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Thermally Conductive Substrates & Thermal Management

by Ian Mayoh — Page 12

Make The Most of High-Frequency Laminates with Resistive Foil

by John Coonrod
ROGERS CORPORATION,
ADVANCED CIRCUIT MATERIALS DIVISION

Resistive foils have been part of PCB laminates for some time and for a wide range of applications. They allow significant savings in space on a PCB in contrast to the use of discrete resistors, even compared to tiny SMT resistors. Some applications even use resistive foils to minimize or eliminate the inductive reactance of an SMT resistive device. Resistive foils can reduce the discrete component device count, free up real estate on a PCB, and even improve circuit board assembly processes. Many high-frequency circuit applications rely on resistive foils as termination resistors for transmission lines or matching resistors for power dividers. Regardless of the application, planar resistor technology has been well defined and established over the years and offers many advantages compared to alternative resistor technologies.

Consistency of resistance values was often an issue during the early days of planar or buried resistors based on resistive foils. Some of the inconsistencies stemmed from how the resistive foils were incorporated into the circuit laminate materials and some issues resulted from how certain circuit fabrication processes impacted the properties of the resistive material. Fortunately, as resistive foil technology has matured, present-day circuit laminate materials with planar resistors achieve consistent resistor values, with minimal changes in those values when subjected to laminate and circuit fabrication processes.

Resistive foils have long been characterized in terms of their nominal surface resistance (R_S) values, or the amount of resistance exhibited by a nominal surface area of the material, such as ohm/square. Common R_S values for resistive foils include 25, 50, and 100 ohm/square, and, in some cases, 10 and 250 ohm/square. When designing circuits with these resistive foils, a simple relationship can be applied to determine the design resistance value of a planar resistor: the length is divided by the width and then multiplied by the surface resistance of the resistive foil material, where the length and the width are the dimensions of the planar resistor used in a design. Other details concerning these resistive foils and how they translate into resistors can be found by visiting the website for suppliers of resistive foils, such as Ohmega Technologies and Ticer Technologies. Ticer offers a close look at its embedded resistor-conductor material and how the reliability and consistency of such materials have been applied to many critical electronic applications, including in many medical electronic devices, with good results.

Using PCB materials with resistive foils to fabricate circuits with planar resistors is fairly straightforward. A circuit pattern is first imaged and etched on the PCB material. In areas where conductive copper has been etched away from the PCB, resistive foil material will be exposed at the surface. This exposed resistive material is then chemically removed. Next, a photoresist is applied to protect the circuit pattern and to have selective openings imaged in the photoresist to define resistors. The copper is then etched in the selectively open areas of the photoresist to expose the resistive material in just those areas. The photoresist layer is then removed so that planar resistors remain formed between copper conductors, as shown by the illustration in Figure 1.

The nominal resistive values of these resistive foils tend to shift somewhat predictably during the process of manufacturing a PCB laminate, and designers should be aware that nominal values for the material may be somewhat different than the actual design values. For example, for a common RF/microwave circuit material with resistive foil that is based on polytetrafluoroethylene (PTFE), the nominal values of the foil change from 25, 50, and 100 ohm/square to 27, 60, and 157 ohm/square, respectively. A circuit designer should consult their material supplier to ensure they are aware of the effective resistive values to use for a given circuit material with planar resistors. Depending upon how a laminate is made, there may be very little difference between the nominal and the design resistive values, although the safe design strategy is to check with the material supplier.

Resistance tolerance for resistors formed from these resistive films can be well controlled, although there are some dependencies in achieving tight tolerance. For example, the physical size of the resistor will have an impact on resistance tolerance, with larger resistors formed from resistive films typically being capable of attaining much tighter resistance tolerance than smaller resistors formed from resistive films. In a study evaluating planar resistors of different sizes based on the commercial PTFE-based circuit material noted earlier, extremely good tolerance results were achieved with medium to large planar resistors from re-

