玻璃纤维增强层压板的一种创新方法承诺可解决今天高科技印刷电路板设计中通常遇到的机械、电气和性能特征上的现有挑战。这种独特编织的玻璃布较平和薄，造成用于机械和激光钻孔的较均匀层压板。此外，玻璃纤维和玻璃/树脂介面的特性将改进抵抗CAF的能力。性能特征因铜线间的均匀绝缘层而大幅增强。减轻的纤维编织效应 (FWE)已获建议为均匀的函数。推论信号偏斜则已完全剔除作为性能的考虑因素。该自主开发的玻璃增强可与一个高性能的树脂系统结合，产生提供极佳信号完整性的层压板。初步测试结果显示一个高性能系统（FR-4电路板）于10 GHz的电气特征为：Dk = 3.00，Df = 0.0040。

Advanced GLASS REINFORCEMENT Technology for Improved Signal Integrity

New glass fabrics promise to resolve challenges in high tech PCB design and fabrication. by RUSSELL DUDEK, PATRICIA GOLDMAN and JOHN KUHN

Among the many challenges facing the electronics industry today are those related to the need for increased speed. These challenges include improved signal integrity and increased product reliability at multi-GHz clock rates with inherently smaller threshold voltages and picosecond rise/fall times. The implication of increased speed continuously challenges the industry.

In recent years, numerous technical papers have proposed methods to deal with these challenges, coining the phrase "fiber weave effect" or FWE to describe one of the central issues associated with the influence of the glass reinforcement fiber on the electrical performance of the PCB[1-7]. While many solutions have been presented to deal with FWE, none have addressed the actual woven glass fabric in the laminate material. The questions posed are these: Can an innovative glass fabric technology improve end product performance? Can a raw material so far back in the supply chain have an impact on leading edge industry challenges?

The answer to both questions is Yes. A new high performance glass fabric technology has been developed that demonstrates uniformity of glass weave resulting in a homogeneous reinforcement layer. Used with readily available resin technologies, this new glass fabric can provide improved physical properties (laser and mechanical drilling, dimensional stability and surface smoothness), superior electrical properties (CAF resistance), and enhanced performance properties (more uniform Dk and circuit impedance, reduced signal skew, and improved signal integrity).

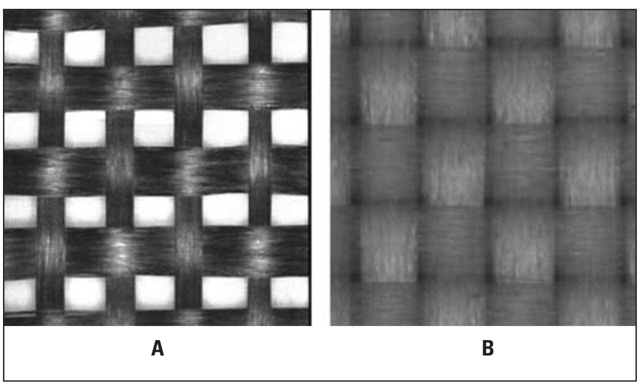

FIGURE 1. 1080 glass fabric in a standard (a) vs. advanced (b) styles.

Many solutions have been proposed to address FWE in circuit boards, however, in all of these approaches there has been an implicit assumption that the glass fabric reinforcement layer itself cannot be improved upon. This assumption is not true. Consider a Style 1080 fabric, perhaps the most commonly used glass fabric in high performance multilayer PCBs. The standard construction of this style involves 60 yarns per inch in the warp or machine direction and 47 yarns per inch in the weft or cross-machine direction. The 1080 designation also specifies the type of yarn, as per IPC-4412A[9].

FIGURE 1 shows standard 1080 (a) and the high performance 1080 (b). Both have been made according to the IPC specification. Each has exactly the same quantity of glass with the same number of warp and weft yarns. The most obvious physical difference between these fabrics is the spread out ribbon-like yarns in

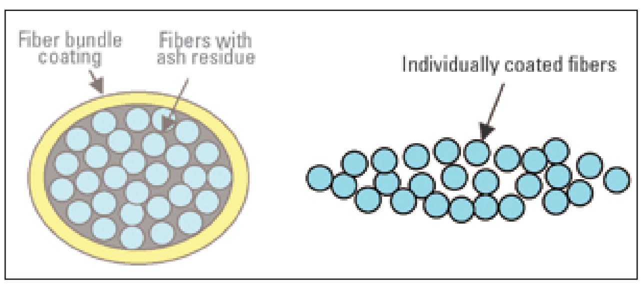

FIGURE 2. Traditional yarn vs. TwistFree™, DirectFinish™ yarn.

