Increased Performance with Cost-Effective HDI Technology

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SUMMARY: With enhanced signal routing and response conditioning, HDI technology enables greater wiring density and closer component spacing. All these improvements are possible thanks to the use of thin film, high-density multilayer substrates.

Electronic systems across the board are decreasing in size while increasing in performance. In compact and portable products ranging from cell phones to smart weapons, high-density integration (HDI) technology is enabling the design of smaller end products that meet higher standards for electrical performance and efficiency.

HDI boards themselves are low-noise products that integrate conductor patterns and other passive components in custom resistor solutions. With enhanced signal routing and response conditioning, HDI technology enables greater wiring density and closer component spacing. All these improvements are possible thanks to the use of thin film, high-density multilayer substrates.

Because these devices can be tremendously complex and their design tied tightly to the end-product performance, most HDI boards are custom-designed to meet the specific requirements of a given application and to deliver the best ratio of price to performance. The design process involves a series of critical decisions that will shape the performance of the HDI and its aptitude for the target application.

The Circuit Foundation: the Substrate

At the foundation of the circuit is the substrate, or base material. Selection of the base material is the first step in creating an HDI scheme. Every choice offers a unique set of behaviors and characteristics that will influence overall operation. Key considerations include power dissipation capability, a primary factor in DC applications, and the dielectric constant, which is of the utmost importance in higher-frequency applications.

Vishay and its clients develop HDI products that incorporate quartz (SiO_2), alumina (Al_2O_3), silicon, ferrites, titanates, aluminum nitride (AlN), or beryllia (BeO). In terms of its performance, quartz makes a good match for high-density patterns. It features a low loss tangent and a CTE of just 0.55 ppm/°C and typically is

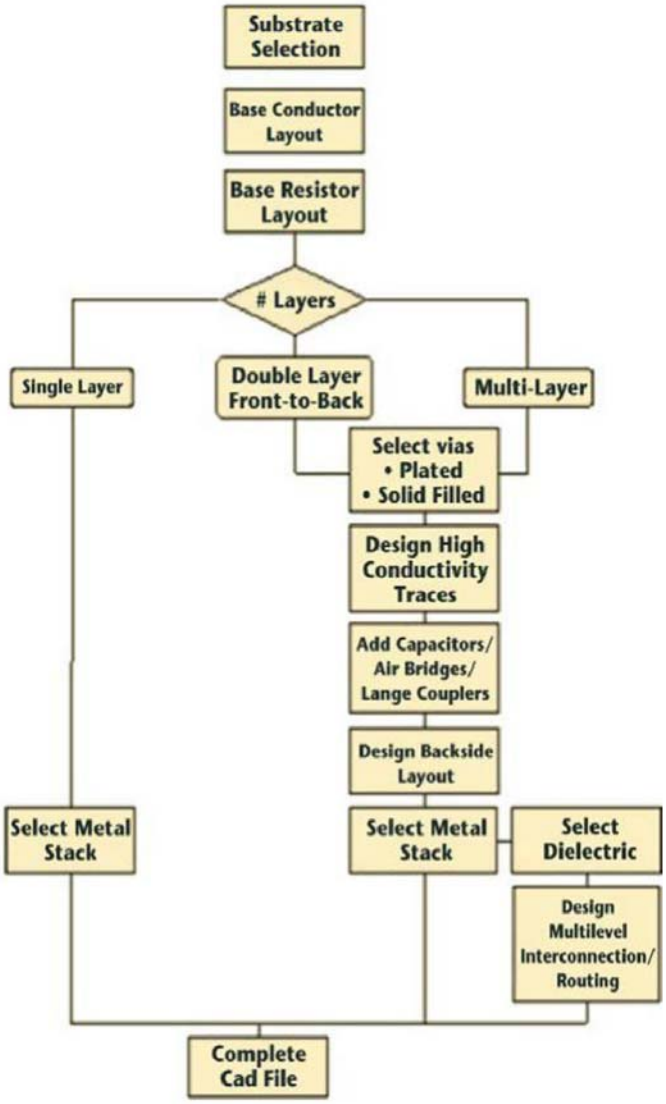


Figure 1: Roadmap to the design of an HDI circuit board.

