The Development of an Advanced Hermetic Power Package
for a Solid State Power Controller

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ABSTRACT
A new, large size hermetic power package has been developed and tested. The package exhibits high integration level, excellent reliability and superior performance characteristics. The manufacturing technique is based upon an integral substrate package (ISP) approach with highly conductive plated copper traces and hermetic feedthroughs, complemented with air fireable thick film technology.

KEY WORDS: Power package, plated copper, hermetic vias, integral substrate package, thick film technology

INTRODUCTION
The increased availability of advanced high power and smart power semiconductors, combined with the effort to miniaturize all electronic components, has underscored the need for new, improved hermetic power packages exhibiting features not commonly available in conventional enclosures. Electrical and mechanical designers continue to encounter difficulties in accommodating their particular needs using existing "off the shelf" items such as metal/ceramic packages.

Metal packages offer the oldest and most well known solution to high power electronic applications, but require fragile glass seal joints around the leads, exhibit high inductance connections at elevated frequencies, and require a thermally conductive isolation between the power devices and the metal base. Traditional ceramic packages with standard metalization techniques are not well suited for high power circuitry and are expensive due to their nature.

The power dissipation capability of any device is limited by the construction materials of the device, the medium to which it is mounted, and the method of attachment. Therefore, a search has ensued for a thermally advanced, high performance interconnection technology capable of accommodating the features described below for power circuit packaging applications.

Thus, some of the major features currently being sought are:
- a high performance package which exhibits thermally and electrically efficient conductor paths with very low inductance connections.
- a large, integral substrate package (in excess of 3" x 2") to serve as both an interconnection pattern for a high density power circuitry and a MIL qualified, high reliability hermetic enclosure.
- a packaging technology which allows for flexibility and short design-to-production cycle.

The below described hermetic power hybrid packages for solid state power controllers were designed and fabricated via the utilization of a plated copper POWER BOARD technology for circuit and package interconnections.

This work is a joint development effort by Teledyne Electronic Technologies [TET] (Los Angeles, CA), as the "customer" and conceptual package designer, and Remtec, Inc. (Norwood, MA), as the initiator of the package design. The customer's conceptual package consists of a metalized ceramic substrate with hermetic via connections and a thermal-mechanically matched solid ring frame (as the package walls) attached with a high temperature solder.
Using its plated copper-on-ceramic technology, Remtec fabricated a large power package with plated copper interconnects, hermetic feedthroughs, internal circuitry, external I/O connections, and ground planes. This new design eliminates more than 60 grams of weight associated with traditional molybdenum based metal packages employing metal-to-glass seals with butt welded copper leads.

The most challenging part of this structure was to produce the metalized ceramic substrate base (see Figure 1). The fabricated substrate had to meet the following thermal, mechanical and electrical criteria:

- assure hermeticity through solid via holes and between ring frame metal pad and ceramic after repeated temperature excursions.

- ensure a low thermal impedance from device to base plate.

- provide high conductivity electrical interconnections within the circuitry and through the via holes.

The plated copper-on-ceramic (POWER BOARD) technology was developed by Remtec, and had been previously employed in several high power designs, including Solid State Power Controllers, DC/DC Converters, IGBT Modules, and RF Power amplifiers and filter modules [1,2].

This technology is an additive copper electroplating process which can be applied to alumina, beryllia, or aluminum nitride ceramic substrates with trace thicknesses from 0.001" to 0.010" of pure, plated copper metallization exhibiting a sheet resistivity as low as 100 micro-ohms per square. In addition, the technology is compatible with air fired thick film processing, permitting the use of gold or silver based materials, resistors, and isolating dielectrics, as well as enabling overplating with nickel, gold, tin or tin-lead. A successive number of consecutive metal-isolation-metal layers can be applied, thus allowing a multilayer pattern capable of carrying heavy currents to be integrated with signal voltages in a high density circuit application. In addition, solid, low resistance hermetic via connections from the front to the back of the ceramic substrate can easily be achieved.

### PACKAGE CONSTRUCTION & MATERIALS

Typical properties of standard power package construction materials[3, 4, 5, 6] are presented in Table I:

**Ceramic Base Material:** Three ceramic materials were considered in selection of the base for the package: aluminum oxide (Al₂O₃), aluminum nitride (AlN), and beryllium oxide (BeO). Aluminum oxide offers two major advantages: low cost and broad availability. However, the relatively low thermal conductivity of alumina sometimes restricts its usage for high power applications.

Aluminum nitride is a likely candidate for the base material [7], with a combination of high thermal conductivity and good CTE match with some ring frame materials (Kovar, Alloy 42), but the development work required to utilize it could not be completed within the required time frame.

Beryllia has the highest thermal conductivity and is still the material of choice in electronic applications where an electrically insulated substrate with very high thermal conductivity is needed. Therefore, BeO was selected as a primary base material for the package construction, although a parallel effort was made to fabricate the packages on alternative ceramic materials.

