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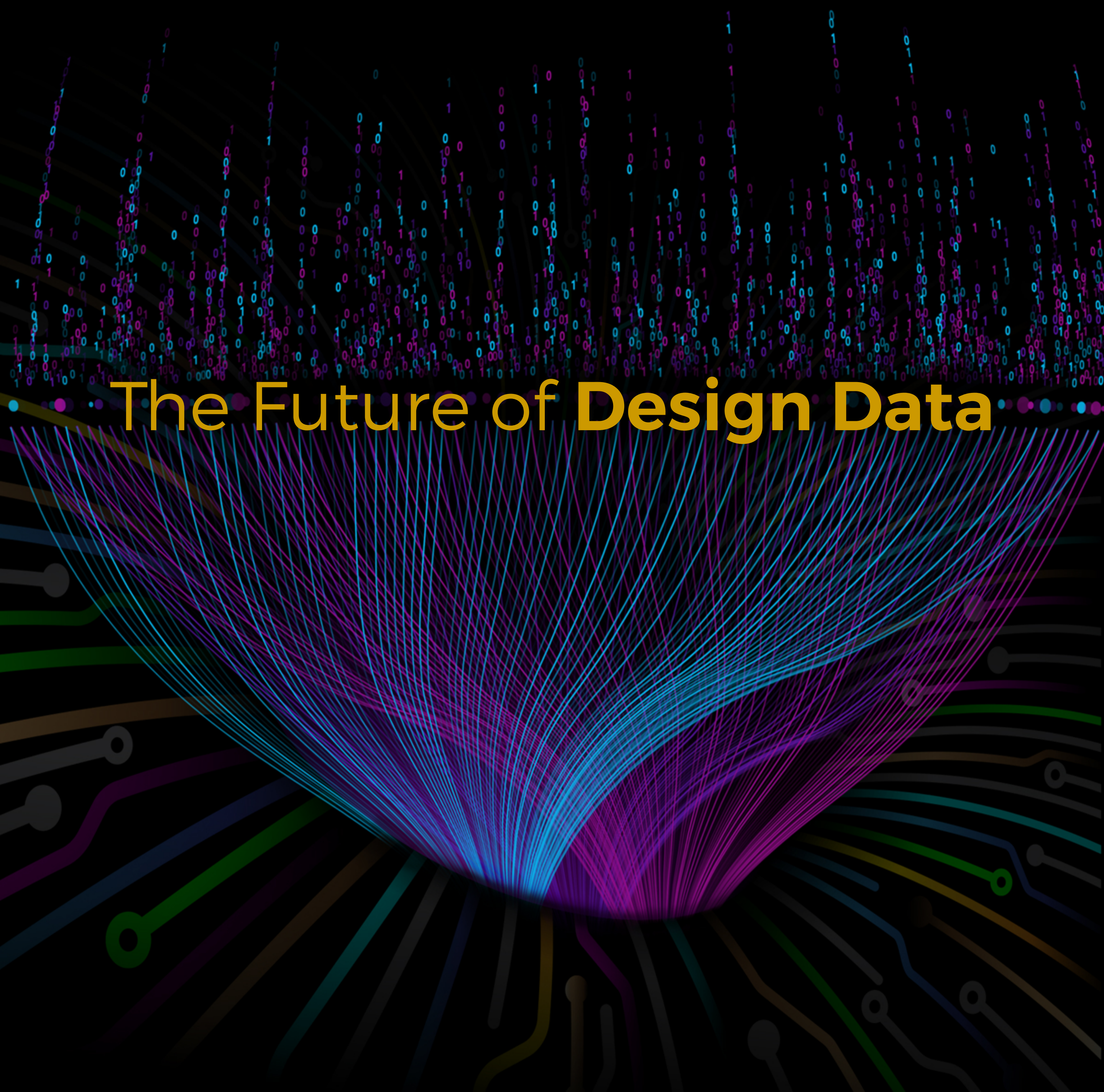


