The Demands of 5G on Printed Circuits

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The global rollout of 5G networks and supporting infrastructure will continue its rapid expansion in this decade and dominate technology innovation that will touch virtually every aspect of our lives. Simply put, 5G innovation will transform consumers, industries, businesses, medicine, transportation, cities and more.

Consider the future:

- Life-saving remote surgeries performed by global medical specialists.
- Self-driving electrified vehicles transporting passengers in new levels of comfort and safety.
- Lightning-fast secure connections enable movie downloads in seconds.
- Internet-o-Things (IoT) enabled cities and towns with the bandwidth to meet environmental and population demands.
- Smart utility grids, industrial facilities, and farming for optimal output and cost benefits.

At the heart of this 5G journey are the carriers, servers, routers, antennas, base stations, modules and components dependent on robust and high-performance printed circuits for seamless high-frequency creation and management. In the 5G world, network or component failure is not an option.

"5G IS ABOUT
TO CHANGE THE WORLD
in ways we can't
EVEN IMAGINE"

DAN ROSENBERG, QUALCOMM[1]

5G challenges traditional PCB design, construction and reliability

The differences in 5G performance demands from the core PCB perspective — versus 4G LTE — cannot be overstated. Reliance on the millimeter wave spectrum (mm-Wave) in the 30-300GHz range and integrated antenna designs in 5G printed circuits will challenge the speed and reliability support of huge data rates over smaller distances across significant numbers of base stations.

Faster data rates and the sheer volume of big data for extreme 5G performance will demand a step-change technology solution in how PCBs are designed, constructed and tested. 5G carriers, module manufacturers, and server and infrastructure device makers will drive these crucial and customized performance parameters for printed circuit response. Innovative high-speed PCB materials in new and highly complex integrated circuit designs will, by default, become the building blocks to enable 5G viability.

The end-user demand for long-term network and component reliability will be equally critical after massive infrastructure investment. Network designers and PCB manufacturers must align with 5G-defining challenges versus the physical reality of creating PCBs that deliver demanded performance no matter where or when the network component is engaged. Standard PCB performance prediction testing will not meet the 5G reliability criteria. OEMs and PCB manufacturers must come together to drive a new normal of customized testing to confidently understand how a PCB component will handle the environmental, mechanical and electrical reliability needs of 5G. This will include a new series of predictive evaluations at the design and end-component phases of the PCB supply chain. It will also require careful in-house and independent third-party testing, expertise and commitment to the gate and deliver the necessary component reliability for network communications, base stations, telecom servers, hardware facilities and core transmission networks.

Will this increase the overall cost of the PCB? Yes, it will. Will there be a return on this cost value-add? Yes, in many ways. Design failure is not an option for 5G to realize its global potential. The cost of failure will become a new cost and liability consideration that will directly impact bottom-line profitability.

Conversely, the considerable opportunity for progressive carriers, component designers and PCB suppliers to ensure long-term performance and reliability will differentiate their networks, devices and core printed circuit designs. The global 5G services market was valued at $48.25 billion USD in 2021 and is expected to expand at a compound annual growth rate (CAGR) of 56.7% over the decade to more than $1.75 trillion USD.

Automotive, medical, industrial, entertainment and telecom are just some of the IoT demand drivers that will fuel the electronic 5G revolution. Strong branding based on performance and reliability across all 5G supply chain parts will differentiate the players and ultimately capture opportunities for this seemingly unlimited disruptive and historical 5G technology journey.

