

Thick Metal Cladding on High Frequency Laminates

In addition to conventional one or two sided copper foil clad substrates, high frequency laminates are also available with a thick metal laminated to one side and copper foil on the other. The thick metal is typically in the 0.020 to 0.500 inch thickness range. It serves as ground plane for stripline and microstrip circuit boards. Some applications show design, process, and performance advantages over laminates clad both sides with thin copper foil.

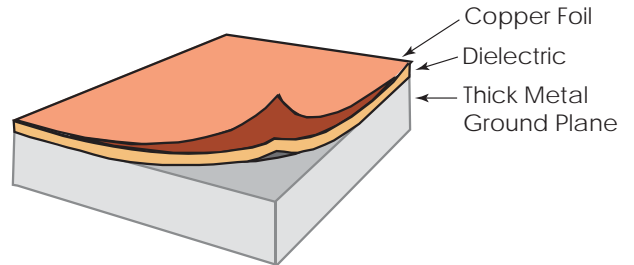


Figure 1.

Advantages of Thick Metal Clad Laminates

Heat Sinking

Glass-fiber reinforced PTFE composites such as RT/duroid 5880 laminate, or ceramic PTFE such as RT/duroid 6010 laminate, have relatively low thermal conductivity values (typically 0.26 and $0.41 \text{ Wm}^{-1}\text{K}^{-1}$ respectively, compared to about $220 \text{ Wm}^{-1}\text{K}^{-1}$ for aluminum metal or 9.7 to $15.6 \text{ Wm}^{-1}\text{K}^{-1}$ for alumina). In high power applications, the designer must accommodate the heat dissipated by active devices, conductor resistance losses, and dielectric loss.

Thick metal ground planes provide high heat flow, keeping component temperature under control. Active and passive components, such as diodes and resistors, are mounted directly on the ground plane in slots or blind holes machined through the dielectric. This design provides maximum heat dissipation at the high heat producing sites.

For high current carrying circuit traces, close proximity and direct bond of the heat sink ground plane and dielectric minimize the heat flow path. Also, thick metal clad laminates eliminate the thermal barrier of solder or epoxy bonding to external heat sinks used with conventional copper foil-clad laminates.

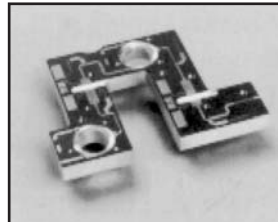


Figure 2: Power amplifier circuit on aluminum-clad RT/duroid 5880 laminate.

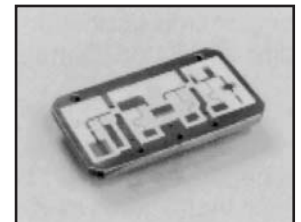


Figure 3: Power amplifier circuit on brass-clad RT/duroid 6010 laminate.

Connector Mounting

When the circuit board and housing are separate components of a package, reliability problems can arise with the use of coax transitions to microstrip or stripline circuits by edge mounted launchers. Coefficient of thermal expansion (CTE) mismatches between the board and the housing induce thermal cycling fatigue failures where the connector pin attaches to the board and can even cause alignment problems during assembly.

There are two ways that thick metal clad laminates can solve this:

1. The composite X,Y plane CTE of the laminate is dominated by the stiffer thick metal layer. CTE mismatch is avoided by selecting the same metal for housing and thick metal cladding.
2. The connector body can edge mount directly to the rigid, integral chassis formed by the ground plane of the circuit board. Vertical slots, rather than holes, in the flange for the mounting screws ease alignment of the connector body. The pin soldered to the trace on the board forms a reliable strain free assembly, as illustrated in Figure 4.

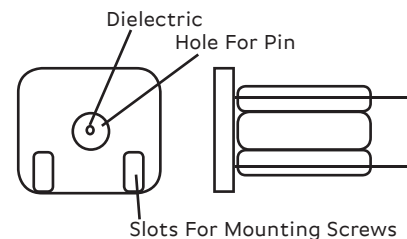


Figure 4. Edge Launch connector with slots for mounting screws to allow vertical adjustment.

Component Mounting

Both active and passive circuit components may be mounted directly onto the ground plane in slots or blind holes milled through the dielectric. For example, conventional die attach methods using eutectic silicon gold or conductive epoxies may be used to bond transistors to the plated ground plane.

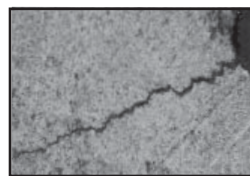
Electrical connections are made by the well known processes of wire bonding, ribbon bonding or soldering. These connections can be between components bonded into, or traces ending at the edge of, slots or blind holes.

In addition to the heat sinking advantage previously mentioned, the thick metal ground plane provides a rigid base for attachment. Selecting a metal as close to a match the CTE of the component improves reliability in extreme thermal cycling environments. As mentioned before, the composite CTE of the laminate is dominated by the stiffer, thick metal layer.

