Rim Watch

The Evolution in Power Surface-Mount Technology

By Mukul Luthra

Driven by the need for high I/O (input/output) density, compactness, low weight, speed and performance, evolution over the last 10 years has taken the circuit assembly and IC (integrated circuit) packaging industry from a 100-mil leaded, bug-like affair to fragile 16- and even 12-mil ultra-thin surface-mount packages. To combat handling and process issues, a line of more robust, areal attachment packages has emerged, such as BGAs (ball grid arrays), PGAs (pin grid arrays) and their variants.

This technological evolution is bringing direct chip attach (DCA) to the forefront. Chip-on-board (COB) and flip chips are becoming common terms and accepted standards in the industry. With this merger, the formerly distinct boundary between a chip and a PCB is becoming less clear by the day.

When you think about all of this evolution, though, the common factor that emerges is that, with a few exceptions, it mostly caters to the very low-power application spectrum. Clearly, the industry has focused considerable attention on developing IC packaging and assembly techniques driven largely by the needs of the "signal" or "low-power" arena.

So, what's happening to the high-power side of things? By "high power," I refer to the region from a few watts to tens of watts. Many applications call for signal and power on the same platform. Is there a parallel surface-mount technology (SMT) power evolution in this field? Data and information on power surface-mount technology are scarce, further evidencing the industry's preoccupation with signal.

Figure 1 shows a range of power packages, both leaded and surface mountable, available to the designer. Add to this list the Hi Quad (not shown), and you have a fairly comprehensive list of packages offered today. The leaded versions dominate the choices compared to surface mountable, which are relative newcomers to the field.

Use of leaded packages alongside surface-mount signal counterparts mandates a mixed-technology (Type 2) process approach for power-oriented applications. Assemblers have developed many novel ways of dealing with mixed processes. Intrusive reflow, also known as R.O.T. (reflow of through-hole) or S.P.O.T.T (solder paste on through-hole technology), is well known and, for want of anything better, "accepted" in the industry.

Nonetheless, such a process requires added pre- or post-reflow operations. Component insertion, whether manual or automatic, and soldering, whether it be wave, reflow or manual, both add to assembly costs. Regardless of the approach, this does not lead to the friendliest of processes both from a yield and reliability standpoint. For power packages, a heat sink attachment (when required) represents yet another manual add-on operation.

To answer these needs, the industry tends to "SMT-ize" as much as possible. In the case of power packages, many adaptations of standard through-hole versions have evolved over the last few years. To illustrate, examine the TO 220 package. This industry standard workhorse has held the number-one spot in the through-hole field. The D2 PAK (TO-263) is a surface-mount version of the standard TO-220 package. Likewise, the DPAK (TO-252) owes its lineage to the I-PAK (TO-251), and the D3 is a surface-mount version of the TO-247. The unique characteristic here is that these packages have been achieved with the most basic of changes; they still retain the basic character, outline and die size capability of the parent package.

Such adaptation minimizes packaging equipment costs while retaining user acceptability. It provides an easier path to standardization and a shorter development and approval time. It's easier to feel more comfortable with the familiar and the proven. Alongside such through-hole derivatives, other JEDEC-approved power surface-mount outlines have become available, such as the PowerSO-

