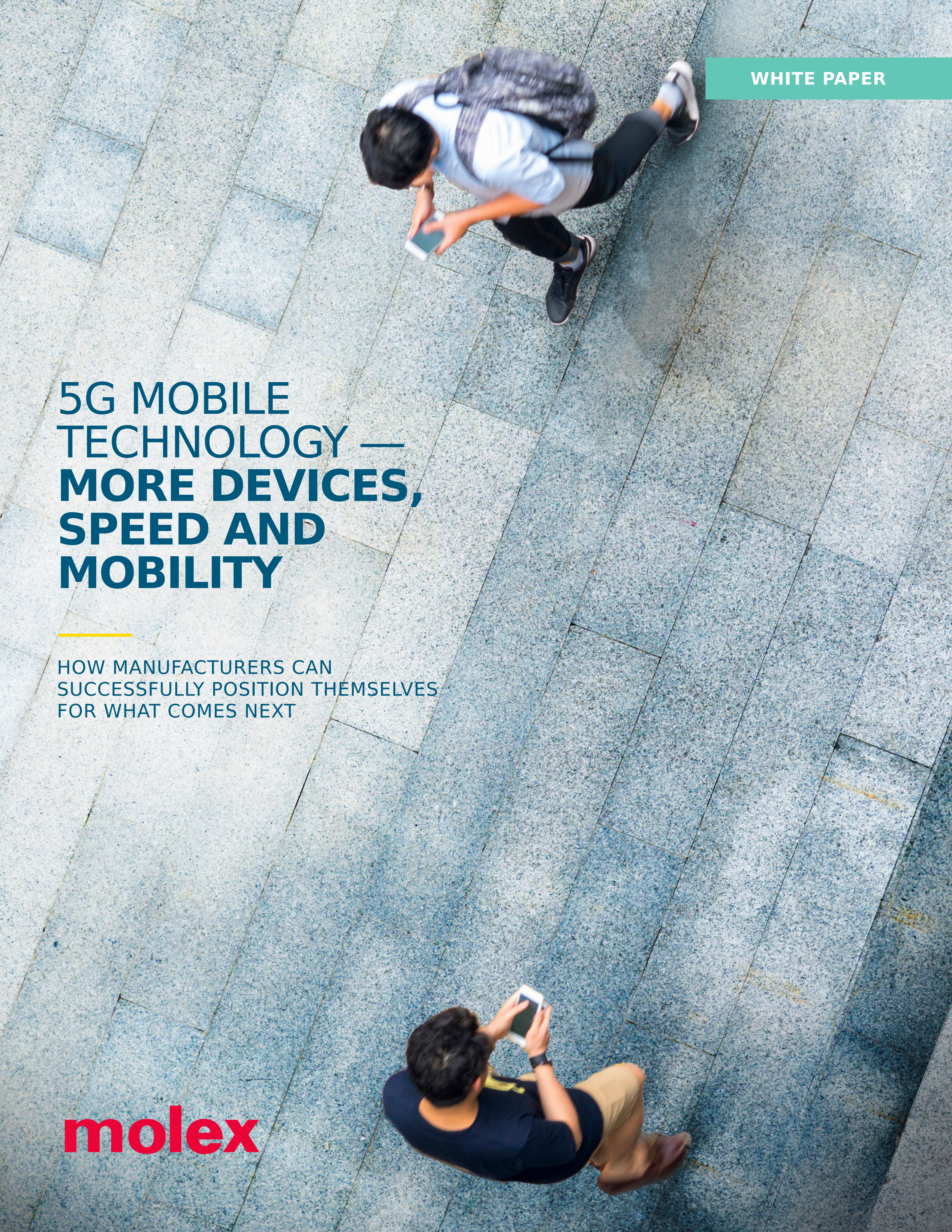


WHITE PAPER

# 5G MOBILE TECHNOLOGY — **MORE DEVICES, SPEED AND MOBILITY**

HOW MANUFACTURERS CAN SUCCESSFULLY POSITION THEMSELVES FOR WHAT COMES NEXT

molex

## 5G Mobile Technology — More Devices, Speed and Mobility




Author
**TIM GAGNON**

INTRODUCTION:

## 5G: The Next Generation of Cellular Technologies

It is not an overstatement that the merger of computers and wireless cellular technology has changed nearly every aspect of society. From commerce to education, and from dating to personal fitness, connected mobile computing devices are inextricably interwoven into our daily personal and professional lives. Also, 5G's tremendous marketing potential can impact many industries, including medical, automotive and industrial. However, the wireless technologies powering today's telecommunications infrastructure (3G/4G communications standards such as GSM and LTE) are simply not capable of delivering on the promises of a digital world on the go. Mobile and embedded device manufacturers are now looking to the future of wireless cellular communications to provide the bandwidth and latency benchmarks needed to realize a genuinely mobile-centric world.

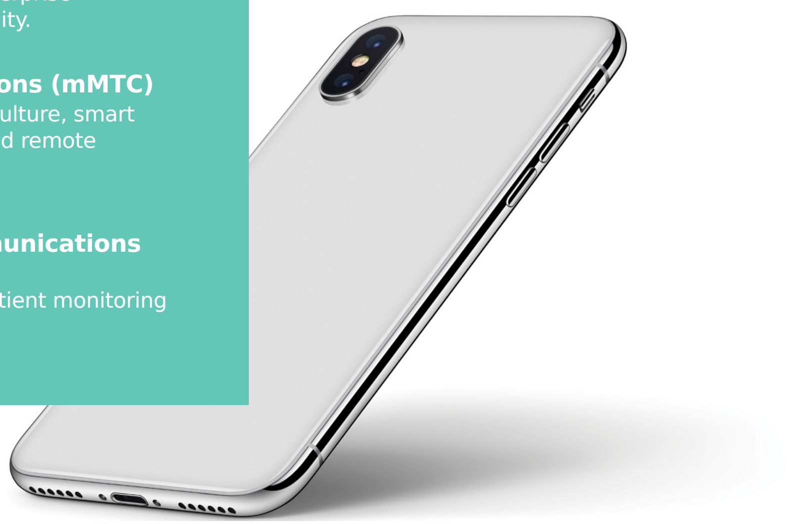
---

The term Artificial Intelligence (AI) was coined in the summer of 1956 at Dartmouth College by John McCarthy. The next generation of cellular networks and device technologies, collectively dubbed 5G or 5th Generation, has begun to roll out globally. 5G represents not an evolution, but rather a revolution in wireless telecommunications. Also, the demand for more mobile devices to have always-on connectivity is pushing original equipment manufacturers (OEMs) that historically may not have integrated wireless cellular communications into their devices to consider the implications of 5G for their product lines. The International Telecommunication Union Radiocommunication Sector (ITU-R) has established three high-level use-case categories for 5G that mobile device OEMs ought to consider for future products:

**Enhanced mobile broadband (eMBB)**
Enhanced indoor and outdoor broadband, enterprise collaboration, and augmented and virtual reality.

**Massive machine-type communications (mMTC)**
Internet of Things, asset tracking, smart agriculture, smart cities, energy monitoring, and smart home and remote monitoring.

**Ultra-reliable and low-latency communications (URLLC)**
Autonomous vehicles, smart grids, remote patient monitoring and telehealth, and industrial automation.



There are numerous advantages to 5G technology, but fundamentally the advantage for mobile computing devices is speed. Today's 4G networks can achieve download speeds of approximately 100 Mbps. In contrast, depending on the specific 5G frequencies employed and the amount of spectrum allocated, it will eventually be possible to achieve real-world download speeds around 20 Gbps. Thus, 5G represents a potential 200x download speed improvement over the current 4G LTE generation of mobile networks. Also, the latency associated with 5G is significantly less (1 ms versus tens of milliseconds) than previous generations, which also contributes to the improved connection speeds. 5G networks can support a million devices per square kilometer versus 100,000 devices in a similar footprint for 4G. 5G also marks the first generation of wireless communications technology to adopt a software-defined networking (SDN) architecture. SDN has many benefits for telecom companies and their infrastructure. Still, for mobile devices, it means that firmware upgrades can deliver new functionality that historically required new hardware.


