Power Modules for Motor Control Applications

For applications in power electronics where significant power needs to be handled in confined spaces, often the choice for packaging is not a set of discrete power components, but a dedicated power module. For that purpose CoolPAK realizes an insert-molded shell which has an integrated metal lead-frame array. These lead-frames also present horizontal areas for housing bare die components as well as forming out the terminals for the outside contacts. **Jim Tompkins and Peter Sommerfeld, Electronic Motion Systems Canada and Germany**

The standard approach to power module design is to choose a suitable substrate which is typically copper on ceramic (DBC - Direct Bonded Copper) or a laminate on a metal plate (IMS - Insulated Metal Substrate). This substrate holds the bare die power components and is typically attached to a plastic frame, which holds the metal terminals for the outside electrical contacts and also forms out fixation features if required. A metal base-plate below the substrate may also be required to increase the thermal spreading capability of the substrate. With the CoolPAK-Technology a different solution to power module design is offered.

Coolpak design

The CoolPAK power module consists of six FETs arranged in a three-phase full bridge configuration. Further components are the thermistor to monitor the power module's temperature, a shunt for current measurement in the ground line of the module and an EMC decoupling capacitor. The lead-frames also form the outside contacts for supply (B+, GND), the motor phases (U, V, W), and the control and monitoring signals (Figure 1).

A central component of the CoolPAK power module is the insert-molded lead-frame shell (see Figure 2 for an unpopulated and a populated shell).

The plastic molding holds an array of metal lead-frames, which present open areas uncovered by plastic. The areas of the lead-frame opening into the cavity of the plastic shell will hold the bare die FETs and the other components required for the power module. The cavity of the shell is potted with silicone gel for the protection of the components and is covered with a plastic, snap-on lid.

Thermal stack

A power module's performance is largely determined by its thermal resistance, i.e. its ability to conduct dissipated heat away from the active bare die components. The thermal stack-up of the CoolPAK module consists of the bare die FETs soldered to the metal lead-frame made of copper core material and attached to a heat sink by thermal adhesive. For comparison, we show also a DBC-based power module, where the bare die FETs are soldered onto the DBC substrate consisting of a ceramic with copper layers on both sides, which is then attached to a heat-sink by thermal adhesive.

Figure 3 shows both thermal stacks and approximate thermal resistances of the various layers. The CoolPAK module does not have the ceramic substrate which is missing from its thermal stack, lowering its thermal resistance significantly. More so, the copper thickness of the metal lead-frame is much larger than the copper layers of the DBC module.

This acts as a further contributor to reducing the overall thermal resistance of the stack for the module by increasing the lateral spreading the heat generated in the MOSFET. A similar effect can be seen regarding the electrical loop

