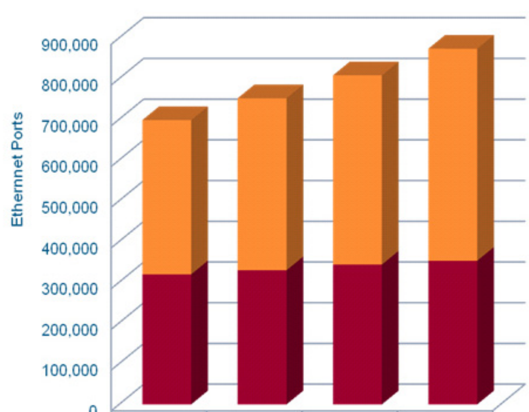
WHITE PAPER

Improving Data Communication Products with Planar Magnetics

The demanding requirements of communication systems continue to increase with each generation. Magnetics have proven particularly challenging. Higher data rate channel performance demands tighter tolerances and reduced product variations. According to IDC Insights' January 2010 forecasts, Ethernet ports growth will be steady for switch ports and increase for desktop and portable PCs and servers in the foreseeable future. (See Figure 1.) As a result, the RJ-45 connector for terminating the Ethernet's twisted pair continues to grow for applications from enterprise switches and routers to power over Ethernet (PoE) and IP phones.



	2011	2012	2013	2014
PCs/Portables/Servers	378,581	422,222	464,646	520,532
Switch Ports	319,383	329,362	343,266	352,774

Figure1. The number of Ethernet ports will continue to increase. Source: IDC.

Today, 1 Gb/s ports are on the verge of eclipsing the sales of 100 Mb/s ports. (See Figure 2.) Over the next few years, 10 Gb/s switching speeds will have an increasing impact in the highest performance systems. The limitations of hand-wound coils become more apparent and require greater design considerations as communication frequencies increase, especially in 10 Gb/s and higher regimes. Specifically, the tradeoffs between insertion loss, return loss, mode conversion (CM2DM/DM2CM), power sum cross talk (ANeXT), and channel crosstalk (NeXT) place additional burden on design definitions at these higher frequencies. Automation processes can improve wound coils and extend their usage but ultimately improved coil designs will be required. (See sidebar on page 6: Wound Coil Manufacturability Issues). TE PlanarMag product technology is poised to address the performance requirements of today's as well as future datacom systems.

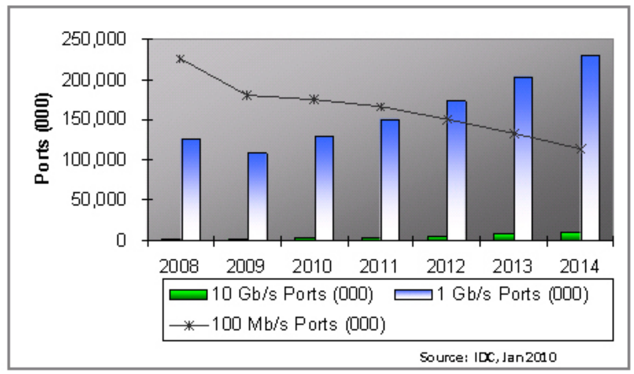


Figure 2. Port speeds for Layer 2 &3 switches will increase dramatically within the next few years. Source: IDC, Jan. 2010 data.

The Application of Planar Magnetics to Data Communications

The technology driver for planar magnetics for data communications applications is the need for increasingly smaller coils to meet form factor requirements combined with more predictable (as manufactured) behavior. In addition to economics and scalability, there are performance advantages for high-speed communication circuits. One of the more subtle areas that can provide significant advantages occurs with the impedance matching requirements for parasitic elements in higher speed Ethernet switching applications.

Historically, the application of transmission theory for impedance matching led to the use of the well-known Bob Smith termination, a 75-ohm resistor from the center tap to a capacitor. System analysis using transmission theory requires terminating the path for any waves with a matching impedance.