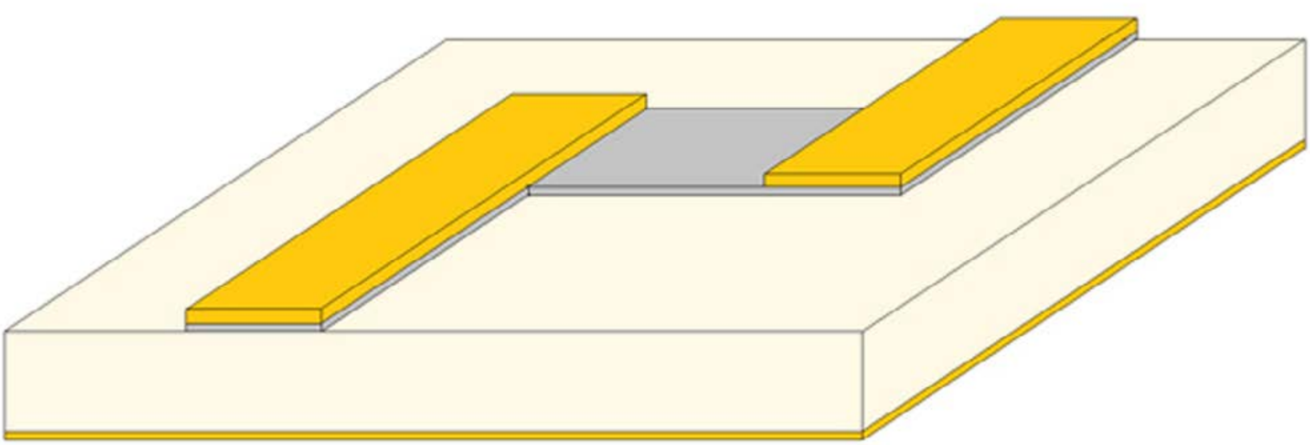

Figure 1: A portion of a PCB shows how planar resistor technology is used to form a resistor (the grey material) between copper conductors.

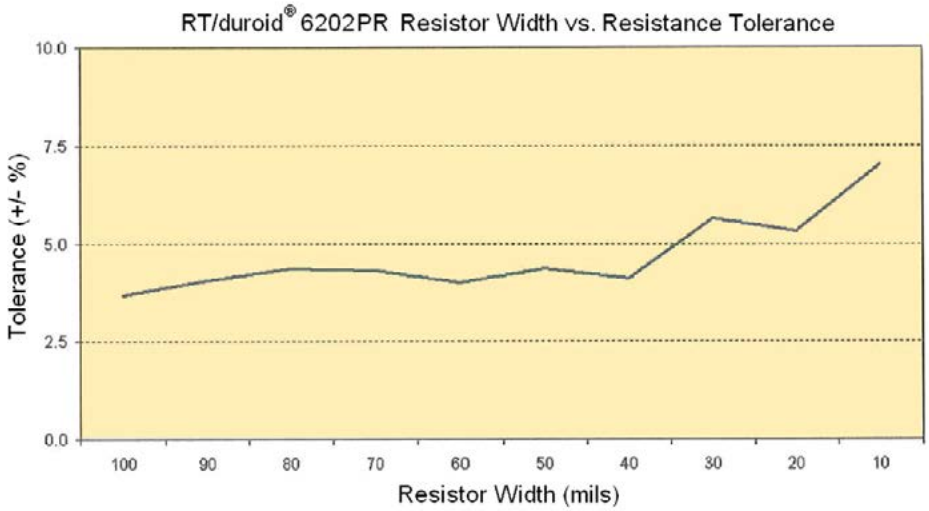

Figure 2: Common PTFE-based high-frequency laminate with planar resistors formed of resistive film show the tight resistor tolerances that are possible.