Speed, latency and long-term reliability for 5G

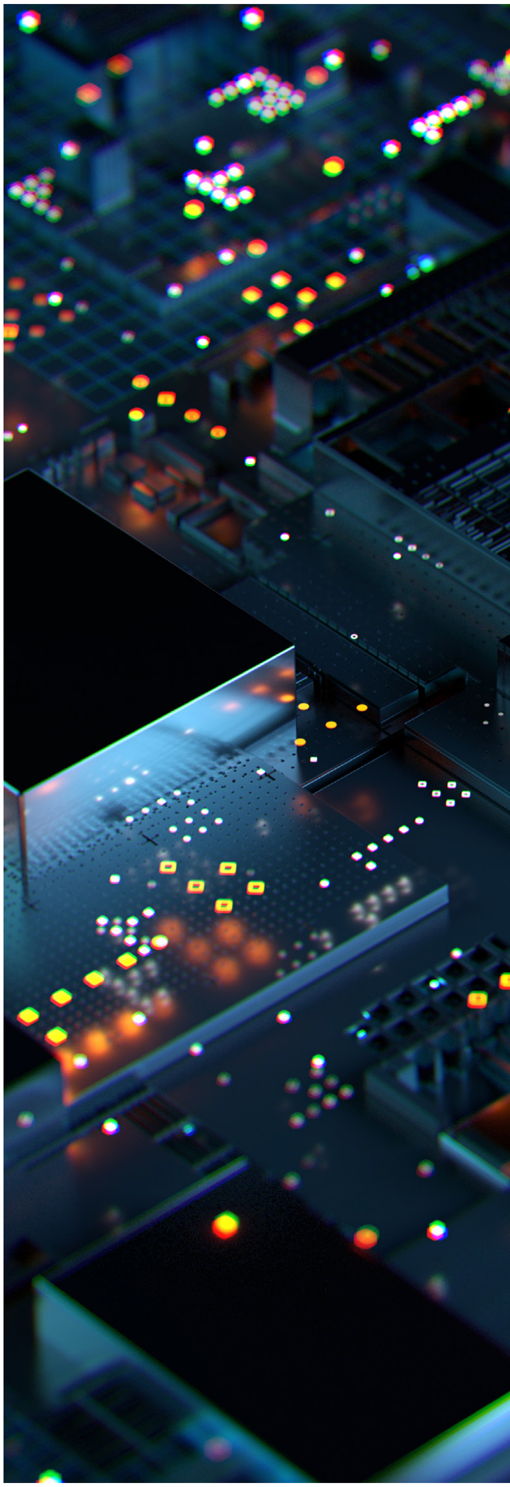
In current development, 5G is reaching peak speeds 20 times faster than 4G LTE, with network speeds of 20GB per second. In comparison, today's LTE speed of 1GB per second network speed is considered state-of-the-art.