## MOBILITY FIRST:

### Work and Play Anywhere

For many of us, mobile devices such as smartphones, tablets and laptops are now our primary, if not only, computing devices. Furthermore, Internet connectivity is as much of a necessity for a mobile computing device as a CPU or RAM is. However, the Internet connectivity aspect of our devices is a bit disjointed. When away from home or the office, our smartphones tend to rely on a cellular connection for Internet access. If we wish to connect a laptop to the Internet, we can either tether our smartphone to the laptop or find a Wi-Fi hotspot at a coffee shop. As for tablets, many come in both Wi-Fi-only or Wi-Fi-plus-cellular models. The bottom line is that Internet connectivity is not quite a seamless solution.

Mobile computing devices with reliable, high-speed, always-on connectivity will empower people to do much more than just send emails and browse the web. Mobile devices will increasingly serve as a hub to experience and control a plethora of new interactions. One of the key use cases of 5G is machine-to-machine communications. Mobile devices will serve as the user interface to interact with smart, connected, embedded systems such as wearables, smart homes/buildings/factories, robots and VR/AR hardware. The interactions can even be remote, empowering users to connect with devices and people anywhere in the world. Given the ramifications of the world-altering COVID-19 pandemic, the desire to work and socially connect remotely has increased exponentially. So too has the demand for products that enable such capabilities.

**Mobile devices will serve as the user interface to interact with smart, connected, embedded systems**

5G offers a chance to consolidate around a single solution for ubiquitous Internet access for all our mobile devices. Conceivably, 5G could enable all our devices to have constant, wireless Internet access, especially in densely populated areas. However, it should be noted that Wi-Fi technology continues to evolve and is not going away — it will likely both complement and compete with 5G.

## Understanding Signal Integrity Management

Designing 5G mobile devices that can achieve the desired high speeds, low latency and low jitter will require engineers to expand their knowledge and tools in their toolbox. Managing signal integrity (SI) becomes increasingly difficult yet more important as the frequency of the signal increases. Some terminology that gets used in discussions about wireless communications and Internet connectivity includes:

**1. Connection speed:**

The number of bits that are transferred per second. This is measured in either megabits per second (Mbps) or gigabits per second (Gbps) and often seen by end users as the defining quality of their connection to the Internet.

**2. Bandwidth:**

The range of frequencies that comprise a communications channel. It is typically measured in megahertz for low-band 5G frequencies, but it can be hundreds of megahertz for mid- and millimeter-wave 5G frequencies. For example, the minimum channel bandwidth defined for millimeter-wave is 50 MHz, while it can reach up to 400 MHz. In short, the wider the channel, the faster the potential connection speed.

**3. Packet latency:**

The amount of time it takes for a packet of data to travel between the source and the destination. Latency is measured in milliseconds. The term “delay” is often used interchangeably with “latency.” However, in some situations, the latency measurement is intended to account for the time it takes packets to make a single roundtrip.

**4. Packet jitter:**

The variation of latency over time. Jitter is measured in milliseconds. Jitter contributes to the perception of stuttering in audio or video streams.

**5. Packet loss:**

Internet Protocol (IP) operates on the delivery principle of “best-effort” as opposed to the more robust yet resource-intense model of “store-and-forward.” As such, due to a variety of reasons related to networking (e.g., network congestion) and wireless communication (e.g., radio frequency interference, multi-path fading, path loss, user mobility), packets can be lost between transmitter and receiver. If utilizing the Transmission Control Protocol (TCP), high rates of packet loss will result in packets being retransmitted, thus negatively affecting the quality of experience by causing the connection to appear slow. Packet loss is measured as a percentage of packets received versus packets transmitted.