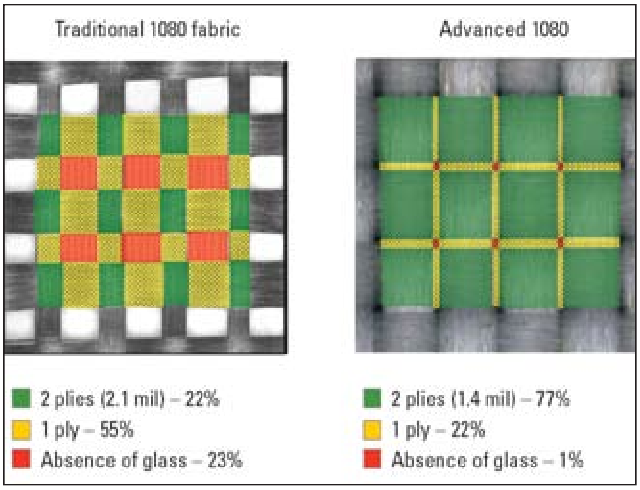

FIGURE 3. Colors overlayed on photos to illustrate layer coverage.

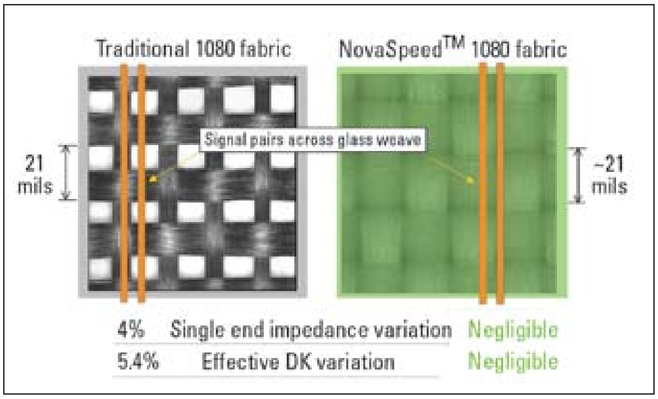

FIGURE 4. Improved signal integrity and clock rate.

the right-hand photo. To determine the properties of these fabrics, we must first understand the underlying technologies.

In the manufacture of traditional fiberglass, the yarns are coated with a vegetable-based starch-oil mixture to facilitate weaving. This coating is then removed in a lengthy heat clean step, after which the yarn bundle receives a silane coating. Depending on the tightness of the weave and/or any ash residue left from the heat cleaning, the individual yarns may or may not be fully wetted by the resin matrix. In addition, the heat-cleaning step reduces the glass fabric strength by approximately one third. Therefore, elimination of this damaging step will create a stronger, more dimensionally stable composite.

Direct application of a final resin-compatible finish during the fiber-forming process provides a better interface between the glass fiber reinforcement and the resin matrix[8]. This resin-compatible finish is applied to the pristine surface of individual glass fibers immediately as they are formed, remaining on the yarn and glass cloth throughout the manufacturing process.

Another significant difference is seen in **FIGURE 2**, where the contrasts between a twisted fiber bundle and the more advanced untwisted yarn are highlighted. Traditionally, the glass fiber bundle is twisted to give strength and mechanical integrity to the yarn and make it easier to weave into fabric. Twisted yarns are somewhat rope-like, making thicker cross-points in the glass fabric (often referred to as knuckles). Twisted glass fiber is also known to contribute to stresses within the laminate.

Untwisted yarn is more ribbon-like, lies flatter and spreads out easily. This yarn construction yields a more consistent fabric, where glass fibers are more uniformly distributed, and weave knuckles and open areas are minimized.

Refer again to Figure 1, which shows two different fabrics with the same amount of glass, but with the glass fibers distributed differently. The traditional glass reinforcement (Figure 1a) is thicker and unevenly distributed, leading to inconsistent substrate properties. There are essentially three differing glass thicknesses in the fabric: areas with two layers of yarns (at the knuckles), areas with just one layer, and the interstices between the yarns where there is no glass. In Figure 1a these areas are very distinct from each other, while in Figure 1b the fibers have been spread out to fill the interstices.