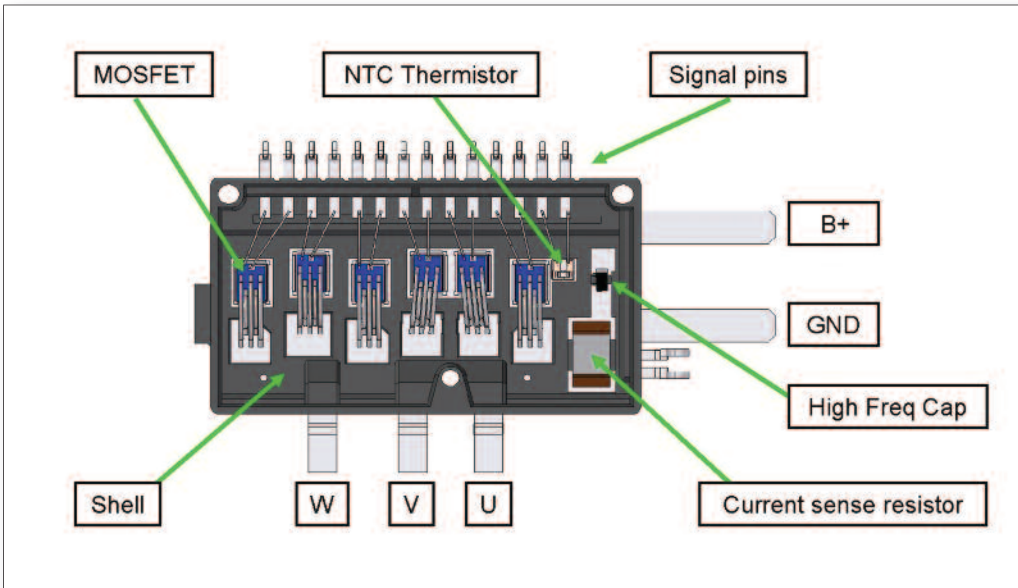

Figure 1: CoolPAK components and placement

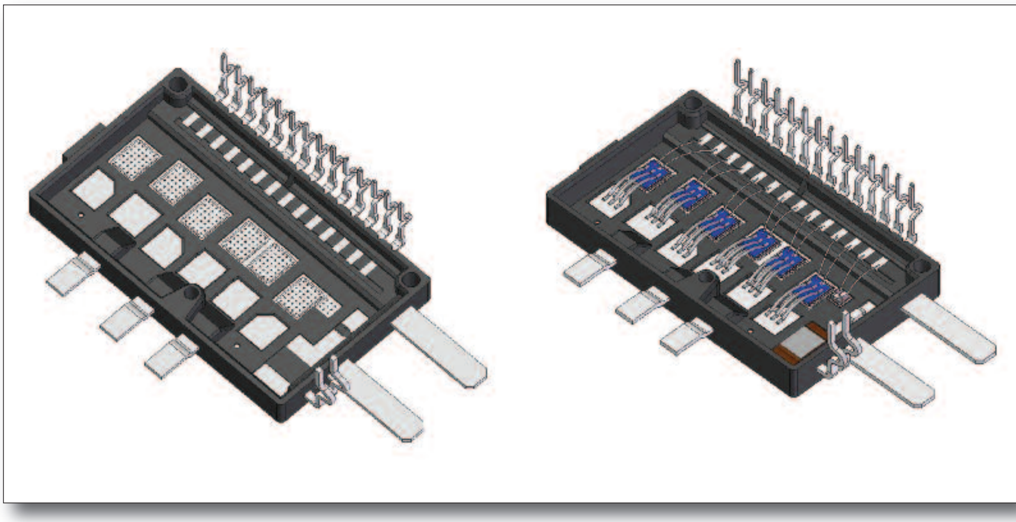

Figure 2: **Unpopulated (left) and populated lead-frame shell**

resistance of the module. Due to the lead-frame technology the resistance is reduced significantly.

Shell and thermal interface

The CoolPAK shell has to facilitate the conduction of heat away from the bare die FETs. This is done very effectively through the metal lead-frame, but care also has to be taken to have an efficient thermal transfer to the underlying heat-sink.

The CoolPAK module has the lead-frames exposed on its bottom-side as well. This way the thermal adhesive can bond directly to the lead-frame and establish thermal contact to the heat-sink directly. With this method, care has to be taken that no lead-frame accidentally makes contact to the heat-sink and thereby causes short circuit conditions. To avoid this, two precautions are taken. Firstly, the plastic shell contains small nubs, which establish a defined gap between lead-frame and heat-sink when the module is placed onto the heat-sink according to Figure 4.

Secondly, the module can be attached by a thermal adhesive filled with glass beads of defined size so as to ensure electrical isolation between lead-frame and heat-sink. The shell also has to withstand the high process temperatures during soldering of the components. The plastic material (PPA) is such that even lead-free soldering operation can be carried out with the shell.

The metal lead-frames are made from copper for high thermal and electrical conductivity. The lead-frame thickness is chosen to be 1mm, which facilitates thermal spreading and increases the thermal transfer per component. Also the current carrying capability of the lead-frames is significantly improved, which reduces the resistive power losses of the module.

In order to run the wire bond interconnection process, the copper lead-frames are Nickel-plated in the relevant areas to provide large wire-bond reliability and manufacturing consistency. For the lead-frames of the signal contacts Aluminium inlays enhance small wire-bond reliability.