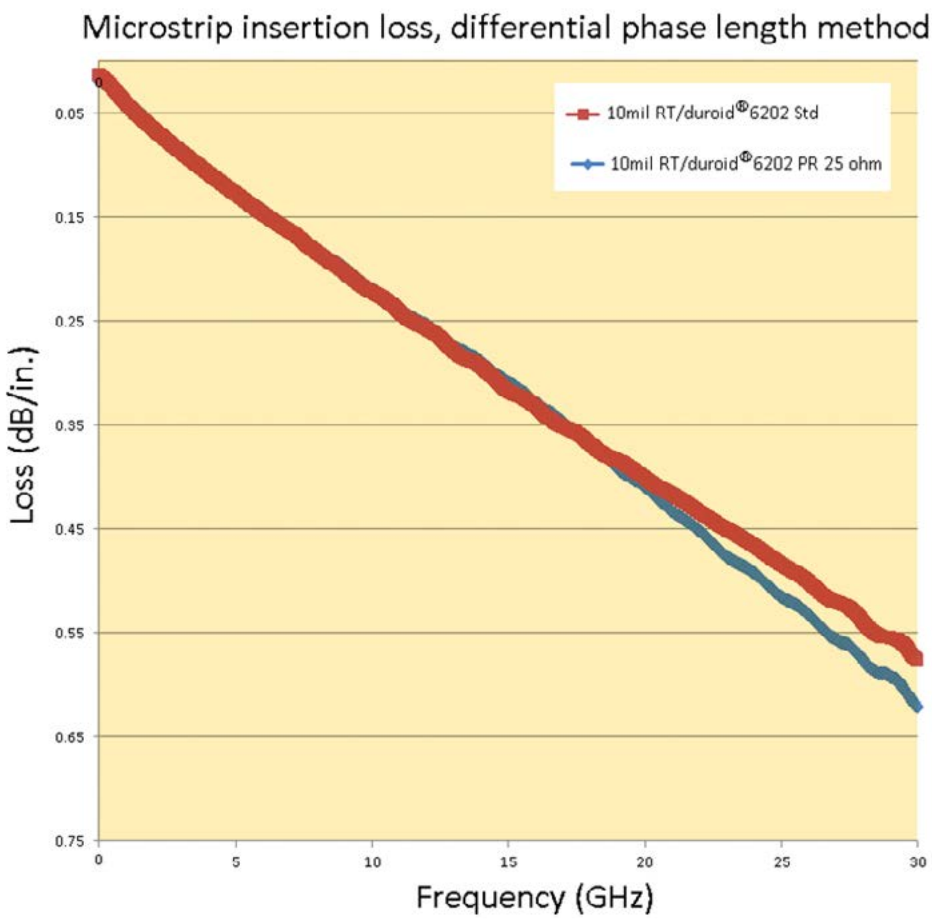

Figure 3: Plots comparing the insertion loss of similar microstrip circuits fabricated on PTFE-based laminates with and without planar resistors.

sistive film and good tolerance results were obtained with relatively small resistors. Figure 2 shows the results of this study for the PTFE-based laminate with resistive film, with values for resistance tolerance plotted as a function of resistor width.

The resistor tolerance values shown in Figure 2 are considered quite good. Surface-mount resistors commonly used in the industry typically have a resistor tolerance of ±10% while higher-quality discrete resistors typically have a resistor tolerance of ±5%.

Insertion loss is often a concern with high-frequency circuit laminates, in particular for laminates with resistive films and planar resistors. Such laminates with resistive films are often used in fabricating RF/microwave power dividers/combiners and such circuits must minimize insertion loss, especially when called upon to handle high signal power levels. Excessive insertion loss in high-frequency circuits that handle high power levels will result in unwanted temperature rises within the power divider/combiner circuit, which can be a destructive mechanism for the circuit.

To better understand the impact of planar resistor technology on the insertion-loss performance of high-frequency circuit materials, insertion-loss testing was recently performed on a standard PTFE-based high-frequency circuit laminate with and without the resistive film and the planar resistors. The materials were evaluated by means of a simple microstrip transmission-line circuit pattern using the differential length test method. Figure 3 shows the results, using laminates with the same copper conductor material and with and without the resistive film and the planar resistors. As the plots of loss versus frequency show, the insertion-loss characteristics are quite similar for the 10-mil circuit laminates, whether or not they include the resistive film and the planar resistors, leading to the conclusion that the resistive layer does not have a significant impact on the circuit material's insertion loss.

Low-loss, high-frequency circuit materials with planar resistor technology have at times been plagued by differences in insertion-loss performance for parts within a circuit build, with some parts showing significantly higher insertion loss than others. Because this did not occur on a regular basis, the cause for deviations in insertion-loss performance was not found for some time.

One theory proposed that if a circuit panel was relatively thin, any mishandling of the circuit laminate could cause microfractures in the laminate's resistive layer and copper, but this was never proven. In another case, an event revealed some circuits with elevated insertion loss within a build of other circuits with normal insertion loss. After an investigation, it was discovered that poor etching quality could result in a significant difference in insertion loss.

When viewed as a cross-section, a copper conductor typically has a trapezoidal shape, due to the standard types of copper etching processes used as part of PCB fabrication. For most high-frequency designs, this trapezoidal shape typically has minimal impact on insertion-loss performance. However, for a circuit material with resistive foil, the trapezoidal shape may result in higher insertion loss than expected. To explore this concern, evaluations were performed by fabricating microstrip transmission lines on high-frequency laminates and pur-

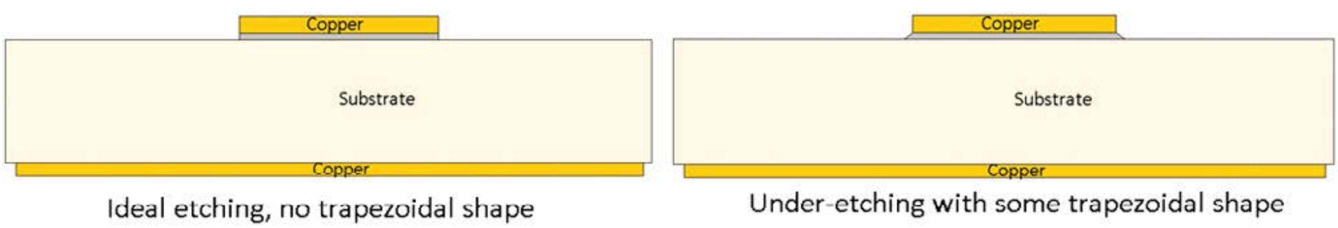

Figure 4: Cross-sectional views of microstrip circuits show where the etching is ideal (left) and where an underetched condition leads to severity in the trapezoidal shape (right).

