

# TLAM SYSTEM DESIGN GUIDE

PART TWO: MANUFACTURABILITY



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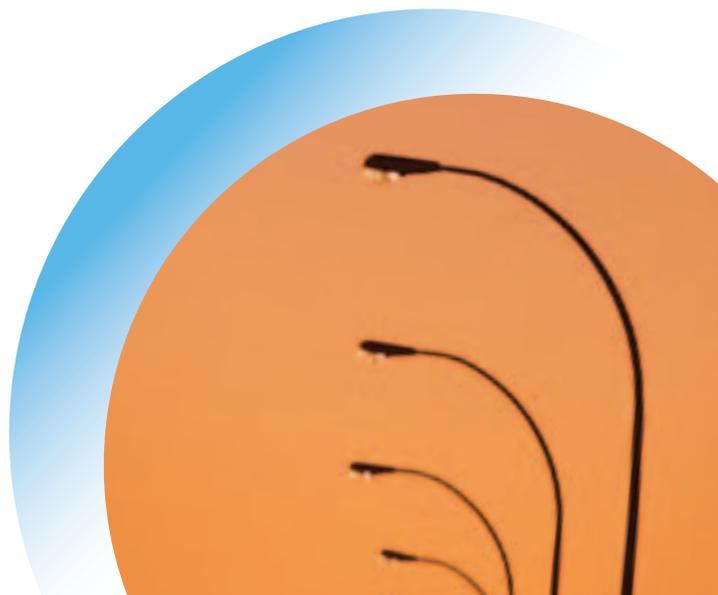
# DESIGN GUIDE

## Part 2: Design Guide for Manufacturing Tlam Substrates

The Design Guide Part 2 provides details for designing Tlam substrates for manufacturability, and for addressing the associated manufacturing controls and evaluation issues. Since the manufacturing, performance and reliability issues are not independent of the Design Guide Part 2, they should be included as an integral part of all manufacturing considerations. Manufacturability should be interpreted in the broadest terms, and should include designing to insure the specified performance, product consistency, quality, reliability, and costs effectiveness.

The Tlam SS substrates manufacturing issues are similar to those for standard FR4 in many respects, although there are a number of special considerations associated with the metal base plate; thicker copper foil, special dielectric isolation, and typically higher power levels. The Tlam SS dielectrics are quite flexible, relative to other competitive thermal materials, which gives Tlam significant advantages over both standard and thermal materials. The Tlam SS substrates are well suited for both SMD and Chip & Wire assembly. Chip & Wire substrates may require the selection of specific surface finish, plating or special surface preparation for specific processes and applications.

The higher thermal conductivity of the Tlam SS dielectrics not only increases maximum device power dissipation and track and via currents, but it can greatly increase the current rating of the leads and connectors. The improved Tlam power dissipation often eliminates costly and awkward thermal and mechanical hardware, and can significantly reduce the product size. This in turn reduces the total product or system manufacturing cost, and as such any comparative cost analysis should not be limited to the power substrate or board.



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# 1.0 Basic Architecture

The Tlam system provides a broad range of Tlam SS substrates by laminating layers of various materials. Tlam SS ML substrates can be combined with FR4 CCL to build the widest combination of PCB constructions.

## 1.1 Single-Sided Tlam Tlam SS Substrates with Base Plate

The most common Tlam SS substrate is built with a metal base plate that is laminated to a layer of Tlam SS dielectrics and a layer of copper foil. The circuit pattern is etched into the copper foil to provide electrical routing and mounting pads for semiconductor devices, connectors and other components. The Tlam SS dielectrics provide excellent heat transfer from the foil and components to the base plate, while maintaining excellent electrical isolation. The base plate gives the Tlam SS substrate mechanical integrity and distributes and transfers the heat to a heat sink.

## 1.2 Tlam ML Substrates

The Tlam ML products consist of a Tlam DS (double-side) substrate and Tlam PP bond ple dielectric. The Tlam DS is a layer of Tlam SS dielectrics laminated

between two layers of copper foil. The circuit pattern can be etched in both copper layers and Plated-Through vias (PTH), which are commonly used to make electrical connections between the layers with the vias being used to enhance heat transfer between the layers. The TLAM ML boards use the Tlam PP as a bond ply to laminate the two-layer circuit to a metal base plate.

## 1.3 Tlam ML Circuit

The Tlam system is especially suited for multilayer construction. The Tlam ML circuits are constructed by laminating one or more Tlam DS substrates and metal base plate or core with Tlam PP dielectrics bond-ply layer which provides adhesion, dielectric isolation and low thermal resistance. The Tlam system provides flexible layers, which make the multilayer exceptionally durable in temperature cycling, power cycling and mechanical vibration and flexing. This reliability feature is unique for this type of high thermally conductive multilayer.

FIGURE 1: Tlam SS Construction

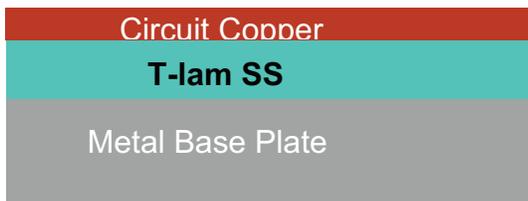
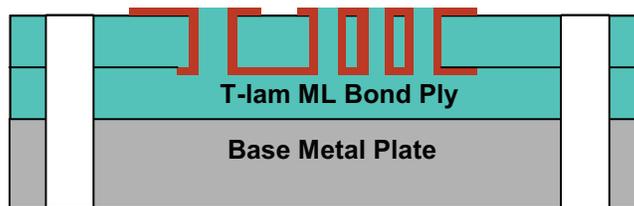