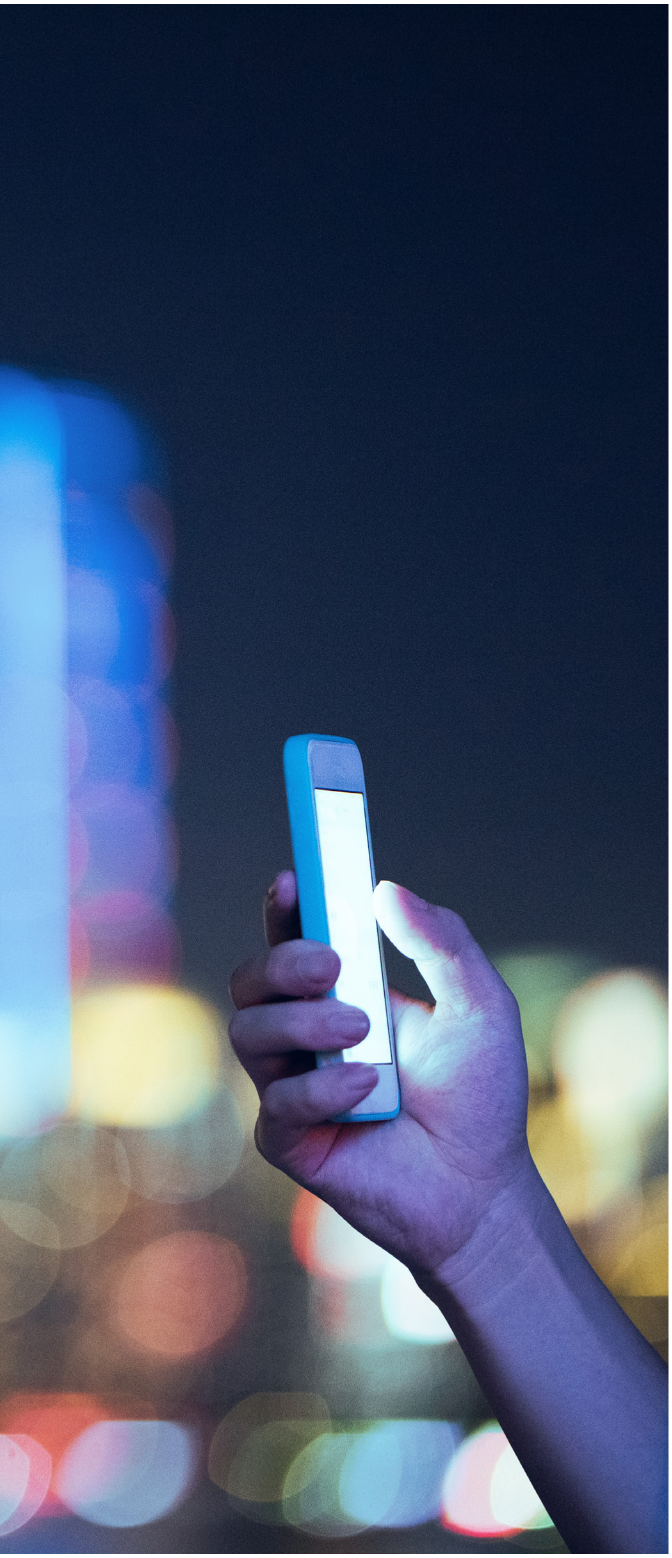
Everyday speeds depend on several factors, such as location, the electronic device design, antenna components and whether the device is in motion. 5G performance will continue evolving as carriers build their networks and improve upon existing services. Industrial and new market segment demands will continue to shape future 5G service capabilities. PCB technology and reliability will be primary factors in achievable peak data speed and service cost.

5G will deliver a quantum leap in technology versus 4G LTE

Critical Design Parameter	4G LTE	5G Projection
Data rates	1 Gbps	10 Gbps
Latency	10ms	< 1ms
Operating frequency ranges	600 MHz – 5.9 GHz	600 MHz - 28/39/80 GHz (for mm-wave technology) using mixed-signal designs
Channel bandwidth (BW)	20MHz	400MHz (frequency > 6GHz)
Download speeds	100 Mbps	10,000 Mbps
Network deployment (years)	2006-2010	2020-2027
Enabling printed circuit technology	Mult-layer Flex/Rigid Flex, Low loss PI or other laminate materials	Ultra Low Loss/ High Thermal dissipation – trace/ board design for signal integrity preservation
Antenna designs	Inverted F or Meander Line Inverted F impedance- controlled corner integrated antenna	Multiple AIP (antenna in package) design for high-freq. directional transmission.

5G will create fundamental changes in PCB performance and reliability. Wireless base stations, bearer networks, transmission networks, and core network hardware facilities will require 5G RF boards, backplanes, motherboards, power distribution boards and other high-performance assemblies supporting mm-wave networks. Base station density and repeater units will place enormous demands for high-frequency hi-speed circuits more than 2X that of 4G infrastructure.