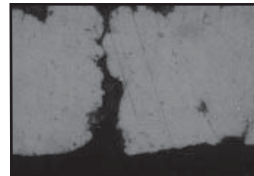
Similarly, selecting a thick metal cladding with matching CTE will benefit reliability of surface mounted components by lowering strain on bonded or soldered leads during temperature excursions.

Thermal Stress Cracking of Conductors

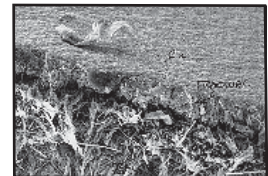
Extreme thermal shock or cycling environments can cause stress crack failure of copper conductors on boards with only thin copper foil cladding, as in Figure 5. Space environments impose particularly severe conditions of large and rapid temperature changes. The X,Y direction CTE mismatch between copper at about 17 ppm/°C versus PTFE-glass composite averaging about 40 ppm/°C from -100 to +150°C is resolved with much of the strain



Typical Thermal Stress Crack
60X



Section of the Same Crack 625X



S.E.M. of the Stress Fracture
145X

Figure 5. Conductor cracking - ED copper after thermal cycling.

being borne by the thin copper foil. Copper tends to work harden and ultimately crack when the strain is great enough. A thick copper ground plane will put virtually all the strain on the soft dielectric to minimize the problem.

Dimensional Stability

Copper foil is normally laminated to PTFE-based dielectrics by clamping and heating the lay-up of foil and substrate layers above the 327°C (620°F) crystalline melt point of PTFE. The CTE mismatch between copper foil/dielectric substrate causes an internal strain to develop in the laminate as it cools. This strain is distributed between substrate and the higher modulus foil according to the relative thickness of each in the laminate. When copper is etched away in the process of fabricating circuit boards, the remaining strain in the substrate is relieved to a degree dependent on the amount of copper foil removed.

Strain relief appears as two familiar concerns to the fabricator. Boards with foil remaining on one side tend to warp or bow concave to the etched side. This is most pronounced with thin boards and may require special fixturing for further processing. The other concern is etch shrink, the X,Y dimensional change when foil is etched away, observed as distortion of the circuit pattern from that of the phototool. The degree of distortion is dependent on many factors, including: orientation of reinforcing fiber in the X,Y plane of the laminate; fraction of foil removed; predominant orientation of circuit pattern elements, and thickness of foil relative to the substrate. Normally, this is handled either by double-etching or by compensating the phototool by adjusting the dimensions to allow for anticipated strain relief. Double-etch involves two masking/etching/demasking sequences. The first removes most of the copper foil that is to be taken away so that most of the strain relief occurs before the second sequence.

However, if the dielectric is securely bonded to a thick metal sheet, the rigid ground plane prevents warp and bow, as well as prevents any distortion of the pattern from the phototool. Feature registration is precise.

Since thick metal is laminated by the same high temperature process as thin metal, the internal strains are still present but are borne more by the substrate. Since the laminate is unbalanced, it can bow or warp as manufactured if the thick metal layer is not thick enough. This condition will persist after copper foil removal. For flatness, thick metal cladding thickness should be at least two to three times that of the dielectric.

Housing

Microstrip circuit boards are usually mounted in a metal housing to protect the active components and provide shielding. Thick metal backed boards are easily installed with machine screws. By counterboring through the dielectric, compressive creep deformation and loosening of the PTFE-based substrate under screw heads will be eliminated. In some cases, the thick metal backing serves as both ground plane and floor of the housing. The creep problem is avoided by fastening the cover to the edge of the floor, or by milling away dielectric where it will fasten to the face.

By contrast, circuit boards from laminates with thin copper foil on both sides require special precautions for mounting in a housing. These efforts are not always satisfactory.

If boards are to be fastened with screws, compressive creep deformation under the screw heads aggravated by thermal cycling in service can lead to loosening. (See RT 4.7.2, How to Avoid Creep Problems on Board Assemblies.) Good contact to the floor for thermal management is difficult.

If the boards are to be fastened by soldering or epoxy bonding to the housing floor, care is required to avoid damage to heat sensitive components. Voids between board and housing floor are hard to avoid. These voids impair heat flow to the heat sink, leading to reduced reliability, as well as increasing the ground return path impedance from circuit ground to component.

Common Thick Metal Options

Aluminum, brass and copper are chosen most often as thick metal claddings, with aluminum the most common. Metal and laminate properties are tabulated below.

