THE pcb design MAGAZINE

AN I-CONNECT007 PUBLICATION

September 2013

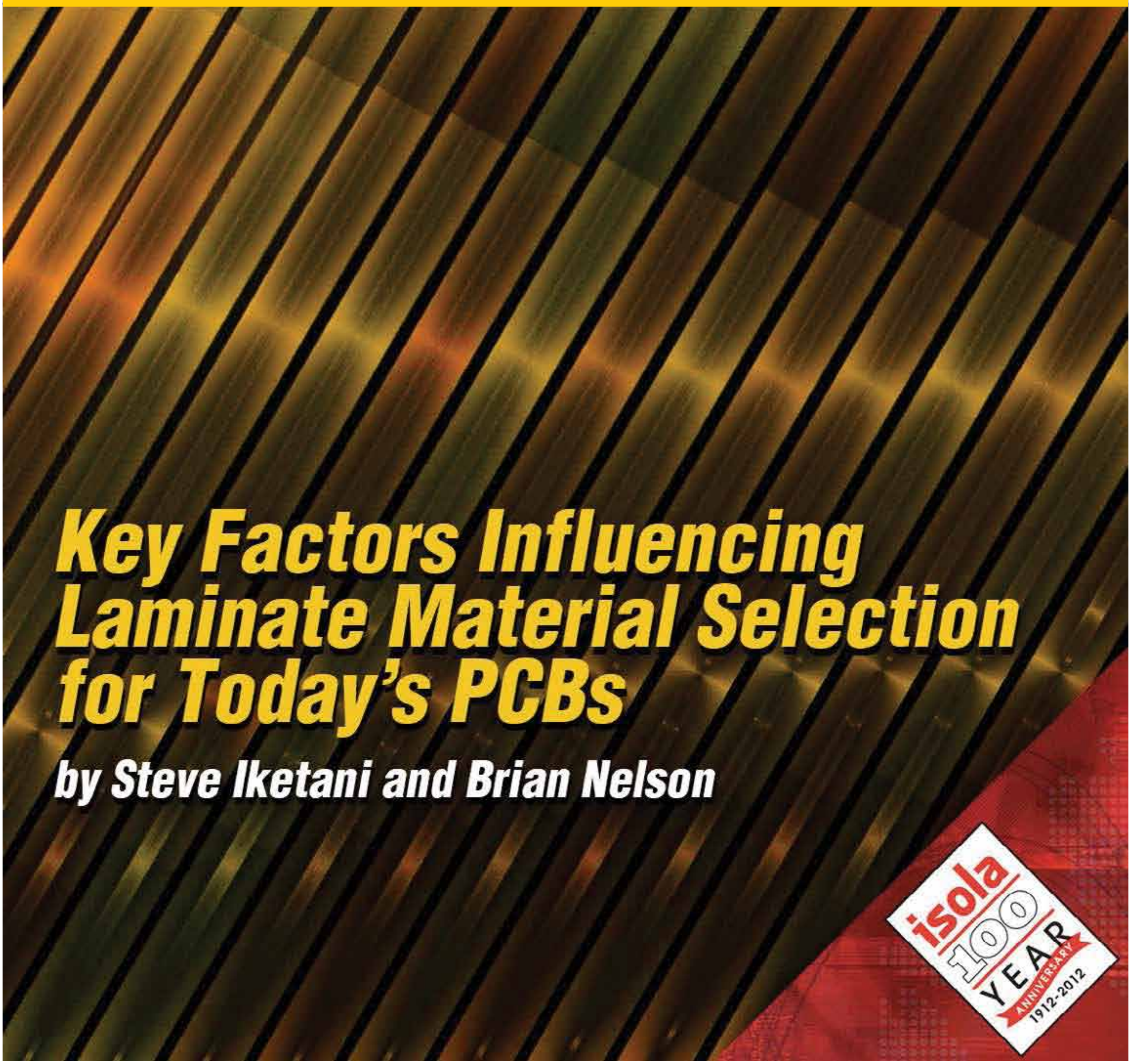
Construction Profiles and Material Decomposition p.18

