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mmWave phased arrays for 5G applications

Harness the power of mmWave spectrum, the next wireless frontier, providing a step order increase in throughput and capacity for 5G fixed wireless and mobile broadband applications.



The advent of 5G technologies and applications will push mobile networks to their limits. Bandwidth-thirsty applications, connected cars, smart factories, mobile health and IoT devices will create an insatiable demand for capacity.

Increasing the capacity and throughput of fixed wireless or mobile networks requires more sites, more network equipment and most importantly, more spectrum. However, spectrum in the low- and mid-bands below 6 GHz is becoming more expensive, more scarce and does not provide the vast swathes of bandwidth required for 5G.

Now the focus has turned to millimeter Wave (mmWave) spectrum, loosely defined as frequencies between 24 GHz and 300 GHz. Historically, mmWave was not practical for mobile communications, but recent technology advances have created new possibilities for its usage. Phased array antenna technology makes it possible to harness the power of the mmWave spectrum and puts us one step closer to a world of 5G — connecting machines, building smart cities and factories, and other exciting applications.

We developed a mmWave phased array radio demonstrator to:

- » **Advance our 5G wireless design and development expertise**
- » **Build partnerships with key suppliers of mmWave chipsets**
- » **Help our customers develop future products, shorten time-to-market and increase revenue**

This whitepaper provides an overview of how mmWave phased arrays will solve bandwidth challenges, meet consumer needs and ensure a step order increase in capacity and throughput.

5G brings high expectations

5G's combination of high bandwidth, massive connectivity and low latency promises to transform industries and spur new applications yet to be imagined. This also means a greater need, and expectation for, bandwidth.

According to the ITU-R, who define the minimum requirements for 5G, the peak downlink throughput should be at least 20 Gbps.¹

With the faster speeds and computing power enabled by 5G comes a need to reliably transmit huge amounts of data without delay. This requires access to a high frequency mmWave spectrum where hundreds of MHz of bandwidth is available.

mmWave radio: Increased capacity and limited range

Millimeter waves (mmWaves) at the top of the radio spectrum have historically been used for radio astronomy, military radar and automotive radar applications. More recently, mmWaves have been used for point-to-point and point-to-multi-point wireless communications. Now mmWaves will form an integral part of 5G mobile networks, providing the much-needed bandwidth. This band of spectrum can support high-speed wireless communication and the transmission of massive amounts of data. mmWave phased arrays are a key technology building block for making 5G successful.

However, mmWave spectrum is not without its own challenges. Until now, the equipment required to use this spectrum was not commercially available for mobile applications and no mmWave spectrum had been auctioned or allocated for 5G. In addition, mmWaves have a very limited reach of just a few hundred meters due to high free space propagation losses, obstruction from buildings and trees, absorption from humidity and attenuation by rain.²

Beamforming: A solution to the mmWave dilemma

Phased array antennas can focus mmWave signals into narrow beams that increase their effective isotropic radiated power (EIRP) and overcome path loss.³ The ability to steer the narrow beam in two dimensions in fractions of a second means the RF energy can be directed exactly where it's needed like a spotlight in a theater focused on the main actor.

As a result, beamforming can maximize throughput for desired users and minimize interference with other users who are served by the same cell site or neighboring cell sites. In particular, this technology provides much-needed capacity relief in high-traffic areas such as malls, airports and stadiums.

¹https://www.itu.int/dms_pub/itu-r/opb/rep/R-REP-M.2410-2017-PDF-E.pdf

²<https://www.rcrwireless.com/20160815/fundamentals/mmwave-5g-tag31-tag99>

³ <https://www.rcrwireless.com/20160815/fundamentals/mmwave-5g-tag31-tag99>

We are proactively investing in mmWave technologies

We have developed a mmWave phased array demonstrator operating at 28 GHz, featuring two cross-polarized, electronically-steerable, 16-element phased arrays. Constructed using commercially scalable mmWave chipsets and PCB material, the 16-element array forms the foundation from which larger arrays with 64, 256 or 512 elements can be quickly developed.

We also developed software to control the two 28 GHz beams for testing. We performed the initial beam characterization with an Agilent spectrum analyzer and gain horn in the lab, before conducting more detailed measurements in an anechoic (echo free) chamber. Finally, the beams carried multiple 5.5 GHz 802.11ac signals to demonstrate capacity by streaming high definition video and other data.

