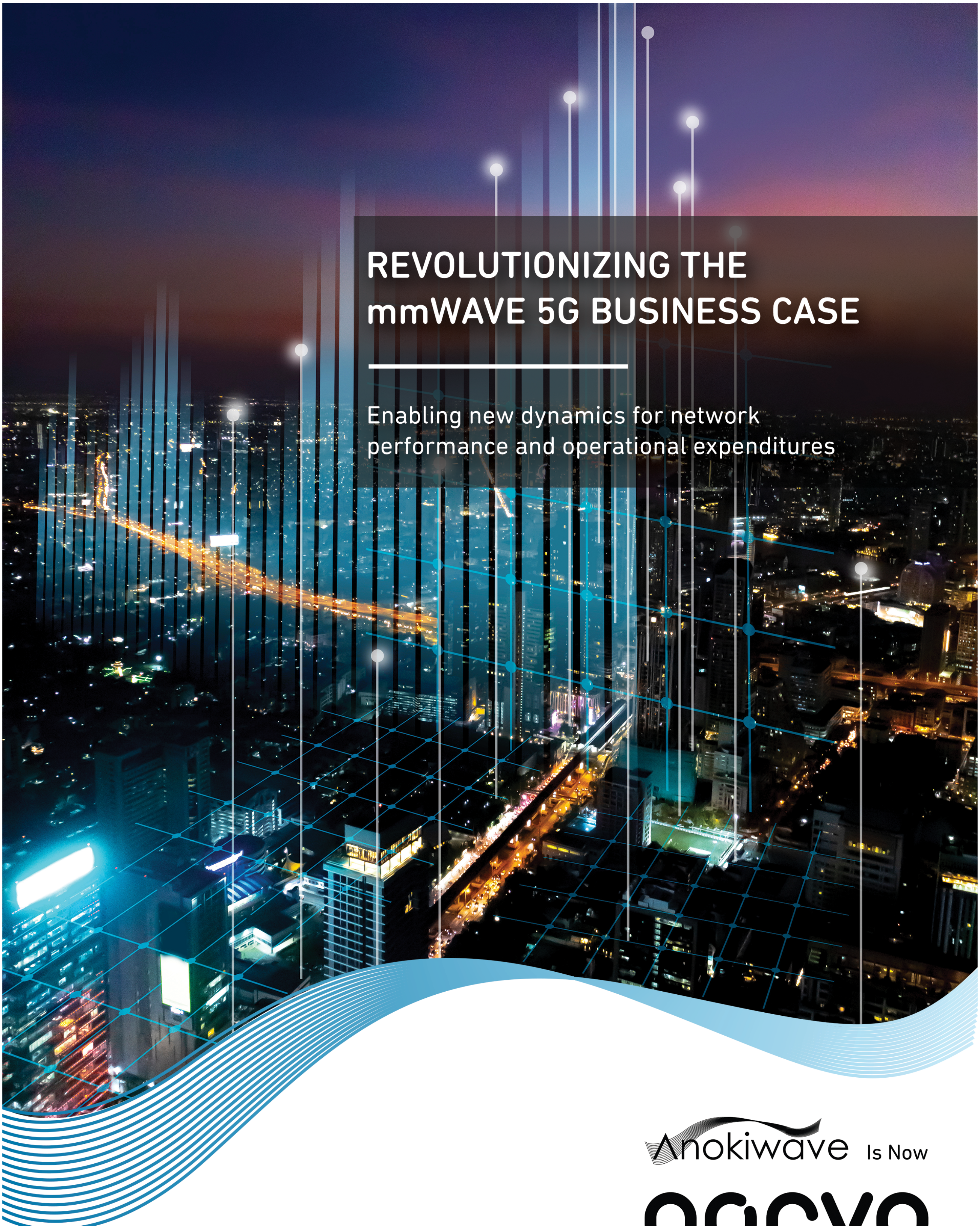
REVOLUTIONIZING THE mmWAVE 5G BUSINESS CASE

Enabling new dynamics for network performance and operational expenditures



Anokiwave Is Now qorvo

www.qorvo.com

beamforming-sales@qorvo.com

In 2024, Anokiwave was acquired by Qorvo. The combination of the two company's unique capabilities enables Qorvo to supply highly integrated complete solutions and SiPs for defense, aerospace and network infrastructure applications.

Anokiwave's innovative portfolio of active antenna ICs, combined with Qorvo's complementary products, global scale and significant market reach, provide new options for high integration and high-performance that will democratize phased array active antennas.

The following whitepaper was written to explain the impact of new IC technology to the 5G business case using Anokiwave's recently introduced silicon ICs for mmWave 5G. References to Anokiwave have been updated throughout the paper to reflect this acquisition.

Executive Summary

The use of mmWave frequency is inevitable to achieve the full potential of 5G.

5G service providers will require mmWave bands to support the emerging trend of "Mobility without Boundaries". While mmWave 5G offers immense potential in terms of bandwidth, user capacity and quality of service, developing a commercially realizable mmWave ecosystem has multiple challenges for providers. Using many of the first or second generation mmWave 5G solutions in the market today, the mmWave 5G business case often does NOT close, leading many to believe that mmWave is not the right solution to satisfy the immense (and growing) demand for data. Qorvo is changing this perception.

Anokiwave, now Qorvo, has been leading the game since before 5G standards existed and introduced today's widely accepted architecture before the FCC even assigned mmWave spectrum to 5G. The company understood that long term commercial success of mmWave 5G required silicon-based front-ends to lower the radio cost, and with every new IC generation, has introduced features, functionality and performance improvements that have enabled service providers to improve the technical performance of networks and prove the viability of mmWave 5G systems. With the introduction of the latest generation of 5G ICs, the last piece of the puzzle has been solved by providing higher power and lower noise figure at a cost point that enables commercial success for the service provider.

This whitepaper provides an overview of the state of mmWave 5G as it exists today, followed by an analysis of how our latest technology has taken the mmWave 5G business case discussion from a typical small-scale (experimental) deployment to an accessible technology for mass scale deployment, which most importantly closes the mmWave 5G business case.

Contents

"Radical industry change is imminent due to the convergence of an unprecedented demand for bandwidth and the continuing advancements being made in the silicon industry. Next generation communication devices will feature phased array antennas and operate at mmWave frequencies using highly integrated silicon ICs. When these ICs are coupled with advanced system architectures, a disruptive and refreshing change to our industry will result." Anokiwave vision - 2014.[1]

mmWave Spectrum: The Inevitable Next Step for the 5G Industry

The industry has spoken, mmWave is essential to achieve the full potential of 5G. According to the recent Ericsson "Mobility Report", published in November 2022 and recently updated in June 2023[2], global wireless data traffic is expected to grow at a 25% annual rate over next 5 years. Among various 5G market segments, Fixed Wireless Access (FWA) is forecasted to lead the group with an 31% annual growth rate.

This exponential growth of demand for wireless data has quickly depleted spectrum resources in sub 1 GHz band (also called low band) in many countries. With the recent introduction of mid-band (frequencies between 1 GHz and 6 GHz) spectrum, the industry is experiencing a temporary relief of wireless congestion. Meanwhile, if history can be a guide, the relief will be short lived as the depletion of today's sub 6 GHz spectrum (low-band and mid-band) resource in major metro areas is projected to happen over next 3-5 years according to GSMA.[3]

Adding to the stress on wireless data networks, the societal trend of untethering has not ended with just cutting traditional telephone lines. The next big wave of "cord cutting" is emerging with the younger generations' preference of "Mobility without Boundaries". *With these mega trends in mind, one must conclude that the march to high band spectrum (mmWave) by wireless industry is inevitable.*

The global deployment of 5G mmWave is now inevitable. It is essential to achieve the full potential of 5G and those embracing 5G mmWave will find themselves with a competitive advantage.[4]

mmWave 5G is Already in Place

The use of mmWave networks is not a new concept for the industry. In fact, mmWave 5G started in 2016 with the first commercial use case launched in 2018, a fixed wireless access (FWA) service, called "5G Home" by Verizon in four US cities. AT&T made the first mobile 5G browsing session on commercial 5G network equipment with plans to rollout 5G service to 19 cities in 2019, while T-Mobile announced multibillion-dollar agreements with Original Equipment Manufacturers (OEMs) for deployment in 2019. Much of this activity in the early days of 5G was powered by Anokiwave's, now Qorvo's, ICs. In fact, the ICs were featured in a 2018 video by the TV show "Daily Planet" and AT&T called "What is 5G?"[5].

