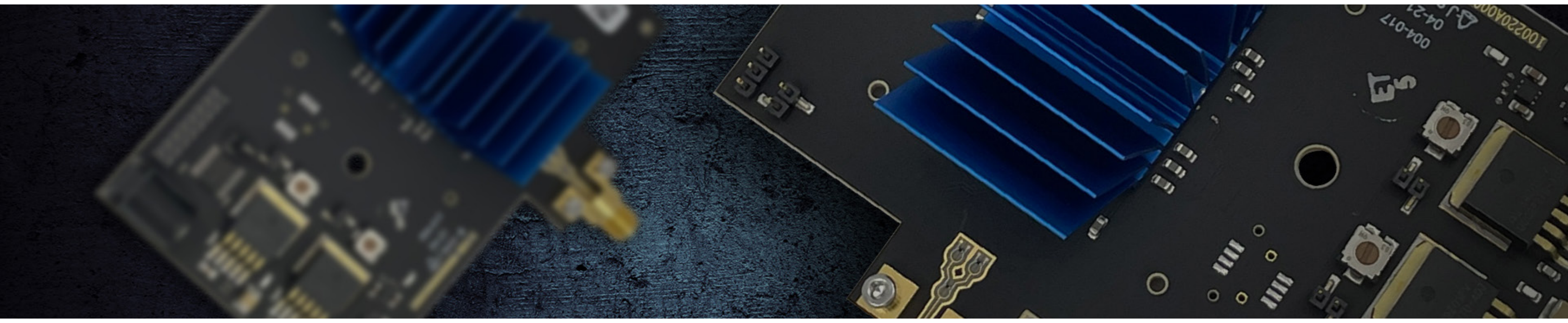
Millimeter-Wave Arrays for 5G Applications



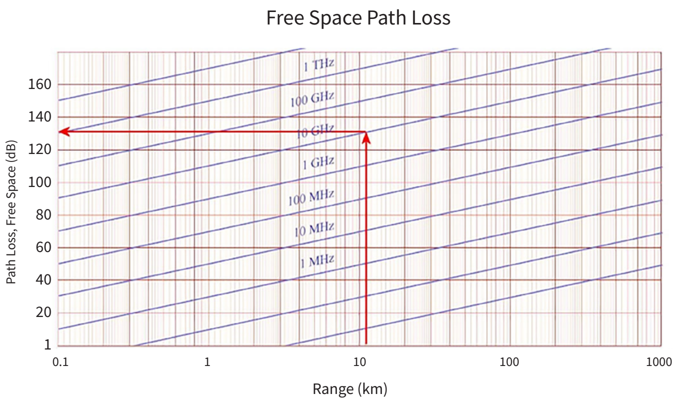
5G is here and brings with it the promise of much higher data rates, lower latency, and increased network capacity. 5G systems are occupying a large portion of the available sub-6 GHz spectrum previously and currently used for 4G connectivity. One of the new aspects of 5G is that millimeter-wave capability is now available for broad commercial use. Along with the use of millimeter-wave spectrum comes the requirement to develop capable and cost-effective radio architectures that can be implemented in commercial products. These radio systems will require beam-steering arrays, capable of scanning over wide angular regions.

The Benefits and Issues Associated with 5G Millimeter-Wave Applications

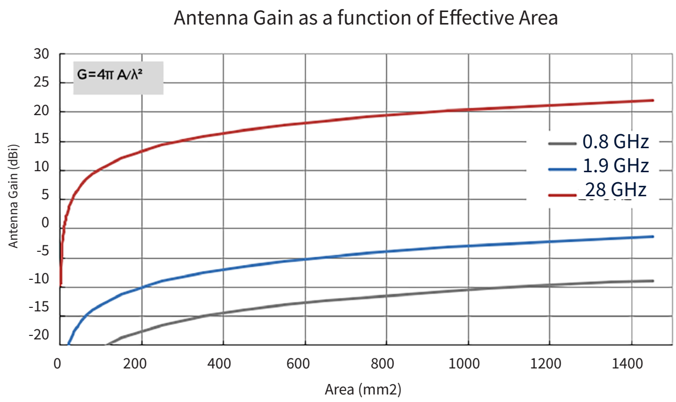
Due to increases in bandwidth of available spectrum, improvements in modulation schemes, and increases in MIMO antenna order, 5G systems can provide higher data rates, increased network capacity, lower latency, and a lower cost per bit of data compared to 4G systems. A 5G system can provide “fiber-like” data rates without the need for a cabled connection, which translates into much higher data rates for mobile applications. As with the previous transitions from 2G to 3G or 3G to 4G, 5G is now providing the substantial improvements expected as cellular systems make the transition from 4G. Sub-6 GHz spectrum is being re-purposed along with bringing up the millimeter-wave spectrum.