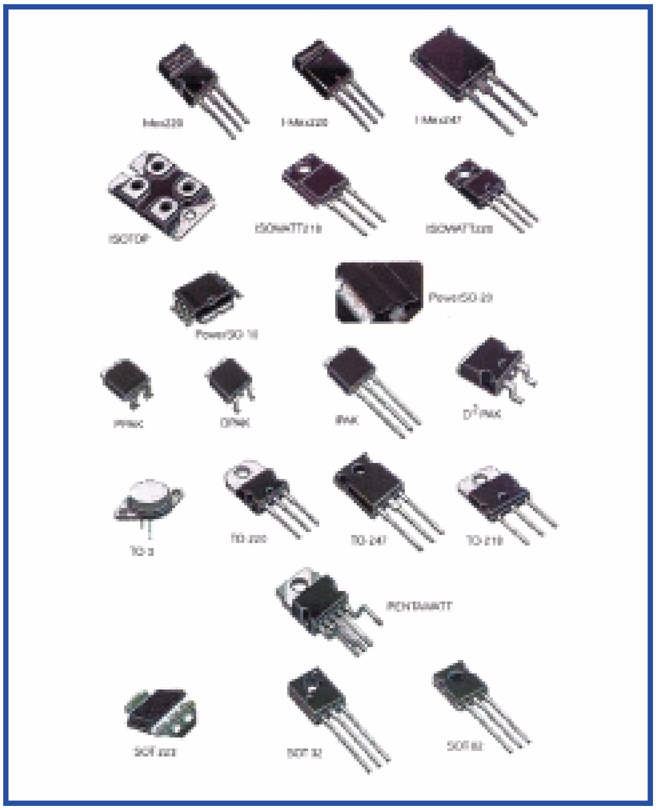

FIGURE 1: Power packages.

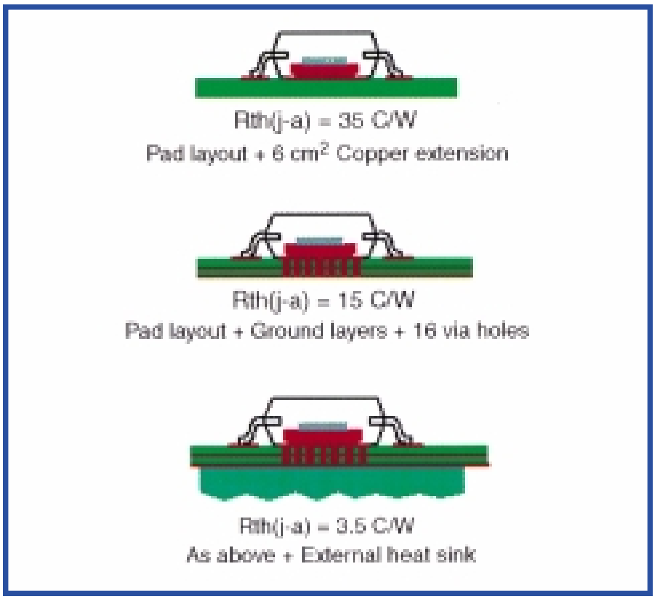

FIGURE 2: Heat sink options: PowerSO package.

10, PowerSO-20 and Hi Quad. These are available in pin counts of 10 to 20, 20 to 36 and 20 to 64, respectively, achieved by standard pitches of 1.27 mm, 1.0 mm, 0.8 mm and 0.65 mm. The Hi-Quad has the same footprint as a standard 14 mm by 14 mm PQFP (plastic quad flat pack).

Merging power surface-mount packages into the mainstream of signal opens up a range of new possibilities to the designer. Surface-mount power packages can be picked and placed and reflow soldered alongside their low-power surface-mount brethren. Similar design rules and standardized processes—one-pass reflow and standard inspection methodologies—make the advantages obvious. Equally exciting is the possibility of integrating the heat dissipation pathway from the device via the substrate itself. This, together with the choice of substrates, offers designers and assemblers a wide application-specific platform upon which to build.

Several options exist for integrating a heat removal strategy (Figure 2). The simplest is an extension of the copper area to which the device is attached. An alternative is the use of thermal vias as a means of extracting the heat onto the secondary side of the PCB. While most recommend that the thermal vias be composed of solid copper—this being the preferred, albeit more expensive, option—some assemblers have tried solder-filled vias successfully. Of the two, copper offers a higher thermal conductivity path from the copper slug. Thus, the heat sink can be integrated into the board itself, depending on space availability and power dissipation and whether forced cooling or natural convection is deployed. Design rules are available for both approaches, relating copper area, temperature and power levels.