In contrast, if the variations that occur with wound coils are eliminated by symmetric and very precise design using planar magnetics, filter theory provides alternate system design considerations. Using filter theory and a highly-matched transformer design, rather than terminate the waves, they are reflected and do not enter the system. A precision match allows the flow of desired frequencies, essentially a very tightly controlled narrow pass filter. This design methodology eliminates the need for a termination without sacrificing performance.

With all of the potential for system improvements, planar magnetics have been difficult to implement – until now.

Substrate-Embedded Magnetics

Advanced magnetic technology leverages the latest 3-D printed circuit board (PCB) processes to manufacture wideband planar transformers and common-mode chokes embedded in a substrate. Well-established PCB techniques are used to more efficiently manufacture reliable, consistent structures. While the approach was known for many years, recent advances in design methodology have reduced the variations that plagued earlier attempts to commercialize planar magnetics for precise datacom requirements.

The process starts by drilling controlled depth holes in FR4 PCB. Next, ferrites are inserted as shown in Figure 3(a). Then an epoxy polymer is applied that fills the cavities as well as surrounding and protecting the ferrite. The special epoxy has characteristics that allow manufacturing processes similar to FR4 for panelization, drilling, and vias to create the PCB two-layer process. After the epoxy polymer is cured, a planarization process ensures a very flat structure. Next two prepreg treatments are performed at elevated temperature and pressure

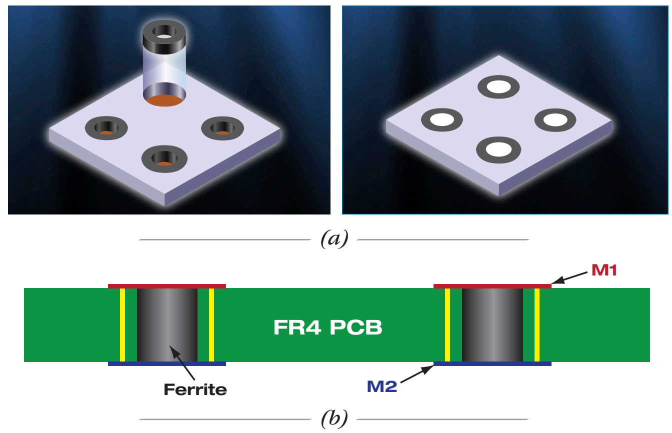


Figure 3. With the two-sided board, standard drilling forms the vias that go inside and on the outside of the ferrites, and for the connections, where etching the routing of the copper creates the windings. A special technique for creating the differential pair is part of a wide-band planar transformer patent.

that allow the copper to adhere to the FR4. The end result is a two-layer board with copper on the top and the bottom.

After the assembly is etched, it goes through a solder mask process that fills in the vias and deposits the solder mask on top. Figure 3(b) shows the results of the process. Since the solder mask is an insulator, this step provides voltage isolation.

After laser marking, a thin tape layer is applied to one side and the opposite side is sawn and singulated into individual components similar to a semiconductor process. Then testing is performed on each device similar to the 100% testing techniques used for semiconductors to verify conformance