Improved Thin-Film Resistor Material p.24

High-Frequency Laminates for Hybrid Multilayer PCBs p.30

Material Selection for SERDES Design p.36

MATERIALS



Key Factors Influencing Laminate Material Selection for Today's PCBs

by Steve Iketani and Brian Nelson

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SANMINA

SUMMARY: Recently, there has been a flurry of new and promising laminate materials entering the market, coming from the four corners of the world. Sanmina's Steve Iketani and Brian Nelson offer their take on materials, from FR-4 to low-Df/Dk laminates, and much more.

Ever greater miniaturization of electronic equipment and its circuitry, along with increasing data traffic rates, continuously pushes the PCB industry to improve performance. The compression of development cycle times has been ongoing for some time, but recently this has created a tsunami-like impact on PCB fabrication, especially in laminate materials. In order for design engineers to find solutions for increasing speed and signal integrity management in PCBs, they must keep up with the constant evolution of laminate materials, primarily on their loss performance attributes.

Today, we are seeing wave after wave of new materials that target improved cost as well as improved performance. Some efforts are in cost reductions at the current performance levels (Figure 1), and other entries are designed to improve performance while attempting to stay at par with existing price levels (Figure 2). These performance-enhanced issuances tend to fall into the spaces between traditional class groupings, creating a more continuous suite of laminate offerings. As a result, there are more tailored choice options for any specific design application, rather than having to select either an over or under laminate available for specification.

The source area for higher-speed materials has been rapidly widening. In the early 2000s, most higher-speed materials came from the US and Japan. Today, materials are being sourced from Taiwan, Korea, Singapore, Hong Kong, and China. The companies and materials may not have the same maturity and application knowledge that the industry is accustomed to, depending upon the manufacturer, its experience, and the duration an offering has been in the market. Despite this general disadvantage, new laminate players continue to charge into the market, providing many materials of lim-