FIGURE 3 further illustrates this concept. For the best mechanical, electrical and performance properties, total glass uniformity is key. This is a direct result of maximizing the amount of two-layer coverage. In Figure 3 we have quantified the amount of zero, one and two-layer coverage using red, yellow and green areas (respectively) overlayed onto the photos from Figure 1. The percentages shown are based on measurements from the photographic images.

Considering that these two fabrics contain the same amount of glass, it can be presumed that the fabric in Figure 1b is thinner than 1a, and this is indeed the case as confirmed by measuring total fabric thickness[9]. In fact, the two-layer areas of glass in the traditional fabric are approximately 50% thicker than the two-layer areas in the advanced glass on the right (2.1 mils vs. 1.4 mils).

In addition to a more uniform glass configuration, this new glass fabric utilizes a lower dielectric constant (Dk) glass composition to reduce the Dk difference between glass and resin. This Dk difference is at the root cause of FWE. In traditional 1080 fabric using E-glass, the Dk difference between the glass and high performance resin is approximately 4 units. With the new fabric this Dk difference is reduced by half. When the lower Dk is combined with smoother fabric, the FWE can be significantly reduced.

In **FIGURE 4**, the photos from Figure 1 have been overlayed with 3-mil lines to approximate scale for illustration purposes. Both fabrics have the same amount of glass but it is distributed differently. Estimates of single end impedance and effective Dk variation for traditional 1080 fabric are based on data presented in a paper by Brist et al at IPC Expo 2004[2].

Among the many proposed solutions to address FWE is the use of a heavier fabric style that has a balanced construction and tighter weave that can reduce the open spaces[7].

TABLE 1. Comparison of 1080 glass products.

	TRADITIONAL 1080	NOVASPEED 1080™
Fabric Thickness	2.1 mil (0.053 mm)	1.4 mil (0.036 mm)
% Coverage (2 / 1 / 0 layers)	22/55/23	77/22/1
Dielectric Constant (Dk)	6.6 – 6.9	4.5 – 5.0
Dissipation Factor (Df)	0.006 (avg.)	0.005 (avg.)

TABLE 2. Comparison of various laminates for Dk and Df.

MATERIAL	DK	DF
Glass Reinforcement	4.5 to 5.0	.005
Laminate A	2.97	.0079
Laminate B	3.12	.0080
Laminate C	2.98	.0039

TABLE 3. Quality and reliability with Novaspeed™.

CHARACTERISTICS	QUALITY/RELIABILITY IMPROVEMENTS
■ Flat, Smooth, Thin Glass Weave	■ Laser Drilling – time/cost savings, hole quality
■ DirectFinish Technology	■ Mechanical Drilling
■ Homogeneous Spread Fiber Weave	■ CAF Resistance
■ No Hollow Fibers	■ Higher Production Yield

TABLE 4. Performance improvements with Novaspeed™.

CHARACTERISTICS	PERFORMANCE IMPROVEMENTS
■ Flat, Smooth, Thin Glass Weave	■ Homogeneous Dk/Df
■ Low Dk/Df	■ Less Impedance Variation
■ Homogeneous Spread Fiber Configuration	■ Reduced Signal Skew, Improved SI

However, addressing the issue by glass style alone does not improve upon the other important aspects discussed above. Indeed, laminate core thickness below about 4 mils cannot be achieved using these heavier fabric styles.

Test Results

TABLE 1 shows initial test data on glass fabrics. The thickness measurements are per ASTM D579 (25 psi). Dielectric constant (Dk) and dissipation factor (Df) for the NovaSpeed 1080 fabric was measured at 10 GHz using the NIST split cavity method at the Materials Research Lab at Pennsylvania State University[10]. These measurements were subsequently corroborated by calculations from test laminates per IPC-TM-2.5.5.5 (stripline method). The traditional 1080 Dk and Df measurements were taken from a table compiled by the IPC 3-12d Glass Reinforcement Task Group and represent data from four global manufacturers of E-glass yarn[11].