Key distinctions in PCB designs for 5G

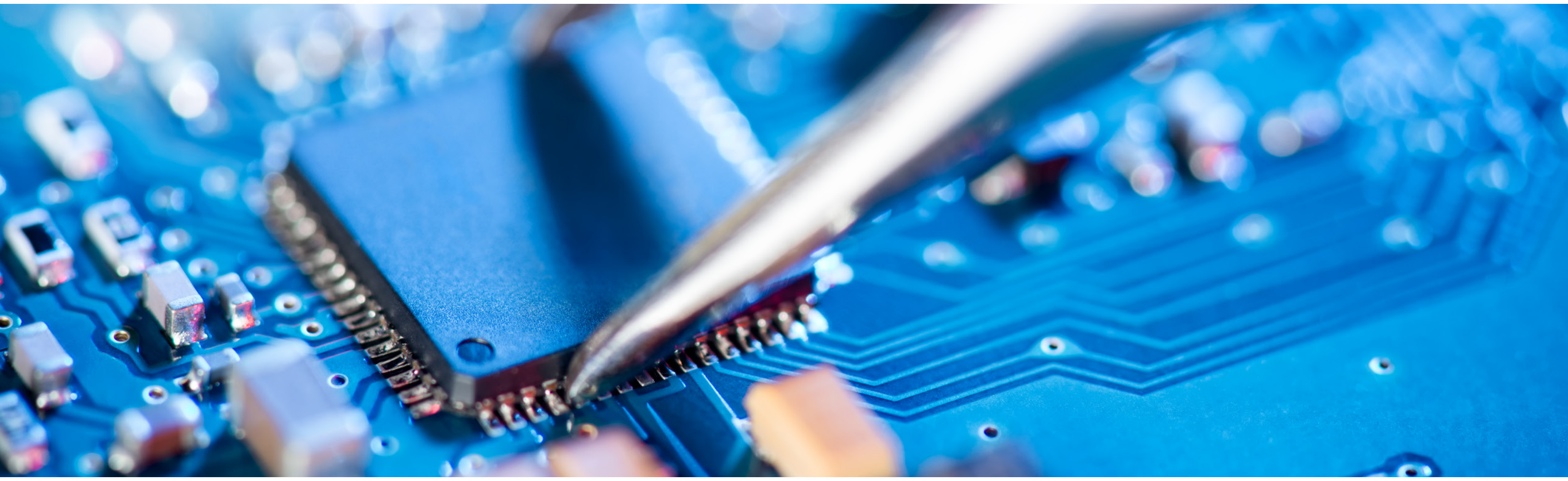
The 5G era will unfold a new normal for the global manufacturing industry delivering PCB products to an ever-growing market. One-size-fits-all will no longer be a viable business model for PCB manufacturers who rely on cost control and volume designs for competitive profit margins. A high degree of design customization will be required to meet critical performance specifications. This customization includes the fundamental variables of:

- Substrate type.
- Copper weight and roughness.
- Trace width and spacing.
- Layer numbers.
- Trace geometry after etch (or additive process).
- Antenna integration.
- Conductive/Dielectric lamination processing techniques.
- Quality control.

PCB manufacturers and partners will differentiate their end products and services in the new 5G landscape with unique solutions and design innovation. Expensive components must demonstrate long-term high reliability in various environmental and end use scenarios.

The significant design and electronic performance demands supporting the technology transition from 4G LTE to 5G include:

- New PCB laminate and copper materials for hi-speed/hi-frequency
- Vastly upgraded construction and performance in communication base stations for MIMO
- Flatness and zero distortion/de-lamination of hybrid PC laminates for signal integrity
- Thermal management of high-speed PCB stack-ups and assemblies
- Low and stable Dk (dielectric constant) and Df (dielectric loss) for ultra-fast signal transmission rates plus ultra-low latency under variable long-term environmental stress
- Challenging evaluation testing/performance prediction for mixed-signal designs
- Zero-Fail Reliability demands in mobile devices, transmission networks and IoT devices
- New Hi-density multi-layer printed circuits incorporating multiple AIP technologies



The risk and cost of 5G network failure

Quality and reliability are critical components of any end product success. Product failure can become a permanent mark on a company's resume, independent of that company's size or industry track record. This is no different for future 5G network services and is magnified due to the vast scope and failure liabilities that lie ahead.

Consider recent history: Exploding cell phone batteries, aircraft software system and automotive airbag failures, poor-quality tires, and environmental disasters. The list is extensive across global history. Field failures are costly, and each one requires both large and small companies to resolve the root cause while simultaneously reaching out to make things right with their consumers. And this all has to happen quickly and never happen again.

Quality and reliability are critical components of any product brand. They are valid for 5G networks, components, base stations, modules, data servers, IoT devices and every aspect of the 5G offering. As noted previously, failure is not an option for 5G's new market demands because resources spent on failure recovery can jeopardize business bottom lines.