**Base Metalization:** Initially the circuit pattern is screen printed onto the substrate using an air fireable metalization on both sides of the beryllia substrate. This base layer provides the foundation for the hermetic holes and the excellent adhesion of the plated metalization. The circuitry is then complemented with an air fireable thick film gold, required for gold wire bond connections to the control circuitry.

Subsequently, the board is electroplated using Remtec's POWER BOARD process with copper, nickel and gold; the gold plating is limited to only the ring frame metal pad. Typical metalization thicknesses are shown in Table II.

**Solid Wall Ring Frame:** Kovar (ASTM Alloy 15) has been a common sealing ring material for numerous ceramic hybrid package designs[8, 9]. It is also often used as a "picture frame" to ensure hermetic seal to an integral substrate package (ISF) base and/or lid (cover). Table I
shows the physical properties of some ring frame materials: Kovar, Alloy 42 and Cold Rolled Steel (CRS). Kovar and Alloy 42 can be used with all ceramic substrates while CRS may be considered only for beryllia and alumina.

The ring frame for the desired package was fabricated from Kovar with a size of 2.345" x 2.825" x 0.215" (x 0.040" thick), and overplated with nickel and gold.

**Soldering Materials:** The major factors considered in selecting the final material and soldering process were reliability, cost and soldering assembly hierarchy. Pb/Sn/Ag 88-10-2 with a melting range of 268-299°C, Au/Sn 80-20 with a melting point of 280°C and Au/Ge 88-12 with a melting point of 356°C were all selected for this process.

Pb/Sn/Ag belongs to the family of soft solders, while Au/Sn and Au/Ge represent hard solders [10, 11]. Hard solder assemblies transfer considerable stress due to thermal-mechanical mismatch and may even result in the fracture of package components. However, hard solder alloys do not degrade by fatigue as a result of thermal cycling. In comparison, soft solder assemblies absorb the stresses due to thermal-mechanical mismatch but are subject to thermal cycling fatigue. This is attributed to their low tensile strength properties (see Table III).

As the gold-tin and gold-germanium soldering was performed in a nitrogen atmosphere, the Kovar ring frame and mating surface of the ISP substrate were gold plated.

The Pb/Sn/Ag material was procured in a paste form which contained an RMA flux. Therefore, no gold finish was required on the ISP ring frame pad.

**Process Flow:** Initially the circuit pattern is screen printed on the substrate to apply the air fireable metalization required for the I/O pads; the board is then electroplated with copper, nickel and gold. The Kovar ring frame is then soldered to the substrate base using the Au-Sn solder in a nitrogen environment, and then tested for hermeticity after 10 cycles from -65°C to 150°C per MIL-STD-883 Method 1010. The overall package construction can be seen in Figure 2.

### MOUNTING TECHNIQUES

The package construction described above represents a complete, functional hermetic housing with integrated metalized circuitry, soldered metal sidewall and I/O interconnects via hermetic through-hole connections.

However, as some portion of the bottom of the substrate surface is used to run circuit traces, this package is in essence a non-isolated enclosure. Various mounting techniques may be employed to convert the package into an isolated entity. The choice of which method to use is dependent upon the particular mechanical mounting method, thermal requirements, and voltage isolation requirements.

Two approaches were considered for this application:

1. Using a thermally filled, electrically isolating organic adhesive to attach the completed package to an aluminum heat sink/baseplate.
2. Using a secondary alumina ceramic insulator to which the package can be soldered without impacting electrical performance. The secondary ceramic spacer can be mounted directly to a metal base using screws or other mechanical means. However, use of such an intermediate board results in a more complex package assembly, thus raising the overall package cost.

Thermal, mechanical and electrical requirements of this project were such that a thermally filled adhesive was chosen as the preferred mounting technique (see Figure 3).

### TESTING

A comprehensive reliability study was implemented on the package construction described above for:

1. **Thermal Shock:** The packages were subjected to more than 400 cycles per MIL-STD-883, Method 1010 from -65°C to 150°C before a failure was encountered. Failure analysis revealed that marginal metal coverage of the through-hole via was the cause of the fault and the metal pattern was changed accordingly. Further testing continues at TET.

2. **Metalization Adhesion:** As part of an ongoing quality assurance program, Remtec performs adhesion testing per MIL-M-28787 Appendix B Section 30.2.1.2. Typical adhesion results exceed 2000 psi, and do not
deteriorate after aging or thermocycling.

(3) **Solderability, High Temp. Bake, Metal Package Isolation, Moisture Resistance, Salt Atmosphere:** In addition, standard tests per MIL-STD-883 for solderability, high temperature bake of the gold plating, metal package isolation, moisture resistance, and salt atmosphere were performed successfully on the final package configuration.

(4) **Bondability:** Long term aging studies of gold wire on the bond pad areas revealed no significant degradation after 1000 hours at 150°C. Aluminum wires were bonded to soldered tabs in the current design, so no heavy aluminum wire bond evaluation was performed.