As expected when bringing to market a commercialized millimeter-wave communication system capability, there are many challenges. A range decrease occurs as the frequency of propagation is increased, which results in the need for higher gains at millimeter-waves compared to sub-6 GHz frequencies. Figure 1 shows plots of path loss and aperture gain as a function of frequency, highlighting the need for higher gain at millimeter-wave frequencies. The need for a high gain steered antenna beam suggests the need for phase shifters in the array design, and to overcome the losses in the phase shifters LNAs and PAs will typically be integrated into the array design, driving cost and power issues.

With a close grouping of beamformer chipsets containing required phase shifters, PAs, etc thermal management becomes a driving issue in design and layout of the millimeter-wave array sub-system. And as always with commercial communication systems, cost must be considered from day one in the design process to ensure product success in the marketplace. Figure 2 lists the benefits and challenges of 5G implementations.



Path loss increases as a function of frequency, requiring more gain for similar range



Fortunately, gain increases With frequency for a fixed size

Figure 1. Path loss and gain as a function of frequency

Benefits	Challenges
• Fiber like data speed • Massive capacity • Low latency • Low cost per bit	• Cost • Power consumption • Thermal performance • Coverage and mobility • Antenna efficiency and multiband support

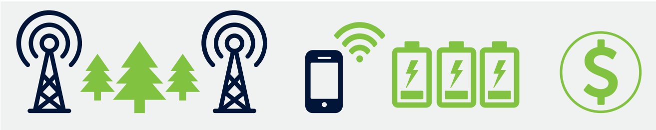


Figure 2. Benefits and challenges of 5G millimeter applications

The 5G Millimeter-Wave Radio Configuration

There are a lot of similarities with a 5G millimeter-wave radio compared to a 4G radio system: A Baseband processor, data conversion sub-system consisting of ADC and DAC sections for digital and analog conversion, and a transceiver section. A main difference with 5G millimeter-wave radios is the need for a high gain steered beam array. With this array requirement, there will now be a need for power and digital interface with the array sub-system along with the typical RF connection to the transceiver. At Taoglas we have developed several millimeter-wave array configurations, which we term an array sub-system, for integration with 5G radio systems. Figure 3 shows a block diagram of a 5G radio system with the array sub-system highlighted.

The array sub-system consists of the antenna array, beamformer chipsets, and additional components such as power regulators and RF and digital connectors. The number of elements in the array will be dependent on the system level requirements such as EIRP, gain, and angular scan range in azimuth and elevation. The beamformer chipsets will contain phase shifters, LNAs, PAs, and switching to allow for amplitude and phase changes to the signals applied to the elements in the array. By applying phase shifts across the elements in the array, the beam can be steered to various angles.

The beamformer chipsets will contain anywhere from 4 to 16 RF ports, with a single RF port being connected to an element in the array. The required number of beamformers can increase quite a bit, based on the number of elements in the array. For example, if a 16-element array is required and dual linear polarization is also a requirement (think V-pol and H-pol for example), there will be sixteen antenna elements in the array, with each element having two feed ports, one for each linear polarization component. This will result in 32 feed ports, requiring connections to beamformers.

A Word on Algorithms

Unlike a sub-6 GHz application where a single broad beamwidth antenna can be connected to a 5G radio port, at millimeter-wave frequencies an array is needed to overcome the drop in range experienced due to path loss. An array brings along with it the expected decrease in beamwidth associated with a higher peak gain antenna. This decreased beamwidth brings the requirement of a "steered beam", where the phase shifters implemented in the beamformer RFICs are commanded to apply a set amount of phase across the elements to steer the main lobe of the array to various pointing angles to optimize the communication link.