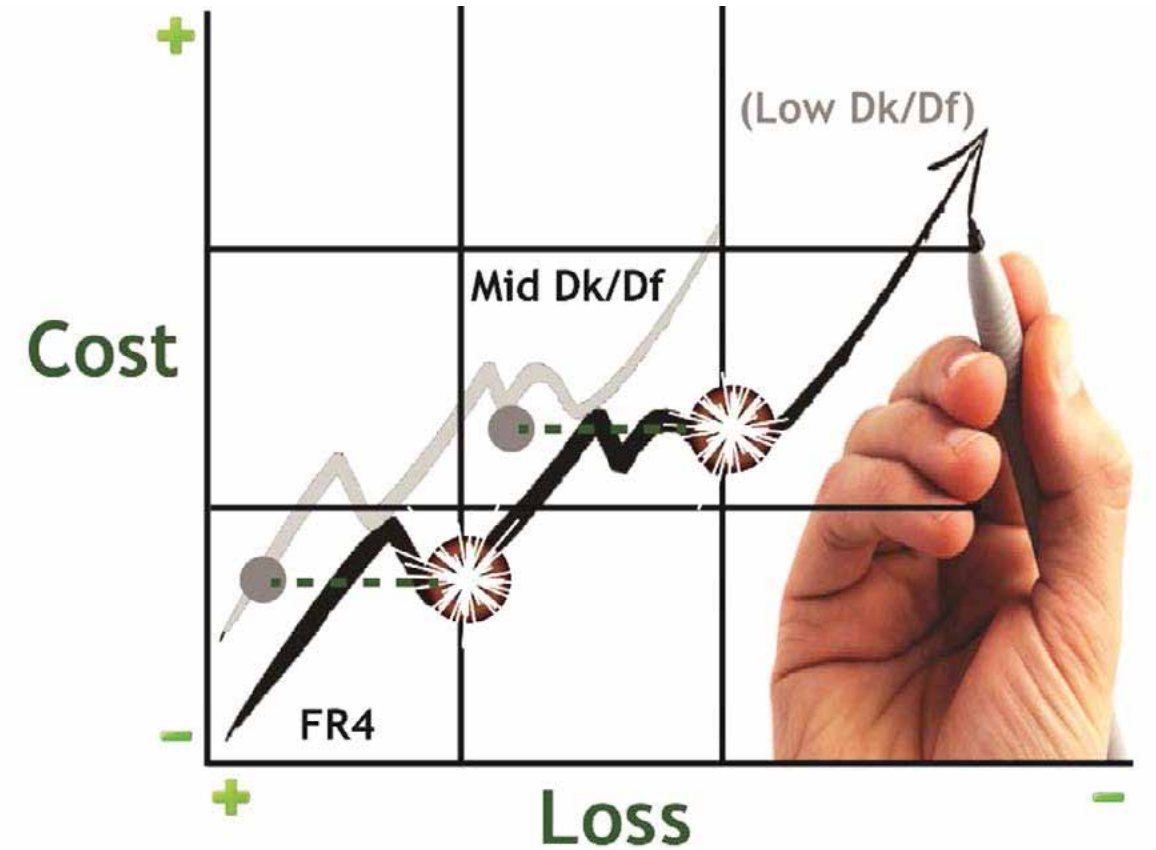

Figure 1. Some efforts address reducing costs at current performance levels.

ited data and background. A large sampling of laminates are plotted for S21 loss at 10GHz in Figure 3, which shows there are many competitive materials available with only incremental performance differences, and a nearly linear slope of options from top to bottom.

FR-4 Class Laminates

PCB material discussions often use FR-4 as a baseline for comparison of material behaviors and, especially, processability. FR-4 will continue to persist in product builds for both its thermal-mechanical strength (a valuable attribute for HDI fabs) and, of course, for its relative low cost. To continue to be in play, FR-4 also needs to provide at least acceptable limits of electrical performance coherent with transmission rates of interest. This has not been a great attribute of FR-4 historically, and our experience points to a maximum usable data rate of around 5–6 Gbps, depending on the design trace widths and routing lengths. The major impediment of using FR-4 is usually its loss tangent (Df). Yet, there have been some industry trends mitigating the loss aspect of FR-4, extending its potential use.

OEM pressure on laminate manufacturers, which began around the time of the then-new requirement to withstand leadfree assembly solder excursions, lead to some other concurrent enhancements and opened up a sub-class within a class: FR-4 resins modified and/or blended in a manner that resulted in some achieving as much as 1/3 reductions in rated Df compared to traditional FR-4s. These select offerings continue in the market, as they present Df improvements at measurably less cost than mid-Dk/Df class entrants, although these modified FR-4s do not enjoy much, if any, of the dielectric constant enhancements of the mid-Dk/Df class.

Even more to this point is the impact of halogen-free on the Df of FR-4. The change is from brominated flame retardants to non-brominated replacements that incidentally require lower content within the resin for effectiveness,