Today in the US, hundreds of millions of mmWave handsets are supported by 100s of thousands of live mmWave 5G basestations. As the industry continues its rapid commercialization of active antennas at mmWave, there is an intense focus on cost reduction by navigating the traditional volume manufacturing curve, developing "next generation" products that close network-level business cases, and leverage economies of scale to achieve cost points similar to WiFi, enabling mmWave 5G to reach its full potential.

Qorvo's goal is to help customers build the most cost-effective arrays by improving the total cost of ownership and has adopted the phrase "WiFi for Infrastructure™" as its mmWave 5G business model.

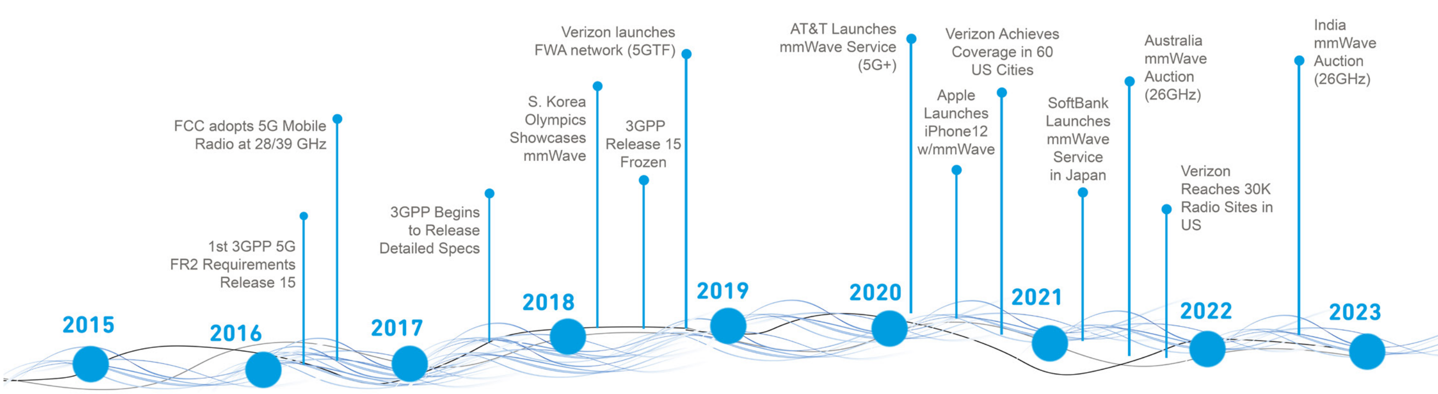


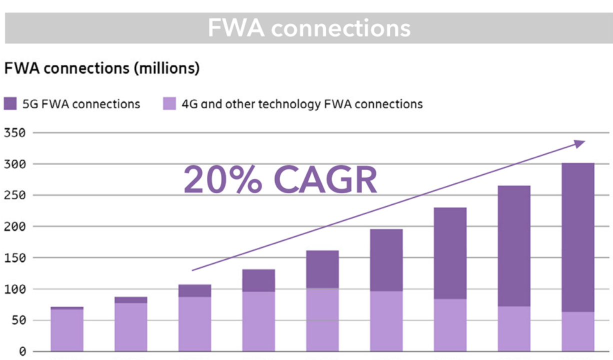
Figure 1: mmWave 5G started in 2016 with the first 3GPP release of 5G mmWave requirements. Today millions of mmWave handsets are supported by 100s of thousands mmWave 5G basestations in the US alone.

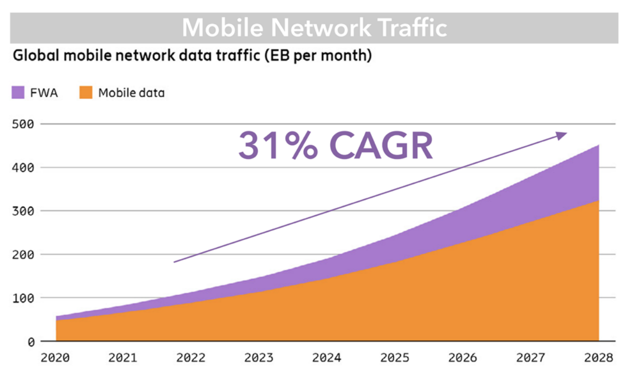
Fixed Wireless Access is the First Use Case for mmWave 5G

Diving deeper into Ericsson's Mobility Report referenced earlier, data shows that within multiple market segments, FWA is leading the growth of data consumption.

Today, FWA is addressing the household broadband connection market where residents enjoy many data intensive applications such as video conferencing, gaming, video streaming, smart home applications and many others. According to Ericsson's "Fixed Wireless Handbook" 2023 Edition[6], Global FWA connections will reach 300M by 2028 with 240M of these FWA connections based on 5G. The Compound Annual Subscriber Growth Rate (CAGR) during this period is 20% given 100M FWA base connections in 2022. *More stunningly, the FWA data traffic growth is projected to be around 31% CAGR during this same time frame.*

Due to the intensity of FWA data usage, mmWave has become the preferred frequency band to address the home broadband market and one of the first exciting mmWave use cases to emerge with concrete demand, enabling operators to "connect the unconnected".

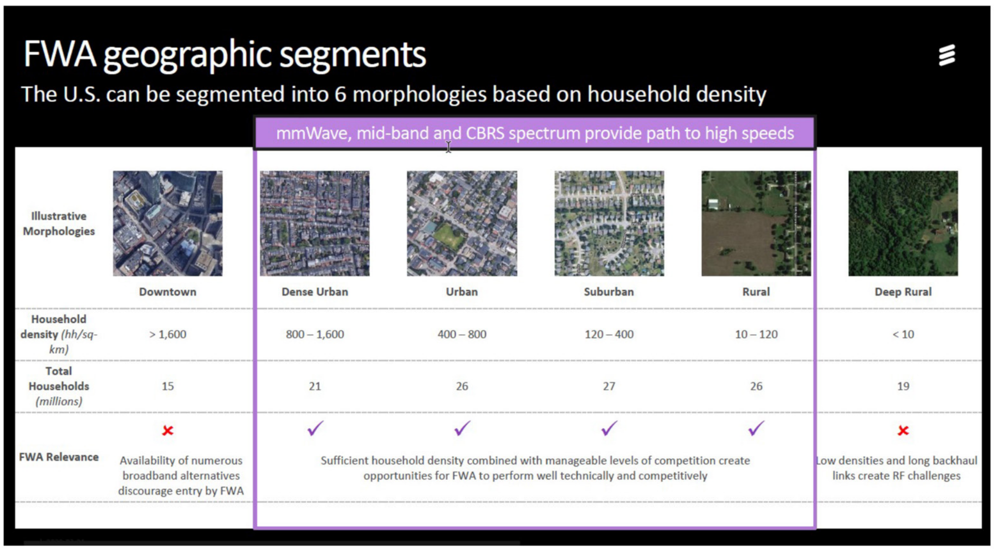




Source: Ericsson Fixed Wireless Acess Handbook 2023 Edition

Figure 2: The ever-increasing demand for data is going to drive the Fixed Wireless Access (FWA) market with mmWave as the preferred frequency spectrum.