In terms of process considerations for power surface-mount devices, there are not a lot of new techniques to learn. Lead connections follow standard rules as any other, but some considerations must be born in mind when it comes to the copper slug. Recommended solder thickness between the copper slug and the board usually ranges from 1 to 4 mils. Excessive thickness here adds thermal resistance but, on the other hand, sufficient solder must be present to ensure complete and void-free bond-ensuring heat conduction through the full surface area of the slug. Solder volumes can be calculated by the same means as for other surface-mount devices, taking into account the density of the solder paste and the total area to be covered, as well as allowing for proper fillet formation at the exposed edges of the copper slug where applicable.

The guideline—proven experimentally to yield good results, based on an 8-mil stencil thickness—is a stencil aperture opening of 75 to 80% of copper land area. Use of several smaller openings like a grid pattern is preferred over one large opening to minimize scooping effects during the print operation; this is highly dependent on the machine setup, as long the requisite solder volume can be controlled.

Reflow considerations are not radically different, either. An understanding of the package's construction is a precursor to proper understanding of its behavior under reflow conditions and to recognizing its impact on the heating equation. When placed on the board, the copper slug is shielded by the main body of the device. In such a situation, thermal transfer efficiency must be high, so that the use of forced-air (or nitrogen) convection ovens is highly desirable. This is in line with the general industry trend.

Use of infrared (IR) ovens is possible, but not desirable, due to the high thermal mass of the power surface-mount components cou-

	Berquist	Hitachi	Denka	CCI-Eurolam
Product:	**Thermal clad**	**MC111C**	**Cool-Clad**	**9101**
Cu Foil (um)	35/70/100/140	35/70	35/70/105	18/35/70
Dielectric Type	Polymer/ceramic blend	ceramic-filled epoxy	Epoxy resin with inorganic filler	Epoxy + glass
Dielectric Thick (um)	75	80/150	80/100/150	90/125/175
Dielectric Breakdown	6 KVAC	2.5 KVAC (80 um)	2 KVAC (80 um)	
TO 220 footprint Thermal resistance		0.65 C/W (80 um) 1.15 C/W (150 um)	0.58 C/W (80 um) 0.65 C/W (100 um)	
PowerSO-10 footprint Thermal resistance	0.6 C/W			1.3 C/W

TABLE 1: Insulated metal substrates: basic comparison of products.

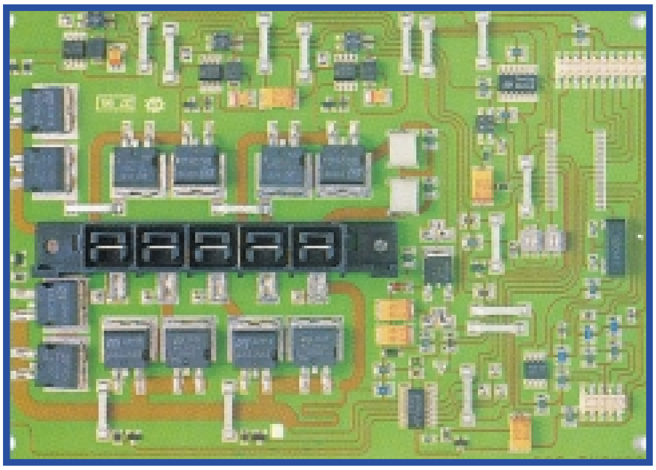

FIGURE 3: An IMS board assembly.