How Copper Properties Impact PCB RF and High-speed Digital Performance

Lightning Speed Laminates

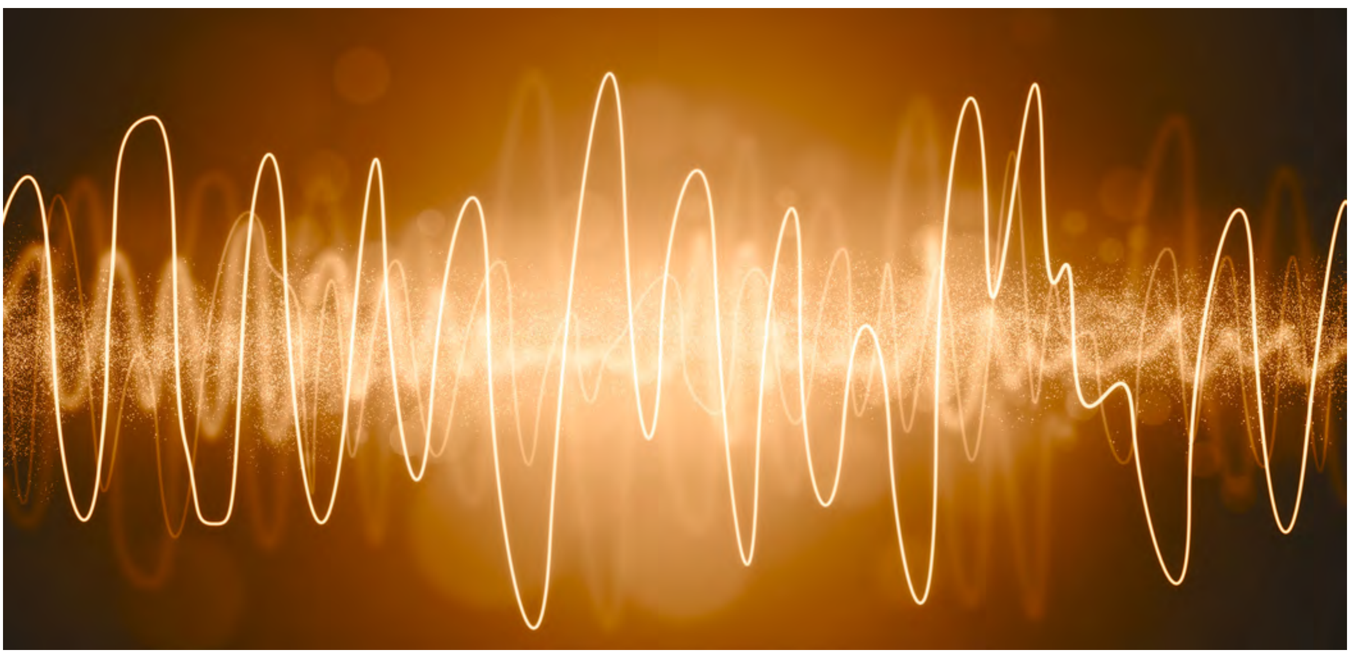
by John Coonrod, ROGERS CORPORATION

It has been well known in the RF industry for many years that copper surface roughness impacts RF performance of PCBs. This analogous statement also applies to high-speed digital applications. To explain the copper surface roughness issue, take a simple two-layer copper circuit, for example.

The circuit is a microstrip with a signal conductor on the top copper plane and a ground plane on the bottom of the circuit. Additionally, the concept of skin depth and wave propagation should be considered. Skin depth is the depth within the cross-sectional area of the copper where the majority of the RF current resides and is dependent on frequency. At lower frequencies, the RF current will have a thicker skin depth and use more of the conductor. At higher frequencies, the skin depth is thinner, and less of the conductor is used by the RF current. For wave propagation, the electromagnetic wave that propagates on the microstrip circuit will be slower for a circuit using a higher dielectric constant (Dk) material. Using a lower-Dk material, the wave propagation is faster, and the propagation delay is reduced.

Rogers has studied copper surface roughness extensively and has a lot of information to share for the interested reader. We know if a comparison is done on two identical circuits with one using a high-Dk material and the other a low-Dk material, the circuits will have slower and faster wave propagation, respectively. However, we found other circuit properties can alter the wave propagation speed, and one of them is the copper surface roughness. To be specific, the copper surface roughness is the roughness at the substrate-copper interface.

Further, we have done experiments where the same material was used with the same mi-



crostrip design, and the only difference was the copper type. In these experiments, we consistently saw that circuits with a rougher copper surface had a slower wave propagation compared to circuits with a smoother surface. A rougher copper will slow the wave, and a slower wave is perceived by the circuit as a higher Dk, even though the Dk of the material is the same for both circuits. When extracting the Dk value from circuit performance, the circuit with the rougher copper will have a higher Dk value than the circuit with a smoother copper. Also, we found that wave propagation is more affected by the copper surface roughness in circuits made using a thinner substrate versus circuits made with a thicker substrate.

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The effect that copper surface roughness has on wave propagation is also frequency dependent, and at low frequencies, the copper surface roughness may have little or no impact on the wave velocity. Frequency dependency is due to skin depth and at low frequencies where the skin depth is thick. The roughness is a small percentage of the cross-sectional area of the conductor being used by the RF current; the effect of the copper roughness has little influence on the wave propagation. However, at higher frequencies—specifically, frequencies where the skin depth is equal to or less than the copper surface roughness—the roughness will have a significant impact on the wave propagation properties of the circuit.

For an RF PCB using copper with a rougher surface, the copper surface will cause an increase in conductor loss, slower wave velocity, and a higher effective Dk. For a high-speed digital PCB using copper with a rougher surface, the copper will cause an increase in insertion loss and propagation delay, and a decrease of the eye opening in an eye-diagram, typically. Many years ago—when digital rates were slower, and the Nyquist frequency was lower—the influence copper surface roughness had on these circuits was minimal. Now, with faster digital rates and higher Nyquist frequencies, the potential effects that copper surface roughness has on these circuits can be substantial.

With many new applications using millimeter-wave technology, which is RF at very high frequencies, the copper surface roughness can have a very large impact on RF performance for these circuits. Insertion loss and phase response of millimeter-wave circuits can be greatly impacted by copper surface roughness. All copper types used in the PCB industry have normal surface variation. The natural trend is that a copper with a rough surface will have much more roughness variation than copper with a smooth surface. The copper surface roughness variation can cause phase variation from circuit to circuit.

Even though my example uses a two-layer copper circuit, a common concern in building multilayer PCBs is that the copper surface roughness may have more impact on the circuit electrical performance than the designer would anticipate. The PCB fabricator will often have a choice of what type of copper to use on certain layers within the multilayer PCB. Typically, their decision is based on their desire to build a robust circuit. To optimize the electrical performance of a circuit, copper surface roughness also needs to be considered.

For more details on this subject, please contact your PCB materials provider. DESIGN007

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