SOLID-METAL THERMAL COLUMNS IN CONVENTIONAL PCBs

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ABSTRACT

PowerVia™ thermal columns are solid-metal, electrically-isolated thermal vias. When used in a conventional surface-mount printed circuit board (PCB), PowerVias improve power device cooling, and offer design options and enhanced manufacturability in electronic packaging.

PowerVias allow the attachment of a fully-assembled FR4 printed circuit board onto a heat sink with the thermal path between the power device and the heat sink impeded by only 1.3 mils of dielectric film, which is integrated into the PCB. The thermal resistance of the PowerVia is 1-2°C/W, depending on the model.

PowerVias can eliminate the need for through-hole mounting of power devices into a surface-mount PCB. This avoids the subsequent (often clumsy) grappling with the independent cooling and electrical isolation requirements of the through-hole devices.

Key words: *power electronics, thermal vias, power device cooling, thermal management.*

BACKGROUND

A PowerVia is a solderable copper patch bonded to the top surface of an aluminum column with Fraivillig Technologies' TPI film (*patented, patents pending,* Figure 2). TPI bond film is a thin dielectric layer of Kapton® MT polyimide film coated on both sides with thermoplastic polyimide adhesive. A power device, such as a D^2Pak and TO-220, is soldered onto the copper surface of a PowerVia that has been inserted into the PCB (Figure 1).

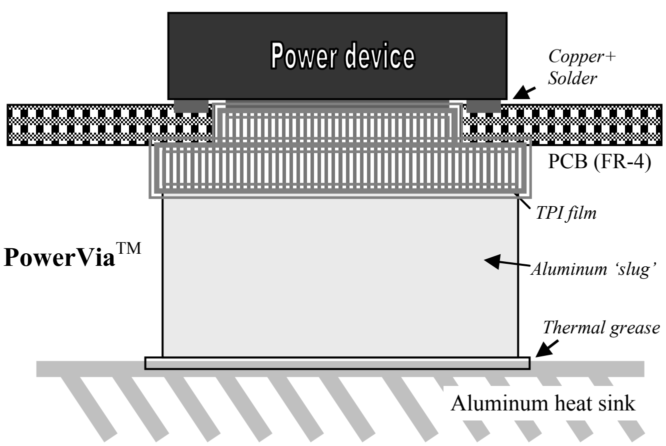

FIGURE 1: PowerVia schematic

FIGURE 2: PowerVia thermal columns

Power electronics systems convert one form of electrical power to another, or convert electrical power to physical motion. These systems are not 100% efficient, naturally, and heat is always a by-product and its dissipation must be considered in design and operation.

Printed circuit boards (PCBs) in power electronics applications often generate heat, largely from the surface-mounted power device components that are soldered to the board. This heat needs to be dissipated, or the resulting temperature rise of the power device will dramatically increase its failure rate. (As 'rules-of-thumb': failure rates for most silicon-based components double with each rise of 10°C of operating temperature, and extended exposure to 150°C+ can be often be fatal.)

A surface-mounted power device, such as a D^2Pak or TO-220, is designed to have heat transfer through their solderable base into the PCB. The PCB is then often mounted onto a much larger heat sink, generally made from aluminum. In conventional designs, heat is passed through the PCB towards the heat sink at *thermal vias*, which are drilled holes in the PCB that have been plated with copper and are sometimes filled with solder. As the PCB and its thermal vias need to be electrically-isolated from --while remaining 'thermally-connected' to-- the heat sink, an insulation pad is placed between the PCB and the heat sink. This provides dielectric strength and conforms to the surfaces to eliminate air entrapment. These pads are made from insulation material that is filled with ceramic to maximize thermal transfer. A significant pressure must be applied to the PCB to ensure thermal transfer to the heat sink (Figure 3).