FIGURE 2: Tlam DS Substrate Illustration



FIGURE 3: Tlam ML Circuit Illustration



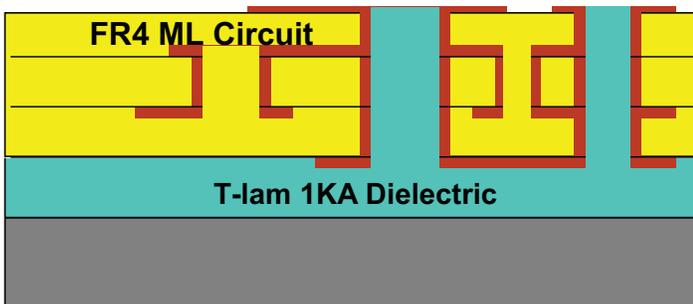
## 1.4 Tlam FR4 Hybrids and Metal Core PCB

The Tlam materials can also be used to produce Hybrid Multilayer Tlam SS substrates, where select Tlam SS dielectrics layers are replaced with lower cost FR4 in layers where good thermal conductivity or special dielectric properties are not required. The FR4 can provide mechanical integrity and can sometimes be used in place of the metal base plate or a thick copper core. Hybrid systems without a metal base plate often depend on a thick copper foil ground plane to distribute the heat across the PCB, and are generally not mounted on a heat sink.

## 2.0 Base Plates

The Tlam SS substrate is built on a metal base plate. Aluminum is typically used for good thermal conductivity; best TCE match to the dielectric, lower cost, lighter weight and fabrication ease. Copper is sometimes used for better thermal conductivity, better mechanical strength, better TCE match to thick copper foil, and compatibility with soldering and plating processes. In most applications, the thermal advantages of the copper base plate are insignificant because the thermal resistance of the base plate is small relative to the thermal resistance of the dielectric layer and the components.

FIGURE 4: Tlam FR4 Hybrid Illustration



## 2.1 Aluminum and Copper Alloys for Punching, V-Scoring and Routing

The standard base plates are aluminum or copper alloys. The specific alloys and hardness recommended for products are dependent on the thickness, layout and the singulation technique. Singulation is defined here as the separating of the panel into individual substrates or boards. The recommended alloys are shown below. Details for the associated singulation techniques are followed by key physical, electrical and thermal properties of the aluminum and copper.

## 2.2 Properties of Aluminum and Copper Base Plates

The following thermal, electrical and mechanical properties are similar for the recommended aluminum and copper alloys, and the typical values shown below will be sufficient for most calculations. More precise numbers are available for the specific alloys on request.

FIGURE 5: Tlam ML Metal Core Illustration

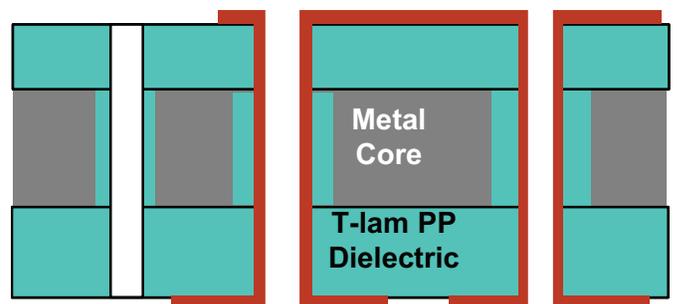


TABLE 2.2: Base Plate Metal Properties

Properties of Base Plate @ 20°C	Aluminum	Copper
Thermal Conductivity (W/m-°K)	190	390
Electrical Resistance (micro ohm-cm)	2.7	1.7
Thermal Coefficient of Expansion (ppm/°C)	24	17
Modulus of Elasticity (10E+06 psi)	10	17
Density (grams/cubic cm)	2.7	8.9

## 2.3 Special Base Plate Materials

The Tlam SS dielectrics materials are exceptionally well suited for a broad range of special materials because their flexibility accommodates a broad range of base plate TCE and thickness. Special materials may be used for mechanical strength, TCE or chemical properties, but such materials typically sacrifice thermal performance or add cost. Examples of a few alternate base materials are steel, nickel, copper/Invar/copper and copper/moly/copper.

## 2.4 Anodized Aluminum Base Plates

Aluminum base plates with the backside anodized are an available option. Anodization can minimize scratching and visual defects that are created during substrate or assembly processing and handling. The anodization will slightly increase thermal resistance and cost, but these increases are very small and may be acceptable where aesthetics is important to an end product. Anodization is typically Type 2 black or clear, but other colors are usually available through the fabricator.

## 2.5 Singulation by Stamping, Scoring and Routings

The choice of the singulation technique is important for unit and tooling cost, sample lead-time, quality and precision and material utilization.

**2.5.1** Milling or CNC Routing is often used for prototypes or very low volume custom products. It requires no tooling and can provide complex shapes and details, but the cost is usually too high for production. When routing is used, holes for mounting or alignment are usually drilled in panel form, which can be done quickly and precisely, and at a lower cost. Routing leaves a flat substrate, but convex shaping can be obtained with a secondary operation, if required.

**2.5.2** Scoring is often used in applications where square corners are acceptable. Scoring is performed by cutting V-grooves between the individual substrate on both sides of the panel, and then breaking out the individual substrates. Although radius corners can be routed, radius corners are generally not economical beyond prototypes. As with routing, holes are usually drilled in panel form. Scoring is used for high volume production and requires no tooling. There is no lost material between parts, which often makes it

cost competitive at high volumes. The edge of the scored substrate is not as cosmetically clean as routed or stamped substrates, and may require secondary finishing operations for some applications.

**2.5.3** Punching is used for high volume production because it usually provides the lowest unit cost when tooled. Punching can provide complex shapes and holes in a single operation. Punching does require expensive tooling and lost material between parts, and does have some limitations on fine detailing and tolerances. The punching tools must be recessed in the circuit area so that the tool only contacts the top surface of the substrate in the foil free border. The width of that border area is typically equal to the thickness of the base plate. Punching typically creates a burr on the upper or dielectric side of the substrate, but it can be removed with a secondary operation if no burr is allowed. The type of punching tool can significantly influence tooling and units cost. The primary types of tools are: single punch with manual index, single turret punch, and multiple punches.

The Single Punch with manual index is the lowest cost tool, and is often made as a soft tool using steel to produce initial stamped parts and to qualify the tool design. This initial tool is then replaced by a hard steel or tungsten carbide tool for high volume production. The soft Tlam SS dielectrics dielectric can often be punched with a hardened steel tool in high volume production, eliminating the need for the more expensive tungsten carbide tooling required by many competitive thermal materials.