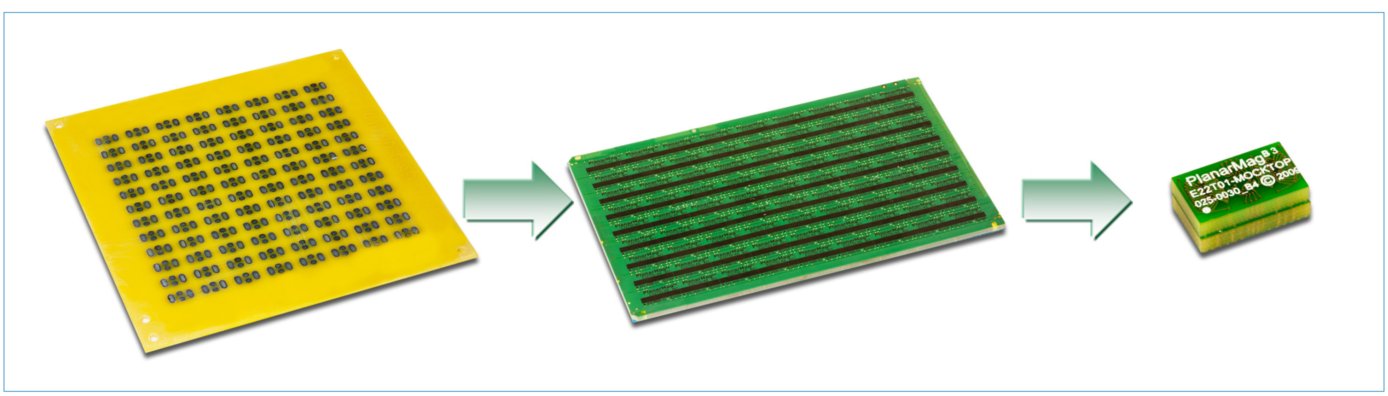


Figure 4. High-volume PCB technology combined with proprietary manufacturing techniques has lead to a highly precise planar magnetic device.

to critical parameters and the consistency of the manufacturing process. The 14 x 16 or 18 x 20 panels contain embedded magnetic components that are pin compatible with targeted discrete coil-based components. Slightly larger than a comparable wound coil's base, the pads align so the planar magnetics can directly replace the wound coil magnetics.

The planar magnetics advantage is complete control over leakage inductance, capacitance, and the shapes of the petals or wrappings. The consistency of the manufacturing process is based on design rules for controlling the depth, the width, and the size of the component.

With embedded magnetics technology, automated processing and proprietary materials are used to embed highly sensitive magnetic ferrites into standard PCBs. As shown in Figure 4, PCB-based technology using precision photolithography allows the manufacturing of boards containing hundreds and even thousands of planar magnetic devices.

The automated processing that leverages well-established PCB technology helps improve performance, quality, and reliability and helps provide previously unattainable supply stability. Highly automated testing on each completed assembly leverages experience for verifying the conformance of semiconductor devices. In addition to resistance, inductance, opens and shorts and high-pot (high potential) testing, in some instances digital testing is performed for high speed parametrics.

Advanced automation techniques applied to wire-wound coils are also improving these assemblies. In fact, state of the art machine-wound chokes combined with planar magnetic transformer have produced outstanding results. However, planar magnetics have substantially greater benefits from automation due to their inherently predictable characteristics.

Embedded Solutions: Application to Connectors

TE PlanarMag product technology is being applied to Ethernet products including integrated connectors, discrete magnetics, and media filtering. Here are three initial products.

The 1G BASE-T Ethernet media filter and isolation transformer (part number 2048107-1) shown in Figure 5 has a 1:1 turns ratio with a tolerance of ±2% at 100 kHz. In addition to meeting the IEEE 802.3 specification, the single-port 1G Ethernet media filter and isolation transformer helps reduce termination component and system costs. The assembly facilitates FCC Class B qualification. Housed in a 24-pin BGA package, the assembly is RoHS-compliant per JEDEC-STD. Target applications include servers, switches, routers, PC, and other consumer devices.

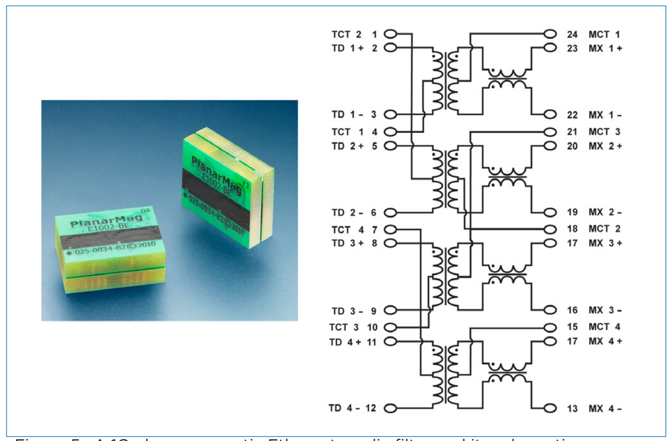


Figure 5. A 1G planar magnetic Ethernet media filter and its schematic.

