# SURFACE-MOUNTING OF POWER DEVICES TO ALUMINUM HEAT SINKS

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ABSTRACT:
All-polyimide heat-sealing with our proprietary TPI bond film of copper to aluminum heat sinks convert tough thermal management applications into surface-mount applications. TPI bond film is the basis of products for a range of thermal management electronic packaging formats:

⇒ PowerSite™ solderable pads enable the solder attachment of discrete power devices, such as a TO-220s or TO-247s, directly to an aluminum heat sink.

⇒ PowerFlex™ technology bonds complex power circuits directly to aluminum heat sinks.

⇒ PowerVia™ thermal columns provide an all-metal thermal connection of PCB SMT-mounted power devices, such as a D2-Paks, to an aluminum heat sink.

These technologies offer improved performance, as well as lower cost over conventional constructions.

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

BACKGROUND:
Thermal management products based on our TPI bond film technology – PowerSites, PowerFlex and PowerVias—offer excellent thermal and electrical performance, as well as enhanced design flexibility, at competitive costs.

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. Its dissipation must be considered in design and operation.

A surface-mounted power device, such as a $D^2$Pak or TO-220, is designed to have heat transfer through their solderable base. The format of the thermal management of power devices depends on the system configuration:

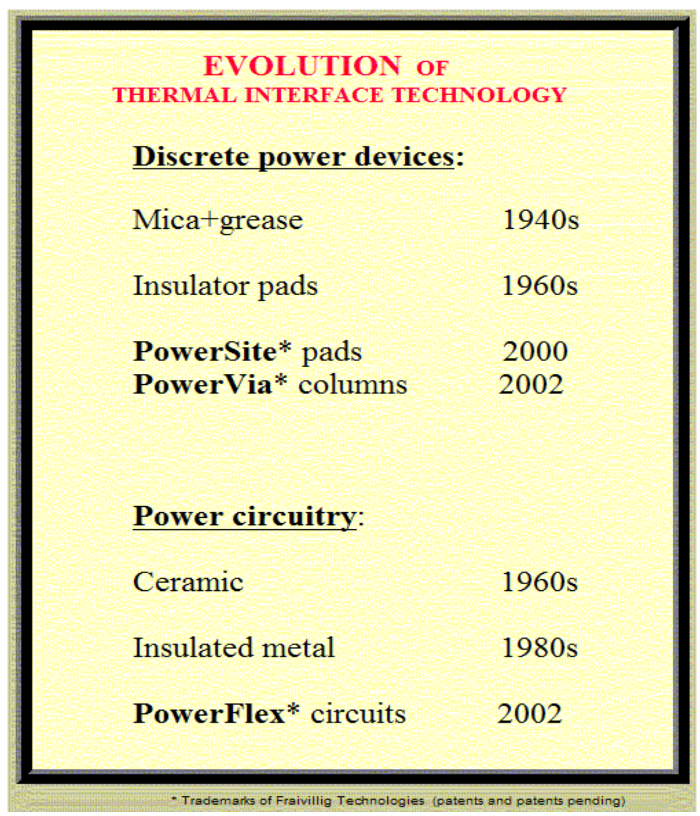
- In many systems, such as AC/DC rack-mounted power supplies, the power devices are mounted to stand-alone heat sinks plugged into the PCB.

- In power systems such as DC/DC board-mounted power supplies, the power devices are soldered directly to a specialized printed circuit board pre-attached to an aluminum baseplate, which in turn is often mounted to a larger finned heat sink.

- In systems with lower power density, such as automotive or motor controls, the power devices are mounted to a conventional PCB with thermal vias, and this entire construction is attached to a larger heat sink.

Our technology enables high-performance products specifically designed for each of these applications.

Adoption of new technology is a typically a slow process, especially in the thermal management of power electronics – there have been few changes and innovations. We believe that our all-polyimide heat-sealing technology is the next-generation in thermal management of power electronics:



## TECHNOLOGY DESCRIPTION

Polyimide electrical insulation has been the industry premium-performance 'standard' for decades. Kapton® film was introduced in 1965, and has been adopted widely for demanding applications. As with many material innovations, the adhesive system lagged the dielectric film in performance. The development of polyimide adhesives has eliminated this weak-link. The physical, electrical and thermal transfer properties of the TPI insulation are stable over wide ranges of exposure.

Thermoplastic polyimide adhesives have excellent bond strength even at very thin thicknesses – our TPI bond film uses about 4 microns (0.16 mil) of adhesive on each side. This 'thinness' maximizes thermal transfer. The strength and durability of the polyimide bond eliminates the need for attachment hardware of the devices or PCB.