Temperature and current monitoring

The power module is fitted with an NTC thermistor, which sits on a small substrate providing the contact pads. This thermistor assembly is attached directly to a lead-frame by a soldered contact, providing good thermal contact. This causes very little thermal lag between the thermistor and the junction temperatures of the FETs, which allows

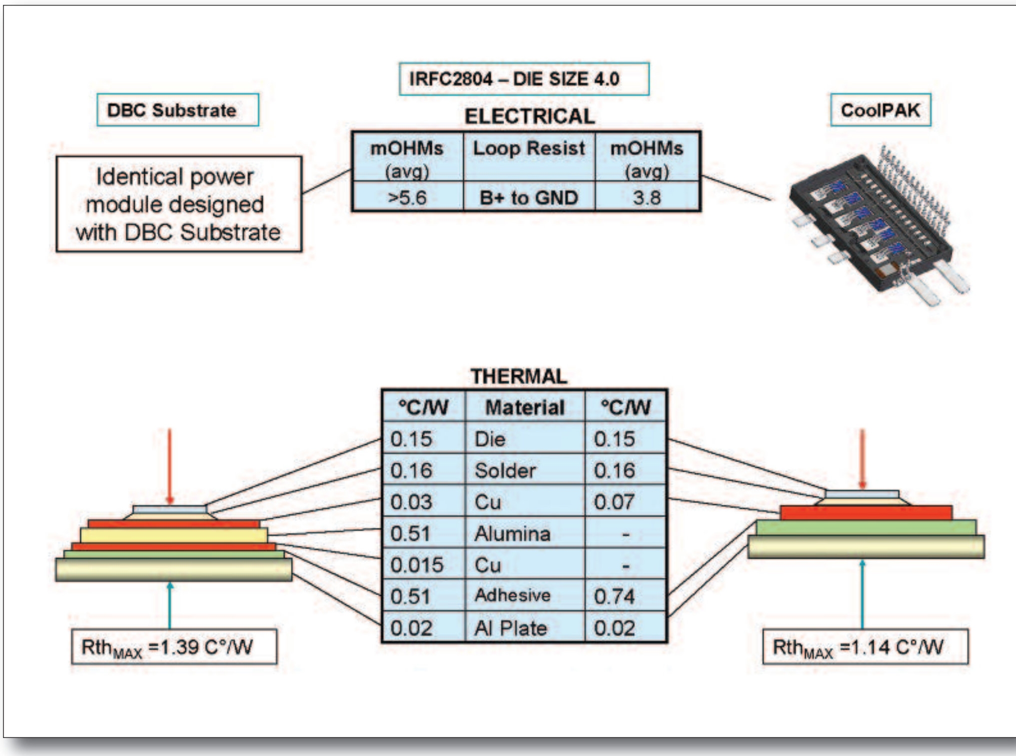

Figure 3: **Thermal stacks and approximate thermal resistances of the various layers for DBC and CoolPAK module**

the active protection of the module against over-temperature. The input current and output voltage of the thermistor are provided via the signal pin outputs.

A shunt resistor in the ground path of the module allows for current measurement. The shunt is chosen to have as low a resistance as possible to keep dissipation down and still provide a good signal-to-noise behavior. The shunt is directly soldered to the lead-frames of the shell. The voltage measurement is realized via the signal pads.

The supply terminal B+ and GND are plated to allow both contact by resistance welding as well as a soldering operation. The same is the case for the three phase terminals U, V, W.

The signal pins are through-hole leads for attachment to a controller board to generate the gate driver signals and measure current and temperature. The signal leads also include a contact to the source of each FET for sensing the voltage.