Turret Punch Press utilizes a single cavity tool with high speed automatic indexing. This can reduce the unit cost at high volume. Tools for Turret Punches are generally used for many more hits and are typically made of tungsten carbide for longer tool life. The tungsten carbide tool is more expensive than a steel tool, but the automatic indexing reduces the unit cost.

Multiple Unit Punches or Multiple Cavity Punches are another way to increase the rate and reduce the unit cost. The tooling is more complex, but reduces the number of hits per cavity. Therefore, it is often possible to build high volume multicavity tools with steel, rather than the higher cost tungsten carbide tool. This option can be even more attractive with the lower abrasiveness Tlam SS dielectrics materials.

The Tlam SS dielectrics material is especially suited for punching, because the ceramic filler content of

the dielectric is much lower than in most metal-based thermal substrates. In addition, the unique Tlam SS 1KA dielectrics filler can act as a lubricant, in contrast to the abrasive alumina used in most competitive products. This gives much longer tool life and less tool sharpening with the Tlam materials. Note: some manufacturers highly thermal conductive materials require the tool to be sharpened every one thousand (1,000) hits.

Punched parts are typically produced with the base plate burr up, or towards, the foil side. This allows optimum seating of the substrate base plate to a heat sink, and a small topside burr can generally be designed around. If the application requires no burr, it can be removed in a secondary operation. The maximum burr for the different singulation techniques is given in section 2.7.

## 2.6 Substrate Camber and Flatness

The flatness varies with substrate layers and thickness and with the technique selected to singulate the substrates. If the base plate or laminated FR4 layer is sufficiently thick and rigid for a given substrate size, and the foil is not excessively thick or irregular, then the flatness shown below can be achieved with the specific singulation techniques. Copper base plates can provide quite flat surfaces over larger areas because the TCE of the base plate matches the foil, and the copper base is stronger than the aluminum for a given thickness.

- Routing and Scoring can achieve +/- 0.001" per in camber, and often less than +/- 0.001" per in flatness across large substrates.
- Punching can achieve +/- 0.002" per in, and often less than +/- 0.002" per in flatness across larger substrates. Punching can shape or bend the substrate surface to provide better thermal contact when mounted to a heat sink or other surfaces. In high power modules, where thermal contact is critical, the bottom surface of the base plate is often formed convex, typically by 0.001" to 0.003" per in. Again, the exceptionally flexible Tlam SS dielectrics allows more convex forming than other high thermally conductive dielectrics.

## 2.7 Panelization and Substrate Tolerances

The Tlam standard panel is laminated in 24"x18" panels. Other panel sizes are evaluated on a business case. The usable panel area depends on substrate size, singulation technique and base plate thickness (T). The basic guide for panel borders, substrate spacing, substrate dimensional tolerance and maximum burrs are shown below based on the recommended aluminum alloys. Copper base plate guides are similar, but insufficient statistical data is available to quantify specific differences. Very small or very large substrates may also deviate from these general guidelines.

TABLE 2.7: Substrate Tolerances for Various Singulation Techniques

Singulation Method	CNC Routing	V-Score one side	V-Score both sides	Punching
Minimum Panel Border mm (inch)	12.7(0.5)	12.7(0.5)	12.7(0.5)	12.7(0.5)
Minimum Substrate to Substrate mm (inch)	1T	2T	0	2.5T
Typical Substrate Length Tolerance mm (inch)	±0.051 (±0.002)	± 0.254 (±0.010)	± 0.127 (±0.005)	± 0.127 (±0.005)
Typical Substrate Width Tolerance mm (inch)	±0.051 (±0.002)	± 0.254 (±0.010)	± 0.127 (±0.005)	± 0.127 (±0.005)
Maximum Burrs mm (inch)	0.002 inch	0.002 inch	0.007 inch	0.007 inch

## 2.8 Corners, Holes and Base Plate Ground Connections

Circuit corners are punched or routed, and scored substrate either have no radii, or the radii are routed or punched in a secondary operation. The minimum radii for the different singulation techniques are shown below.

Mounting holes and alignment holes can be drilled or punched. Punched holes are the lowest cost, but do require a more complex stamping tool. Drilled holes are done preferably in panel form to minimize handling and to utilize high speed and high precision standard PCB equipment. A small number of alignment holes are required in all panels for standard processing. In general, post singulation hole drilling is less precise and more expensive.

Some applications require ground connections from the circuitry to the base plate. Generally, this is a special operation, and a cost to be avoided where possible. If a ground connection is needed, there are a number of standard approaches to select from:

- Milling or drilling shallow flat bottomed hole into the top of the base plate can allow aluminum wire bonds from the base plate to the circuitry. Although this may be a simple and lower cost technique, it

is only applicable to chip and wire products with aluminum wire bond capability.

- A more general approach is to drill a small hole for a press-fit pin, which can be inserted down into the base plate, and soldered to the copper circuitry with the components. The individual pin insertion will increase costs, and should be automated in high volume products. Often stand-offs or other hardware at mounting holes can be used for the ground connection and serve a dual function.
- Drilled and plated holes are also possible, but require a number of special preparation steps and operations. This approach is easier with copper base plates, which can be plated directly.

Although there are other options for base plate ground connections, they are not standard processes at this time. Many products can utilize existing leads of connectors to provide the ground connection off the substrate. The current requirement for the ground connection can vary with product and function. For example, the connection may be a low current connection for a ground shield, or it may be required for a high current fault.

Note: Some fault current connections are controlled by regulator agency rules.