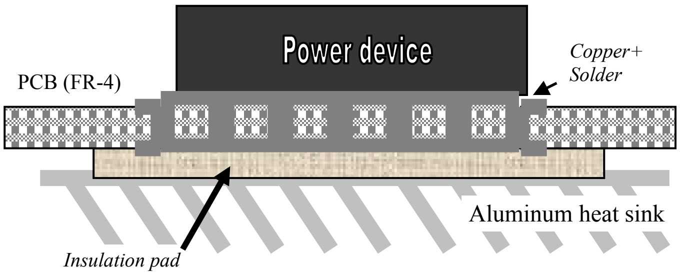

FIGURE 3: Conventional thermal via schematic

As the PCB must be mated intimately against the heat sink for heat transfer, often the entire heat sink must have an insulation layer to prevent electrical shorting across that surface. Obviously, in this configuration, the PCB can only have components mounted on one sides (see above).

Or, the heat sink can be built to have a 'ledge' where the power devices will rest, and ensure separation between the rest of the PCB and heat sink across the surface. (Figure 4) This allows the mounting of devices on both sides of the PCB.

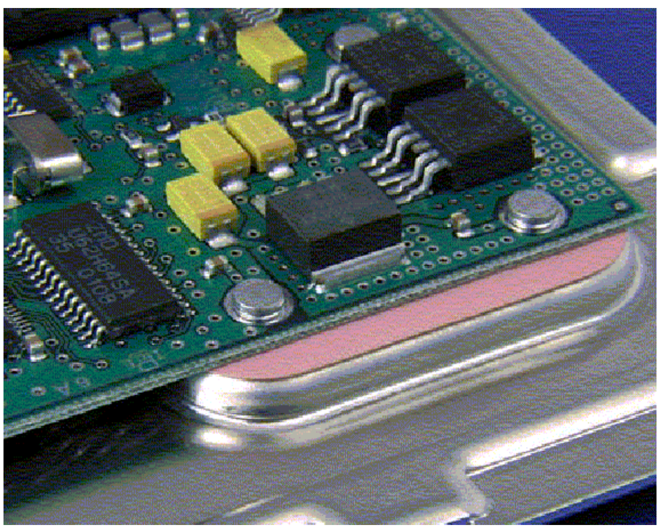

FIGURE 4: PCB + contoured heat sink with conventional insulation pad [1]

PowerVias offer the following advantages versus existing plated-through thermal via technology, including:

- Higher thermal transfer, mainly due to its solid metal structure
- Reduced pressure dependency of thermal transfer
- Component mounting on both sides of the PCB with a flat heat sink surface.

TECHNOLOGY DESCRIPTION

The structure of a PowerVia consists of a solid aluminum column made by cutting an aluminum extrusion to length. TPI bond film (1-mil Kapton MT film with 0.15 mil of thermoplastic polyimide on each side) adheres a copper surface to the 'top' of the aluminum column. (This copper allows the soldering of a power device.) The TPI film is also swept and bonded around the sides of the aluminum column to provide electrical insulation for the structure.

PowerVias are made either by bonding printed circuits of TPI/copper laminates to the heat sink, or by bonding cut-pieces of TPI film and copper foil. In both cases, the placement of the film+foil is done by picking-and-placing the raw materials onto a hot 'slug' of aluminum feedstock (patented). The permanent TPI bond of the copper to the aluminum is achieved by pressing the structure at 300^{o}C and 600+ psi. The automated process provides excellent reproducibility. (Figure 5)

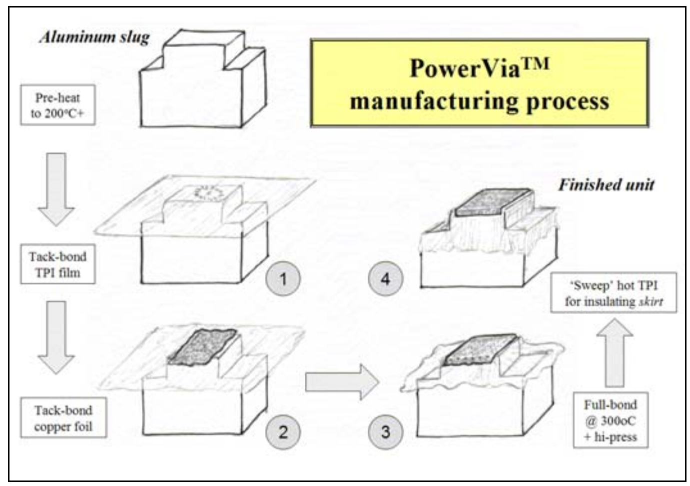

FIGURE 5: PowerVia manufacturing steps

The size of the 'face' of the PowerVia – with the copper surface—corresponds to the size and/or thermal requirements of the device to be soldered.