"Companies adjust after a failure with actions like adding testing, changing suppliers and implementing safety checks. These additions would have been costly even at the beginning of design but are even more expensive after a field failure when they are now essential to continue delivering and selling a product,"

Orcad PCB Solutions, May 2018

5G is likely one of the most remarkable disruptive technologies. The core 5G drivers are complex and customized PCBs that enable a module, base station, multiple-input and multiple-output (MIMO) antenna system, big-data storage and IoT with lightning-fast responses. PCB design and performance will be the bedrock of the 5G revolution. But what happens if those critical components are jeopardized by environmental applications (rain, humidity, corrosives, contaminants, heat) or design/operational stresses? In short, the network experiences a critical failure that it must remedy immediately. Impacts can range from loss of mobile communication and internet to more severe breaches in government security, public safety, smart-city operations, medical procedures and Vehicle-to-Everything (V2X) infrastructure. Mission-critical device failure in a 5G network can disrupt daily routines or put lives in jeopardy. Liability is a genuine concern.

Recent studies have attempted to quantify the cost of a carrier system or component failure:

- **Over $300,000/hour**
  Average cost of a server network downtime[2]
- **$9.000/minute**
  Average recovery cost of a server network downtime[3]
- **91% of corporations**
  say hourly downtime exceeds $300K[4]

Evolving from 4G LTE to 5G demands a better approach to advanced high-density interconnect (HDI) PCB manufacturing techniques that help manufacturers maximize the density of the embedded electronics while reducing the loss of RF signals at high frequencies. High reliability is one of the critical design specifications for 5G. Mission-critical services such as connected robotic factories, remote surgery, patient care and driverless cars require a continuous connection to the network.

From the 5G system perspective, loss of trust could occur over time or in a single instant, and network outages could be life-threatening, with corresponding supply chain liabilities far beyond the losses of traditional network downtime:

- Factory downtime would slash revenues, result in layoffs and damage supply chains
- A self-driving car falsely detecting a traffic situation could be disastrous
- Loss of connectivity or expanded latency during a remote surgery would signal an emergency

The technical standards for 5G networks apply to PCB suppliers and place a new and bright spotlight on the role of PCB reliability in zero-failure networks. The critical communications between network drivers and PCB suppliers will determine the rollout success. Careful and systematic new evaluation protocols for 5G electronics will drive supply chain trust.

Harmonizing 5G design applications with PCB production technology

High-volume commodity PCBs for a standard design application have historically involved very little communication between OEM design teams and PCB manufacturers. Circuit designers with minimal hands-on knowledge of the detailed manufacturing processes and challenges could still successfully specify a multi-layer fine-line design, yielding excellent final results due to the availability of standard laminate and copper constructions and fine line print/etch processing techniques.

Before 5G, printed circuit designers, in relative isolation, created new designs captured in CAD/CAM formats and confidently handed them off to qualified fabricators. Skilled board builders manage the procedure with existing technology options to develop the evaluation prototypes. This minimal designer/manufacturer interface has proven a cost-effective and successful approach until 5G.

5G complexity and design demands disrupt the entire logistics chain from R&D through design and manufacturing. Exponential increases in PCB performance demands and complexity are forging a new normal due to the massive new MIMO requirement for millimeter-wave frequencies and beamforming.

New levels of collaboration and communication between designers and manufacturers will become a critical link for cost-effective product reality. The value of new 5G predictive testing protocols must be recognized and included in new design rollout and evaluation planning.

One of the significant impacts of 5G will be in terms of the requirement of increasingly smaller designs and, therefore, high-density interconnects with thin board traces. If not handled correctly, it can lead to degradation in signal performance. Signal delay and data flow are at risk. Communication between designers and PC fabricators should be clear and aligned to transform a design concept into a practical reality.