The 10/100 BASE-T media filter (part number 2048108-1) shown in Figure 6 is a single port 10/100 Ethernet media filter and isolation transformer that meet the IEEE 802.3 specification and facilitate FCC Class B qualification. Housed in an industry standard pin-to-pin configuration for compatibility using castellations, the assembly is RoHS-compliant per JEDEC-STD. These PlanarMag discrete Ethernet transformers are well suited for the TE Mag45 (RJ-45) product family. Target applications include PCs, consumer devices, low-density routers, and access points.

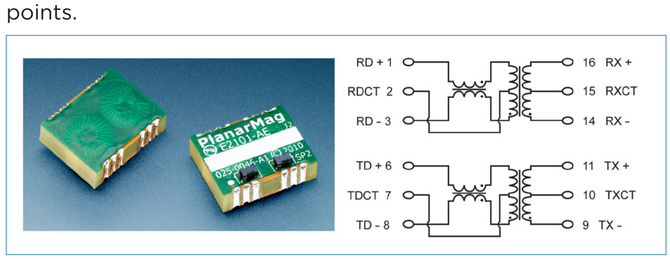


Figure 6. A 10/100 planar magnetic Ethernet transformer and its schematic. Two discrete surface-mounted chokes are pick and place mounted on the planar magnetic assembly to reduce differential to common mode or common mode to common mode noise.

The 1G Mag45 ICM (Integrated Connector Module), shown in Figure 7, is the first fully integrated connector utilizing the PlanarMag embedded magnetic product technology. The low-profile configuration targets applications that require reduced height and small form factor footprint such as laptop and notebook computers.

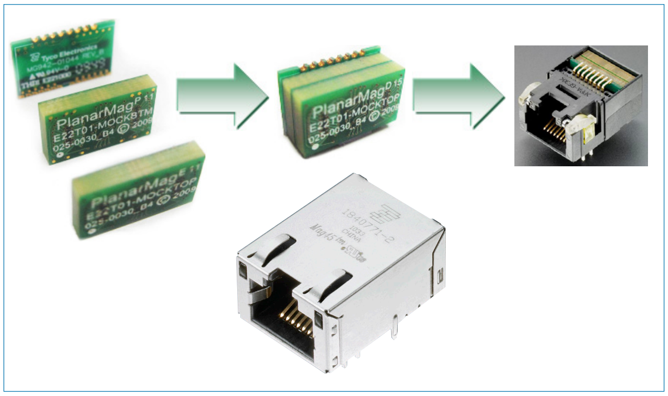


Figure 7. An Integrated Connector Module (ICM) with embedded planar magnetics.

PlanarMag product technology is readily adaptable to ganged and stacked configurations. Figure 8 demonstrates its scalability in two popular configurations.

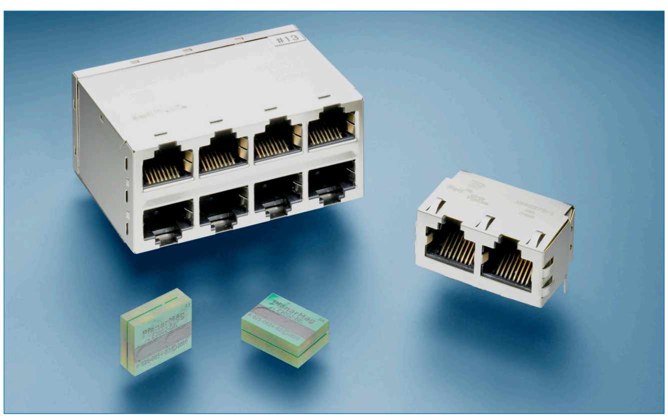


Figure 8. PlanarMag technology can be readily adapted to ganged and stacked packaging configurations.

Common attributes of these products include a single-port configuration and media filter and isolation transformer. The products provide demonstrated improvements over coil-wound designs. Figure 9 shows the performance of a TE PlanarMag product compared to a coil-wound product.

