

Packing mmWave Circuits into 5G Microcells

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Fifth Generation (5G) wireless cellular networks promise performance that will meet every mobile user's need, including reliable voice service, fast data, and steady video links.

But such achievements will not come overnight, and they will call for a 5G network infrastructure with more cell sites than ever, capable of transmitting and receiving higher frequencies than ever, to gain the bandwidth to meet the great expectations of 5G New Radio (NR) wireless technology.

It is not the "same old" RF/microwave technology. Rather, 5G radios require circuit materials not only capable of low signal loss well into the millimeter-wave (mmWave) frequency range but operating continuously and reliably within the tight confines of some cell sites that will be the fraction the size of a shoe box!

Construction of the network infrastructure for 5G wireless networks involves the addition of smaller cells to existing cell towers and radio equipment. Large-area cells known as macrocells are being supplemented by smaller femtocells, picocells, and microcells as part of what is being called "the densification of 5G network infrastructure."

More cells are needed to provide wireless coverage at mmWave frequencies. Signal wavelengths are shorter at higher frequencies and mmWave signals propagate across shorter distances than lower-frequency signals. They are also more attenuated through building materials than lower-frequency signals, requiring small indoor cells for optimum wireless coverage within indoor cell sites, such as shopping malls and office buildings.

Smaller Cells

In 5G network infrastructure, the large cell towers that have identified earlier wireless cellular network generations will be outnumbered by many thousands of smaller 5G cell stations as needed for dependable radio access at mmWave frequencies. Macrocells with those large cell towers will still provide coverage for many users, especially over long ranges, and lower frequencies, but smaller cells will need to "fill the holes" for extensive signal coverage at higher frequencies and densely populated areas with large numbers of users.

Smaller cells provide a ready means of adding users to a 5G network and existing macrocells. Each small cell functions as a cellular base station, sending and receiving signals from users. A small cell adds its own data capacity to a 5G network's macrocells, increasing the overall 5G network capacity. Small cells have smaller coverage areas than macrocells and serve less users than macrocells.

While a microcell may serve many more than 2000 users at one time over a coverage distance as great as 25 km, a microcell may provide network access for as many as 2000 wireless users but only at a distance as far as 1 km and with much less transmit power.

Picocells, designed for indoor and outdoor sites, may reach only 200 m, and connect as many as 100 users. Femtocells, designed only for indoor use (and more controlled environmental conditions), will transmit at the lowest power levels, and provide a range of only about 50 m, or about 30 users at one time, such as in an office building.

Obviously, for 5G mmWave frequency coverage in densely populated areas, many smaller cells will be needed, such as on every lamppost as some cellular carriers have suggested. The operating environment for 5G NR PCBs poses many challenges, not just within the confines of a miniature 5G cell housing but with all the electromagnetic (EM) noise sources in proximity. The requirements for circuit materials to reliably serve the PCBs in those small cells, including for transceivers and antennas, are quite demanding.

Materials That Fit

Substrates for the PCBs in 5G small cells must support the high precision for very small circuit features enabling not only low-loss signal transfer at microwave frequencies but closely spaced circuit lines and traces that will squeeze as many analog, digital, optical, and power functions into a limited housing size as possible. Prepreg materials for 5G small cell PCBs should be characterized by permittivity or dielectric constant (Dk) that is consistent across the length and width of the material and for a temperature range that compares to the expected operating conditions of a 5G small cell.

Consistent Dk ensures that circuit traces formed on the dielectric material will maintain the tightly controlled impedance needed for low-distortion analog mmWave signals and high-speed-digital (HSD) signals with good signal integrity (SI) and low latency. Consistent Dk and impedance also translates to higher-frequency circuits with less phase distortion, as essential for many of the phase-based modulation schemes of 4G and 5G networks and the timing of their HSD circuits.

Prepreg and laminate materials for 5G small cell circuits should also have minimal dielectric loss; for a laminate, low dielectric loss should be coupled with low loss for the conductive cladding. A laminate circuit material should have a smooth conductive surface, which benefits both higher frequency mmWave analog signals and HSD signals, supporting good circuit SI performance. A smooth conductor surface minimizes signal distortion at the small wavelengths of mmWave frequencies with minimal delays for HSD signals.

Low conductor loss is also a prerequisite for the conductive cladding of any circuit laminate specified for use in 5G NR small cells, to minimize signal attenuation at higher frequencies and limit the thermal dissipation of signal power as heat within such a small, confined volume. The type of dielectric material will also contribute to the thermal dissipation capabilities of a circuit laminate, important for densely packed 5G small cells operating with a maximum number of users and at its transmit power limits.

While few circuit materials can meet the challenges of emerging 5G wireless networks, especially those with multifunction, densely packed circuit assemblies that must fit within the tight confines of small cells, I-Tera® MT40 very low-loss laminate and prepreg materials from Isola Group may come close. The laminates feature typical Dk of 3.38, 3.45, 3.60, or 3.75 measured in the z-axis or thickness at 10 GHz. It remains within ± 0.01 of that Dk value even across a wide operating temperature range of -40 to +140°C to provide the consistent impedance needed for low-distortion circuitry at mmWave frequencies.

I-Tera® MT40 very low-loss laminate and prepreg materials also feature low dielectric loss, detailed by a typical loss tangent or dissipation factor (Df) of 0.0028 at 10 GHz. The materials have the thermal conductivity needed for long operating lifetimes in tightly enclosed small cell housings, at 0.61 W/m-K.

These materials can be formed into HSD and mmWave circuits without elaborate micromachining or fabrication processes, allowing circuit manufacturers to create consistent low loss plated thruholes and microvias for interconnecting multiple circuit layers in multifunction circuit assemblies. After all, 5G small cells may be no larger than a shoebox, but users will expect full 5G voice, video, and data performance at all times and from 5G cells of all sizes.