Referencing the aforementioned Ericsson Fixed Wireless Handbook, insightful methods to develop business cases for FWA are outlined. As shown in Figure 3, addressable markets for FWA systems are those with zero or only one Fixed Broadband (FBB) provider, with housing densities ranging from dense urban (800 to 1600 households per km^2), urban (400 to 800 households per km^2), suburban (120 to 400 households per km^2), and rural (10 to 120 households per km^2).

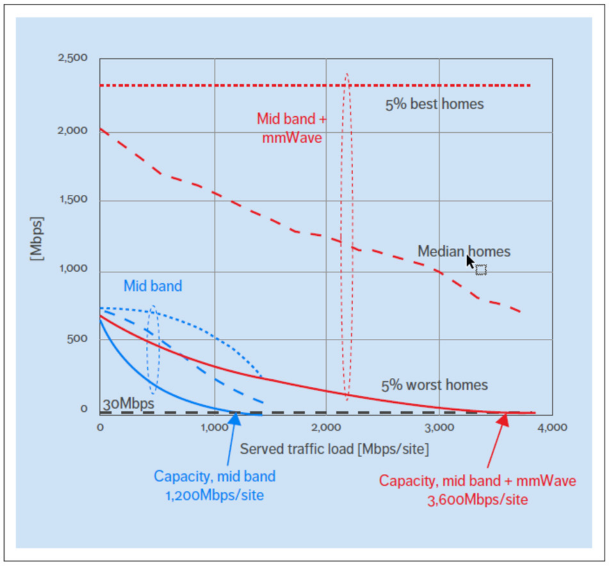


Source: Ericsson MWC mmWave Summit | 2022.09.28

Figure 3: To develop a FWA business case, addressable markets are first defined.

For each market, FWA is initially deployed using existing infrastructure operating at mid-band frequencies to meet existing FBB performance. As customer uptake increases, mmWave technology is used to dramatically increase the number of customers that can be served, as well as the overall traffic load to meet FBB data rate requirements for all users. Furthermore, mmWave assets can be added as data rates per household continue to grow, and additional customers are captured. As shown in Figure 4, adding mmWave FWA technology offers fiber like data rates delivered during non-peak periods as well as minimal viable data rates delivered during peak usage periods.

These user experienced data rates are critical to allow market penetration compared to cable and fiber Communication Service Providers (CSPs). If FWA falls below these levels, customers will not migrate away from existing systems at any cost point. These data rates represent benchmarks for use cases involving dense urban, urban and higher density suburban areas.



Source: Ericsson Technology Review | 2022.11.10

Figure 4: Adding mmWave to existing infrastructure enables user experienced data rates of 100 Mbps at nonpeak and ~30 Mbps at peak – a critical metric to allow market penetration for FWA.

Given the strong projection of demand for mmWave frequency bands, the industry must overcome the remaining impediments to enable large scale deployments of 5G FWA systems. The cost of first-generation gNodeB and CPEs are still relatively high, and today's CPEs lack the performance to effectively implement optimal cell site performance and deliver data rates to the end users. Also, the lack of diversity in the 5G mmWave modem IC marketplace is inhibiting new entrants into the CPE ecosystem.

The business case for mmWave 5G assumes a high-power CPE device with performance to close the link, enabling high "fiber like" data rates, but this device does not exist in today's ecosystem. Ongoing innovation in silicon-based IC technology is necessary and will enable service providers to harness the mmWave FWA use case through lower OPEX and CAPEX costs.

An early proof point of mmWave FWA is from the Government of India, who believes that mmWave FWA is the most economical way to leapfrog other nations in "breaking down the digital divide", avoiding the need to deploy expensive last 100m fiber feeds. The savings derived by not deploying that last 100m of fiber is in the range of 1 billion dollars per a recent GSMA estimation. In India, Reliance Jio is planning to launch a FWA network called "Airfiber" to leverage its 26GHz spectrum acquired during 2022 spectrum auctions.

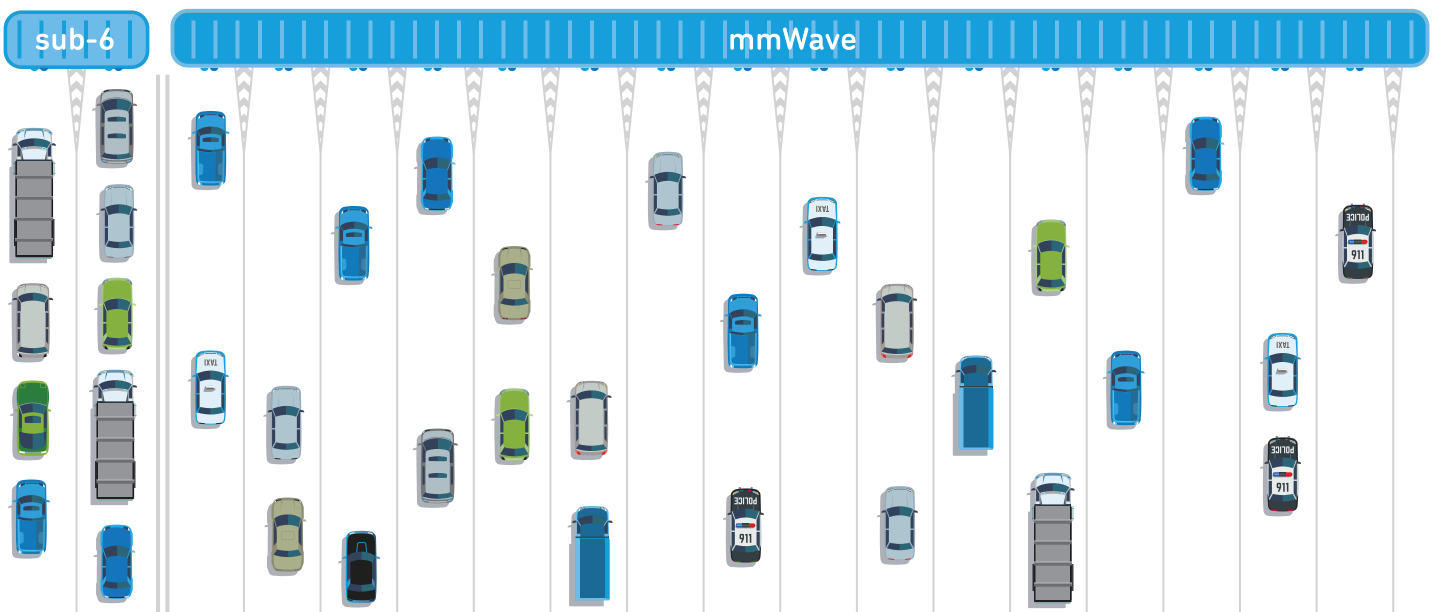


Figure 5: mmWave adds capacity to the busy sub 6 GHz spectrum allowing faster, less congested connections.

Achieving True mmWave Commercialization

Although the thesis to support mmWave proliferation is strong, the industry must take the next step of proliferating 5G mmWave by leveraging the accomplishments already in place and by innovating further, improving performance and reducing cost to that of a WiFi connection to achieve true commercialization of mmWave networks.

Cost is an important piece of the mmWave 5G growth equation. If history can predict the price point that will proliferate a new mmWave CPE for FWA, look no further than the WiFi router. Today, a mmWave 5G CPE cost is at several hundreds of dollars; although this sounds expensive in comparison with today's WiFi router, one needs to understand that the innovations mentioned in this white paper will dramatically drive down the cost of the CPE.