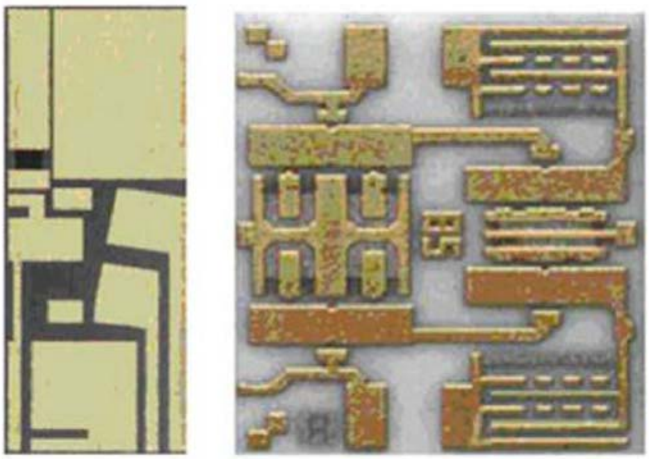


Figure 2: Examples of conductor patterns with special routing for externally mounting components.

chosen for microwave or millimeter-wave low-power/low shunt capacitance. The main drawback to selecting from quartz substrates is their very high cost. At a friendlier price point, alumina offers a cost-effective alternative suitable for standard hybrid or medium-power microwave applications. Both options have a minimum thickness of 5 mils, which makes them twice as thin as the remaining three substrate choices.

Silicon, aluminum nitride, and beryllia feature much higher thermal conductivity than do quartz and alumina. From among these three substrates, silicon is the best fit for medium- and high-power DC applications, as well as for high-density, fine-line interconnections. A common choice for high-power microwaves, aluminum nitride makes an ideal CTE match to silicon devices. Finally, with ratings of 300 W/M at 25°C and 240 W/M at 100°C, beryllia features thermal conductivity nearly twice that of the nearest comparable base material.

The Base Conductor and Routing Scheme

Once the designer and user establish the appropriate substrate for HDI, it's time to select the conductor material and routing schemes for the circuit. The conductor material is the first metal layer that makes all the major routing connections, and conductor lines must be designed not only to withstand the current they will carry, but also to provide resistance low enough not to interfere with device performance.

Current density and conductor impedance have a direct effect on circuit performance, so the choice of metal used as the base conductor aluminum (Al) and gold (Au) can have significant ramifications. For widths up to 20 mils, gold is capable of conducting five times the maximum amperage handled by aluminum. The advantage persists to a lesser extent in wire bonds over 40 mils long. Because gold is limited to a 2-mil diameter, aluminum has the advantage in achieving much higher amperages.

Though vias (through-hole or filled) are added to the HDI at a later stage, their placement must be decided at this stage. Like substrate and base conductor, the type of via selected will differ according to the application. Either plated through-hole conductors or simple holes for pin alignment help to identify via placement.

The Base Resistor

Knowledge of the resistor material, power, temperature coefficient of resistance (TCR), tolerance, and application is required for effective circuit design because again, the choice of material dictates performance of the circuit.

Nichrome and tantalum nitride are two of the most common resistor materials, with nichrome able to handle much lower TCR values and much higher sheet resistivity than tantalum nitride, but with less resistance to environmental degradation. Sheet resistivity and current density are inversely related, and different line widths are required by different substrate materials to achieve a target sheet resistance.

Quartz has the lowest line-width requirements, needing a width of only 0.5 mA/mil to reach 25 ohms/sq. Alumina, too, requires only thin lines, requiring 4 mA/mil for the same resistance value. Silicon and aluminum nitride demand lines of 20 mA/mil and 19 mA/mil, respectively, for 25 ohms/sq, while Beryllia demndas 32 mA/mil to achieve 25 ohms/sq and 4 mA/mil for 200 ohms/sq.