**6. Transmission channel noise:**

This is background RF noise that contains frequency elements that overlap and potentially interfere adversely with the transmission frequency of interest.

**7. Distortion:**

This occurs when there is an alteration to the originally transmitted waveform. Linear distortions can alter amplitude and phase, while nonlinear distortion results in changes to the frequency. These changes can result in the receiving element “hearing” something different in the baseband signal than what was transmitted. These are referred to as receiver errors.

**8. Multipath fading:**

A receiver can receive multiple copies of a transmitted signal due to signals bouncing around the physical environment. These signals can destructively interact with each other, resulting in a faded or weakened signal that may prevent the receiver from extracting useful information.

**9. Path loss:**

As a radio wave travels through the air, it encounters multiple phenomena that result in signal attenuation. These losses include propagation loss that is a result of the natural expansion of the electromagnetic wave in free space. Diffraction losses occur when the wave is obstructed by an RF-opaque object. Lastly, absorption losses occur as waves penetrate various objects.

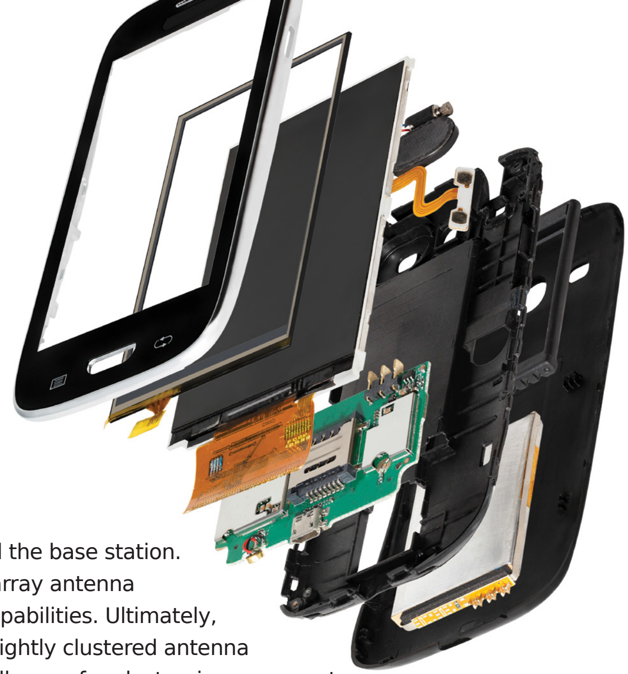
## The 5G Operating Environment

The 3rd Generation Partnership Project (3GPP) has defined the 5G air interface between devices and cells as New Radio (NR). The frequency allocation for 5G is divided into two overarching bands, FR1 and FR2. The current NR standard shows frequency support ranging from around 600 MHz to over 50 GHz. Furthermore, research and development efforts are underway for even faster speeds, with frequencies approaching 100 GHz and higher. From an electronics design perspective, this is a large chunk of the spectrum with very different signal characteristics between the lower and upper limits of the 5G frequency range. This fact will force engineers to consider early in the design process which frequencies they will support in their products, as the decision will impact many aspects of the later development phases, as we will see in this white paper.

The first band, referred to as FR1, is further divided into a low band (600 to 700 MHz) and a mid band (2.5 to 3.7 GHz). The FR1 band is already a very crowded portion of the electromagnetic spectrum. 3G/4G cellular radios are not the only devices operating in the sub-6 GHz spectrum. These frequencies are also filled with Wi-Fi, Global Positioning System (GPS), Bluetooth and Zigbee communication signals. Other non-communication devices, such as microwave ovens, also operate in this range and can be quite electromagnetically noisy as well. The abundance of electromagnetic activity below 6 GHz, along with the desire for faster data rates, has necessitated the move to higher frequencies of the electromagnetic spectrum.