Given the history of the silicon industry, there is no doubt the cost targets of mmWave equipment will be reached and the perceived deficiency will be resolved and will follow the WiFi proliferation example.

The success of the silicon industry is built on cutting costs by increasing the levels of integration, so it may come as no surprise to many that the mmWave front-end in today's 5G equipment is rooted in silicon technology and is poised to lead the cost cutting curve. Anokiwave, now Qorvo, a silicon industry leader, has successfully achieved 90% cost reduction within 4 generations of silicon mmWave beamforming ICs (BFICs) over the past 6 years. Even better, the performance of these products has quadrupled on every KPI benchmarked by industry analysts.

Since the mmWave front-end makes up the lion's share of gNodeB and CPE equipment cost and energy consumption, the impact of these savings provided on both CAPEX and OPEX are huge. In a recent blog article, entitled “Bending the mmWave 5G Energy Curve", the energy savings in a real-world metropolitan city is showcased. The Radio Unit (RU) using the new generation of our beamformer ICs (BFICs) can bend the energy consumption curve downward over the next decade even with the projected growth of mmWave sites.

Along with cost reductions, the technical challenges of commercializing mmWave must be addressed and resolved:

1. Shorter range associated with high path loss result in small cellular cell size.
2. Signal blockages due to buildings, trees, and other obstacles.
3. High cost of mmWave equipment plus the cost of deploying denser networks with more nodes.
4. Cost of updating existing infrastructure to support mmWave 5G gNodeB equipment.
5. Regulatory issues such as assigning mmWave spectrum to MNOs in a timely fashion before the data congestion in urban areas occurs.

These obstacles/challenges are not new to wireless industry. It is a living story repeated when the industry migrates from generation to generation and from low-band to mid-band to mmWave spectrum. However, the pace of this migration, driven by continued data growth, is uneven and varied from country to country. *With commercial mmWave deployment already a reality in US, it is just matter of time before these challenges are addressed fully.*

Addressing the Market Challenges with Silicon IC Innovations

The market challenges described in the previous section are identified as Scalability, Technical and Commercial and are shown in the outer ring in Figure 6. These market challenges flow to the system impact to the Cellular Service Providers (CSPs) and include manufacturing cost, BOM (CAPEX) cost, OPEX cost, quality of service and time to market metrics. Finally, the impacts of these challenges to the mmWave radio include production test time, economies of scale between radio types, radio size, DC power which impacts OPEX and CAPEX, coverage area, user capacity and supply chain management.

Many of the technical challenges of commercializing mmWave are solved with IC innovations. The latest ICs from Qorvo provide orders of magnitude improvements of signal levels between the gNodeB and CPE in the system, allowing higher user capacity, larger coverage areas, and increased quality of service, lowering the CAPEX requirements for the Cellular Service Provider.

These interdependent challenges at the market level, system level and radio level must be addressed comprehensively to further enable the mmWave ecosystem.

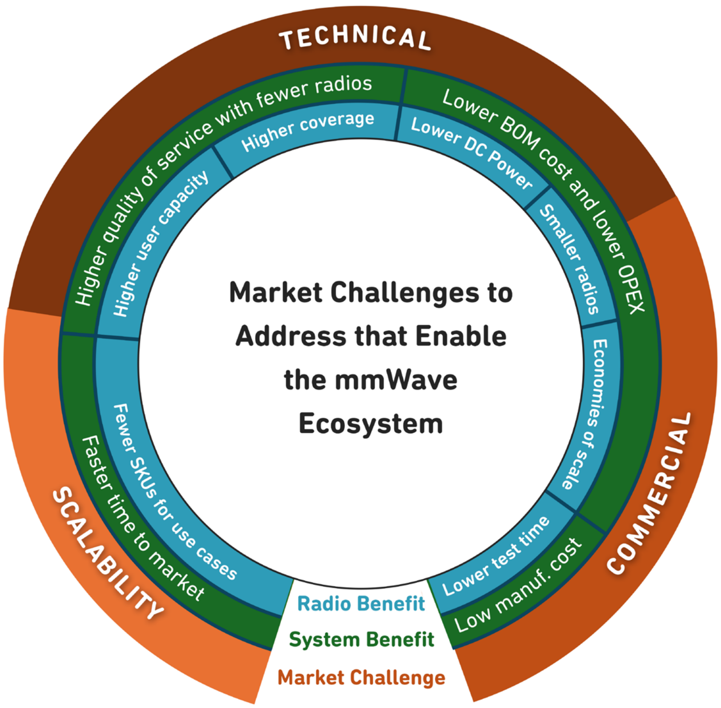


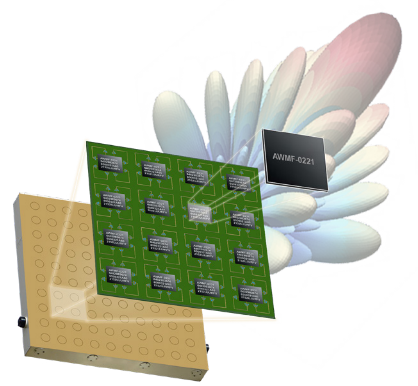
Figure 6: Market challenges to solve that enable the mmWave ecosystem to proliferate.

mmWave radios differ from sub 6 GHz radio systems in several ways. First, signals that are transmitted at mmWave decrease much faster over distance than signals at sub 6 GHz. Second, performance metrics, such as amplifier output power, noise figure, linearity and DC power are much harder to achieve at mmWave frequencies due to fundamental physics of semiconductors. At sub 6 GHz frequencies, both semiconductors and antenna systems have evolved over the last several decades to enable a mature ecosystem, allowing operation of wireless technologies at low-cost points, and present a very well-known business case to wireless providers and CSPs for FWA applications.

To overcome these differences between operating in lower bands vs. mmWave, phased array antennas are used for mmWave systems. Fundamentally, phased array antennas use many elements to avoid transmitting energy in unwanted directions and to send energy in a particular direction by changing the amplitude and phase of each signal at every element. This energy can be steered in different directions by varying the phase and amplitude at each element. Phased array antennas have been used for more than 5 decades in government markets which can tolerate much higher cost points compared to commercial markets. These higher cost points allowed engineers to focus on performance that included liquid cooling solutions, high test and calibration costs and exotic semiconductor technologies.

As the market for mmWave phase array antennas grew into commercial applications, Anokiwave, now Qorvo, led the way in developing solutions that validated first generation mmWave 5G networks. We invented the quad BFIC architecture, which allowed symmetric implementation of phased array antennas in a printed circuit medium, with high volume/low-cost scalability, that are used in both base stations with large numbers of ICs and antenna elements and CPE applications with much fewer ICs and antenna elements at a much lower cost point.

Anokiwave, now Qorvo, produced the first commercially available mmWave 5G ICs using low-cost silicon-based processes with high integration of multiple functions, including digital control circuitry. Thermal solutions have been developed that allow passive cooling of large arrays over commercial temperature ranges, enabling world-wide deployment. These first-generation networks proved the ability of radios to support fiber like data rates in FWA applications.



Anokiwave, now Qorvo, invented the quad BFIC architecture, which allowed symmetric implementation of phased array antennas with high volume/low-cost scalability, that are used in 5G equipment enabling a much lower cost point.

Closing the mmWave 5G Business Case

Developing a commercially realizable mmWave 5G ecosystem one needs to address CAPEX costs, OPEX costs, quality of service and scalability to address available markets. In surveying solutions available today, we conclude that using today's mmWave equipment, the mmWave 5G business case faces challenges, leading many to believe it is not the right solution to satisfy the immense demand for data. Qorvo with its latest IC technology is changing this perception.