Table I: Typical Properties of Thick Metal Options

Property, Units	Aluminum	Copper	Brass
Alloy Number	6061	110	Cartridge
Tensile strength, kpsi	7	35	45
Specific gravity	2.7	8.9	8.5
Specific Heat, J/kg ⁻¹ K ⁻¹	960	385	375
Thermal conductivity Wm ⁻¹ K ⁻¹	180	390	120
Thermal expansion, ppm/K	24	17	20
Resistivity, microhm•cm	3.7	2	6
Relative cost / area	1.0	1.5	1.4

Notes:

1. Values when interface roughness is 70 micro inches.
2. Both sides of the ground plane normally have the same roughness.

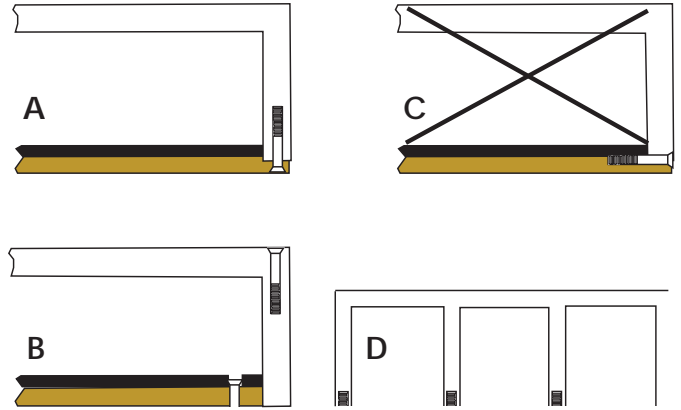


Figure 6. Typical housing configurations, including one (C) that is not recommended.

Table II: Typical Properties of Thick Metal Clad Laminates

Property, Units	Value	
Ground plane/dielectric interface		
Peel Strength lbs./in. width (1)	RT/duroid 6010 0.025 in thk	24
	RT/duroid 5880 0.031 in. thk.	30
Shear Strength, lbs./in. (1)	RT/duroid 6010	1350
	RT/duroid 5880	1500
Surface Roughness, microinch (RMS) (2)	70	
Ground plane thickness tolerance, in.		
	Standard	Table III
	Tight Tolerance	± 0.002"
Parallelism, in. (2) (3)		0.002 max

Metal thickness options are given in Table III. These thicknesses and tolerances are considered industry standards, allowing for reduced lead times and standard pricing. These and other thicknesses are available with a tight tolerance of 0.002".

Table III: Industry Thicknesses (inches)

* Copper cladding is not available on TMM* materials

Copper*	Brass	Aluminum
0.020 ± 0.0035	0.020 ± 0.003	0.020 ± 0.003
0.032 ± 0.004	0.025 ± 0.003	0.025 ± 0.003
0.040 ± 0.005	0.032 ± 0.004	0.032 ± 0.0035
0.050 ± 0.006	0.040 ± 0.004	0.040 ± 0.004
0.064 ± 0.006	0.050 ± 0.005	0.050 ± 0.005
0.093 ± 0.007	0.064 ± 0.005	0.063 ± 0.005
0.125 ± 0.007	0.093 ± 0.006	0.080 ± 0.006
0.187 ± 0.008	0.125 ± 0.006	0.090 ± 0.006
0.250 ± 0.010	0.250 ± 0.009	0.100 ± 0.007
		0.125 ± 0.007
		0.160 ± 0.009
		0.190 ± 0.011
		0.250 ± 0.014
		0.313 ± 0.015
		0.375 ± 0.017
		0.500 ± 0.023

Selection of Ground Plane Alloy

The cost of the ground plane alloy is often a compromise between many factors, including design, manufacturability, processing cost, and service exposure, among others.

Cost

Aluminum has the lowest cost per area for a given thickness, but if thickness is dictated by mechanical strength requirements, brass may be the best choice.

Power

Copper is best for high power applications where high thermal conductivity for heat sinking is needed. It has twice the thermal conductivity of aluminum and three times that of brass. It also offers a good match of CTE to silicon chips and copper foil. The high specific heat of aluminum may be desirable for certain duty cycles, especially those with short term, high heating rates.

RF Losses

At high frequencies, conductor losses, including both the circuit trace and return (ground) path, become significant. Conductor losses are a function of electrical resistivity and surface roughness. RF losses can be minimized by specifying a smoother dielectric/ground plane interface, but the trade off here is in reduced bond strength.

Copper or aluminum is preferred over brass for high frequency, low loss applications, because of the higher resistivity of brass.

Weight

Aluminum's very low specific gravity and high strength to weight ratio is often preferred for weight critical aerospace applications.

Machinability

The high temperature of the lamination process tends to anneal metals, fully annealing both aluminum and copper. Intricate machined shapes for these metals are not recommended. Tapped holes require great care and threads are easily stripped. Where possible, use configurations in which the fasteners do not require tapped holes in the clad metal. (See figure 6, where preferred configurations A,B,D are contrasted with C.)

Brass machines well, with close tolerance control and provides reliable tapped screw holes.