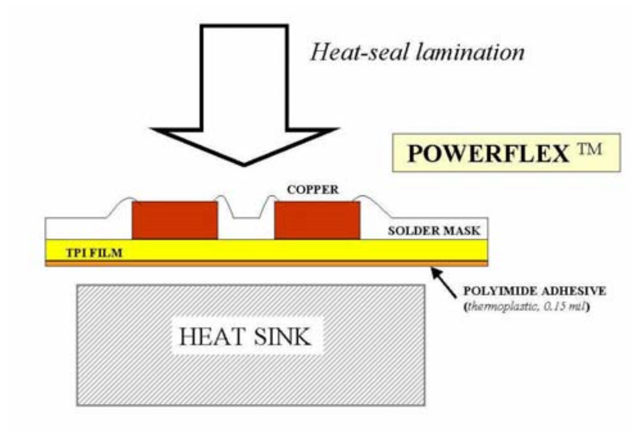
Properties of our TPI bond film appear below:

**TPI bond film properties** (130TPI-2)

| Property | Value | Method |
|---|---|---|
| **Thickness** | 1.3 mil (0.033mm) | ASTM D374 |
| **Voltage breakdown** | >4000 Vac | ASTM D149 |
| **Thermal impedance** [1] | 0.1 $^{o}$C-in$^2$/W | ASTM D5470-95 (Laminate of TPI, copper, solder) |
| **Thermal resistance** [1] | TO-220 = 2.7 $^{o}$C/W<br>TO-247 = 0.7 $^{o}$C/W | Rj-s (using Anatech pulse test) |
| **Tensile strength** (TPI bond) | >600 psi at 25 $^{o}$C<br>>200 psi at 150 $^{o}$C | ASTM D412 |
| **Shear strength** (TPI bond) | >4000 psi at 25 $^{o}$C<br>>2000 psi at 150 $^{o}$C | ASTM D412 |
| **Operating range** | -65 to 200 $^{o}$C | OEM testing |
| **Flammability** | V-0 | UL-recognized |

Thermoplastic adhesives can be heat-sealed under high temperature and pressure for a durable bond. The residence time is very short (especially in comparison to conventional thermoset adhesives, which require long cure time). The residence time in the press station (see opposite) is generally 10-30 seconds depending on the size of the part. Thermoplastic adhesive systems enable economical single-unit production. The temperature resistance in the application requires a high glass-transition temperature of the adhesive, which drives up the heat-seal temperature. The polyimide adhesive on our TPI bond film is be heat-sealed at 250-300$^{o}$C.

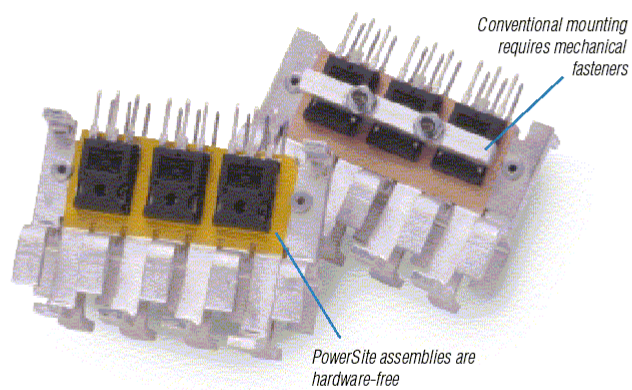
A diagram of a PowerFlex printed circuit (based on TPI bond film) appears below:




In all applications of our TPI bond film, air is permanently eliminated between the copper surface (where the power device will be soldered) and the heat sink during the high-temperature / high-pressure heat-sealing process.

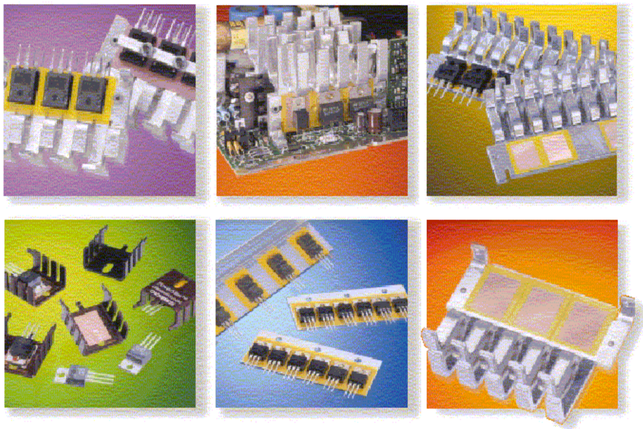
An overview of each format of our technology follows:

PowerSite™ solderable pads enable the solder attachment of discrete power devices, such as a TO-220s or TO-247s, directly to an aluminum heat sink. PowerSites replace pressure-dependent insulation pad + hardware constructions.