TABLE 2.8: Circuit Feature Tolerances of Singulation Types (Radius Corners, Bridges, Hole Diameter)

Feature Tolerances	Drilled	Routed	V-Scored	Punched
Corner Radius, Outside Minimum	NA	0	NA	0.7T
Corner Radius, Inside Minimum	NA	0.7T	NA	0.7T
Bridge, Edge to Hole Minimum	NA	0.5T	0.5T	1.5T
Hole Diameter Minimum	0.2T	NA	NA	1.0T
Hole Diameter Tolerance	±0.002 inch			±0.005
Hole Location, Hole to Hole Tolerance	NA	0.025 (0.001)	NA	0.001 inch
Hole Location, Hole to Edge Tolerance	NA	0.005 inch	0.010 inch	0.001 inch

## 3.0 Copper Foil

### 3.1 Material Selection and Properties

The metallization, or foil layers, are used for electrical routing, heat conduction and distribution; and for pads to solder, epoxy, and wire bond components and connectors. As with standard printed circuit boards, the foil material is IPC Class 2 electro-deposited (ED) copper, and is available in six (6) standard weights: ½ oz, 1 oz, 2 oz, 3 oz, 4 oz and 6 oz. The thickness and resistivity of the standard weight copper foils are shown below.

In addition to the standard ED copper foil, other copper foil thicknesses are available and compatible with the Tlam system. The initial foil thickness may be increased during via plating, or reduced during surface conditioning. Aluminum foil is also available, and can provide a lower cost and lower weight alternative for thermal planes; but does have some process compatibility issues with vias and electrical connections. In some applications, it may be possible to use the aluminum foil for wire bonding.

### 3.2 Line Width and Edge-to-Edge Space Considerations for Manufacturability

In principle, the Tlam etching and plating processes are identical to those used with standard PCB. Tlam can typically achieve the same lines and spaces as PCBs, with the same manufacturing trade-offs. The etched copper foil tolerance is typically +/-20% of the foil thickness. There are two differences that may apply to Tlam:

- The T-preg dielectric is softer and line position stability may be less with very fine lines.
- Tlam is usually used for improved performance at higher power levels, and foil thicknesses are typically greater than standard PCB.

The following are minimum line widths and edge-to-edge spaces and preferred minimum line widths and spaces for manufacturability with standard processes. The preferred limits can increase yield or process ease, but they are not required. Smaller lines and spaces may be achievable, but may require special processing and increase cost.

TABLE 3.1: Resistivity of Copper Weight per Area

Copper Weight Oz.	Thickness, mm(mils)	Resistivity @ 20°C, m ohm/sq	Resistivity @ 130°C, m ohm/sq
0.5	0.018(0.7)	0.956	1.367
1	0.036(1.4)	0.479	0.686
2	0.071(2.8)	0.239	0.343
3	0.107(4.2)	0.160	0.229
4	0.142(5.6)	0.120	0.171
6	0.213(8.4)	0.080	0.114

TABLE 3.2: Minimum Line Widths and Spaces for Various Copper Weights

Copper Weight, oz	0.5	1	2	3	4	6
Minimum Line Width, mm(mils)	0.127(5)	0.204(8)	0.305(12)	0.381(15)	0.508(20)	0.635(25)
Minimum Line Spacing mm(mils)	0.127(5)	0.254(10)	0.381(15)	0.508(20)	0.635(25)	0.762(30)
Preferred Min. Line Width mm(mils)	0.254(10)	0.381(15)	0.508(20)	0.508(20)	0.635(25)	0.762(30)
Preferred Min Space Width mm(mils)	0.254(10)	0.381(15)	0.508(20)	0.635(25)	0.762(30)	0.889(35)

### 3.3 Line and Space Considerations for Performance and Safety

Electrical or safety considerations may require greater line widths and/or spaces than the defined minimum or preferred limits for manufacturability.

#### 3.3.1 High Currents

High currents may require increased line width. The Tlam width for high currents are significantly less than for standard FR4 PCBs because the Tlam is much more effective at removing the heat from the traces. The Laird Technologies T-guide for Performance provides the maximum current for various line width and foil thickness.

Note: If the line width is very fine or the foil very thick, it may be necessary to compensate for edge etching contours, but such factors will vary with fabricators and their processes.

#### 3.3.2 Line Spacing for Performance and Safety

The Tlam line spacing for performance and safety are a function of working and rated voltages and are often defined by the safety regulatory agency, which governs the end product. These agencies may include UL, VDE, EC and CSA. The spacing may be limited by operating voltages, peak transient voltages, peak recurring voltages and comparative tracking index (CTI). Other influencing factors may include power levels, function and environment exposure. UL and EC have spacing requirements based on levels of moisture and cleanliness, as defined for different pollution levels.

These regulations are complex and product specific, and beyond the scope of this design guidelines. It should be noted that there are major differences in spacing for applications, environment, and interpretation of the application. For example, UL508C and UL840C cover industrial controller products, but UL840 can allow much smaller spacing if the pollution level or transient levels are controlled or known. This is important for manufacturing because it can allow the product to be designed much smaller and may make significant reductions in material and labor costs. Size can also be a major competitive feature of the end product.

If the minimum spacing is not controlled by regulatory agencies, there may still be special spacing requirements imposed by the end product working or rated voltage, or by the spacing required for hipot testing. The use of the safety agency rules for minimum spacing is recommended for products with high working and rated isolation voltages, even if those agencies do not govern the products.

#### 3.3.3 Hipot Testing

Hipot testing is often required at levels above the rated operation and isolation voltages, as a screen for potential defects or to reduce hipot testing time. Therefore, the spacing between lines and the edge of the substrate, mounting holes and ground pads must be increased to insure that there is no arcing during such hipot testing. The following minimum spacing between lines is recommended to prevent surface arcing at 20°C and 60% relative humidity.

TABLE 3.3: Minimum Circuit Spaces for Given Hipot Test Voltages, Vac and Vdc

Hipot Test Voltages, Vac	Hipot Test Voltages, Vac	Minimum Spacing mm(inch)
1000	1500	1.0(0.040)
1500	2000	1.5(0.059)
2000	3000	2.54(0.10)
2500	3500	3.81(0.15)
3000	4200	5.08(0.20)
3500	5000	6.35(0.25)

## 3.4 Plating, Solder and Special Coatings

The exposed copper foil can be a good material for the most common electrical and mechanical connections, including soldering, epoxy chip attaching, wire bonding and mechanical contacts. Although the copper is metallurgically compatible with many solders, epoxies and wire bond materials; copper is easily oxidized in storage and high temperature processes. Therefore, the surfaces are often cleaned, coated or treated to improve the ease, quality and reliability of the solder, epoxy and wire bond joints and interfaces.