This requirement to steer the array beam results in the need for a digital connection to provide control of the array by the baseband unit. Once an array is designed, the testing phase starts with a calibration process where the amplitude and phase distribution across the elements in the array are determined for the boresight beam as well as a series of beam positions at scan angles along the azimuth and elevation axes as well as off axes beam positions. A 16-element array in a 4 by 4 element configuration can have 100 to 200 unique beam positions required to cover the entire field of view (FOV). These beam positions are determined during the array sub-system calibration process and the amplitude and phase coefficients are stored in a look-up table for use during radio system operation. Algorithms will vary from system to system depending on the application, but all algorithms will need the capability to access and control the amplitude and phase distribution across the elements of the array.

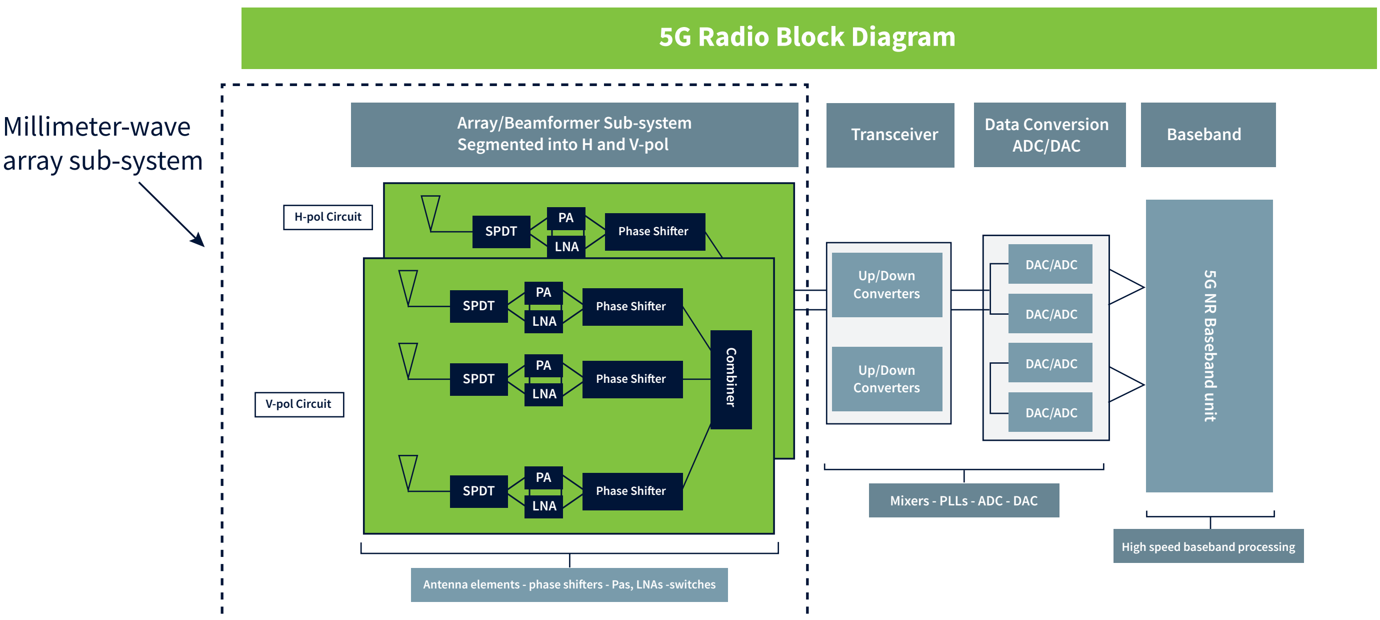


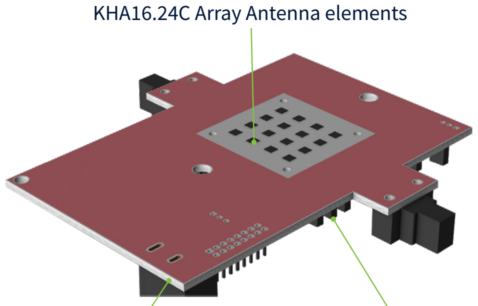
Figure 3. Millimeter-Wave radio block diagram

Value Proposition from Taoglas: Complex Multi-layer PCB Design for Millimeter-wave Array

At millimeter-wave frequencies coaxial cables and connectors are used sparingly or not at all, if possible, due to the losses associated with these components and cost. With the task at hand being to design a millimeter-wave array capable of scanning along one or both major axes, the best approach for cost and performance considerations is to design the entire array sub-system on a single multi-layer PCB. A typical approach is to etch the array elements on one side of the PCB and mount the beamformer chipsets and other components on the opposite side of the PCB. With connectors for RF, digital, and power integrated onto this PCB, the array sub-system is ready to make a connection to the transceiver portion of the 5G radio system.