The 'neck' of the PowerVia corresponds to the thickness of the PCB, typically about 62 mils.

The 'shoulder' of the PowerVia rests on the bottom-side of the PCB.

The overall height of the PowerVia allows separation of the PCB from the heat sink.

The base of the PowerVia is considerably larger than the face, which allows heat-spreading, increasing transfer to the heat sink.

A PowerVia is inserted into the PCB before electronic components are added to the top-side of the board. Insertion can be done manually or with automation. The PowerVia is held in place during circuit processing by press-fitting into the routed hole in the PCB and/or with pressure-sensitive adhesive between the shoulder and the PCB bottom-side. (Figure 6) If the PowerVia is press-fit into the PCB, it is recommended that the copper foil extend past the edge of the face to protect the Kapton insulation during insertion.

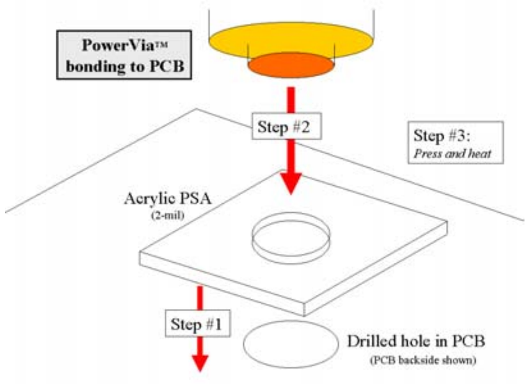

FIGURE 6: PowerVia insertion into PCB

When the surface-mount power device has been soldered to the PCB (along with the other components on the top-side), the PCB can be placed onto the heat sink. A thermal compound, such as thermal grease or phase-change material, is put on the base of the PowerVia before the PCB is mechanically-attached to the heat sink to maximize heat transfer. Electrical isolation is *not* required at this interface. Pressure dependency is not an issue with PowerVias, as it is with conventional thermal vias + insulation pads + mounting hardware. Insulation pads need much more pressure to optimize their thermal transfer than grease and phase-change materials. (Figure 7)

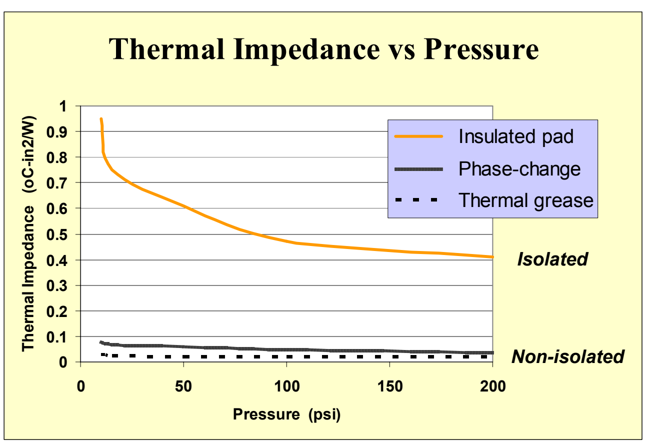

FIGURE 7: Pressure dependency of interface systems [2,3,4]

As a reference point, on a PowerVia, the thermal impedance of the TPI+copper+solder interface (case-to-sink) is only about 0.1 ^{o}C-in^{2}/W. This heat-sealed and soldered interface has no pressure dependency.

The thermal transfer of PowerVias is considerably greater than that of conventional thermal vias with insulation pads. A side-by-side comparison is given below for a D2Pak. Both circular and rectangular PowerVias were tested. (Figure 8)

Thermal resistance comparison [5]

Control board with soldered-on D2Pak, bolted to heat sink

Thermal method	Active area	Rj-s
PowerVia (circular footprint)	0.08 => 0.20 sqin (Face-to-base)	4.4 ^{o}C/W
PowerVia (rectangular footprint)	0.20 => 0.30 sqin (Face-to-base)	2.7 ^{o}C/W
Thermal via + pad	0.30 sqin	11.4 ^{o}C/W