As previously described, the Dk of the NovaSpeed glass fabric is lower than that of E-glass in traditional fabric. More precisely, the Dk of this fabric is midway between that of E-glass and typical high performance resin systems. Thus the Dk difference between glass and resin is half of that seen in typical laminate products.

TABLE 2 shows Dk and Df results at 10 GHz with the low Dk 1080 glass fabric alone, and with three commercially available resin systems. These resin systems, while high performance, are not characterized as "exotic" but are considered to be "FR-4 processable." The bulk glass measurements were done using the NIST split cavity method and all other measurements are per IPC-TM-650 2.5.5.5 stripline method.

Conclusion

Based on the known characteristics of this advanced glass fabric, direct improvements can be predicted. The flat, smooth laser-drillable glass fabric will have improved laminate surface planarity and inherently lower surface roughness, as compared to laminate made with traditional glass fabrics. Improvements in "telegraphing," laser-drilled hole geometry, hole plating quality and laser drilling speed can be expected. Where mechanical drills are used, a reduction in drill wander can also be expected. Furthermore, the high strength properties of a directly finished fabric, combined with the more uniform distribution of the glass fiber yarns, provides improved dimensional stability in circuit board laminate applications.

The use of a direct finishing technology combined with the spread fibers of untwisted yarn results in greatly improved wettability and resin impregnation (of the glass bundles), and therefore the highest quality glass-to-resin bond is ensured. This property is the main factor in improved CAF resistance. An electrochemical migration phenomenon similar to CAF is caused by hollow fibers. This low Dk glass fabric exhibits zero hollow fibers. **TABLE 3** summarizes these characteristics with corresponding quality and reliability improvements.

TABLE 4 identifies performance improvements that result in the fabric with the combination of an improved finishing method, a non-twist glass, and a proprietary low Dk glass formulation. The printed circuit substrate exhibits a homogeneous Dk and Df, leading directly to less impedance variation and reduced signal skew, resulting in improved signal integrity.

An advanced glass fabric has been utilized in several high performance commercial resin systems to generate test panels with superior electrical properties at 10 GHz. However, by using a unique manufacturing process and proprietary low Dk glass formulation, a homogeneous reinforcement layer has been developed that is unlike traditional glass fabrics. In fact, the key features of this proprietary technology are not addressed by existing industry specifications.

It is expected that FWE can be completely eliminated as a performance constraint in high speed PCB susbstrates with the use of this novel technology. This new glass fabric could represent a paradigm shift for PCB substrate performance. PCD&F

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REFERENCES

1. K. Dietz, "Fine Lines in High Yield (Part XCVIII): Advances in Reinforcement Structures," Tech-Talk in *CircuiTree*, November 2003.
2. G. Brist, B. Horine, G. Long; "High Speed Interconnects: The Impact of Spatial Electrical Properties of PCB due to Woven Glass Reinforcement Patterns," S18-5-1, IPC Expo/SMEMA Council/APEX/Designers Summit 2004.
3. E. Bogatin, S. Zimmer, "Achieving Impedance Control Targets," *Printed Circuit Design & Manufacture*, April 2004.
4. S. McMorrow, C. Heard, "The Impact of PCB Laminate Weave on the Electrical Performance of Differential Signaling at Multi-Gigabit Data Rates," DesignCon East 2005.
5. E. Bogatin, "Skewering Skew," *Printed Circuit Design & Manufacture*, April 2005.
6. J. Loyer, R. Kunze, X. Ye, "Fiber Weave Effect: Practical Impact Analysis and Mitigation Strategies," *CircuiTree*, March 2007.
7. L. Ritchey, "Intelligent Design," *CircuiTree*, April 2007.
8. J. Kuhn, "Advanced Reinforcement Technology Presents New Design Opportunities for Printed Circuit Boards", ECWC 10 Conference at IPC Printed Circuits Expo/APEX/Designers Summit 2005.
9. IPC-4412A, "Specification for Finished Fabric Woven from "E" Glass for Printed Boards," January 2006, IPC, Bannockburn IL..
10. NIST Split Cavity method for measurement of relative permittivity [Dk] and loss tangent [Df], subsequently standardized as IPC-TM-650 2.5.5.13.
11. Committee Report of Woven Glass Reinforcement Task Group 3-12d from IPC Apex/Expo 2007 (ipc.org/CommitteeDetail.aspx?Committee=3-12D).