Table 1: mmWave Phase Array Radio specifications

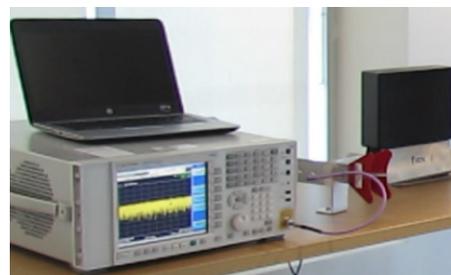
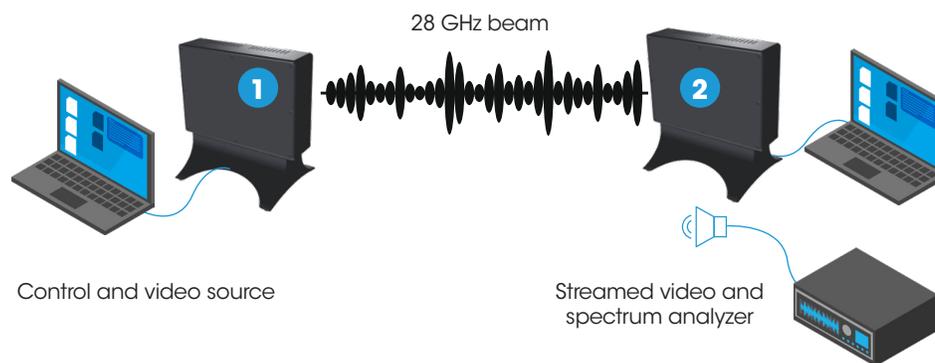
Specifications

| | |
|----------------|--|
| Baseband | IEEE 802.11ac (5.5 GHz) upgradeable to 5G |
| Band | 28 GHz |
| Transmit Power | 37 dBm EIRP per array |
| Phased Array | Two 16 element cross-polarized arrays |
| Beamforming | Software defined analog beamforming |
| I/O Connectors | 4x GigE for user data, configuration & debug |
| Cooling | Passive convection / conduction |

Demonstration setup

The demonstration setup, shown in figure 1, consists of two 28 GHz phased array radios each connected to a laptop via an ethernet connection. The laptop on the left streams the source video to the laptop on the right over the 28 GHz radio link. A horn antenna connected to a spectrum analyzer measures the received signal and displays in the frequency domain as shown in figure 5.

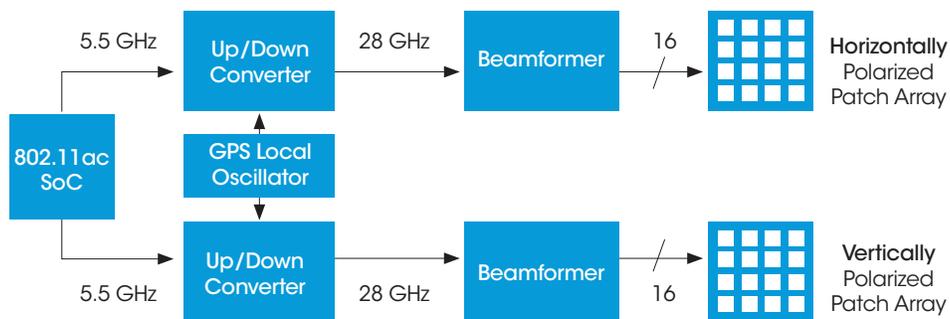
Figure 1: Demonstration setup



System architecture

Figure 2 features the high-level system architecture. Considering the transmit flow, the ethernet input from the laptop connects to the Wi-Fi baseband (IEEE 802.11ac) providing two 5.5 GHz output signals, which are upconverted to 28 GHz and fed to the two beamformer chipsets. Each beamformer divides the 28 GHz input signal into 16 signal streams, adjusts the phase and amplitude of each stream for beam steering/shaping, and outputs 16 signal streams which individually feed the 16-element patch array on the reverse side of the board. The receive flow is essentially the opposite of the transmit flow where the same phase and amplitude adjustments are applied by the beamformer. The two polarizations provide diversity for 2x2 MIMO.