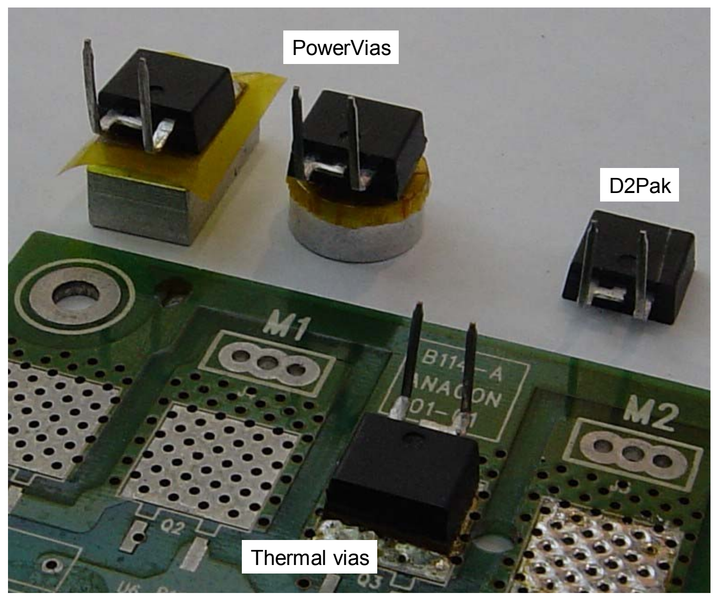

FIGURE 8: PowerVia types and thermal vias

NOTE:

- These values are the total thermal resistance of the interface system, junction-to-sink. Therefore, the internal resistance of the device is included in the reading.
- Each sample was mounted on an aluminum heat sink during thermal testing. At the interface, the PowerVias used thermal grease; the PCB used a Bergquist 900S insulation pad. Applied pressure was approx. 100 psi.
- Measurements were done with an Anatech pulse tester (Figure 9). Thermal resistance was recorded when the system reached steady-state.
- The thermal resistance of the thermal via + pad set-up includes an estimated 7.2 ^{o}C/W from the D2Pak die junction to the interface pad, which includes the solder-filled, plated-thru holes. The insulation pad and its interfaces added an additional 4 ^{o}C/W of resistance. Advanced thermal via design may reduce these resistances incrementally.

FIGURE 9: Anatech thermal analyzer

In addition to thermal benefits, PowerVias offer packaging design and processing advantages over conventional methods:

- The use of PowerVias can simplify the OEM supply chain, as well as provide enhanced design options. The finished assembled PCB (including PowerVias) only needs to be attached to the heat sink, with minimal mounting considerations. Electrical concerns are eliminated.
- High thermal transfer is possible with double-sided PCBs. This feature can save space, weight and raw materials.
- Heat-spreading within the PCB should not be required for moderating the temperature rise of power components. Often, thick copper PCBs are utilized for heat-spreading (=> *circuit board as heat sink*)…. as PowerVia thermal columns take the heat straight to the heat sink, less-expensive PCBs – with thinner copper – can be used.
- On many existing designs of power electronic PCBs, the heat-generating components have often been removed from the PCB for cooling considerations. Power devices, such as TO-220s, are then used in a through-hole format, and need to be clamp against a metal housing or a stand-alone heat sink –with added insulation pads—for thermal cooling. PowerVia technology allows the consolidation of all components, *along with their assembly, cooling and electrical isolation requirements*, onto the PCB surface.
- PowerVias can facilitate fully-populated PCB subassembly testing. Even without a heat sink attached, the PowerVias have enough thermal mass to buffer a test ramp-up.

