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PCB Materials for High-power RF Applications

Lightning Speed Laminates

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Most commercial PCB-based applications that use high power are typically associated with cellular base station technology; however, there are other applications. There are also several things to consider when working with high-power RF applications. This column will concentrate on PCB-based power amplifiers used in base station applications, but the basic concepts discussed here will apply to other high-power applications.

Most high-power RF applications will have issues with thermal management, and there are a few fundamental relationships to consider. One relationship is the loss-heat relationship. A circuit with higher loss will cause higher heat to be generated when high RF power is applied. Another issue is frequency heat, which causes more heat to be generated at higher frequencies. Additionally, any dielectric material that is subjected to an increase in heat will have a change in Dk (dielectric constant), and that is the thermal coefficient of dielectric constant (TCDk). There will also be a change in insertion loss with a change in temperature. These changes in Dk due to TCDk can impact the RF circuit performance and could be problematic for the application.

There are multiple materials and PCB properties that should be addressed for the loss-heat relationship. Sometimes, when a designer chooses a low-loss material for a PCB application, they will only consider the dissipation factor (Df, or loss tangent). The Df is related to the dielectric losses of the material; however, a circuit will have other losses. The overall loss of a circuit, as it relates to RF performance, is

insertion loss. Insertion loss is made up of four other losses and is a summation of dielectric loss, conductor loss, radiation loss, and leakage loss.

A circuit using a very low loss material with a Df of 0.002 and very smooth copper will have relatively low insertion loss. The same circuit using the same low-loss material, but using a high-profile electrodeposited (ED) copper instead of smooth copper will lead to an increase in insertion loss.

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Copper surface roughness will have an impact on the conductor loss of a circuit. To be clear, the surface roughness that is a concern for losses is the copper surface roughness at the copper-substrate interface as the laminate is made. Additionally, if the circuit substrate is thin, the copper planes will be closer together, and the copper surface roughness will have a larger impact on insertion loss compared to a circuit using a thicker laminate.

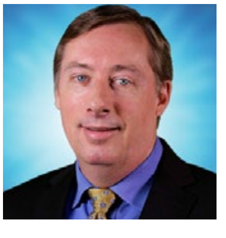
For high-power RF applications where thermal management is typically an issue, choosing a laminate with low Df and smooth copper can be advantageous. Additionally, choosing a laminate with high thermal conductivity is generally a smart thing to do as well. The high thermal conductivity will assist in moving the heat more effectively out of the circuit and into the heat sink.

The frequency-heat relationship basically causes more heat to be generated when there is an increase in frequency, with the assumption of the same RF power being applied at both frequencies. As an example taken from some thermal management experiments done at Rogers, we found that a microstrip transmission line with an applied RF power of 80 watts at 3.6 GHz had a heat rise of ≈50°C. When that same circuit was tested with 80 watts applied at 6.1 GHz, the heat rise was ≈80°C.

There are several reasons for having an increase in temperature with an increase in frequency. One reason is the Df of a material will certainly increase with an increased frequency, which will cause more dielectric losses and will ultimately cause an increase in insertion loss and heat. Another issue is the fact that conductor losses naturally increase with an increase in frequency. Some of the conductor loss increase is due to a thinning of skin depth as frequency increases. Additionally, with increased frequency, the fields will condense, and there will be more power density in a given area of the circuit, which will also increase the heating effects.

Lastly, TCDk, which has been mentioned several times in this column previously because it is a material property that is often overlooked, is basically how much the Dk will change with a change in temperature. In the case of power amplifier circuits, they often have ¼ wavelength matching networks, and these networks are sensitive to Dk fluctuations. When the Dk changes greatly, the ¼ wavelength matching will shift, and the power amplifier can vary in efficiency, which is very undesirable.

In summary, when selecting high-frequency materials for high-power RF applications, the material should have low Df, relatively smooth copper, high thermal conductivity, and a low TCDk. There are many tradeoffs when considering these material properties, along with the final end-use application requirements. Therefore, it is always wise for the designer to contact their material supplier when choosing materials for high-power RF applications. **DESIGN007**



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