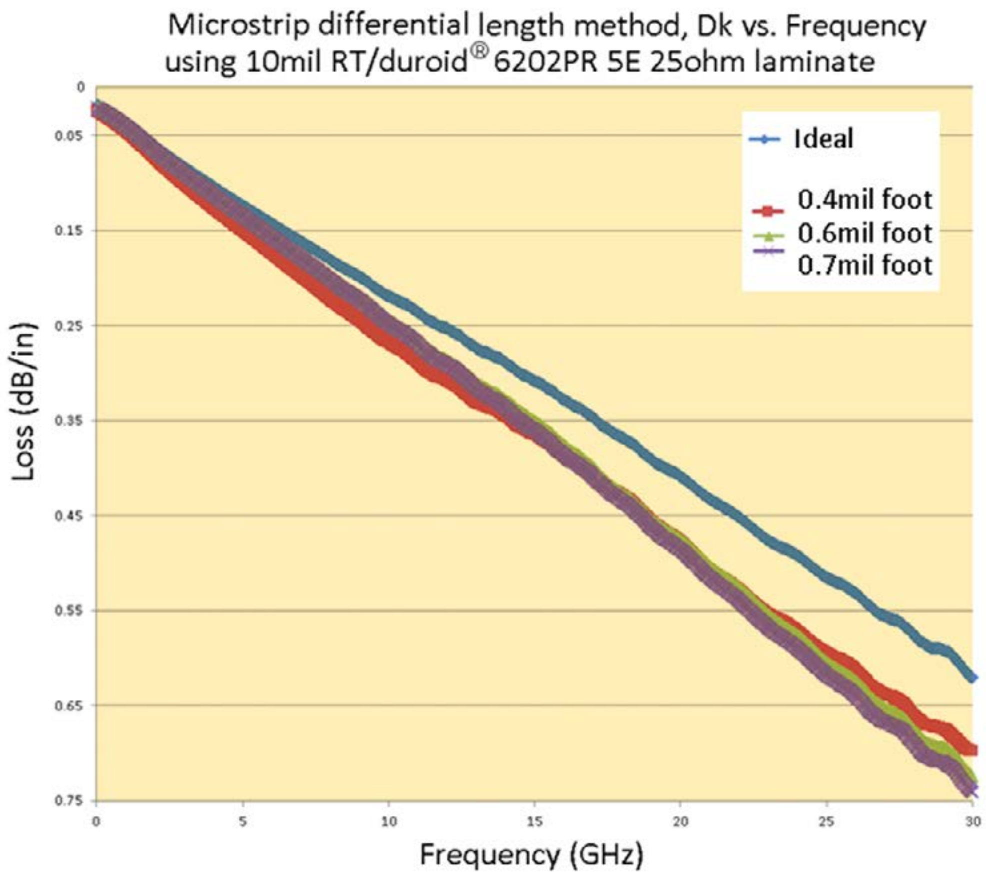

Figure 5: Microstrip insertion loss comparisons of circuits made on the same PTFE-based high-frequency materials with planar resistors and with varying etching quality.

posely underetching the conductors to cause different levels of severity in the trapezoidal shape, as shown in Figure 4.

These evaluations of the trapezoidal shapes involved a 10-mil-thick substrate, a high-frequency PTFE-based circuit material with a 25-ohm planar resistive layer. Circuits were processed under a number of different conditions, with the intent to create trapezoidal shapes with varying severity. Unfortunately, the differences in trapezoidal shapes were not large, and some circuits were found to be near ideal while others had trapezoidal shapes oversized by 0.4, 0.6, and 0.7 mils at the foot of the conductor on each side. As Figure 5 shows, these differences in trapezoidal shapes resulted in only small differences in insertion loss, notably when compared to the near-ideal circuits.

Although the trend in Figure 5 corresponds with the theory that a more severe trapezoidal shape would result in higher insertion loss, the differences in the trapezoidal shape were not significant and the insertion loss differences were also considered minor. In general, the study warns of the need for concern with etching quality when using laminate materials with resistive foils and planar resistors, but it is not clear how severe the etching quality must be affected before it impacts the insertion-loss performance of a circuit laminate with planar resistors. **PCB**

John Coonrod is a market development engineer for Rogers Corporation, Advanced Circuit Materials Division and a regular columnist for The PCB Design Magazine. To contact Coonrod, or read past columns, click here.