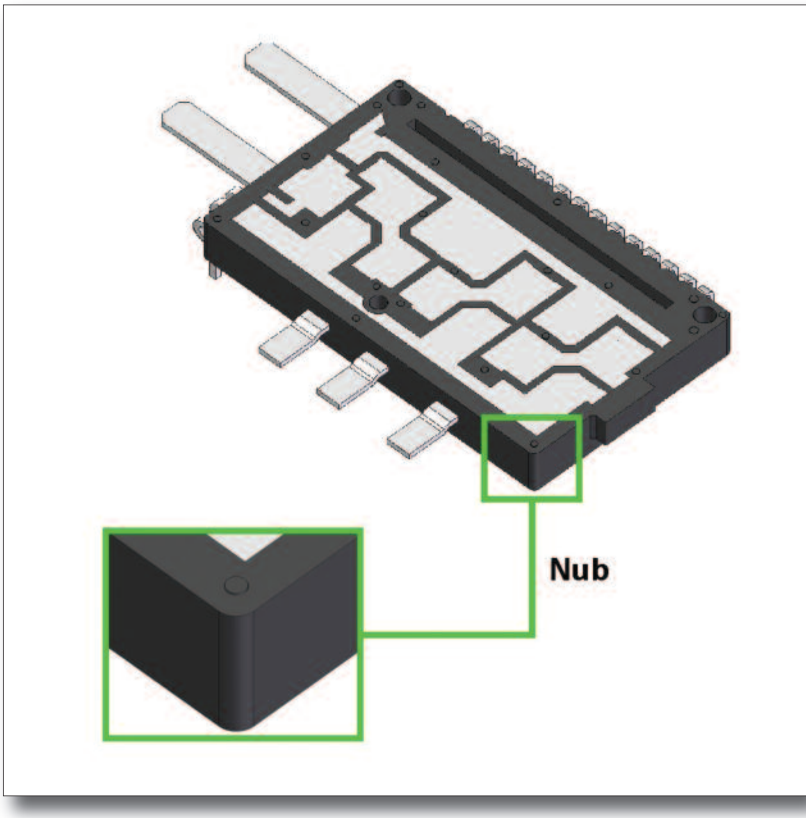

Figure 4: **Small nubs establishing a defined gap between lead-frame and heatsink**

Process technology and reliability

The manufacturing of the CoolPAK technology uses common module assembly technology. The areas for the placement of the bare die FETs are defined by dispensing solder resist, which is cured. Within the confines of the solder resist pattern the solder paste is dispensed into which the bare die FETs are placed.

The soldering process is conducted in a multi-chamber vacuum oven. This allows the solder joints to reflow and minimize the amount of solder joint voiding. This is of particular importance for this power module since the solder joint is the first thermal contact layer to the bare die FET and needs to be as thermally conductive as possible.

The reflowed modules undergo a cleaning process. After this the bare dies are wire bonded to the relevant areas on the lead-frames and contact pads. The wire bond process is being controlled regularly to ensure quality of bonds. Finally the module is potted with silicone gel which protects the electronic components from dust and moisture.

The parametric test of the power module tests every FET and the other components. For the FETs a batch related analysis is performed on the parameters stored. Over and above the requirement of every parameter being in between a lower and an upper limit a further constraint is applied in that statistically every module is discarded whose FETs have measurement values on any parameter more than a certain multiple of the standard deviation away from the mean of the batch. This applies even if the value itself is between the lower and upper limit. This "maverick test" method has been taken over from semiconductor manufacturing, where it proved out to be very efficient in rooting out a suspect product.

The reliability performance of this module has been tested extensively. The most important test which addresses the central innovative components of the module is the power cycling test. In this test the module is subjected to cyclic periods of passing significant current and off-periods. This leads to a cyclic variation in the junction temperature of the FETs and of the entire thermal stack. The CoolPAK technology has proven itself to conform to all application specific specifications for automotive applications.

Application examples

The CoolPAK technology is currently being used in high volume production for an automotive electro-hydraulic steering ECU for a 14V system voltage. The module is required since the discrete solution is not able to handle the required electrical power. It is also being trialed for automotive electro-hydraulic steering ECU for a 28V system. Again the power handling capability of the technology is required to comply with the power requirements of this application.

Further areas of use could be general brushless DC motor drives, electric heaters for automotive applications, active rectification and electric resistance welding.

Conclusions

CoolPAK shows significant advantages in thermal performance and cost over conventional power module technology. This is due to fewer components, simpler assembly technology at good current carrying capability. The technology lends itself particularly to applications where high power handling is required in constricted space envelopes.