### 3.4.1 Exposed Copper Surfaces

Exposed copper surfaces should be ED copper plated, shipped in sealed packing materials, and stored in nitrogen after opening. Exposed copper will have a limited shelf life, which is dependent on initial condition, packing, storage and final application.

Exposed copper that will be used to solder surface mount components and leads are often coated with an anti-oxidant, which is removed by the heat during the soldering operation. Such materials maintain a clean and un-oxidized solder surface, and extend the shelf life of the Tlam substrate or PCB.

Exposed copper used for aluminum ultrasonic wire bonding must be smooth, continuous, and kept exceptionally clean. Slightly oxidized copper surfaces may require a chemical, abrasive or plasma cleaning to assure a good wire bondable surface.

### 3.4.2 Solder Resist

Solder resists are often required to limit and control solder coverage, and to protect lines from mechanical or environmental damage and contamination. Standard PCB solder resist processes and materials are used with Tlam. Since the Tlam is typically used at higher powers and currents, the foils are generally thicker and more difficult to completely cover at the edges of tracks. Therefore, it is often necessary to apply thicker or multiple coats of solder resist; where complete edge coverage is required. If the design requires guaranteed edge coverage for safety or regulatory rules, the solder resist is generally not sufficient, and an appropriate conformal coating or potting compound can be applied after assembly to guarantee coverage.

### 3.4.3 Solder Coating

The Tlam substrates can be provided with the standard solder coatings on copper pads and traces. Although

solder dipping, solder plating and solder paste screening are all available processes; the standard Hot-Air Leveling solder coating is the most common technique and it is often the most economical coating. It is also easier to apply to products with metal base plates. Hot-Air Leveling eliminates copper oxidation, guarantees good wetting, and provides a thin and uniform solder coating. A tin-lead eutectic solder is usually used, but other low temperature soft solders are also possible.

### 3.4.4 Plating

Plating can reduce oxidation, provide mechanical protection, and improve the surface for special soldering and wire bonding operations. Tlam materials can be used with all the standard plating materials that are used with PCB and ceramic substrates. These can include Nickel, Solder, Silver, Gold, Tin, etc. The most common include:

- Nickel (Ni) plating can be used for both soldering and wire bonding, and the typical thickness is 100 to 300 micro-inches. Ni does slow the oxidation rate, but Ni oxide is more difficult to see and remove, relative to copper oxide. Ni can improve the wire bond surface, and is often plated with a 7 to 12% phosphorous content to improve the surface finish for aluminum ultrasonic wire bonding. Nickel plating can be electroless or electrolytic, but electroless is normally preferred for PCB and Tlam.
- Nickel plus a flash of gold (Au) is often used to prevent the Ni from oxidizing. The Au thickness should not exceed 15 micro-inches on a surface that will be soldered. The Au is lost in the soldering and ultrasonic wire bonding operation, and both joints are made to the underlying Ni plating. The gold plating can be electrolytic Au or immersion Au. Electrolytic Au should be 3 to 5 micro-inches, but immersion Au should be 8 to 10 micro-inches to eliminate porosity that could allow the underlying Ni to oxidize. Immersion Au is typically used with electroless Ni, and preferred for board manufacturability. If the surface is used for gold wire bonding, thicker Au may be required and 15 to 50 micro-inches are recommended.
- Solder plating is possible, but today Hot-Air solder coatings are quite well controlled, more common, and they cost less. If solder plating is required, the recommended nominal thickness for unfused Sn/Pb is 300 micro-inches.

## 4.0 Electrical and Thermal Vias

Vias are used to make electrical connections between foil layers of the Tlam multilayer boards as they are used in standard PCBs. They can also be used to enhance the thermal conductivity between non-isolated copper foil layers. In general, the process and capability is identical to those for PCBs, with the exception that the isolated vias cannot go through the metal base plate or heavy metal core foil of the Tlam.

### 4.1 Electrical Connections

Although small vias or PTHs are often used for lower currents, Tlam is often used on high current products where small vias must handle significant currents. The maximum current ratings for vias are a function of size, wall thickness, foil thickness, dielectric thickness, type of dielectric, and maximum base plate temperature. The maximum current of vias is limited by the maximum via temperature, and because the Tlam is thermally superior to the standard PCB, Tlam vias can handle significantly higher currents. See the Laird Technologies T-guide for Performance for maximum current rating of Tlam vias.

### 4.2 Thermal Enhancement

As with standard FR4 PCBs, the vias can be used to transfer heat from one foil layer to another. However, with Tlam, the heat transfer can be further improved by removing the heat through the dielectric and the aluminum base plate. It is the combination of the thermal vias and Tlam dielectric that makes the Tlam multilayer system so thermally effective. The thermal resistances between the Topside pads and the base

plate, using multiple thermal vias, are shown in the Laird T-Guide for Performance, and are a function of via size, via pitch, via wall thickness, foil thickness, dielectric thickness, and maximum base plate temperature. See Figures 5 and 6 on the back page for examples of thermal vias in Tlam DS and hybrid FR4 multilayer Tlam ML constructions.

Many multi-layered Tlam boards are often Tlam PP dielectric and FR4 hybrids. These boards use Tlam dielectric in critical thermal layer between the FR4 multilayer PCB and metal base plate. The Tlam PP dielectric provides excellent thermal transfer and electrical isolation, and use ML FR4 use thermal vias to enhance thermal conductivity through the less critical and lower cost FR4 layers. The combination reduces the total board cost and increases trace stability in complex fine line computer board applications.

## 5.0 Component and Mechanical Hardware

### 5.1 Component Considerations

The Tlam system is designed for SMD and chip and wire components and connectors. The Standard PCB and Ceramic substrate assembly rules are generally applicable. Thru-hole components are not generally suited for metal-based substrates like Tlam, but provisions can be made for select thru-hole components. Such thru-hole provisions will carry a cost penalty, and should be very limited.