Resistor Ratings and Design

Typical ratings for standard resistors include a resistance range of 5 ohms to 2 megohms, absolute tolerance of 5% to 0.1%, and ratio tolerance of 1% to 0.01% depending on the range. These figures change when microwave resistors are taken into consideration. Such devices offer resistance parameters ranging from between 10 ohms and 1,000 ohms, with an absolute tolerance and ratio tolerance both of 0.5% and absolute TCR of less than or equal to 200 ppm/ºC.

With their narrower specifications, microwave applications tend to require lower-value resistors designed in a stripline format. In this manufacturing model, the resistor layout is a simple rectangle without any cuts that could cause reflection and affect VSWR characteristics. Trimming enables the tight resistance values required while maximizing yield, and a method called edge-sense trimming around a center line can limit the ill effects of trimming and maintain frequency response. Finally, the use of a high-temperature stabilization procedure produces very stable resistors and minimizes drift over time or temperature.

The Fit: The HDI Shape

The substrate material can be cut into virtually any shape to meet the space, shape and size requirements of the end product. Using CO_2 cutting, Vishay can create the necessary form, complete with in-hole drilling to enable inclusion of the necessary through holes, vias and filled vias, as well as two-sided-substrate patterning and edge-wrap metallization.

The smaller the end system, the more likely a multilayer solution will be needed. This more complex approach often demands design on a CAD system, as the many factors that must be taken into account include conductor routing, vias, resistor cells, added active devices, special features such as capacitors, Lange couples, and any associated interconnects. The selection and interaction of different layer applications also play a role in determining the effectiveness of an HDI for a particular application. As much as is possible, all of these elements must be optimized to contribute to performance of the end device.

As far as positioning the substrate, placement parameters require a position tolerance of 0.003", placement a minimum of 0.002" from the substrate edge to the circuit, an inside corner radius of 0.005" minimum, and 25% removal of the substrate.

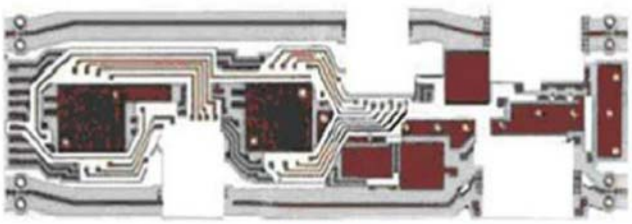
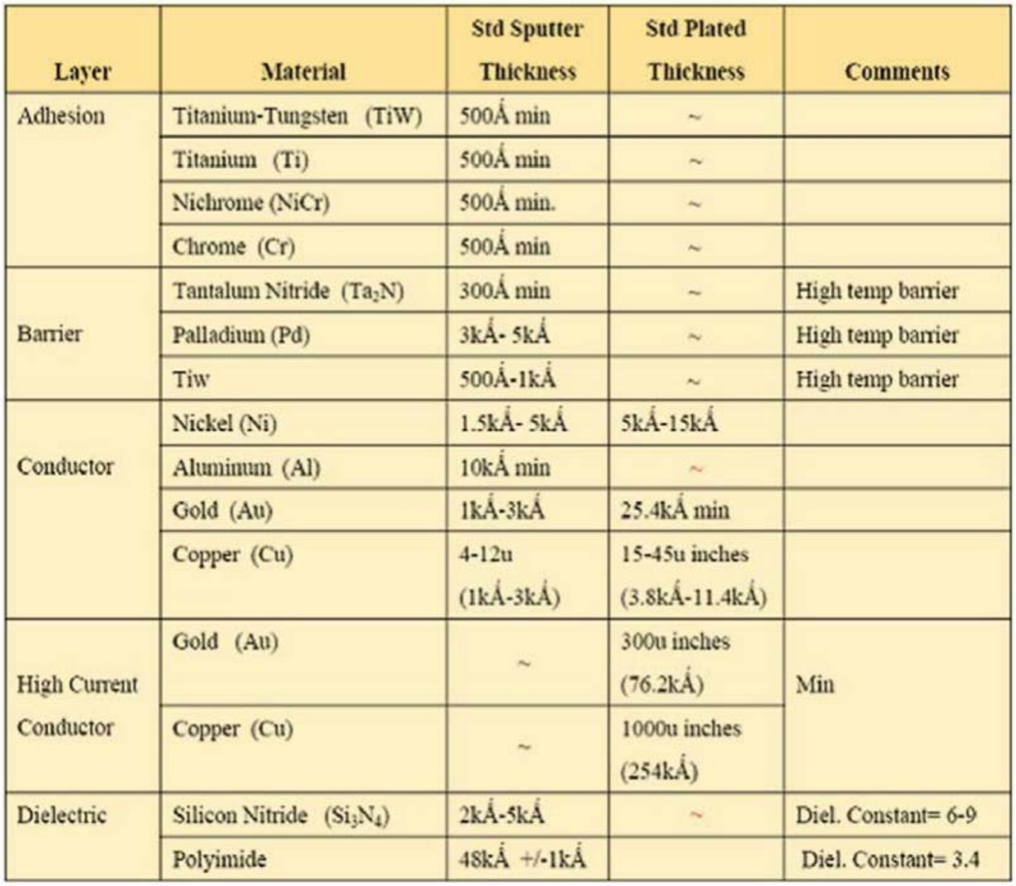