Using mmWave equipment available today, the mmWave 5G business case faces challenges, leading many to believe it is not the right solution to satisfy the immense demand for data.

Qorvo with its latest IC technology is changing this perception.

Building upon multiple generations of released and field deployed mmWave silicon IC solutions, the new fourth generation of Qorvo ICs set the underpinnings to making mmWave 5G a commercial and technical reality at a mass scale. Qorvo's products redefine innovation at every level and *provide an unmatched combination performance of the functions, features and commercial benefits to enable the 5G use case.*

Qorvo's new family of ICs provides higher linear power levels with lowest Error Vector Magnitude (EVM) performance, lowest noise figure performance and features like Zero-Cal®, temperature compensation techniques, higher levels of silicon integration and wideband operation.

The Zero-Cal® feature and temperature compensation techniques, when combined with appropriate PCB layout of array feed networks, can dramatically reduce, or eliminate the need for array level calibration, decreasing radio cost and reducing CAPEX.

Our latest ICs provide higher linear power as well as improved noise figure performance, providing an order of magnitude improvement of signal levels between the gNodeB and CPE in the system architecture. Using these ICs in mmWave equipment results in higher user capacity (higher data rates), higher coverage areas (fewer cell sites) and increased quality of service with fewer radios, lowering the CAPEX requirements for the CSP.

The broadband operation allows hardware manufacturers to develop single radio SKU's that can be scaled in production around the world for different regions with different operating bands. This leads to faster time to market and higher volumes of fewer radios, further reducing CAPEX due to leveraged volumes across multiple markets. Figure 7 shows the new IC features mapped into the prior market challenges shown on the left – demonstrating the latest beamformer ICs have solved the problems associates with taking mmWave 5G networks to the future and developing a commercially realizable ecosystem.

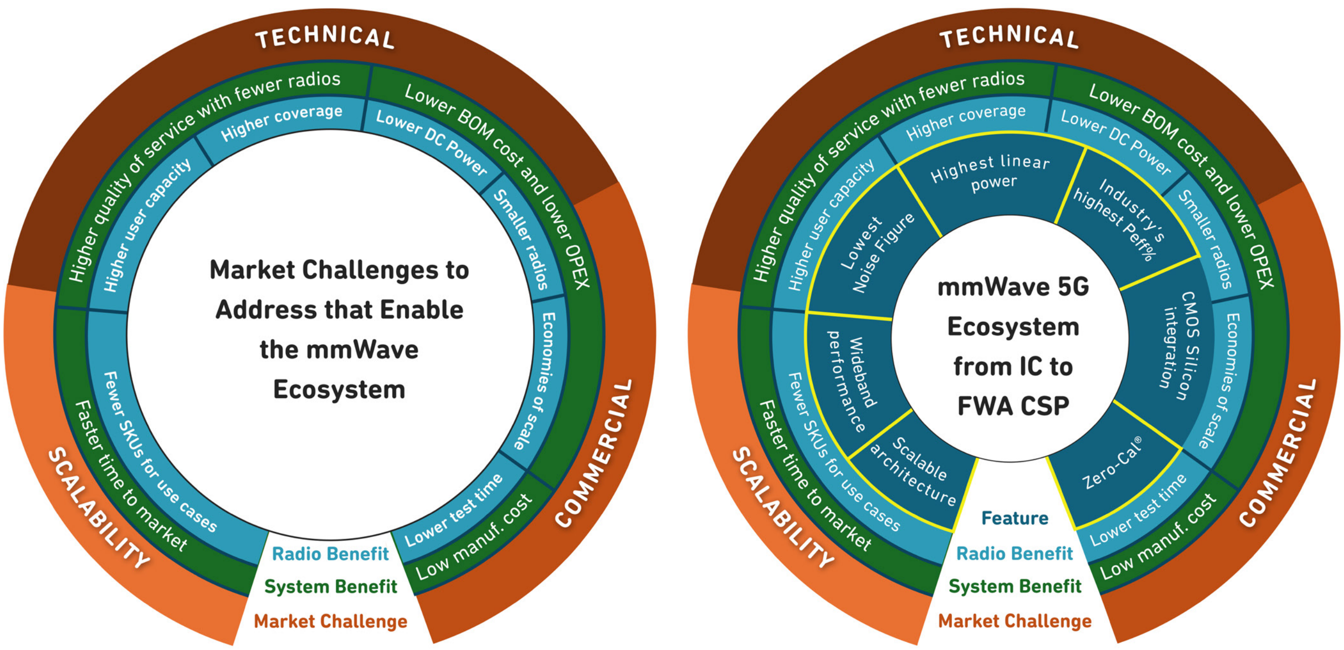


Figure 7: Superior IC performance solves the mmWave 5G commercial and technical roadblocks and closes the mmWave 5G business case.

To understand the impact Qorvo's IC technology on the 5G ecosystem, a comparison was made between current available radios (both gNodeB and CPE equipment) with new improved radios that implements Qorvo's IC technology. *This comparison demonstrates the impact to the CSP business case.*

The table below shows the resulting data from this analysis.

	Today' Solutions (Early mmW 5G Generations)	Qorvo Enabled Solutions	Qorvo Advantage
gNodeB Power (EIRP)	62 dBmi	68 dBmi	6 dB
gNodeB Rx Sensitivity (EIS)	-114 dBm	-120 dBm	6 dB
CPE Power (EIRP) (for equivalent cost and DC Power)	36 dBmi	48 dBmi	12 dB
CPE Rx Sensitivity (EIS)	-109 dBm	-113 dBm	4 dB

UPLINK budget improves by 18 dB
DOWNLINK budget improves by 10 dB
RESULTS in >4X more coverge area

Figure 8 shows an example Qorvo enabled CPE array supporting 48 dBm EIRP and -113 dB sensitivity, while Figure 9 shows measured antenna patterns for this array. *With features such as Zero-Cal® (shown in Figure 10) and temperature compensation techniques (shown in Figure 11), calibration of these arrays can be drastically reduced or eliminated, decreasing production cost.*

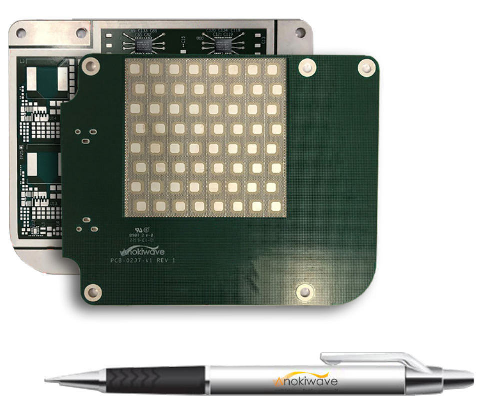


Figure 8: CPE sized array with Qorvo's IC technology improves EIRP by 12 dBm and sensitivity by 4 dB.

With Qorvo's technology, CPEs can be built that support EIRP levels of 48 dBm with sensitivity levels of -113 dBm. This represents a 12 dBm improvement in EIRP and 4 dB improvement in sensitivity compared to existing equipment.

The CPE device with performance to close the mmWave 5G link, enabling high "fiber like" data rates, can now exist in today's ecosystem.