### 5.2 Mechanical Hardware and Mounting Issues

As with PCB, the Tlam foil and surface mount pads are not recommended as supports for mechanical hardware and substrate mounting. The flexibility of the T-preg, which provides the superior resistance to thermal-expansion damage, does reduce the absolute peel strength of the Tlam. This is generally not a problem with components, but can be an issue with mechanical hardware and support, which can generate both higher forces and higher torques. Torque is important because it can create a peeling action on the pads. Components generally do not exert torque, and their strength is a function of pull strength.

Mounting holes with screws, rivets and clamps are generally recommended to support the substrates, subsystems and larger hardware. If it is necessary to solder large components or hardware to the Tlam without mounting screws, the components or hardware should be designed to only apply pull forces and not peel forces because Tlam pull strength is very much higher than the peel strength. The Tlam peel strength is 6 pounds per linear inch (pli), whereas the pull strength is approximately 1000 psi. This relationship between peel and pull strength is also true for standard PCBs, and it is generally not recommended to attach heavy components or mounting hardware by solder on standard PCBs.

### 5.3 Tlam Board and Substrate Mounting Issues

#### 5.3.1 Card or Slot Mounting

Tlam substrates, or boards that replace a PCB, may be mounted as a card or in slots. If the base plate is thicker and heavier than a standard PCB, wider slots or additional mechanical support may be required. Also, double-sided connector contacts are not applicable with base plates. Often it is necessary to select thinner base plates and layers to fit standard slots, and a thinner copper base plate can provide the same function as aluminum at a slightly higher cost.

The T-preg improves thermal conductivity to ground planes or the base plate, but it is important to be sure that the extra heat is removed. The mounting technique may remove some heat and be important to overall thermal performance of the system. Important factors include:

- The ground plane or base plate provides excellent heat distribution and may be sufficient to provide transfer of the heat to ambient air in the conventional card rack.
- If the power levels are sufficiently high, it may be necessary to remove heat with metal slot clamps, increased board spacing, or forced convection. It should be noted that slot or clamp temperatures may be different than the ambient air temperature. See the T-guide for Performance for more specific thermal data and recommendations.

#### 5.3.2 Heat Sink Mounting



At high power levels, it is often necessary to mount the Tlam substrate directly to a heat sink, or the heat sink directly to the Tlam. The heat sink must be flat and have a satisfactory surface finish. Mounting holes and base plate thickness must be sufficient to guarantee good thermal contact and pressure through the life of the product, and through the heating and cooling cycles of the specific application. Good thermal contact can be improved with a convex surface on the bottom of the Tlam base plate, and with the addition of thermal interface materials like greases, pads or coatings. Laird Technologies provides a broad range of high performance interface materials. The mounting and thermal interface issues are more like those encountered with power component and modules than with PCB component mounting. Good thermal contact may depend on many factors including base plate material, size, shape and thickness, mounting screw size, number, location and torque, and support/rigidity from components, potting and mechanical braces. The Laird Technologies T-guide for Performance provides additional information to help with your system's thermal management.

## 6.0 Inspection and Test

### 6.1 Electrical Testing

#### 6.1.1 Short and Open Testing

Most boards of any complexity, or with fine lines and spaces, should be 100% Short and Open tested. This capability is available at most fabricators. If the lines and space can be sufficiently over-designed or simplified, it may be possible to eliminate short and open testing, and associated costs. High current testing may be required in some power products, but this capability is not as readily available at all fabricators, and should be avoided if possible with adequate design margins.

#### 6.1.2 Hipot Testing

Substrates or boards that have a high isolation voltage requirement, or rated isolation voltage, should be 100% hipot tested by the fabricator before shipment and should be sample checked at incoming inspection or before assembly. High isolation voltage may be required between circuitry and base plate, or between

input and output circuitry. DC hipot testing is preferred for Tlam and other metal-based substrates because of the higher capacitance, but AC is usually possible. If the end product requires 100% hipot testing by regulatory agencies, it is generally preferable to test at 120% of the rated voltage, to allow reduction of the test time from 1 minute to 1 second. If the material, layout and edge spacing is not sufficient for such elevated voltage testing, the necessary testing may be very time consuming and expensive.

#### 6.1.3 Special Testing

If there are special critical electrical substrate requirements for the end product, it may be worth testing them at the substrate level. These may include capacitance, resistance, high current, etc. These tests are not typically performed by the fabricator and need to be specified and agreed upon if required. Optionally, such tests can be performed by the user at incoming inspection, or simply guaranteed by over-design. The T-guide for Performance can help with requirements to guarantee by design and nominal values.

### 6.2 Mechanical and Dimensional Inspection

In general, mechanical dimensions and tolerances are determined by artwork and tooling, but select critical dimensions should be checked to assure that the process is in control. Critical dimensions should be sampled at the fabricators outgoing inspection and the user's incoming inspection. Important parameters may include substrate size, hole locations and size, pattern to substrate location, line width and spacing, and base plate and metallization flatness and finish.

### 6.3 Virtual Inspection

Visual inspection should include workmanship, cleanliness and condition, visual color, oxidation and finish, special marking requirements like part number, date code, serial number, etc., and special packaging requirements.

Visual inspection should not be used to guarantee critical performance or as a screen for critical defects.

## 7.0 Tlam Procurement and Ordering

Laird Technologies primarily provides Tlam SS and Tlam ML substrates, and the PCBs are ordered through qualified PCB fabricators. Laird Technologies can provide a list of qualified fabricators or work with the board shop of your choice. Procurement drawings should use the Laird Technologies substrate part numbers and descriptions to avoid substitution of other products with different properties.

## 7.1 Substrate Description System

The Tlam material descriptions use a building blocks system. There are three (3) types of substrates available and the material description system for them is listed below.