Figure 3: With CO_2 cutting, almost any shape of HDI board with multiple holes can be achieved.



Layer	Material	Std Sputter Thickness	Std Plated Thickness	Comments
Adhesion	Titanium-Tungsten (TiW)	500Å min	~	
	Titanium (Ti)	500Å min	~	
	Nichrome (NiCr)	500Å min.	~	
	Chrome (Cr)	500Å min	~	
Barrier	Tantalum Nitride (Ta_2N)	300Å min	~	High temp barrier
	Palladium (Pd)	3kÅ- 5kÅ	~	High temp barrier
	Tiw	500Å-1kÅ	~	High temp barrier
Conductor	Nickel (Ni)	1.5kÅ- 5kÅ	5kÅ-15kÅ	
	Aluminum (Al)	10kÅ min	~	
	Gold (Au)	1kÅ-3kÅ	25.4kÅ min	
	Copper (Cu)	4-12u (1kÅ-3kÅ)	15-45u inches (3.8kÅ-11.4kÅ)	
High Current Conductor	Gold (Au)	~	300u inches (76.2kÅ)	Min
	Copper (Cu)	~	1000u inches (254kÅ)	
Dielectric	Silicon Nitride (Si_3N_4)	2kÅ-5kÅ	~	Diel. Constant= 6-9
	Polyimide	48kÅ +/-1kÅ		Diel. Constant= 3.4

Figure 4: Film materials available for particular layer applications, and the thickness of each type.

The Electrical Path: Vias and Crossover Solutions

Plated through-hole and filled vias are suited to differing applications. While the formed represents the least expensive solution, it is functional only in HDIs requiring a simple front-to-back electrical path. Through-hole patterns require a minimum 0.005" ring around each hole to compensate for the tolerance build-up caused by hole placement, manufacturing alignment, diameter tolerances, slight laser entrance hole rounding, and other factors. Plated through-hole designs require a minimum thickness of 0.8 times the substrate thickness with a typical impedance of less than 20 milliohms.

When improved thermal conductivity to the back side of the circuit is required, filled vias offer a better solution. They offer the designer as many heat channels as the area allows, and additional thermal conductivity is enabled by the placement of components directly over the via for maximum heat transfer from those components. To improve signal transmission, the designer can use filled vias to provide additional low thermal conductivity paths to ground plate heat sinks. Gold or copper filled vias require a diameter of 7 mils to 20 mils with typical impedance of less than 3 milliohms.

When crossovers are necessary, air bridges are configured on the conductor pattern through the depositing and patterning of a layer, placement of a second layer in place over it, and subsequent removal of the first layer. Air bridges require a minimum gap of 0.5 mils between lines, a tolerance of 0.1 mils, minimum line width of 0.5 mils, and bridge height of 300 to 500 microinches.