Corrosion Resistance

Aluminum alloy 6061 has excellent corrosion resistance and is usable as is in many environments.

Copper alloy 110 oxidizes readily and corrodes rapidly when exposed to industrial pollutants, such as oxides of sulfur or nitrogen, or to high humidity and salt spray. Corrosion resistant plating is mandatory for all applications.

Brass is better than copper but poorer than aluminum. Protective plating is usually recommended.

Plated Through Holes

Both copper and lead free cartridge brass alloy ground planes can be processed in standard plating lines for circuit boards without special precautions. Alloys with lead contaminate plating baths.

Plated through holes to aluminum are more troublesome. Aluminum's thin, dense, adherent, corrosion resistant oxide surface layer must be removed to get the plated metal deposit to adhere to the reactive metal surface beneath. Using solutions of strong reagents, such as nitric acid, to strip this oxide layer requires great care to avoid carryover to subsequent baths. A "double zincate" treatment that involves oxide removal, zinc plating, stripping of the zinc, and replating with zinc is sometimes used. It is a difficult process to control. The high viscosity of some of the solutions prohibits plating in high aspect ratio holes.

Processing Thick Metal Clad Laminates

In general, conversion of thick metal clad laminates to microwave circuit boards uses standard printed circuit board processes and equipment without major modification. The following covers the modifications and precautions that are needed.

Cleaning

Solvent cleaning and degreasing of thick metal clad laminates require no special precautions. However, bright dip solutions, such as hydrochloric acid for pre-cleaning copper for application of photoresist or screening ink, require masking of thick aluminum cladding to prevent rapid attack. Thick copper and brass need not be masked, since the only effect is a brightening action.

Note:

Abrasive scrubbing with pumice or the like should be avoided with any RT/duroid copper-clad laminates. The micro-scratches on the foil form stress risers, which tend toward later stress cracking in thermal cycling environments.

Masking

Thick metal ground planes, particularly aluminum, are attacked by some process solutions such as bright dips, plating baths, or etchants. Where this is true, it is necessary to mask the thick metal.

Selection from among available masking methods calls for consideration of the complexity of the surface to be masked, materials availability, EPA and OSHA requirements for solvent handling, the quantity of parts to be processed, and cost.

1. **Platers Tape** is quick, convenient, and low cost for masking flat, uncomplicated surfaces. Simply press the self-adhesive tape to the surface to be masked, with care at corners and edges. Overlapping strips of tape will prevent seepage of process solutions. As an extra precaution, edges and seams may be painted with a solution resistant lacquer, which will peel off when the tape is removed. Both ends of through holes need to be covered.
2. **Photoresist Film** is an alternative to platers tape for uncomplicated surfaces. The film is laminated onto ground plane, exposed and developed, and then stripped after processing.
3. **Liquid Photoresist**, applied by spraying, brushing or dipping is effective for complex, convoluted surfaces. However, it may fail to either tent over or fully coat the wall of small diameter holes. In such cases, other provisions such as plugs are needed.
4. **Lacquer** is applied similarly to liquid resist, but with the advantage that the higher viscosity lacquers will tent over small to medium diameter holes. The walls of larger holes and cavities will be coated in spray or dip coating. The lacquer is normally stripped by a suitable solvent after processing.

Imaging

Thick metal ground planes are unaffected by screen printing or photo-mask processing chemicals. The rigidity and flatness of thick metal laminates ensure accurate reproduction of the artwork on the copper foil, often exceeding that of conventional laminates clad with thin foil. Etch shrinkage is eliminated to gain close tolerance feature registration.

Etching

Copper etchants readily attack the most common metals used for thick cladding, making masking mandatory. Inadequate masking not only can damage the part, it may contaminate the etching baths for other jobs. Ammonium Persulfate can be used to etch aluminum backed boards without having to mask the metal.

Applications:

Thick metal clad RT/duroid laminates are gaining increasing acceptance among microwave design and process engineers.

Thick metal clad, high dielectric constant materials, such as RT/duroid 6010 ceramic-filled PTFE composite, are replacing alumina substrates in power amplifier applications. They offer good thermal management and dimensional stability combined with cost effective processing.

"Super component" designs take advantage of the dimensional stability of thick metal clad dielectrics for transmission lines connecting discrete circuit elements on aluminum chips mounted in cavities in the ground plane. The result is a compact, highly reliable module which overcomes many of the interconnection and housing problems associated with a module based only on alumina chips.

Thick metal clad laminates of low dielectric constant materials, such as RT/duroid 5880 microwave laminates, are finding use in many stripline and microstrip designs, from radiating elements in large antenna arrays, phase shifters, power dividers and feed networks for these antennas, to discrete microwave device packages such as filters, couplers, and switches.

Many system designs have used the opportunity found in the unique properties of thick metal clad RT/duroid laminates to lower cost and increase reliability.

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