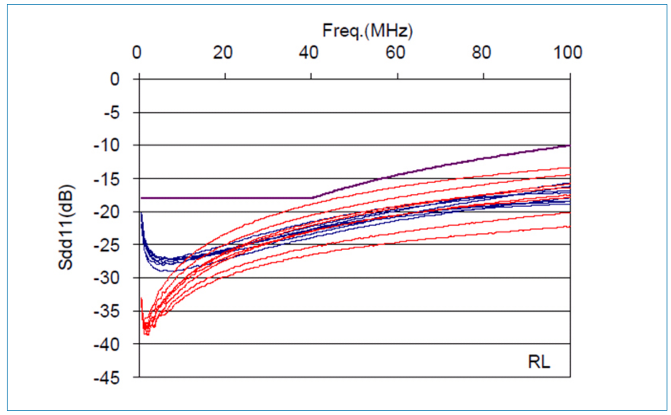


Figure 9. Mag45 connectors with PlanarMag product technology (blue) demonstrate more repeatable cable-side differential return loss when compared to Mag45 connectors with hand-wound coils (red).

Because of the controllability in the manufacturing of the embedded planar magnetics, it is possible to characterize the design by applying filter theory as opposed to transmission theory. Today, with wound coils, impedance matching is an art with iterations performed until matching is achieved. Any variations create impedance mismatches that can cause spikes and anomalies associated with parasitics that are related to electromagnetic interference or compliance and specification performance issues.

Since the PlanarMag product structure performs as a tightly-controlled narrow pass filter with a high degree of consistency and repeatability, the Bob Smith termination used for impedance matching can be eliminated or the components reduced in many applications. Testing for IEEE 802.3 as well as electromagnetic interference (EMI) and surge testing have demonstrated this capability. This tight control and consistency has allowed customers to reduce the components on their board and also reduced components in TE Integrated Connector Modules while delivering products that truly match the system requirements. In addition, PlanarMag product technology helps facilitate consistent product lead times and supply chain for main-stream, high-volume applications.

In many applications, especially those with noisy environments, the magnetics solution could involve a combination of special transformer and choke technology. As a result, simulation tools are one of the essential elements for replacing wound coil designs with planar technology. The simulation for PlanarMag product designs uses CST and EDS modeling tools, with imported data from a Gerber file, the electronics industry file format for CAD/CAM, and the assumptions for the characteristics for the ferrite material.

While the technique is not unlike that performed for coil-based designs, the results are much more consistent because the process variations in planar magnetics are much more rigidly controlled than the variations in wound coil designs, such as the tightness of the coil winding itself. Once the impedance of the system is characterized, the embedded planar technology has the capability of matching it and verifying that match through modeling and design processes and consistently achieving tight distribution in production.

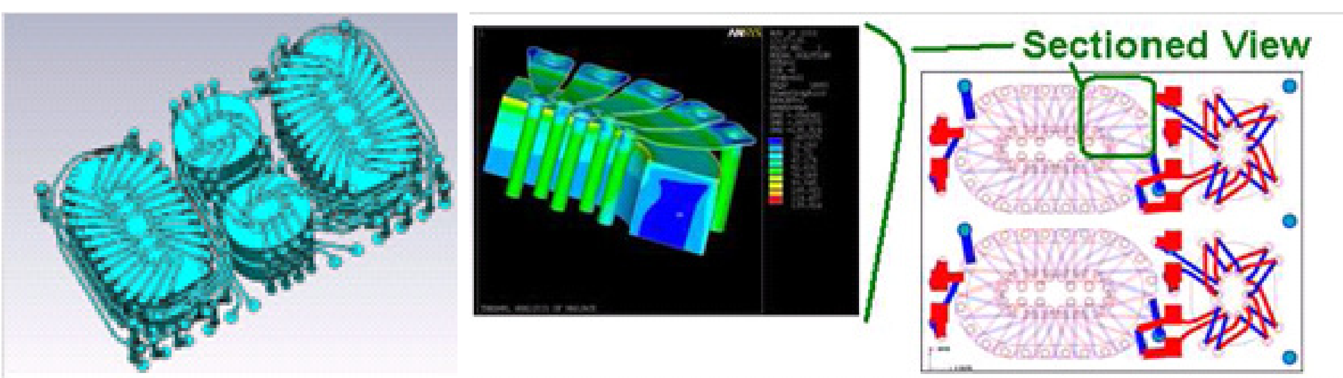
Based on test bench measurements with empirical data and correlation to the simulations in an iterative process, the simulation environment has been refined and correlates extremely well with the actual empirical measurements for the planar magnetic designs. The results are designs with the integral details resolved much more quickly and design-to-manufacturing implementation occurring much faster.