The advantages of PowerVias are summarized below:

PowerVia Advantages	
Features	**Benefits**
Thermal resistance of only 1^o to 2^o C/W -- depending on PowerVia model-- with *no pressure dependency*	• Excellent cooling of power devices • Consistent cooling across devices • Cost savings in PCB-to-heat sink attachment
Physically-robust, highly thermally-conductive dielectric insulation	• All-polyimide durability • 4000Vdc dielectric strength • Only 0.1^oC-in^2/W of thermal impedance[6]
Conventional FR4 construction	• Cost savings • Can eliminate need for thick-copper PCBs for heat-spreading • Can eliminate separate thru-hole subassemblies for power devices (with cooling+isolation requirements)
Double-sided surface-mounting of components on PCB possible	• Design flexibility • Denser packaging
Supply-chain simplicity	• Separates PCB and heat sink considerations in manufacturing • OEM can buy the fully-assembled PCB and then place it onto the heat sink, with minimal mounting considerations • PCB manufacturer can test fully-assembled PCB at high-power, without a heat sink (utilizing the thermal mass of the PowerVias)

TECHNICAL CHALLENGES

Adoption of new technology is a typically a slow process, especially in the thermal management of power electronics. Conventional thermal vias + insulation pads have been used – and have performed adequately—in thermal management applications for decades. The following technical challenges must be addressed for PowerVia technology to become the new standard:

- *PCB thickness consistency* – the neck length of the PowerVia needs to match the thickness of the PCB to ensure proper soldering of the power device to the PowerVia.

- *PCB machining* – the holes routed in the PCB need to match the dimension of the PowerVia to ensure a snug fit before device soldering. For a rectangular PowerVia, this would only have to be precise on two facing sides. Pressure-sensitive adhesive can be used on the backside of the PCB (on the PowerVia shoulder) to ensure bonding.

- *Volume drives cost* – to ensure widespread use, the cost of each PowerVia needs to be small in comparison to the value that it delivers. PowerVias can be made economically with an automated process in high-volume. Standardized dimensions need to be established. Standardized power device sizes (such as D2Paks and TO-220s) and PCB thicknesses (i.e., 62 mils) are a very good start.

TECHNOLOGY FORMATS AND COST

PowerVias can be manufactured either in rectangular or cylindrical formats. Rectangular aluminum slugs are made by cutting-to-length aluminum extrusions. Cylindrical aluminum slugs are made with round aluminum extrusions on a screw machine. In both format, the TPI film and copper surface are precisely placed on the face of the aluminum slug with a heated pick-and-place process, and then heat-sealed permanently at 300^{o}C and 600+ psi.

The cost of a PowerVia unit, depending on volume and model, would range from less than $0.15 to $0.60. It is understood that improved performance with a new technology is welcomed, but generally only when the system costs are comparable (or less) than the conventional approach. Present thermal via designs have cost considerations with specialized insulation pads, attachment hardware+labor, and often special contoured heat sinks.

Custom PowerVias can also be manufactured to OEM specifications. Features could include special footprints, heights and even printed circuit patterns. Customization and low-volume production increases the unit cost of the PowerVia, naturally.

TECHNOLOGY APPLICATIONS

PowerVias can be used effectively in various ways. Each of the following methods connects the system components thermally, but isolates them electrically:

- *Individual surface-mount power devices to a heat sink*. As described above, the power devices would be soldered to the PCB (with PowerVias), and then the PCB would be attached to the heat sink. The heat sink could be tailored to the specific cooling demands of the application.

- *A PCB to a heat sink at its thermal vias or thermal pipes*. With the copper-heavy PCBs now being used, the job of heat spreading and radiating is often carried by the internal conductors (example: DC/DC board-mounted power supply). If this heat dissipation is not sufficient to ensure reliable operation, PowerVias soldered directly the surface of the PCB at the thermal vias or thermal pipes add to the cooling capability, or provide a path to an attached heat sink. This heat sink attachment can be optional and application-dependent. (NOTE: In this embodiment, a hole does not need to be routed in the PCB to accept the insertion of the PowerVia.)

- *A daughter PCB to a mother PCB* (example: board-mounted power supply or multi-chip module –MCM-- to the larger board). In this application, the conductors of the larger board could be used to spread the heat generated by the smaller power board.

OEM applications that could benefit from PowerVia technology include:
- Power supplies
- Automotive control modules
- Motion control modules
- Motor control modules.

In thermally-demanding applications, the fully-assembled electronic module using the PowerVias would be mated with the appropriate heat sink.

In less-demanding applications, the thermal mass of the solid-metal PowerVia may provide enough cooling capability for the soldered-on power device to be used without the addition of a heat sink.

ACKNOWLEDGEMENT

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