**7.1.1** Single-sided substrates having five (5) building blocks in the material description:

Tlam SS 1KA 04 AL5 040 02

Tlam SS indicates that it is a single sided PCB substrate

- 1KA indicates that the 1KA dielectric is used in the substrate (Options: 1KA and HTD)
- 04 indicates that the dielectric is 4 mil (0.102 mm) thick (Std. Option of 4, 6 and 8 mils or 0.102, 0.152 and 204 mm)
- AL5 indicates that the substrate uses 5052 aluminum as base metal (Std. Options: AL5-5052H34, AL6-6061T6)
- 040 indicates the base metal thickness of 0.040 inch (Std. Options: 0.040, 0.059, 0.080 in or 1 mm, 1.5 mm and 2.0 mm)
- 02 indicates that 2 oz copper is used on the substrate (Std. Options 1, 2, 3, 4 oz)

**7.1.2** Double-sided substrates having four (4) building blocks in the material description.

Tlam DS 1KA 06 02/02

Tlam DS indicates that the substrate is a double-side PCB substrate (i.e., CCL for FR4)

- 1KA indicates that the 1KA dielectric is used in the substrate (Options: 1KA)
- 06 indicates that the dielectric is 4 mil (0.102 mm) thick (Std. Option of 6 and 8 mils or 0.152 and 0.204 mm)
- 02 indicates that 2 oz copper is used on one side the substrate (Std. Options 1, 2, 3, 4 oz)
- 02 indicates that 2 oz copper is used on second side the substrate (Std. Options 1, 2, 3, 4 oz)

**7.1.3** Bond Ply substrates for ML constructions having two (2) building blocks

Tlam PP 1KA 10

Tlam PP indicates that the substrate is an uncured dielectric used to bond the ML PCB to the base metal plate or individual Tlam DS boards together.

- 1KA indicates that the 1KA dielectric is used in the substrate (Options: 1KA)
- 10 indicates that the dielectric is 10 mil (0.254 mm) thick (Std. Option of 8, 10 and 12 mils or 0.204, 0.254 and 0.366 mm)

## 7.2 Typical Procurement Specification

The procurement specifications and drawings will vary with products and product applications, but the following is a checklist of items that may be important in a typical Tlam substrate and board procurement specifications:

- Substrate or Board Outline Drawing with dimensions on length, width and thickness, hole locations and sizes, dimensions on radii and special features, base or board flatness, shape and surface finish requirements, and tolerances on all of the proceeding parameters where applicable.
- Gerber files or equivalent files for all foil layer layouts, interconnect via locations, special panel drilled hole locations, marking, solder resist layout, labeling and logo artwork, and location reference points.

The Board specification will call out the substrate requirement using the part numbering system outlined in Section 8.1 with PCB fabrication requirements such as solder resist type, thickness and layers, marking ink type and color, special plating, coatings, and solder requirements. The plating and solder requirements may need details on application technique, composition and additives, thickness and surface finish. The details and tolerances may be left to the fabricators discretion in standard or non-critical products, or they may need to be defined precisely in products with high performance requirements, or with special assembly processes and materials. Chip and wire products generally require more detailed specifications to ensure compatibility

with special materials, processes, and equipment. Fine line SMD may require more precise position and tolerance details. Special fiducial, or reference points, may be required for automatic assembly.

- Special electrical requirements may be specified, or they can be controlled by the selection of materials and design. It is important to be specific if requirements are critical, non-standard, and if special testing or screening is required. See Section 6.1 for typical electrical requirements and tests. If testing is specified, define as 100% or the required sampling plan. Special testing may increase the fabricators cost and prices, and should only be used when the parameters cannot be controlled with materials, process or design.
- Mechanical requirements are generally controlled by the drawings and specifications, and the selection of materials. If such requirements are critical, lot sampling or screening tests can be defined to monitor and confirm compliance. See Section 5.2 for examples of special mechanical requirements. As with special electrical testing, special mechanical testing will also increase cost, and should be avoided where possible.
- Other requirements may include C of C, special packing, storage, cleanliness, labeling, etc. The fabricator will use their internal standards, if such special requirements are not clearly specified and agreed upon in advance.

## 8.0 Assembly Guide



Tlam is essentially a printed wiring board with special mechanical, thermal and electrical performance properties. The top foil, coatings and solder resists are the same materials and use the same fabrication processes as standard printed circuit boards, and therefore are generally compatible with the same assembly processes. The primary differences for Tlam that may affect assembly are:

- Higher physical and thermal mass with metal base plate.
- Typically thicker copper foil for higher current and power levels.
- Softer and less rigid dielectric layers.
- Not suited for thru-hole components.
- Often mounted on heat sinks to dissipate more heat.

## 8.1 SMD Assemblies

The top metal foil pattern and solder resist should be designed for SMD components using the same pad size, space and tolerance guide used with standard PCB. Very fine lines may be a little less stable because of the softer dielectric, but this is typically not a problem in most products. In general, the more flexible Tlam SS dielectrics eliminates or reduces thermal mismatch problems, which may occur with standard FR-4 PCBs, and generally this makes Tlam more accommodating with the fragile and larger components that are most affected by TCE mismatch.

The solder reflow process must transfer more heat to the Tlam substrate because of the higher thermal mass or heat capacity of the base plate and the thicker copper foil. This may require higher temperature settings and/or slower belt speeds for the reflow equipment. Equipment with conduction heating is ideal for maximum heat transfer with products that have metal base plates, but convection and IR heating are often used because that equipment is more readily available on standard PCB assembly lines. Many convection and IR systems allow a larger degree of heating from the bottom or base plate side, which provides faster heat transfer without overheating topside components. Tlam with no base plate, or with components on both sides is most easily reflowed in

convection or IR systems, but it is still important to guard against overheating low mass components.

Tin/Lead (Sn/Pb) eutectic solders are most commonly used, but some non-eutectic Tin/Pb and Tin/Silver (Sn/Ag) eutectic solders can be used. The Sn/Ag solders are stronger with a slightly higher reflow temperature, and are often used for power die or when a two solder system is required. The maximum recommended reflow temperature is 260°C, and the time at temperature should be minimized to reduce flux hardening. A nitrogen, or forming gas atmosphere, will also reduce flux burning and hardening, and usually is required if reflowed at the higher temperature extremes or with a higher temperature solder like the Sn/Ag solder. The Tlam SS dielectrics resin is similar to the FR4 resin, and the same fluxes, cleaning materials and cleaning systems are typically used.