For its PlanarMag products, TE uses a 3D-electromagnetic simulator with unique design techniques to create patented proprietary winding structures. Examples are shown in Figure 9. This design capability allows subtle nuances to be addressed quickly for a variety of standard as well as custom applications. The next step to enhancing TE's PlanarMag simulation process is full integration, where the complete mechanical design is modeled including integrated circuits and the parasitic traces on the host board, through the pin of the connector, and finally to the RJ-45 plug.

For wound coils, what works for one customer's application frequently does not work for another customer's application. As a result, customization is a common requirement for wound coils. With the higher performance and highly repeatable PlanarMag product technology, standard products can be used in many applications. The standard products will help meet specific customer needs without incurring a custom cost adder and avoid the time-to-market lag from both the design and qualification delays as well as potential unavailability of product in production.

A big issue that customers have today with wound coils is the length of time to obtain new designs and then the additional length of time required to qualify those new designs. The reuse of substrates in PlanarMag product technology minimizes changeovers in the factory and leads to even greater consistency and higher quality and increased reliability as well as reduced time for design and qualification.

If customization is required, rather than at the coil level, it can be performed at the ICM level.



(a) (b)

Figure 10. Physical 3D model (a) and section 3D thermal model (b) for a planar magnetic transformer facilitate the rapid transition from design to manufacturing.

The Potential of Planar Technology

The data communications industry has demanded more automation, greater predictability, improved quality, better performance and, of course, lower cost for wound coils. With TE PlanarMag product technology, all of these previously illusive goals can be achieved. The attributes of PlanarMag products helps deliver significant advantages for data communications applications. The substrate-based technology provides substantially greater control over the impedances and other design attributes compared to wound-coil devices. In addition, more-tightly controlled impedances can eliminate the matching termination and reduce system costs. Finally, high-volume, scalable manufacturing with consistency and quality allows highly-predictable processing to provide customers a highly-reliable supply chain. The end results are performance for today's high-volume data communications applications and a path to the future.

Wound Coil Manufacturability Issues

Typical hand-wound coils meet existing performance goals by as much as a 2/3-design and 1/3-art process. Predictability is very difficult because of the human element involved in hand-winding. As the frequencies increase, the design aspects become less and less predictable. As a result, the art aspect, the number of iterations performed until matching is achieved, will increase.

With automation, predictably increases, since all elements of the process are monitored and targeted for continual improvement. However, automation can be used only at lower frequencies. As frequencies increase, the size of the toroid decreases and it gets more difficult for machines to handle the initial step of threading the needle.

For hand-wound coils, the ability to predict performance and yield becomes increasingly difficult, especially at frequencies of 10G or higher. The continued use of hand-wound coils at higher frequencies will mean more errors, more production rejects, lower yields, and, consequently, higher prices. In addition, the amount of labor content will increase as well — further increasing costs.

Today, magnetic windings are predominantly manufactured by hand in factories in China. While about 100,000 people wind these coils, manufacturing consistency varies depending on the expertise of the workers and turnover can be as high as 50%. When downturns and the resulting layoffs occur, even experienced workers can be eliminated. When the market improves, it can take several months to train and develop the new workforce and reestablish supply continuity. This work force situation has lead to extensive product supply shortages and quality issues. As a result, the datacom industry is not looking for a solution to the wound-coil problem, it's looking for a replacement for wound coils.