MEASURED TRANSMIT AND RECEIVE SCAN PATTERNS

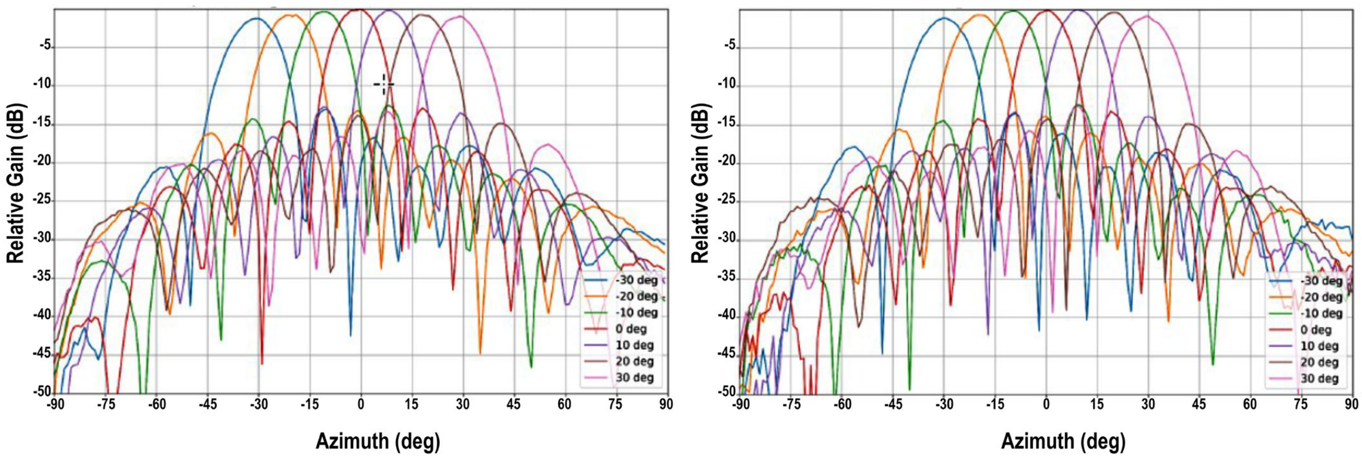
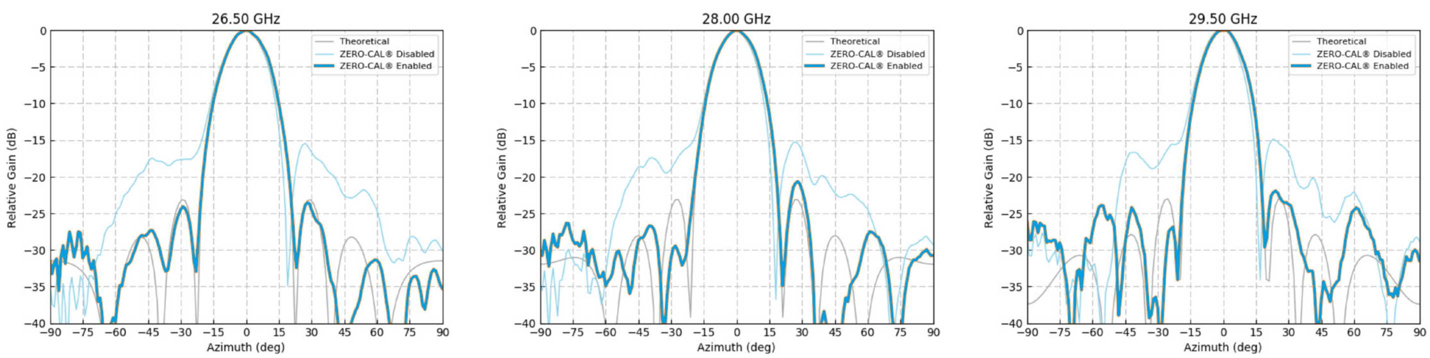


Figure 9: **Proven antenna performance:** One of the things in which Qorvo takes pride is providing ICs that successfully work in mmWave active antennas



✓ Qorvo Zero-Cal® technology ensures:

- ✓ Each IC to self-align to prescribed performance levels
- ✓ High device to device and channel to channel repeatability

Figure 10: **Measured results** showing near ideal performance and 5 dB improvement in the sidelobe levels with Zero-Cal® applied and no other calibration required

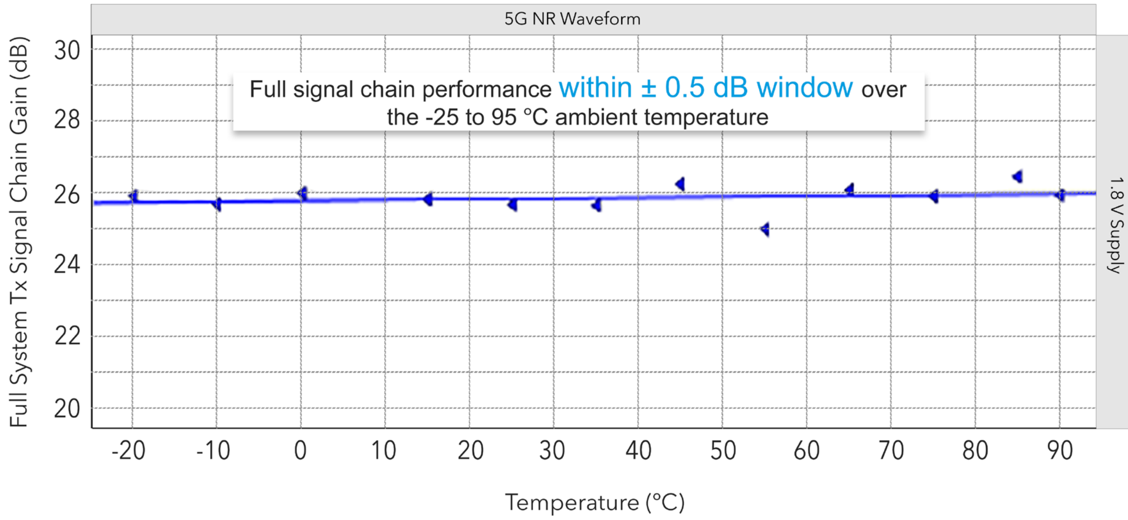


Figure 11: An entire mmWave signal chain (BFIC, IF up/down converters, and LO synthesizer) maintaining a ±0.5 dB gain window across the entire temperature and frequency range, without requiring user feedback or exotic control mechanisms.

The net effects of these improvements on system performance are game-changing. Using the new IC performance and modeling an entire mmWave cellsite, we can demonstrate to network operators and OEMs a dramatic difference in performance and economics. The details of the basic cell model are described in Appendix A.

Calculating link budget with the improved performance of Qorvo enabled equipment, we find the **uplink** (from the CPE to gNodeB tower) **improves by 18 dB**, while the **downlink** (from the gNodeB tower to the CPE) **improves by 10 dB**. Using a simple rule of propagation physics to maximize return on investment (ROI): “Every 6 dB added to a mmWave link budget, either by increasing EIRP on transmit or reducing sensitivity (EIS) on receive, will result in 4X the amount of coverage area”. This translates to completely different dynamics on the network performance, cost of deployment and operational expenditures.

At a system level, for the operators, this means:

- Greater coverage and number of users per site:
  - **>4X more area** covered per cell site
  - **>3X additional users** for a given data rate
- Lower CAPX per user, per site, and per gNodeB:
  - **>70% lower cost** per km^2 for mmWave coverage
  - **Faster ROI** and shorter payback period to positive cash flow

These results are market revolutionizing and for the first time, make mmWave 5G not just technically viable but also commercially viable at scale.