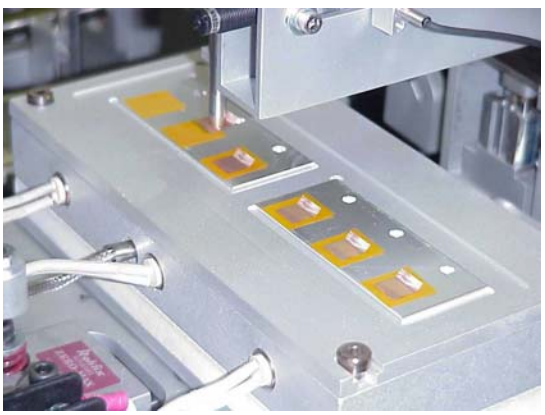



PowerSite technology utilizes TPI film --thermoplastic polyimide adhesive coated on Kapton® MT film-- to bond copper patches to aluminum. PowerSites offer high thermal transfer, as well as physical and electrical durability. The improvement in thermal transfer with PowerSites is most beneficial in power electronics application with high thermal demands. Reduction in device operating temperature is as high as 2$^{o}$C/W of dissipated heat for a TO-220 and 1$^{o}$C/W for a TO-247. With the elimination of attachment hardware, PowerSites have no pressure dependency, reduce SKUs, and allow the placement of other PCB components closer to the heat sink subassembly (UL clearance to 'ground').

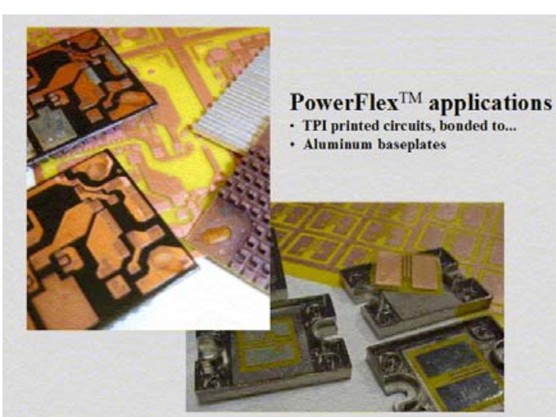
PowerSite can be bonded to a wide range of heat sinks: flat, formed, finned.



PowerSite precision-placement and bonding is done on automated equipment.



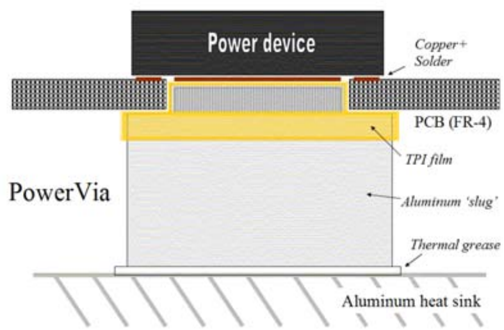
PowerFlex$^{TM}$ printed circuits with TPI bond film use on conventional circuit materials and processing, yet provide thermal performance comparable to Insulated Metal Substrate (IMS, trademark of The Bergquist Company) and even Direct-Bond Copper ceramic (DBC).



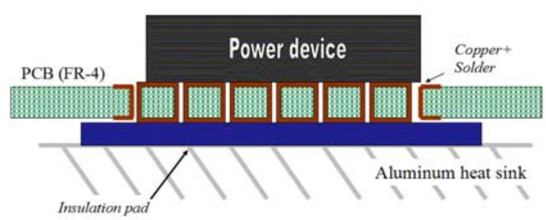

In addition to lower cost than other premium thermal circuitry technologies, PowerFlex offers enhanced design advantages:

- ⇨ Physical flexibility (plastic film dielectric) – interconnection can extend beyond the plane of the heat sink,
- ⇨ Can be bonded directly to practically any shape or size or material type heat sink (assuming that the heat sink can withstand the lamination process),
- ⇨ Allow circuitry to extend past the edge of the heat sink (perhaps connecting to other subassemblies),
- ⇨ Use conventional circuit processing equipment and materials,
- ⇨ Physically robust (plastic film dielectric and metal heat sink),
- ⇨ Can be made into literally any dimension (width or length) and,
- ⇨ The PowerFlex can be bonded directly to an aluminum heat sink. This eliminates the cost and complexity of the hardware attachment and pressure dependency, and also reduces thermal resistance.

PowerVia$^{TM}$ thermal columns provide an all-metal thermal connection of PCB SMT-mounted power devices, such as a D2-Paks, to an aluminum heat sink.