**ELECTRICAL & THERMAL PERFORMANCE:**

**Electrical:** The device for which the package in this paper was designed is from a family of Solid State Power Controllers (SSPCs) produced by TET. This particular design controls 15 Amps to a load from a 270 V input and, through remote control features, can replace both electromechanical circuit breakers as well as load switching relays while providing fault current limiting. The traces of this package must exhibit 1000 V RMS isolation and be able to withstand several hundred amperes short circuit current.

As such, the primary electrical parameter of interest in this package is the sheet resistance of its internal conductors and the resulting net resistance in series with the external load. The values for the developed package are compared in Table IV with those of more traditional metal packaged SSPCs. The latter type requires large diameter aluminum bond wires to connect one or more glass to metal feedthroughs.

In either technology, the "resistance to the outside" can be tailored to fit the application. With metal packages, unless one is willing to solder copper jumpers to the pins, the limiting factor is the resistance of the 0.02" to 0.025" diameter Aluminum wire, at approximately 1.1 and 0.8 milliohms respectively. By combining several pins in parallel, this resistance can be lowered to approximately 0.25 milliohms at the cost of increasing the package size (i.e., pins are usually on 0.2" centers). The most reliable packaging approach uses a Kovar glass to metal seal with a pure copper lead butt welded to the outside. The use of Kovar, however, adds approximately 0.7 milliohms per 0.08" diameter lead.

With the **POWER BOARD** approach, several options are possible to lower the series resistance. The plating thickness of copper can be increased to approximately 0.005", lowering the sheet resistance to around 0.1 milliohms per square. One square need not occupy more than 0.3" to 0.4" on a side to reach the outside of the package. As the package I/O connections employ through-hole vias, the via resistance must also be considered. For the design described herein, 16 parallel vias (0.006" diameter) provided approximately 0.5 milliohms of series resistance. This could easily have been halved by increasing the number of parallel vias. Also, because this technology is compatible with standard multilayer thick film techniques, an alternative design with no vias is conceivable where copper traces are brought directly to the outside under the seal ring. Such an approach has many potential advantages but has not been tried to date.

**Thermal:** The thermal requirements for the package described herein is only 1°C/W but the thermal resistance in any power unit is largely controlled by the size of the device dissipating the power. As a number of power chips of various sizes were required to meet the needs of the family of SSPCs being built by TET, the package itself had to have a very low thermal impedance. However, to provide additional voltage isolation, as well as a level surface to the backside of the units, a thermally conductive epoxy film of 0.002" to 0.003" thick was applied to the back side metalization. Even with the epoxy overcoat, the thermal resistance of a power chip 0.5" x 0.5" within the described package is less than 0.1°C/W. The thermal impedance of this system can obviously be improved by designing the unit for solder attach at the next assembly level.

**CONCLUSIONS**

In conclusion, a new packaging interconnection technique for high power, hermetic packages of large size has been proven to exhibit high integration, excellent reliability and superior thermal and electrical performance. The manufacturing technique is based upon an integral substrate with highly conductive plated copper and hermetic
feedthroughs, complemented with air fireable thick film technology.

A comprehensive testing program was carried out to demonstrate the high performance thermal, mechanical and electrical parameters of this newly developed hermetic power package. In addition, high reliability was demonstrated when tested in accordance with MIL-STD 883. Various mounting techniques were explored and the optimal solution for the given application chosen.

The test results and performance characteristics of the study indicate that the newly developed packaging technique will serve as a cost effective tool for high density power applications.

ACKNOWLEDGMENT

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REFERENCES

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| TABLE I: PHYSICAL PROPERTIES OF SUBSTRATE AND RING FRAME MATERIALS |
|----------------|----------------|----------------|----------------|----------------|
|                | AlN            | BeO            | Al₂O₃          | Kovar          | Alloy 42       | CBS            |
| Thermal Conductivity (W/m K) 25°C | 25°C | 170 | 200 | 26 | 17 | 17 | 60 |
| Co. of Thermal Expansion (ppm/°C, 25°C to 300°C) | 100°C | 140 | 200 | 20 | na | na | na |
| Young's Modulus (10⁶ psi) | 4.5 | 6.8 | 6.7 | 5.1 | 7.8 | 12.7 |
| Density (g/cc) | 60 | 50 | 44 | 25 | 23 | 29 |

<p>| TABLE II: TYPICAL METAL THICKNESSES |</p>
<table>
<thead>
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<th>PLATED METAL</th>
<th>THICKNESS</th>
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<tbody>
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<tr>
<td>Nickel</td>
<td>.0001&quot; - .0002&quot;</td>
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<tr>
<td>Gold</td>
<td>.00003&quot; - .00006&quot;</td>
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<table>
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<th>TABLE III: PROPERTIES OF SOLDER COMPOSITIONS</th>
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<td>Thermal Conductivity (W/m K 25°C)</td>
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<td>Co. of Thermal Expansion (ppm/°C, 25°C to 300°C)</td>
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<tr>
<td>Ultimate Tensile Strength (Kpsi)</td>
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<th>TABLE IV: COMPARATIVE FEEDTHROUGH RESISTANCES</th>
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<td>VALUE</td>
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<td>BOARD TRACES (3 mil Cu)</td>
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