Taoglas brings a high level of expertise to this task due to previous experience in multi-layer PCB design and de-bug where RF, digital, and power need to coexist in an optimized PCB stack-up. The PCBs used for millimeter-wave array applications can approach 10 to 12 layers or more, so care is taken regarding trace routing for the RF and digital lines. Figure 4 shows a typical PCB stack-up for a millimeter-wave array. Looking at the complexity of the PCB design it becomes clear that this is an exercise involving multiple engineering disciplines: electromagnetics, RF systems, digital, power, mechanics, thermal, and algorithm development.

KHA16.24C Array Antenna elements



An example PCB stack-up and layer definition

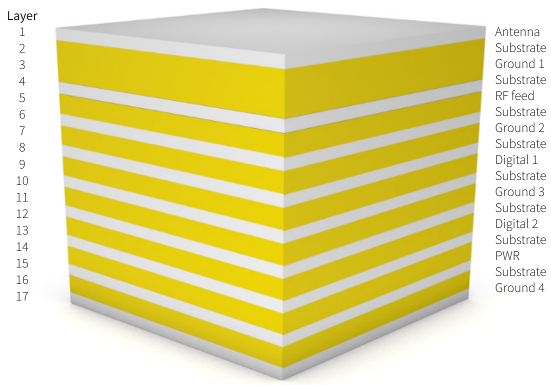


Figure 4. An example of PCB layer assignment for a millimeter-wave array

An Example

An example of a millimeter-wave array capable of integration with existing and new 5G radio architectures is the **Taoglas KHA16.24C array**. This array sub-system is a 16-element array configured in a 4 by 4 configuration to allow for good scanning and beam control along both the azimuth and elevation planes. The array provides dual linear polarization capability by designing in two feed ports at each element in the array. Four Mixcomm "Summit" 2629 beamformer chipsets are integrated into this array sub-system to allow for full amplitude and phase control at each element port in the array. The array is configured with two RF connectors, one for vertical polarization and the other for horizontal polarization, a SPI bus for digital control of the beamformer chipsets, and a connector for power. The array sub-system is all contained on a single, multi-layer PCB which contains the array elements, the beamformer chipsets, power regulator circuit, and connectors. The entire connectorized array sub-system is about the size of a business card, making this array easy to integrate into a host radio system.

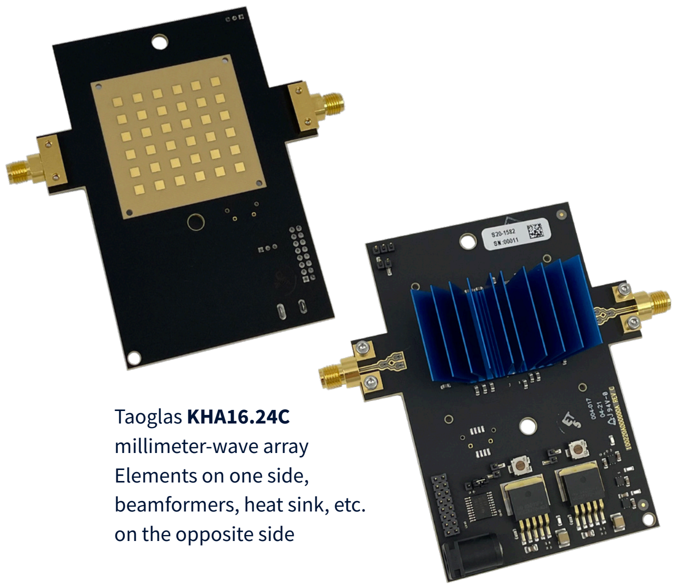


Figure 5. Taoglas KHA16.24C millimeter-wave array

Conclusion

With the advent of 5G millimeter-wave utilization there is a need to understand the impact on the antenna system and how to integrate and optimize for best radio system performance. The need for arrays presents a definite difference in antenna system design and integration compared to sub-6 GHz applications. Developing an array sub-system for integration with various 5G radio systems targeting a wide range of applications, with this array system connectorized and delivered with calibration coefficients for easy bring-up of control from baseband to the array makes sense in terms of shortening system development and reducing complexity. The Taoglas KHA16.24C millimeter-wave array meets this need.