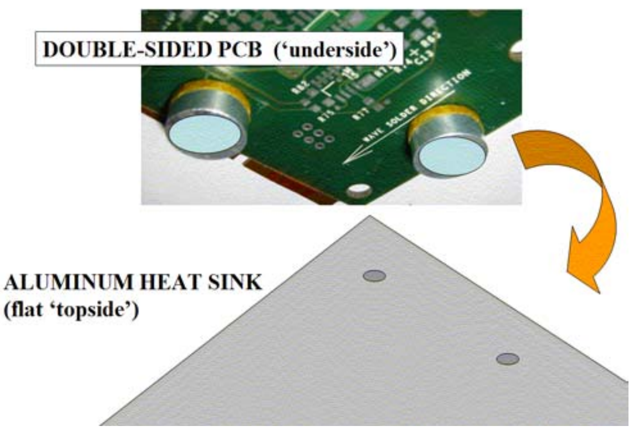

PowerVias replace plated-thru PCB holes + insulator pads. In conventional thermal via constructions, the PCB needs to be bolted up –under high-pressure-- against the heat sink:




**Conventional thermal via (drilled-and-plate)**

PowerVias are manufactured by laminating a copper patch with the TPI bond film to the top of an aluminum column. The column can be rectangular or cylindrical (see following). A 'shoulder' is required for supporting the PCB.

PowerVias are inserted in the 'underside' of a FR4 printed circuit board (the power components would be soldered to the 'topside'). The fully-assembled PCB is not attached to the heat sink, with thermal grease or phase-change material under the PowerVia columns.

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PowerVias offer the following advantages over conventional thermal-via constructions:

- ⇨ Thermal resistance of only $1^o$ to $2^o$ C/W --depending on PowerVia model-- with *no pressure dependency.* This is much lower than conventional thermal vias + insulator pads, which have a very high pressure dependency as well.
- ⇨ Physically-robust Kapton dielectric insulation, with no cut-through concerns at final assembly (PCB onto heat sink).
- ⇨ Allows component assembly of both sides of the PCB, enabling increased packaging density.
- ⇨ Supply-chain simplification – the fully-assembled PCB and heat sink only need to be mated at the end of the process, and there are no worries about pressure dependency and potential shorting. In addition, the PowerVias have enough thermal mass to allow 'live testing' of the PCB assembly before mounting to the heat sink.

**THERMAL PERFORMANCE**

PowerSite solderable pads have a thermal impedance that is a fraction of conventional insulator pads, while being comparable to IMS and slightly higher than ceramic wafer. (NOTE: Low thermal impedance translates to high thermal transfer. A PowerSite pad includes TPI film + copper + solder joint.)

**THERMAL PERFORMANCE**

| Technology | Thermal Impedance ($^oC$/W/sqin) [1] | Comment |
|---|---|---|
| PowerSite | 0.1 | Same construction in single-layer PowerFlex |
| Insulation pads | 0.2 - 0.5 | Attachment hardware required |
| IMS | 0.1 | Alumina-based, Attachment hardware |
| DBC | 0.05 | Alumina-based, Attachment hardware |

<u>POWERSITE COMPARISON TESTING</u> -- the following test was run with a single power device with a high heat load mounted to an aluminum heat sink with an R-value of $5^oC$/W. Junction temperature was determined by an Anatech pulse test, a very accurate method. Both TO-220 and TO-247 packages were tested with a range of insulation materials, and with/without air flow.

**POWERSITE THERMAL PERFORMANCE:**
**Junction Temperature ($^oC$) at High Power Dissipation** [1]

| Interface Material | TO-220 (8 watt) | | TO-247 (15 watt) | |
|---|---|---|---|---|
| *(Air Flow, lfm =>)* | 0 | 100 | 0 | 100 |
| Mica / grease | 94.4 $^oC$ | 74.5 | 112.8 | 81.4 |
| BN-filled silicone sheet | 103.5 | 81.4 | 114.4 | 84.0 |
| Kapton MT / phase-change | 100.0 | 79.3 | 112.4 | 81.8 |
| Kapton MT / BN-silicone | 104.7 | 83.7 | 116.5 | 85.1 |
| Alumina-filled silicone sheet | 107.8 | 87.0 | 120.8 | 90.4 |
| PowerSite | 90.8 | 69.5 | 108.4 | 77.5 |

The PowerSite demonstrated better thermal performance in all cases. Its thermal advantage over the most common interface material, alumina-filled silicone sheet, is about $2^oC$/W for the TO-220 package and about $1^oC$/W for the larger TO-247 package.