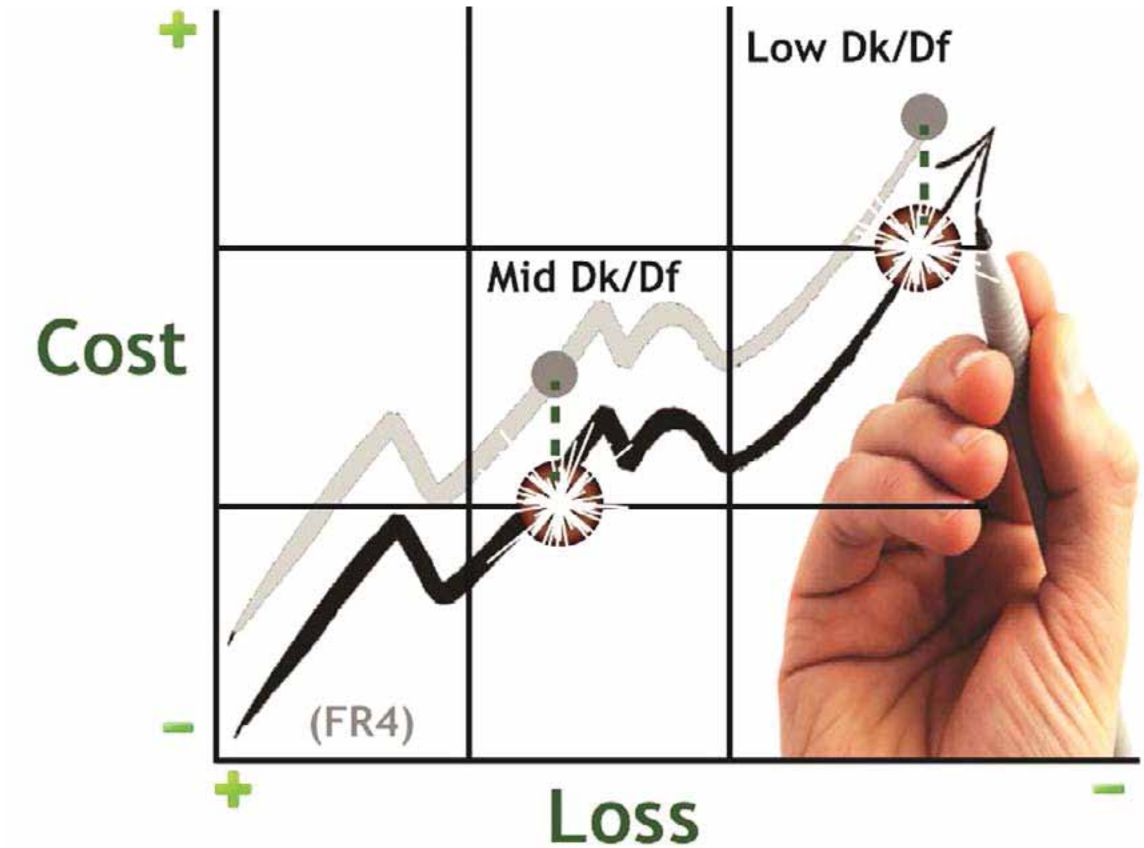

Figure 2. Other efforts focus on increasing performance while staying at today's price point.

that being the ability to conform and certify to UL94VO flame. This flame-retardant change has a measurable impact on Df. Many have taken note of halogen-free FR-4s, with Df ratings in the range of 0.010– 0.016 and at measurably lower cost than many of the mid-Dk/Df class materials. Ultimately, the mid-Dk/Df materials have loss tangents available that are lower still, well down into the 0.008 range, but at an appreciable cost premium.

Financial budgets, as well as loss budgets, tend to dictate the want and feasibility of using lowered Df FR-4s as opposed to opting into a mid Dk/Df material. As cost is always a focal point, most designs opt for the least costly laminate that will deliver the performance attributes needed for that design application. Using over-engineered material for a design application is more often the fault of market offerings forcing designs to over-buy on unneeded attributes in order to acquire the needed ones. As the material market continues to fatten out its class offerings, using over-engineered materials becomes less necessary. This is further demonstrated by the limited but available option of acquiring select lead-free FR-4 items on spread weave glass styles. As the primary benefit of these styles has been mitigation of differential impedance timing skew, these FR-4 offerings are targeting a specific performance aspect, whereas before these premium glass styles were only available bundled with higher performance resin systems.