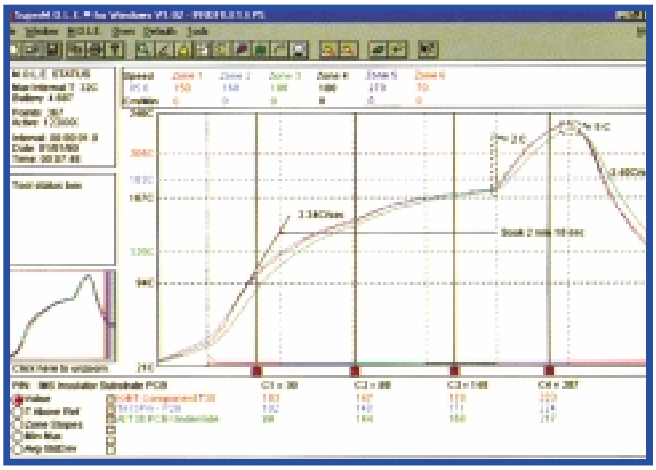

FIGURE 4: Thermal profile of the IMS assembly.

pled with shielding effects of the body, leading to Delta T management difficulties. Since the reflow and solder bond below the copper slug is not visually inspectable in most cases, process control is key, which means ensuring the thermal profile and its repeatability as seen by the slug and the solder paste below. Certain packages such as the PowerSO-10 and PowerSO-20 have a relief in the plastic body that provides a window for edge fillet inspection as a partial clue to the solder bond and, hence, the process.

For truly high-power applications with power surface-mount devices, an IMS (insulated metal substrate) may be used. This type of substrate has been around for a while, but its use so far has been mainly in certain niche applications and has been not widely prevalent in the industry. Table 1 provides information on a few IMS suppliers' products and their characteristics. IMS substrates provide a highly conductive heat pathway from the device to the metal substrate, which, depending on the total area and dissipation, can serve as a heat sink in itself or be attached to an external common heatsink. As with everything, there are tradeoffs. IMS substrates dictate a single-sided board, and this may not support a complex circuit. The solution is to partition the power portion onto the IMS and the interconnection to a conventional signal board.

Figure 3 shows such an IMS board assembly (done by myself) with several surface-mount power devices; reflow has performed in a full forced-air convection oven. The use of forced-air convection is mandatory in the case of an IMS due to the high inherent thermal mass of the metal substrate and because its reflective surface has poor IR absorption factor. Figure 4 is the thermal profile achieved and shows the feasibility of such a process in maintaining narrow Delta T, despite the diversity of components on the assembly. The high thermal conductivity of the substrate's metal mass minimizes the Delta T itself by quickly redistributing the heat energy absorbed in a forced-air convection oven.

In any circuit assembly, due consideration has to be given to rework management. This is perhaps the hardest part in the case of power surface-mount technology because conventional means are not readily appropriate. Bringing the copper slug beneath the package to liquidus temperature is a difficult task because of the high thermal mass and indirect thermal accessibility; it is almost impossible in the case of an IMS, since the assembly acts as a massive heat sink.

With help from PACE, Inc. (Laurel, MD), I found a suitable rework methodology. The solution lies in almost recreating the thermal profile as in the original reflow, using backplane forced-air convection heating and raising the local temperature around the component zone to approximately 180°C. Once the requisite preheating temperature is attained, desoldering tools with appropriate tips become usable for effective component removal and replacement. Employing backplane heating makes it possible to remove and replace packages such as PowerSO-10 and DPAK on IMS panels. In the case of IMS as compared with FR-4, the preheating takes considerably longer, and the panel, being a heat sink, gets very hot in the process, requiring appropriate safety precautions.

The finished assembly shown in Figure 3 is actually a power module developed for high-power motor driving applications and is capable of more than a kilowatt of power output while dissipating several tens of watts itself. The assembly has been attained in a single reflow operation with no other process steps involved. The application for such assemblies is growing in the automative industry, in home appliances such as washers and air conditioners, and in industrial segments with strong growth potential in Asia Pacific.

Conclusion

Designers and assemblers can take advantage of the newer surface-mount power technology that can provide cost-effective and seamless assembly processes between power and signal packages. Assembly and inspection can be standardized, and manual assembly steps can be eliminated. Assembly processes required are inline with modern equipment and readily adapted without any major reeducation. Heat sink capability can be built into the board itself. Use of insulated metal substrates can provide intrinsic heat sink capability for high-power applications. Areas where power and signal must coexist are the prime targets to benefit from this development.

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