Communication Service Providers		Printed Circuit Manufacturers
Denser and More Complex Networks	⟷	New High-Speed Materials
More 5G Hardware/Antennas per Unit Area	⟷	Thinner Signal Traces/ Semi-Additive Processes
Increased Network Operating Expenses	⟷	Signal Integrity (EMI Cross talk, Capacitance)
Emerging Market Latency Demands	⟷	Thermal Management for 5G Power Demands
CyberSecurity Issues	⟷	Environmental Stresses and PC reliability
"Big Data" Management	⟷	On-board antenna designs/customization

UL Solutions services for 5G PCB performance and reliability evaluation

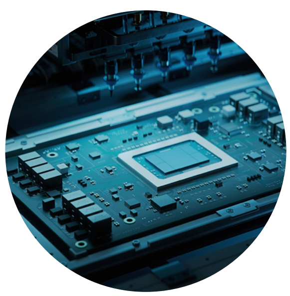
The 5G PCB must address all required specifications when carrying and receiving signal transmissions, maintaining complex electrical connections and regulating critical functional device controls. Environmental deployment cannot compromise the PCB's performance or reliability. Challenges for 5G PCB designs at a base level will include:

- New low-loss material solutions and mixed constructions
- Thermal management resulting from higher signal transmission demands
- Maintenance of signal integrity at vastly higher speeds
- Prevention of electromagnetic interference (EMI) losses

Important terms and definitions associated with enabling 5G PCB solutions will become mission-critical communications between the application designers and PC fabricators. The challenge is transforming the 5G carrier/module design into viable real-world solutions.

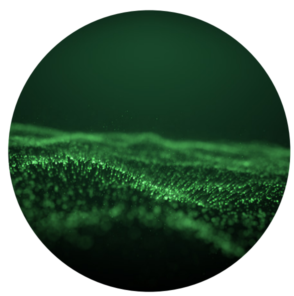
Controlled Impedance

Impedance defines a transmission line's opposition to current flow. Controlling electrical impedance is performance-critical in complex PCB designs and densities.



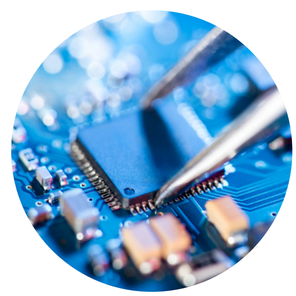
Hi-Voltage PCB

High Voltage circuit design requires rigorous structural and trace layout protocols to accommodate maximum power transmission and associated thermal risks to PWB reliability.