Lower-profile copper options, those smoother than reverse-treated foil (RTF), have not really appeared in FR-4s. We believe this is because greater trace loss benefit can be realized by investing in other lower-Df resin systems rather than using cost premiums to clad relatively lossy FR-4 with finely surfaced coppers. Leadfree FR-4s also enjoy regular use in high-speed applications as part of stackup hybridization, reducing cost by being relegated to power, ground, analog and other non-critical layers, while often improving the overall thermal-mechanical

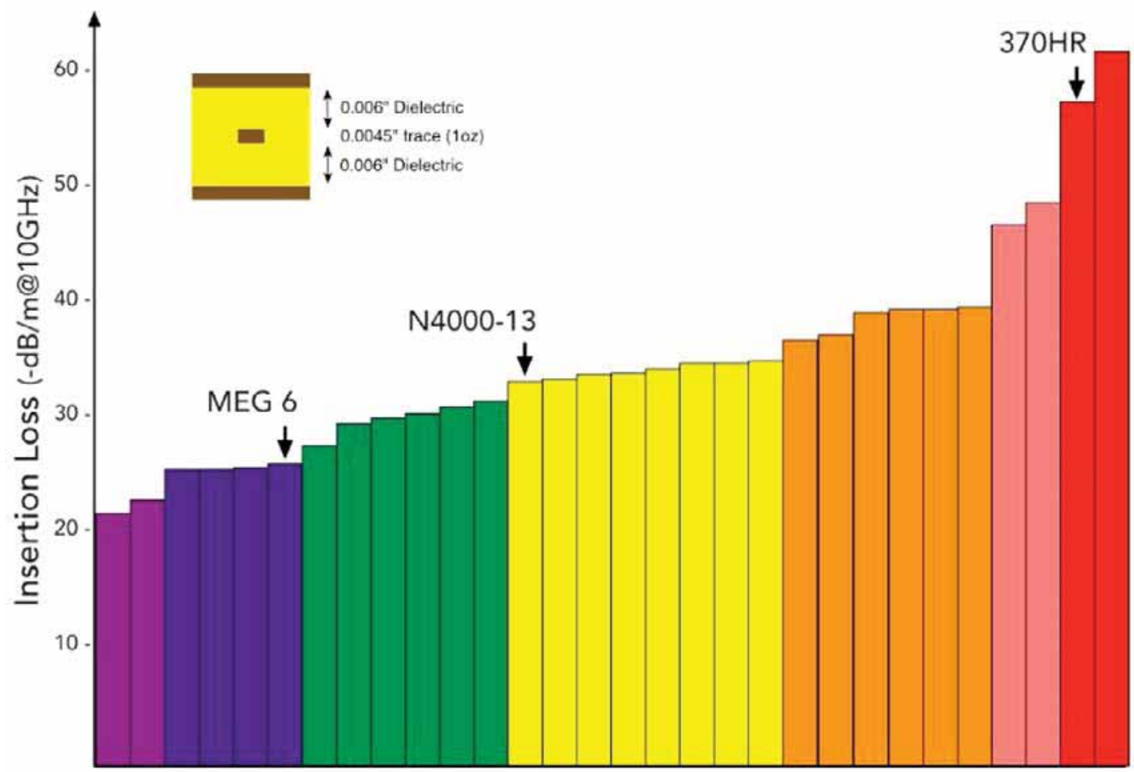

Figure 3. A variety of competitive materials are available, with only incremental differences.

performance compared to all high-performance material stackups.

Mid-Dk/Df Class Laminates

There is even a more dynamic mid-Dk/Df market at present. Mid-Dk/Df is defined here as having a dielectric constant measurably lower than FR-4, meaning at or below 4.0 and a Df rating in the range of 0.007–0.013, with a number of entries rated at or below 0.010. This class of materials has existed since the issuance of GE's Getek circa 1988, which was followed by Park-Nelco's N4000-13 and its equivalent competitor materials. Nelco also added low-Dk/Df options to N4000-13, as did several of its competitors over time.

Changes to this class came fast once RoHS dictates were being adopted. These are highly modified epoxy-based systems, some blended with cyanate esters, PPEs, PPOs and other proprietary content to achieve their performance targets. These now long, complex molecules were not proving very adaptable to the elevated temperatures of lead-free assembly and their impact on CTE-Z. Modifications were again needed and established mid Dk/Df players did just that, but only incrementally to protect their existing resin UL qualifications, which would be lost and require a new qualification cycle if UL Labs were to determine that a resin had changed to the degree of designating it as a new system.