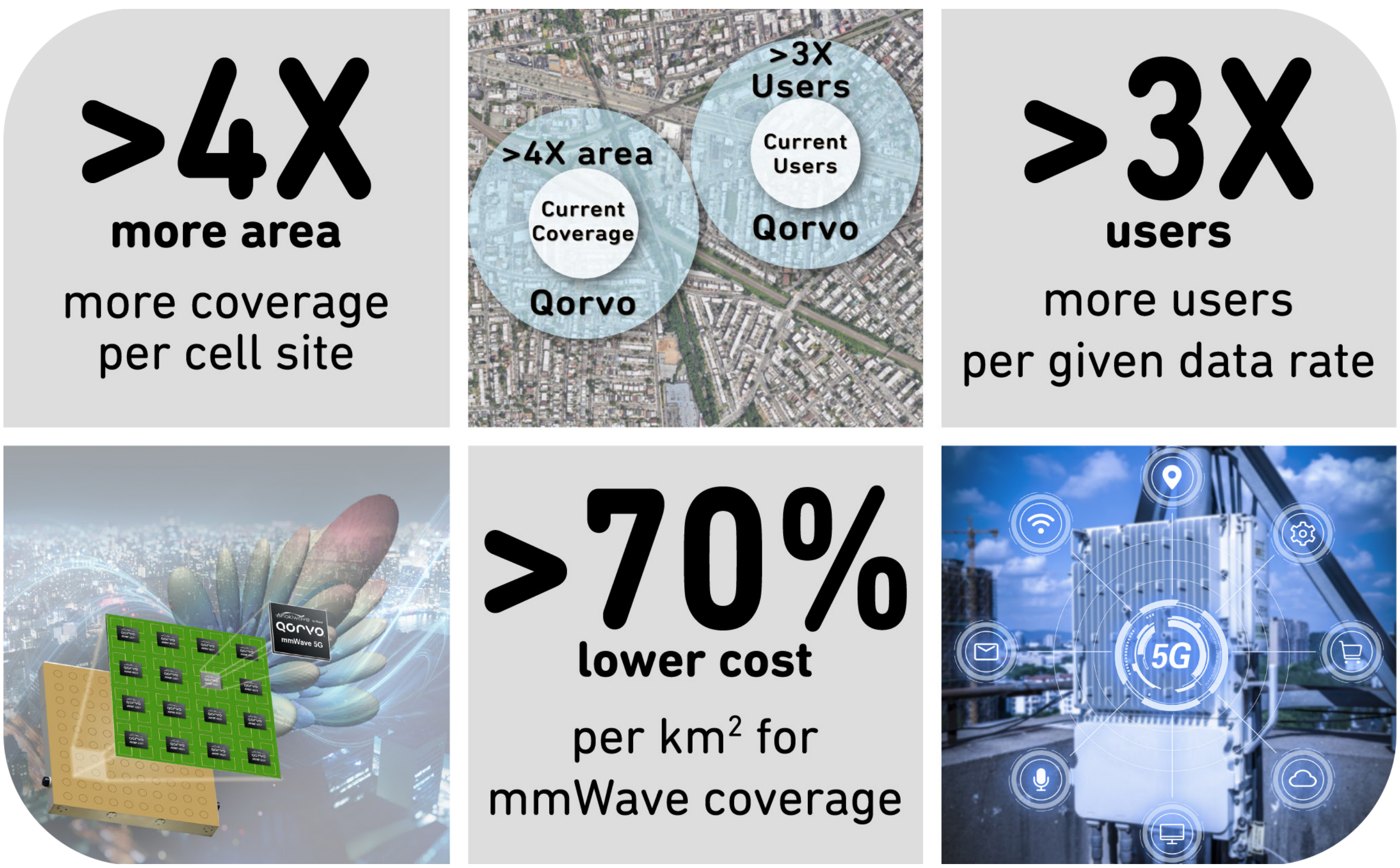


Figure 12: Qorvo ICs used in CPE and gNodeB equipment redefine the mmWave 5G economics

Enabling a New World

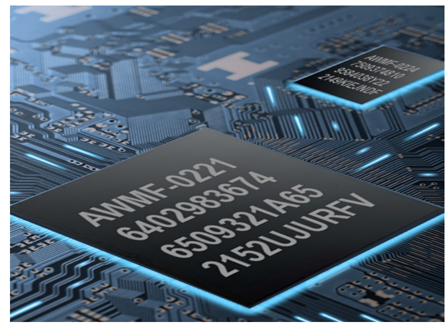
Before the 3GPP standards were even established, Anokiwave, now Qorvo, was developing the first mmWave IC for 5G. We saw this market coming and were called “crazy” for investing in mmWave silicon ICs for phased array antennas, yet we persisted because we saw the importance of this market. That speaks to the vision and to the choices made in terms of technical architectures and key performance indicators to provide a solution that was and continues to be appropriate for the market.

As early as 2014, Anokiwave's Chief Systems Engineer predicted the use of mmWave in 5G communications in an article, dated May 8, 2014:[7] "*The industry is at a juxtaposition where the exponential demand for increased data rates coupled with Moore’s Law’s relentless march of silicon IC improvements are enabling low cost mmWave phased array antenna solutions, new radars, communication systems and even 5G handsets in the near future. The industry is indeed at a tipping point.*"

We developed these ideas and presented them in an article published in the Microwave Journal in 2015[8] discussing technology that would enable compact, low-cost arrays for commercial applications – fundamental in the rollout out of 5G infrastructure.

The resulting IC technology from that early work was introduced to the market in 2016, well before mmWave was part of the 3GPP standards. Since that first IC was introduced, we have provided continued year over year innovations and has enabled each phase of mmWave 5G technology.

Today, in 2023, with the latest beamformer ICs we have truly taken the mmWave 5G business case discussion from a typical small-scale deployment to an accessible technology for mass scale deployment, which most importantly closes the mmWave 5G business case.



Over the 20+ years of delivering commercially deployed beamformer ICs, Anokiwave, now Qorvo, has the experience and understanding of nuances of commercially deployable mmWave phased array antennas, unlike any other company, and is proven by the unique features of the ICs that make mmWave 5G commercially viable at scale