Signal Integrity

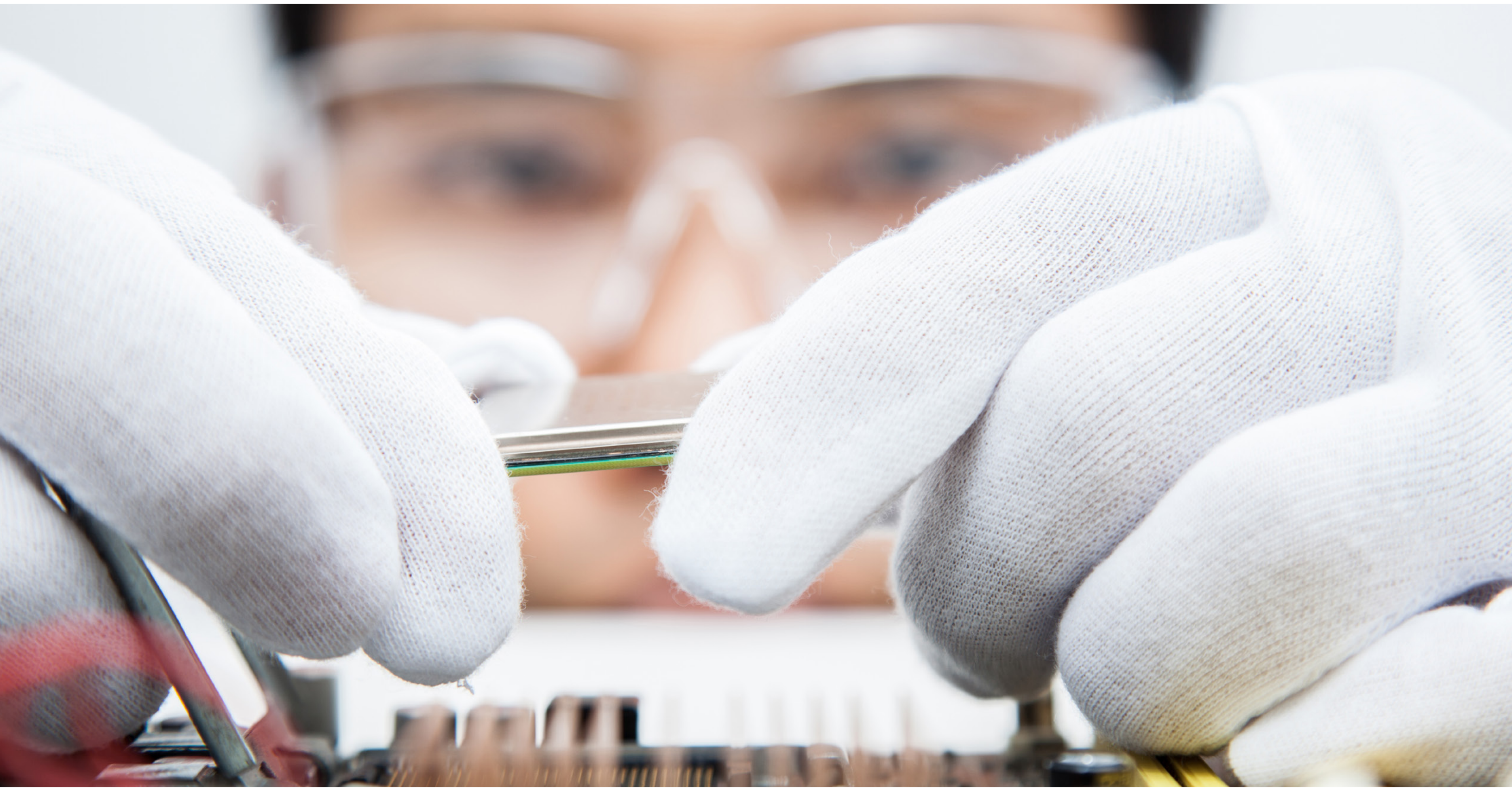
Signal Integrity is a measure of signal quality as it travels in PCB pathways. High frequency designs can impact timing and transmission of signal quality resulting in "bad" data.



Hi-Frequency

High Frequency PCB Design is used for signal transmission performance in Mobile, Medical, Industrial and Microwave applications.

Carriers, module suppliers, IoT device OEMs and all stakeholders across the 5G supply chain must clearly understand that 5G circuits are unlike previous components. Fortunately, proper performance testing and application reliability simulations can significantly lower this risk and deliver confident intervention at multiple phases of the PCB design process. Savvy OEMs and 5G system decision-makers understand the clear bottom-line impacts of requiring additional testing and associated development timing in their 5G designs. Vastly improved component reliabilities more than compensate for the payoff in these compliance requirements. Similarly, PCB fabricators who make an extra effort on 5G customized qualification testing can differentiate their products and build OEM confidence as primary suppliers for 5G PCB designs.



UL Solutions for 5G Printed Circuits

UL Solutions offers 5G Printed Circuits testing service that provides fundamental grounding and guidance to network engineers and OEM's next-generation 5G board designs and their translation to actual PCB performance and reliability. The program focuses on PCB challenges and design-phase testing programs to validate 5G environmental performance predictions and component demands.

Successful completion of UL Solutions 5G Printed Circuits testing delivers program certification and confirmation of client training and understanding of next-level 5G Technology infrastructures, evaluation criteria and successful delivery of the PCB product. The program encourages extraordinary partnerships between OEM designers and PCB manufacturers to harmonize 5G component design performance and testing needs. This winning partnership ultimately results in a differentiated, cost-effective solution for the 5G service network.