The second band, FR2, contains millimeter wavelength (mmWave) frequencies ranging from 24 to 39 GHz. The advantage of mmWave frequencies is — simply put — the higher the frequency, the faster the data rates. The low-band frequencies offer 4G-like 25 to 200 Mbps downloads while the FR2 band can potentially provide a 20 Gbps downlink. From a physics perspective, millimeter waves have wavelengths roughly of 1cm to 1mm, which relates to a frequency range of approximately 30 GHz to 300 GHz.

The increased speeds do come with a trade-off. First and foremost, the propagation of these frequencies is very much line-of-sight (LOS) constrained. The higher frequencies also attenuate more quickly over a distance, so they do not travel as far (known as path loss) and have a more difficult time penetrating buildings and dense vegetation. To compensate for these losses, more cells must be deployed, especially in urban environments. A variety of cell configurations are available to deal with the realities of the millimeter-wave frequencies. These range from femtocells that can handle approximately a dozen devices with a range of tens of meters to metro cells that can handle hundreds of devices over a range of hundreds of meters.



## Design and Engineering Considerations

5G represents a significant improvement in wireless communication performance. That performance boost does come at the cost of increased complexity and unique engineering design challenges. Specifically, those challenges include:

- **Signal transmission**
- **Power and thermal management**
- **Antenna module placement and size**
- **High-frequency intra-device signaling**

First, there will need to be tight coordination between the mobile device and the base station. The 5G NR relies heavily on multiple input, multiple output (MIMO) phased-array antenna architectures to enable beamforming, beam-steering, and beam-tracking capabilities. Ultimately, this can maximize the data rate between endpoints at scale. However, the tightly clustered antenna configurations needed for large MIMO architectures create performance challenges for electronic components.

At higher frequencies, the physical distance between antenna elements is minuscule. Also, more 5G components and higher frequencies means that more power will need to be budgeted to the communications subsystems. Handling mmWave RF power and dissipating the associated heat in this environment is challenging and requires innovation in system design and material selection. For example, moving to fourth-generation gallium nitride (GaN)-based field-effect transistors with higher power densities will enable the smaller packages needed by massive MIMO architectures. Other crucial components that can significantly affect 5G NR performance in mobile devices include the antenna and connectors. Both have their unique challenges and considerations when looked at in the context of the 5G operating environment.

## More Antennas, Less Space

While 5G represents a revolutionary upgrade from a technological perspective, its rollout will be diverse as carriers build their networks with different spectrums, which will have different reach, latency and data-carrying capabilities. Although it will take several years to achieve ubiquitous 5G coverage, the many different versions of 5G network builds will accelerate the pace. Consequently, rural regions of the globe might never reap the benefits of mmWave-supported data rates because of the attenuation properties previously discussed. They may very well be supported only by sub-6 GHz frequencies, and thus their 5G networks will have similar download capabilities (speed and latency) as 4G LTE.

Furthermore, mobile devices released during the 4G-to-5G transition will almost certainly have to incorporate multiple antennas to handle 3G and 4G LTE waveforms in addition to 5G. Also, Bluetooth LE, IEEE 802.11 Wi-Fi and GPS will continue to operate in the sub-6 GHz band for the foreseeable future. This means that the choice between mmWave and sub-6 GHz antenna design is not necessarily an either-or proposition. Therefore, the decision to add antennas tuned for mmWave frequencies will have ramifications for mobile device OEMs during their design and engineering phases of product development. Of course, choosing not to include mmWave antennas has performance implications that might impact product sales, or at the very least, create some confusion for consumers.

5G's sub-6 GHz bands are much closer to current 4G LTE frequencies. At these relatively lower frequencies, the placement of the antennas is only part of the performance equation. There is a strong relationship between the antenna and the mobile device's internal configuration in determining the overall resonance performance of that device's wireless communications. Given user preference for thin mobile devices, antenna engineers must consider the physical design, material selections and internal component configurations when tuning the antenna design.