In many ways, this hamstrings the laminators in industry-critical efforts to improve resin systems. Once a resin system formula has been locked down, it takes about a year for a laminator to get that new product through laminate UL, and the multi-months-long fabricator UL qualification extends that time even further. So, pressures of time-to-market and return on investment can run very counter to the need to advance a resin system beyond some limited scope despite the need for a fuller reinvention.

The market was able to manage for a few years, but HDI has become more complicated, BGA pitches smaller, and plated over via-in-pad and sequentially laminated build-up boards designs are much more prevalent today. The need to cross that UL line has been made evident and several laminate suppliers have responded with new, more robust and performance-improved systems. Not only have they been addressing the thermal-mechanical requirements, but they have also been able to chip away at bettering Df values and have moved into more expansive options of spread weaves and copper smoothness offerings, as well as leveraging new supplier sources for lower Dk/Df glass types.

All these changes have enabled new class within a class, a spate of mid-Dk/Df materials measurably above the traditional ones but still situated below the cost and performance absolutes of the ultra-premium low-Dk/Df class. The traditional mid-Dk/Df materials were showing some good use in the 5–10 Gbps space, but running short of really supporting the upper end of that range, forcing some designs into over-specifying of materials until these new issues started appearing. The new mid-Dk/Df+ class is targeting use as fast as 12.5 Gbps depending on trace widths and routing lengths. This in turn has put pressure on the low-Dk/Df class of materials to either reduce their cost as-is or create better performance versions to satisfy the ramping development of 20–25 Gbps and faster designs. Not surprisingly, both actions are taking place now.

Low-Dk/Df Class Laminates

To better understand the low-Dk/Df class of materials, we define them as having Dk values at or below 3.7 and Df ratings at or below 0.005. A number of the mid-Dk/Df materials can easily make this Dk range if enhanced with low-Dk glass, but not while also in the range of Df. These two values together then define a distinct class. The present standard bearers are Panasonic's Megtron-6 and, to a lesser extent, the Rogers 4000 series of ceramic hydrocarbons. But there are more players today and many more in the queue and coming.

The thermal-mechanical behavior of these materials is always important as they are often relegated to very complex, HDI designs and so must be able to endure multiple lamination cycles at lead-free temperatures, which is quite challenging; it is very difficult for laminators to concoct complex molecules that deliver very high electrical performance while remaining mechanically stable and robust. All the materials of this class have proprietary resin formulations, so it is not possible for us to know their entire makeup, although at the farthest end, most have measurable content of PTFE (e.g., Rogers Duroids, Taconic, etc.).

Cost always plays a big part in any product design, so the PTFE-laden materials are still limited players, although we're seeing some very large platform boards experimenting with PTFE-based laminates for the sake of mitigating attenuation over traces on the order of about a meter. But these are 25+ Gbps R&D designs and not what is being built regularly today. Product in the 8–12.5 Gbps space has given Megtron-6 much of its market. Targeted transmission rates have been increasing toward 20–25+Gbps, thus driving the need for even lower-loss materials, most preferably ones that do not have the high cost and processing challenges of PTFEs.

A number of these have been introduced in recent quarters and are under evaluation. Performance claims are just that, always warranting independent testing and measurement. We are especially interested in seeing how any high-end materials behave, as testing clicks through frequencies of, 5, 10, 12.5 GHz or more and how well they survive the rigors of modern HDI fabrication and assembly processes. Also, former background testing is often front and center today, with requirements of CAF, insulation resistance and the like being demand items and significant filters of acceptance for a number of OEM industries.

Overall, as a fabricator, we are very encouraged to see such a huge flurry of new and promising laminates entering the market and are optimistic laminators will continue providing answers to our most pressing needs and demands of signal integrity and speed. **PCBDESIGN**

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