POWERFLEX COMPARISON TESTING -- the following test was run with single power devices mounted to small aluminum plates (1.5" x 1.5"), which in turn was bonded to a large pin-fin heat sink with conductive adhesive. The amount of power dissipation in the PowerFlex single-sided construction was comparable to that given by the equivalent IMS format.

**POWERFLEX THERMAL PERFORMANCE:**
**Maximum Power Dissipation at Tj = 150 °C** [1]

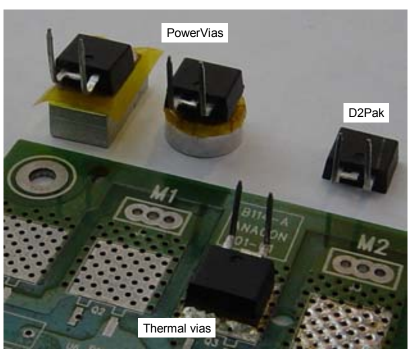
| **Interface Material** | **TO-220 (watt)** | | **TO-247 (watt)** | |
|---|---|---|---|---|
| *(Air Flow, lfm =>)* | 0 | 100 | 0 | 100 |
| IMS | 16.6W | 23.1 | 25.4 | 40.1 |
| PowerFlex | 16.8 | 23.7 | 24.2 | 38.0 |

NOTE: If the PowerFlex could have been bonded directly to the heat sink, the maximum power dissipation would be even higher (the baseplate-to-heat sink interface would be eliminated).

POWERVIA COMPARISON TESTING -- the following test was run on a D2Pak soldered to either a PowerVia or a thermal via on a PCB, and then attached to a large heat sink.

The thermal via requires an insulation pad, the PowerVias do not.

Both circular and rectangular PowerVias were tested (see below).

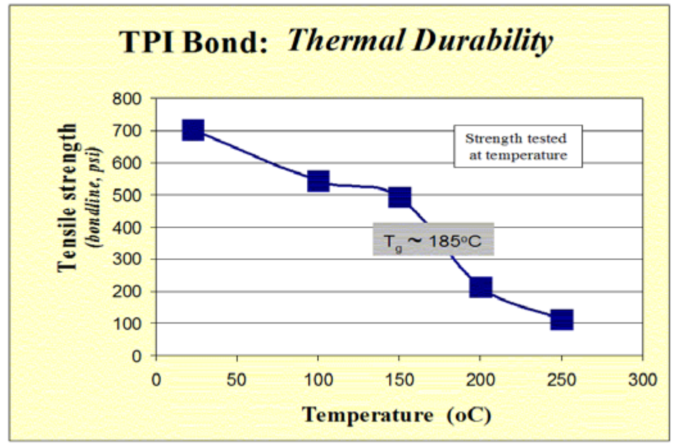



**POWERVIA THERMAL PERFORMANCE:**
*Control board with soldered-on D2Pak, bolted to heat sink*

| **Thermal method** | **Active area** | **Rj-s** [1] |
|---|---|---|
| PowerVia (circular footprint) | 0.08 => 0.20 sqin (Face-to-base) | 4.4 °C/W |
| PowerVia (rectangular footprint) | 0.20 => 0.30 sqin (Face-to-base) | 2.7 °C/W |
| Thermal via + pad | 0.30 sqin | 11.4 °C/W |

The thermal transfer of PowerVias is considerably greater than that of conventional thermal vias with insulation pads.

THERMAL DURABILITY -- the all-polyimide TPI bond film withstands a wide-temperature range, thermal shock, heat+humidity, shock-and-vibe, and solvents. The bond strength of the polyimide adhesive on the TPI film is resilient up to, and beyond, its glass-transition temperature. [1]




Our TPI-based products can operate continuously at 200°C and withstand exposure at 300°C. This feature may be especially critical with the adoption of no-lead solders with high reflow temperatures.

**APPLICATIONS**

Packing densities are getting tighter. Electronics are getting hotter. Reliability and cost pressures are greater than ever. We believe that our TPI-based technologies –PowerSite, PowerFlex and PowerVias-- are the next-generation of packaging solutions for demanding electronics applications in power supplies, automotive control, motor and motion control, and CPU chip-sets.

**REFERENCES**


1. Tests run by Parker Chomerics, 1999-2003. Thermal testing was done with an Anatech pulse tester. Tensile strength testing was done with a custom heated fixture and strain gauge.
2. *PowerSite, PowerFlex* and *PowerVia* are trademarks belonging to Fraivillig Technologies
3. *Insulated Metal Substrate* and *IMS* are trademarks belonging to The Bergquist Company.