Figure 2: System architecture



Aluminum enclosure and PCB layout

A single 8-layer Tachyon® 100G PCB contains mounts all the mmWave RF components as shown in figure 3. The Wi-Fi chipset is mounted on a separate PCB not shown here. An aluminum enclosure houses the PCB where the cavity walls align with the silver tracks on the PCB for RF shielding between mmWave components and improved heat dissipation. We designed an intricate feed network to connect each beamformer transceiver to the corresponding patch array element on the opposite side of the board.

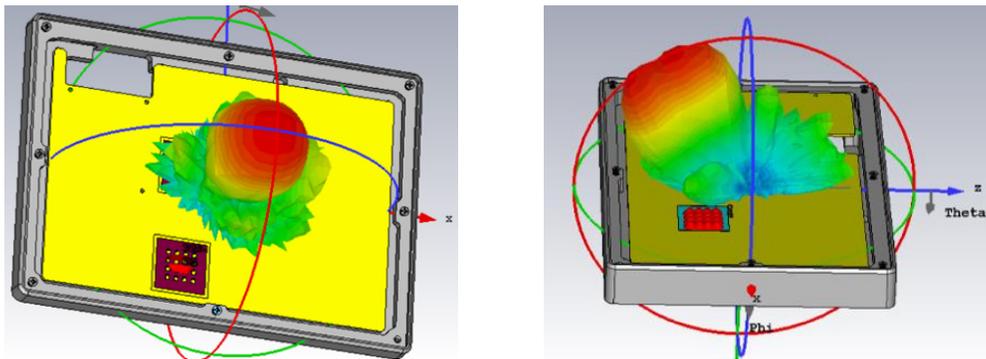
Figure 3: Aluminum enclosure and PCB layout



Extensive simulation to improve the design

During the design phase, we used RF simulation software to complete the phased array and feed network design and iteratively enhance the performance, as shown in figure 4. Simulations included the effects of the enclosure walls. The design worked very well on the first build of the phased array with no tuning or adjustments required, proving that the simulation software is an excellent tool to perform designs at mmWave frequencies.

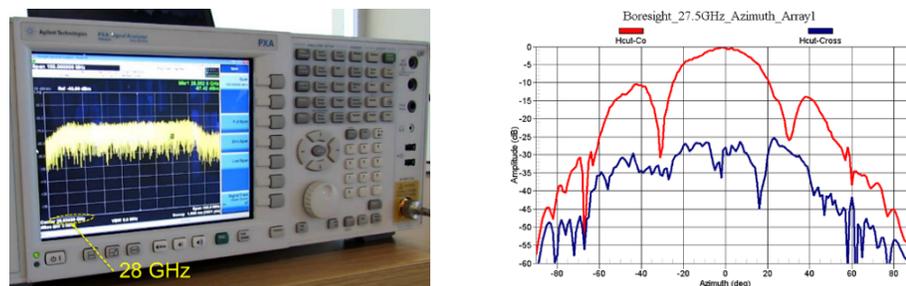
Figure 4: Simulations results



Over-the-Air (OTA) testing

During testing, the Agilent signal analyzer was used to measure the received 28 GHz signal and observed performance in the frequency domain, as shown on the left side of figure 5. We performed further testing and characterization of the mmWave phased array radio in an anechoic (echo-free) chamber. See the right side of figure 5 for example results from the first-pass prototype.

Figure 5: Over-the-Air measurement results



A partnership to create the future

Our experience developing and investing in the mmWave phased array demonstrator helps us better understand your needs when it comes to developing mmWave and phased array technologies for 5G applications. Through a joint design and manufacturing (JDM) partnership, we can develop a mmWave phased array radio for your specific requirements.

Reduce your time to market and lower your investment costs by tapping into our mmWave design expertise. We'll share our knowledge of the design, development and manufacturing of mmWave phased array radios, and the materials and components you need to build them. We anticipate mmWave RF chipsets will be in high demand, so we've developed partnerships with key suppliers to make sure we have the parts you need the parts you need when you need them.

We have deep expertise in related wireless communication products, such as small cells, base stations, remote radio heads, massive MIMO active antennas and microwave point-to-point systems. We design and manufacture these products for many of the leading RAN infrastructure and Microwave OEMs today. Our manufacturing expertise pairs with our strong supplier and partner network to make your ideas a reality.

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