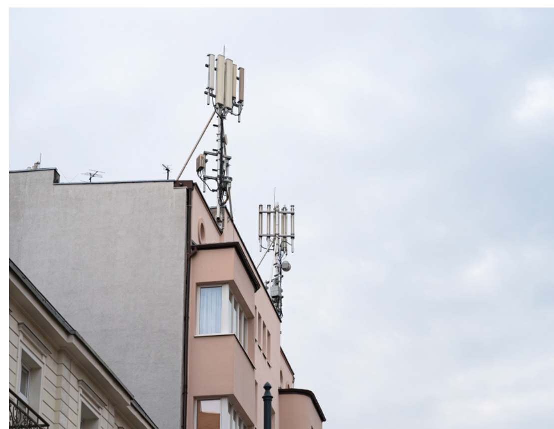
Alternatively, at mmWave frequencies, the interaction between the antenna and the phone body is not as much of a concern. Instead, the challenge is that the covering over the antenna, be it metal, glass or even plastic, is no longer electrically thin and can have significant negative impacts on the radiating performance of the underlying antenna. Also, the placement of the antenna with respect to the device user's hand can have effects on mmWave transmission and reception. Coupling tailored antenna design and unique antenna placement along with slot-based design or frequency selective surface (FSS) design principles can optimize the radiation patterns of mobile device antennas. Furthermore, antenna-tuning techniques such as aperture and impedance tuning can improve gain over a wider bandwidth and improve battery life, as a tuned antenna draws less current than an untuned antenna in order to deliver the same amount of transmitted power.

## Making the Connection: Impact of Connectors on Transmission Paths

In addition to managing the challenges of the air interface and associated antennas, extremely high-frequency 5G signals also introduce further challenges for monolithic microwave integrated circuits (MMICs), chip-to-package interconnections, board traces, cable assemblies and connectors. Propagation of signals at gigahertz frequencies causes cables and traces to act as transmission lines rather than simple wires. The current and voltage vary in magnitude and phase over the length of a transmission line. Transmission lines can introduce difficult-to-troubleshoot errors if not handled correctly during design. If trace lengths are longer than one-fourth of the signal wavelength, the transmission-line effects must be considered during design. Additionally, at those lengths, there are antenna effects that could have impacts, such as electromagnetic interference and crosstalk, that must also be handled by the designer.

Connectors can also introduce challenges to achieving an effective and efficient mmWave-based system. Component designers must contend with requirements that constrain the geometry, size and material selection of connectors while still having to match the characteristic impedance of the entire transmission line. Impedance matching is crucial to reducing signal reflection and achieving maximum power transfer. This, in turn, maximizes the amount of energy radiated by the antenna to generate the strongest wireless signal possible for the receivers. 5G connectors must be able to handle significantly higher power than previous generations (15A+ instantaneous current draw is possible in certain situations). Other design considerations for next-generation connectors include:

- **Short RF terminals**
- **Increased shielding**
- **Unique shielding placement**



Transmission lines can introduce difficult-to-troubleshoot errors if not handled correctly during design.

## A new balance must be achieved between the more stringent electrical characteristics of 5G connectors and their mechanical performance, cost and manufacturing complexity.

**High-speed connectors:**
Pushing millions of bits across a series of components at speeds dictated by 5G standards inside consumer-grade products presents significant challenges, even for those who have experience in designing 3G or even 4G devices. Connectors must be carefully designed and manufactured to minimize any impedance variations along the transmission line. Otherwise, signals may be reflected and result in degraded performance. External signals can also pose a threat. Therefore, connectors must sufficiently protect the system and prevent external signals from electromagnetic interference (EMI) and capacitive pickup, which becomes increasingly challenging at higher speeds.

