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POWER INTEGRITY

Thermal Management of High-Frequency PCBs

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Thermodynamics can be a difficult enough subject to understand. But when combined with high-frequency PCB design and fabrication, it can really get complicated. Thermal management of PCBs has received a lot of attention over the past few years and it will probably continue as new technology pushes the limits of this issue.

For simplicity purposes, we will only discuss two sources of heat generation. One source of heat on the PCB is an active device or chip generating heat. The other source occurs when RF power applied to the circuit causes the heat. Of course there can be a combination of these sources, but to keep this column simple, the individual sources will be addressed independently. And for simplicity, examples will be given for a double-sided (microstrip) circuit, with a heat sink attached to the ground plane side of the circuit.

The basic concept of thermodynamics related to PCBs is concerned with thermal conductivity, heat flow and thickness of the circuit. In the case of a double-sided circuit, the copper has extremely high (good) thermal conductivity, but the substrate is typically in the range of a thermal insulator with very low conductivity. Having a high heat flow is good for keeping the circuit cooler by more efficient heat transfer from the heat source to the heat sink. The heat sink is designed to dissipate the heat away from the circuit and is typically a large metal plate bonded to the PCB with some cooling functionality.

As mentioned, most substrates used in the high-frequency PCB industry have low thermal conductivity and are in the range of 0.2–0.3 W/m/K. A common tradeoff to improve heat flow and ultimately thermal management is to use a thinner substrate, which gives a shorter heat flow path and enables more efficient transfer of heat to the heat sink. If the heat source is a chip mounted on the circuit, this is sometimes helpful and often copper-plated vias are placed beneath the chip to act as thermal channels to the heat sink.

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In the case of a high-frequency circuit with PCB circuit traces that heat up due to RF heating, the selection of thinner substrates may be troublesome because it can generate even more heat. The heat generated by RF heating is from insertion loss, and a circuit with more loss will generate more heat. Typical high-frequency RF circuits are of the controlled impedance variety, and a thicker substrate will require a wider conductor to maintain this impedance. A thicker substrate and wider conductor will generally have lower insertion loss, which means there will be less RF heat generated. Unfortunately, a thicker substrate will have a longer heat flow path from the RF heat generated on the signal plane to the heat sink on the ground plane.

There are some tricks that can be beneficial for using thin, low-loss, high-frequency laminates. When a laminate is relatively thin, the conductor surface roughness will contribute to the insertion loss to a greater extent than a thick laminate. A thin laminate using copper with a smooth surface will have less conductor loss, which in turn will cause lower insertion loss and a smaller amount of heat generated. Additionally, the thinner laminate will be a shorter heat flow path, so thermal management issues will benefit.

The selection of material becomes more important for high-frequency, high-power PCB applications. Even though a thicker substrate will have a longer heat flow path, it can be less of an issue if the substrate has a very low dissipation factor. The lower dissipation factor will reduce the insertion loss and cause less RF heat generation. Ideally it would be good to have a substrate with very low dissipation factor and a high thermal conductivity; however, that is an extremely unusual combination of properties for high-frequency laminates. The substrates that typically offer the lowest loss are the PTFE-based laminates, and most of them have thermal conductivity numbers in the range of 0.2 W/m/K–0.3 W/m/K.

Recently, there has been several laminates brought to the market claiming high thermal conductivity and low loss. Many of these laminates, depending on how they were tested, do not have as high thermal conductivity in actual use as one might expect. There are exceptions, though, including RT/Duroid 6035HTC, which has a very low dissipation factor (0.0013 @ 10 GHz) and extremely high thermal conductivity at 1.44 W/m/K.

The general desired properties of circuit materials for thermal management of high frequency PCBs are low dissipation factor, high thermal conductivity and smooth copper for thin constructions. However, there are typically some tradeoffs, so it is recommended that you contact your material supplier when designing a new PCB application where thermal management is a concern. **PCBDESIGN**

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