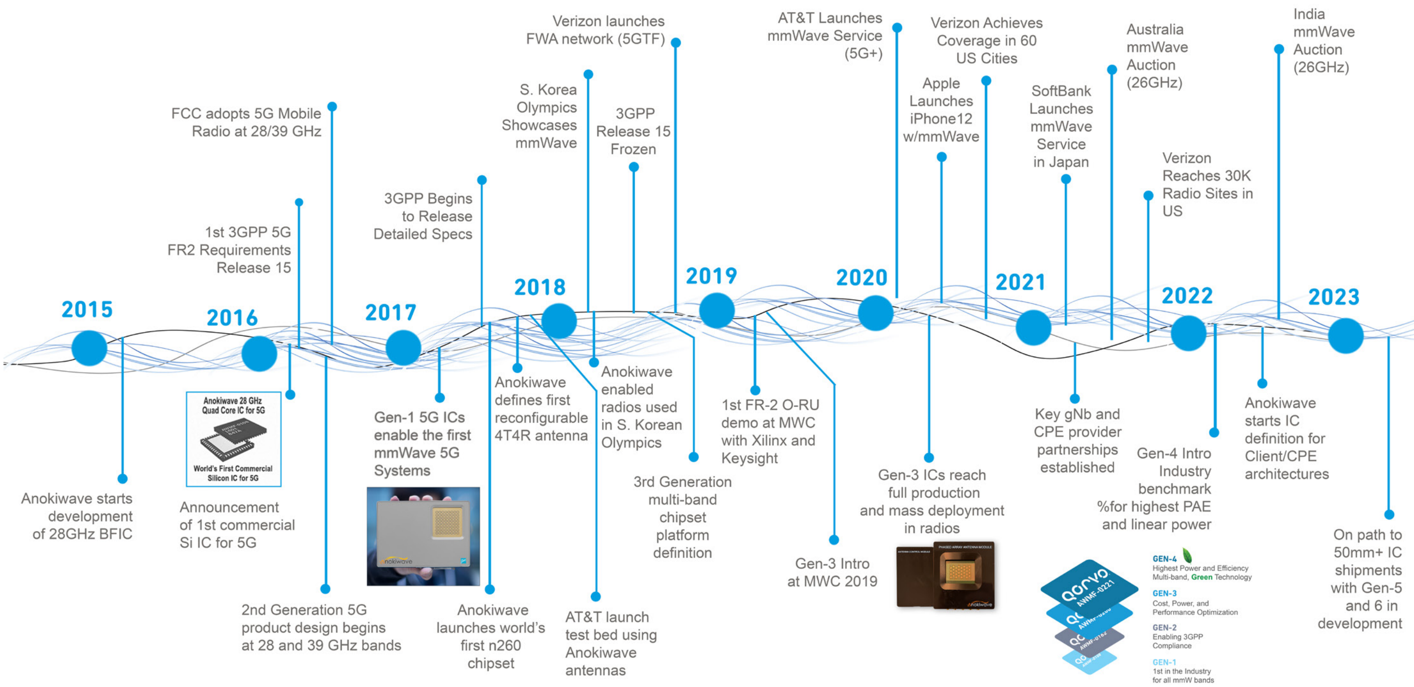


Figure 13: Anokiwave, now Qorvo, saw the mmWave 5G market coming years ago and with continued year over year innovations has enabled each phase of this new technology – well ahead of the industry.

Next Steps

The excitement around the mmWave market emergence is something we see in our careers maybe once or twice if we are lucky. For many, the viability of mmWave is a question of cost, knowhow and technical expertise, spanning everything from waveforms and frequency bands to antenna power, sensitivity and the production and manufacturability of phased array antennas. Anokiwave, now Qorvo, always understood these technical issues, and recognized that radio level cost would drive the commercial viability of mmWave 5G networks.

Producing a mmWave radio from Bill of Materials (BOM) to deployment that is cost effective enough to close the business case significantly benefits from the magic of silicon integration. Anokiwave, now Qorvo, the mmWave industry pioneer, has taken 90% of the mmWave front-end cost out over past 6 years with 4 generations of silicon IC innovations, setting the stage to making mmWave 5G a commercial and technical reality at a mass scale.

As the industry leader and pioneer, we made the right call to introduce the quad BFIC architecture before FCC even assigned mmWave spectrum to 5G. This architecture has been widely adopted across the mmWave 5G ecosystem. By foreseeing the cost challenge of commercializing mmWave 5G networks, we again led the industry by choosing silicon CMOS, that supports high levels of integration and functionality, as the baseline choice to realize a mmWave front-end to lower the radio cost. Our early generation IC's have been implemented in virtually all the operational systems, proving the technical viability of mmWave 5G networks.

Fast forward to 2023, with multiple commercial mmWave networks in operation, the focus of the industry is shifting to ways that proliferate mmWave 5G into regions and countries where it can create impactful economic, societal and environmental benefits. Qorvo is enabling that industry focus.

Anokiwave Is Now Qorvo

About Anokiwave

In 2024, Anokiwave was acquired by Qorvo. Anokiwave's innovative portfolio of active antenna ICs, combined with Qorvo's complementary products, global scale, and significant market reach, provide new options for high integration and high-performance that will democratize phased array active antennas.

The two companies' technologies enable a unique combination of innovation + commercial scale + reputation to deliver with proven commercial success across mmWave 5G, SATCOM and D&A markets.

- mmW Silicon ICs
- Intelligent Array IC Solutions®
- mmW Algorithms to Antennas®

Abbreviations

3GPP: 3rd Generation Partnership Project

BFIC: Beamformer Integrated Circuit

BOM: Bill of Materials

CAGR: Compound Annual Subscriber Growth Rate

CAPEX: Capital Expenditures

CMOS: Complementary Metal-Oxide Semiconductor

CPE: Consumer Premise Equipment

CSP: Communication Service Provider

EIRP: Equivalent Isotropic Radiated Power

EIS: Effective Electronic Sensitivity

EVM: Error Vector Magnitude

FBB: Fixed Broadband

FCC: Federal Communications Commission

FWA: Fixed Wireless Access

gNodeB: Next-Generation Node B

GSMA: Global System Mobile Association

IC: Integrated Circuit

KPI: Key Performance Indicator

Mbps – Megabits per second

MNO: Mobile Network Operator

OEM: Original Equipment Manufacturer

OPEX: Operational Expenses

PCB: Printed Circuit Board

ROI – Return on Investment

RU: Radio Unit

WiFi: Wireless Fidelity

Endnotes

1,7 - Article: "The Industry's Next Tipping Point", May 8, 2014. Corman, Moosbrugger. Article Link

2 - Ericsson Mobility Report, Published November 2022, and updated June 2023. Report Link

3 - GSMA: 5G mmWave Deployment Best Practices Whitepaper, Published November 17, 2022. Whitepaper Link

4 - Qualcomm Press Release: "Global Mobile Industry Leaders Commit to Support 5G mmWave", June 27, 2021. Article Link

5 - Discovery Channel Daily Planet Video, "What is 5G", April 13, 2018. Video Link

6 - Ericsson Fixed Wireless Handbook 2023 Edition. Handbook Link

8 - Article: "Highly Integrated Silicon ASICs: a Disruptive Technology for AESAs", November 13, 2015. Gresham, McMorrow, Corman, Jain. Article Link

Appendix A

Methodology to generate a basic cell site model:

- During peak data usage periods, all customers must receive a minimum of 30 Mbps downlink; Uplink data rates are approximately 10% of downlink for typical customers, set at 3 Mbps during peak data usage periods.
- During non-peak data usage periods, data rates comparable to fiber rates of > 100 Mbps to 1 Gbps should be supported for customers.
- For a typical gNodeB, Tx mode is approximately 50% of the time, while Rx mode is approximately 20% of the time, with other modes used during the remaining 30% of the time.
- For simplicity of the model, a 400 MHz 5G NR waveform is assumed for both uplink and downlink.
- Deployment strategies could include sub 6 GHz 5G technology initially, followed by deployment of mmWave assets after cell capacity nears 100% to offload the sub 6 GHz. This model will focus on the mmWave deployments and assumes line of site connectivity between the gNodeB and CPE, with sub 6 GHz systems filling the void for customers that cannot obtain line of site connectivity to the base station.
- The model assumes that customers are randomly but evenly distributed across the cell site with each cell site including three radios located axially every 120°.
- The model randomly selects customer range to the cell, calculates the Signal-to-Noise Ratio (SNR) for the link, determines the modulation and coding scheme (MCS) level for data transfer, and then calculates the average time required to support the specified data rate for this customer. The model continues to add customers until either the 0.5 second downlink limit or the 0.2 second uplink limit is reached. The model then outputs the total number of customers supported for these conditions.
- The gNodeB radio was operated in a 2T/2R mode for the initial cell site analysis. Further analysis for the radio operating in 4T/4R mode and 8T/8R mode showed significant improvements in the number of users supported and total throughput for the cell site. (4T mode is achieved by electronically subdividing the radio phased array in half, and using two data streams per subdivided aperture, for a total of four available data streams on transmit. The resulting transmit power density is reduced by 6 dB per data stream. Similarly, the 4R mode is achieved by electronically subdividing the radio phased array in half, and using two data streams per subdivided aperture, for a total of four available data streams on receive. The resulting receive sensitivity is reduced by 3 dB per data stream. The 8T mode is achieved by dividing the original radio phased array into four quarters, results in a total of 8 data streams, each data stream operating at a transmit power density reduced by 12 dB compared to the 2T mode. Similarly, 8R mode is achieved using four quarters of the original radio phased array, with a decrease in sensitivity of 6 dB per data stream.) The relative improvement in cell performance using Qorvo technology was slightly higher in these 4T/4R and 8T/8R modes.