**Micro connectors:**
5G connectors must fit into the tiny spaces afforded by modern mobile devices. Stacked connectors allow for densely populated flexible and rigid circuit boards. Despite the stringent physical constraints, 5G electronics must still meet demanding requirements for scattering parameters, such as voltage standing wave ratio (VSWR) and insertion loss (IL). Well-designed connectors should minimize reflections, degradation and distortion of the signal while reducing its physical footprint. Connectors and the associated wiring harnesses must also have adequate shielding to be effective at cutting down on EMI; this is even more crucial at mmWave frequencies.

## Tomorrow's 5G Components, Today

Components used in 5G applications must meet exacting electrical and mechanical requirements for use in mobile devices. 5G components must be incorporated into devices that will, at least initially, include legacy 3G/4G and Wi-Fi hardware as well. The use of mmWave frequencies will be a first for consumer mobile devices. Additional considerations for 5G component selection include:

1. **Low latency, low noise:**
   5G offers significant speeds, but at the cost of increased design complexity. Components must be carefully designed to ensure there is little or no impact to signal integrity and overall system performance.

2. **High density:**
   Components must be small and energy efficient to achieve the densities needed to meet the performance specifications for 5G NR, such as massive MIMO antenna architecture.

3. **Cost-effective:**
   5G components have exacting requirements yet are also expected to be embedded in everything. That means the components must be relatively low cost while also offering better performance than current 4G technologies.

4. **Manufacturability:**
   The design of 5G components and systems may be complex, but the manufacturing processes for the physical components should not be overly complicated. 5G manufacturing tools and techniques must offer good yields at low costs while also meeting the stringent physical and electrical performance characteristics.

5. **Robustness:**
   5G components will be everywhere. Therefore, they must be able to handle the abuse that comes from being embedded in mobile devices, which includes a wide range of environmental conditions and varying use cases.

## THE MOLEX ADVANTAGE

Collaborating with Molex gives our OEM customers a leg up in the race to market for their 5G mobile devices. In addition to our extensive product line and professional staff, we offer capabilities and services that would be expensive and difficult to replicate in-house. Some of the highlighted capabilities include:

**High-speed micro connector design expertise:**
Mobile devices must meet exacting aesthetic requirements, such as minimum product physical dimensions (e.g. thickness, weight). Cramming more and more capability into mobile devices while also operating at extremely high speeds means that components must be incredibly well designed, both mechanically and electrically. They must also be physically robust to stand up to the abuse that mobile devices encounter daily.

**Antenna design expertise:**
5G devices require unique antenna design practices and materials, especially at the higher frequencies. Molex has in-house design professionals who can assist in designing 5G antennae for client-specific applications.

**5G anechoic chamber for both sub-6 GHz and mmWave antennas:**
Testing to ensure a 5G-powered product meets specifications requires facilities and equipment that are not widely available. This is especially true for mmWave hardware. Molex's test facilities are capable of testing low-band, mid-band and millimeter-wave 5G frequency bands. Working with Molex during product development gives OEMs confidence that their products and associated components have been thoroughly tested before the product launch. This can significantly reduce the risk of delays in getting a product to market.

**Advanced simulation software:**
Robust electromagnetic structures solver software applications are incorporated into the design process, including, Ansys High-Frequency Structure Simulator (HFSS) and Computer Simulation Technology's (CST) Studio Suite. HFSS is based on the finite element method, while CST offers a variety of solvers that work in the time and frequency domains.

**Advanced MID technologies:**
Molded Interconnect Device/ Laser Direct Structuring (MID/LDS) capabilities allows for the tight integration of complex electrical and mechanical structures in three dimensions. MID/LDS technologies allow for smaller 5G components than do more traditional 2D manufacturing processes in which the two design domains are not nearly as integrated. 5G manufacturing capability: We can help OEMs balance 5G electrical and RF requirements with mechanical and ease-of-manufacturing requirements. Our manufacturing capabilities are world class and allow for rapid turnaround of tailored designs for OEMs.

Order No. 987652-2481 USA/0K/GF/2021.01 