In the case of a supported air bridge, polyamide is used as the first layer, which remains intact, supporting the bridge in a more stable and durable structure. If epoxy or solder is used to attach components to the substrate, addi-

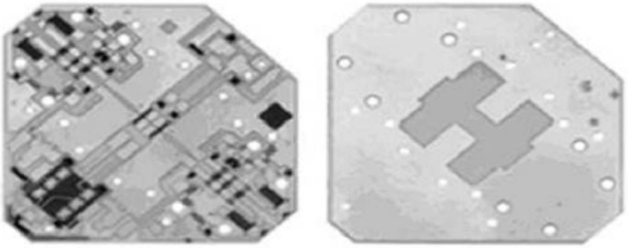


Figure 5: An example of an array patterned on both the front and back sides.

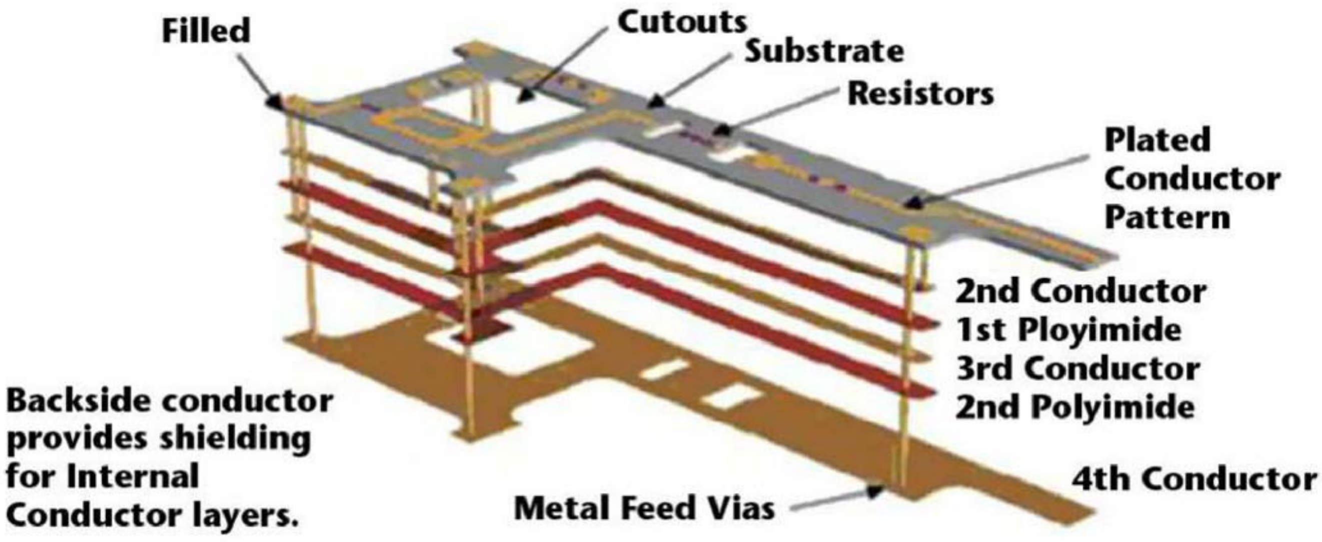


Figure 6: Expanded view of a thin film multilayer HDI circuit designed for a military helicopter. The design used almost all of the design and process options available, and after significant R&D effort was manufactured with reasonable yields.

vides a cost-effective alternative to top-surface multilayer designs.

If a single-layer front-and-back combination can't provide the necessary layers, then layers

ɪn either side of the circuit in a
gement.

material such as polyamide, or
ɪn nitride, serves as insulation
layers. While polyimide offers
ɪg properties and processing
ɪ general no stacking restric-
ither material.

uld be noted that process com-
between layers should be ex-
ɪign engineers, as these issues
ɪse of multiple metal stacks on
ɪic layers. **PCBDESIGN**

William Cuviello is a senior product marketing manager at Vishay Intertechnology with 24 years of experience in general sales and application engineering management for specialty film products. Cuviello has published and presented papers at technical symposiums in Europe and the United States on thin film HDI, design guidelines, and frequency response of thin film chip resistors.