Solder rework is possible, but will require supplementary heating because of the large thermal mass of the base plate. In general the Tlam substrate should be pre-heated from 85 to 115°C, and then the components can be removed by applying local heat to the individual components using a soldering iron or a hot air jet. As with PCB, rework should be avoided whenever possible.

## 8.2 Chip and Wire Assemblies

Chip and wire assembly is basically like a Chip-On-Board assembly, except for higher power products. The power dissipation is often similar to ceramic power modules, but costs are much lower and more like a printed circuit board. In fact, with the heat spreading of the thicker copper foils or soldered copper heat spreaders, the Tlam can often provide thermal resistances as low as the Direct Bond Copper (DBC) alumina and aluminum nitride, without the inherent high prices and the TCE mismatch cracking weaknesses of the DBC alumina and aluminum nitride.

### 8.2.1 Die Attach

Die attach can be performed with epoxy or soft solder, although some higher temperature soft solders or long curing epoxies may not be compatible with the 1KA Tlam SS dielectrics.

Most common silver, gold and insulating die attach epoxies are suitable, with curing temperatures of 150-175°C for periods of 1 to 1½ hours. Epoxy die attach

is typically done directly to exposed copper pads. Many conductive epoxies are not compatible with Ni plating or aluminum metallization, although most common plating materials are available for Tlam. Epoxies are typically dispensed or screened. Screening provides the best control and uniformity, but does require a flat surface with no pre-assembled components. Die attach epoxy curing should be done in ovens with a nitrogen atmosphere to prevent oxidation of wire bond pads. A programmable heating/cooling cycle is preferred, although manual curing with adequate cooling in a closed nitrogen oven is acceptable. Although these generalizations apply to typical die attach epoxies, each die attach epoxy is different and compatibility should be reviewed with manufacturer and testing.

Typical Tlam die attach solders are Sn/Pb eutectic or Sn/Ag eutectic. Typically, solder die attach metallization is copper, Ni plated copper, Ni plated copper with Au flash, or Hot solder leveled copper. Solder application can include preforms or pre-coated solder pads, screened solder pastes and dispensed solder pastes. Solder reflow temperatures should not exceed 260°C, and lower times and temperatures are preferable to reduce flux hardening and burning. Reflowing in nitrogen or forming gas may be required to reduce flux burning and hardening, and to make cleaning easier. The Tlam SS dielectrics resins are similar to FR4 resins, and the same flux and cleaning systems are typically compatible.

### 8.2.2 Wire Bonds

Wire bonding to Tlam is equivalent to wire bonding to standard Chip-On-Board, and standard Chip-On-Board techniques and controls are generally applicable. Gold Thermo-Sonic and Aluminum Ultrasonic wire bonding are both commonly used. Gold wires of 0.7 to 2.0 mils are common, but 3.0 is available with special equipment. Aluminum wires of 1.0 to 2.0 are common, but wire of up to 25.0 mils is available with special equipment. Aluminum wire of 5, 8, 10, 12 and 15 mils. are common in power products.

Gold wire bonding is typically bonded on copper foil with a Ni plated barrier and a gold plated finish. See section 3.4 for additional plating information and recommendations.

Aluminum wires can be bonded to clean copper foil or Ni plated copper foil. A gold flash is often added to the

Ni plating to minimize oxidation. See section 4.4.3 for additional plating information, including thicknesses and finish.

Large Aluminum Wire Bonding may be required or preferred for the high current Tlam products. Such bonding requires high ultrasonic energy, which is sensitive to proper bonding equipment, tools and clamping. These details are outside of the scope of this paper, but specific application support is available from Laird Technologies or through the large aluminum wire bond equipment manufacturers.

## 8.3 Mechanical Assemblies

The Tlam with integral base plate provides its own mechanical structure. In power module applications, Tlam replaces both the ceramic substrate and their more expensive copper base plate, eliminating the solder or epoxy substrate attachment process and alignment and the inherent ceramic/base plate reliability problems in temperature and power cycling of ceramic modules. In PCB applications, the base plate can provide the mechanical structure for the system and larger components, and often eliminates multiple supplementary hardware.

The inherent thermal properties of the Tlam often eliminate the need for mounting and for individual component heat sinks, insulators, screws, clips, and brackets. This often reduces the total system cost in power products despite the higher cost of the high performance materials. These simplifications often make possible easy assembly automation with simple pick and place equipment.

As with standard PCBs, mechanical connections for board mounting or very heavy components should generally not be made with solder joints to the copper foil. This can be more important where the metal bases are heavier and the Tlam SS dielectrics layers are softer than FR4. Mechanical connections may include screws, rivets, clamps, slots, etc. When the proper mechanical support is used, the softer Tlam SS dielectrics can provide superior mechanical reliability with better resistance to thermo-mechanical mismatch and mechanical vibration.

The mechanical support can also be an integral part of the thermal management system, and sometimes the primary means of removing heat from the system. Normally, the mounting is a supplement to the natural

or force convection cooling of the board or the primary heat sink. See section 5.3 for details on mounting and related thermal issues. See the T-guide for Performance for related thermal performance data.

## 8.4 Coating, Encapsulations and Potting

Tlam substrates can be stand-alone end products or can be integrated into a system. They can be packaged as an integral part of a power module, or they can be mounted, inserted, or stacked like a standard PCB. As with the standard ceramic substrate or PCB that they replace, they often require a coating, encapsulation or potting as protection against the environment conditions. Those conditions can include moisture, dirt, chemicals and mechanical damage. The protective materials are often controlled by regulatory agencies in many of the high voltage and high power products.

As a general rule, the materials that are used on the equivalent ceramic substrate or PCB are applicable, but because of the broad range of available materials, compatibility should be confirmed with the protective material supplier and Laird Technologies.

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