Automotive, medical, industrial, entertainment and telecom are just some of the IoT demand drivers that will fuel the electronic 5G revolution. Strong branding based on performance and reliability across all 5G supply chain parts will differentiate the players and ultimately capture opportunities for this seemingly unlimited disruptive and historical 5G technology journey.

UL Solutions for 5G PCB customized testing service highlights

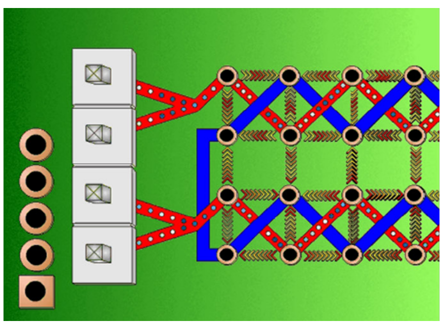
UL Solutions offers the following 5G PCB testing services.

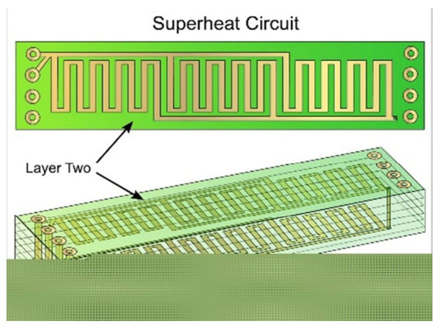
Conductive Anodic Filament (CAF) Failure

Conductive Anodic Filament (CAF) formation is driven by chemical, humidity, voltage and mechanical means. It is characterized by a sudden loss of insulation resistance that occurs internally in the PCB with the formation of Cu dendrites across conductor paths in high-density circuit boards.

Interconnect Stress Test (IST)

Provides an accelerated PWB reliability and performance assessment by passing a pre-determined constant DC through a specifically designed PWB test vehicle (coupon). Benefits include PTH integrity, customized sample testing for the design vehicle and data production representing actual 5G environmental conditions and design stresses.





ATC Thermal and Environmental Conditioning

Accelerated thermal Cycling, thermal shock and reflow simulation typically expose 5G test vehicles to temperature exclusion ranges of -40 °C to 150 °C for defined cycles, e.g., 1000. Thermal expansion coefficients between components and PCBs cause strain in solder and embedded copper structures, inducing fatigue or failure of the PCB. Mixed material 5G laminate designs for high speed require customized ATC testing simulating PCB stress impacts and critical lifecycle 5G device demands.

Micro-sectioning for Failure Analysis and Design Validation of Multilayer 5G Components

Microsection analysis is a specialized examination technique for PCBs' internal quality and failure modes. Cross-sectional views of circuit structure provide critical visual integrity evidence for complex designs and troubleshooting issues such as thermo-mechanical or solder reflow failures, trace shorts, opens and other defective components. UL Solutions has a netword of sceince-based testing service laboratories with advanced testing capabilities and equipment to identify costly design and reliability evaluations.

Trust UL Solutions to help you simplify market access to your innovative 5G-enabled products. Learn more about our 5G testing services or contact us today.

Endnotes

1. Grand View Research, “5G Services Market Size & Share Report”, 2022-2030, https://www.grandviewresearch.com/industry-analysis/5g-services-market

2. Gartner, “The Cost of Downtime”, https://blogs.gartner.com/andrew-lerner/2014/07/16/the-cost-of-downtime/

3. Ponemon Institute, “Cost of Data Center Outages”, https://www.ponemon.org/research/ponemon-library/security/2016-cost-of-data-center-outages.html

4. TechChannel, ” The Cost of Enterprise Downtime”, https://techchannel.com/IT-Strategy/09/2021/cost-enterprise-downtime

Other sources:

5. How much does an unplanned IT outage cost?, https://www.ringcentral.com/us/en/blog/how-much-does-an-unplanned-it-outage-cost

6. Breaking Down Data Center Tier Level Classifications, https://www.coresite.com/blog/breaking-down-data-center-tiers-classifications

7. Sustainability and the life of a base station, https://www.nokia.com/networks/insights/5g-future/base-station

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