EconoPACK^{TM} +
A package with enhanced characteristics

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Abstract

Increasing the efficiency of high power frequency converters is one of the main challenges in power electronics of the last years. The power semiconductors have to follow this requirement with reduced losses by state of the art silicone and by increasing the power density to higher current ratings. The increased power density will be also driven by rising operational temperature of the system and especially of the power module. Since many industrial power module types have been standardized over the years the module developers is given the task to fulfill also these requirements including the increase of the power density within an existing module footprint. The solutions to this task involve the integration of new chip technologies as well as the introduction of new package technologies.

1. Introduction

A new concept for high efficiency inverter designs with power ratings i.e. higher than 100kW was developed with the EconoPACK™ + power module, shown in figure 1, first by Infineon at the end of the 90´s [1]. This first EconoPACK™ + design was developed using state of the art technologies. One part of these technologies was originally designed for low power modules from Infineon. It offered the opportunity for a flexible control pin configuration to follow the application requirements of different topologies within one power module package and footprint.

For inverter solutions with the EconoPACK™ +, standard control pin positions are established and flexible pin positions are therefore not needed. Furthermore, in high power inverters parallel connected EconoPACK™ + modules, beside their originally purpose as a six pack, are very often used.

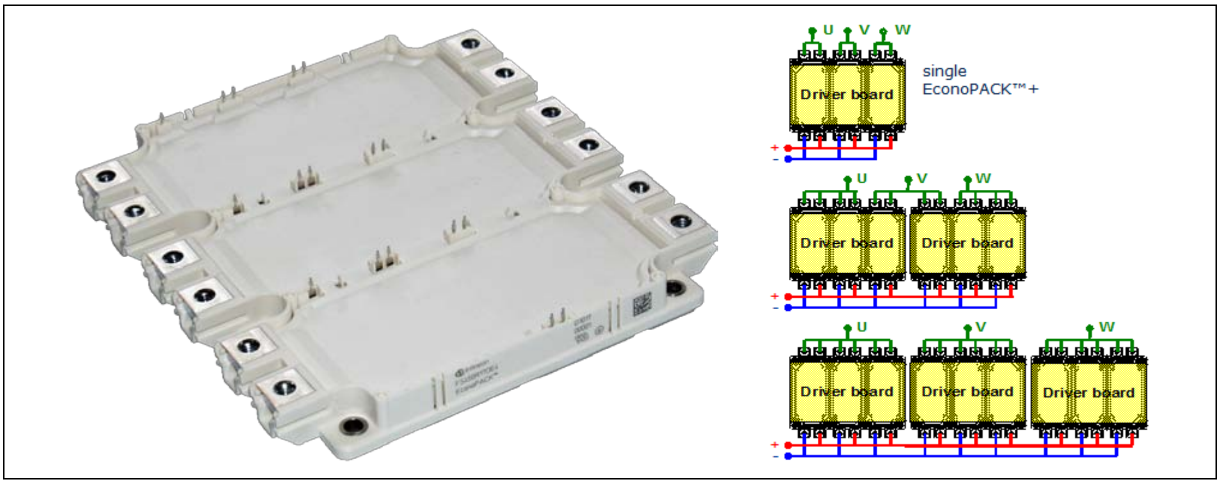

Fig. 1. EconoPACK^{TM} + Module and typical setups in high power frequency converters

High power inverters for industrial applications with its huge capacitor bank and heavy output bus bars are having more and more special requirements for mechanically rugged parts. Existing and new high power applications with increased requirements like windmill inverters are going to use high power modules with improved features and behaviors compared to the last 10 years.

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2. Enhancing the EconoPACK^{TM} + to handle tightened application requirements

Several mechanical measures are taken to serve expanded application requirements.

2.1. Mechanical ruggedness of the power module frame

One of these new application fields is the electric power train in e.g. door to door delivery vehicles or in hybrid city busses. Such kinds of hybrid vehicles are covered by the group of commercial, agriculture and construction vehicles (CAV). All the equipment, including the power module as a part of the power train, installed into the vehicle has to withstand an increased vibration and shock load when the craft is in use.

As power modules are not just ideal electronic devices but also units of significant mechanical size and weight, inverter designers have to take into account the mechanical robustness of the system. Depending on the field of application, harsh vibration and shock conditions must be considered. Beside an adequate mechanical design of the inverter assembly to decouple the power electronics from destructive environmental conditions, the key devices such as capacitors and power modules should be self-protecting also. A rugged inverter- and power module frame design is needed to withstand environmental loads.

As a first indication of a rugged frame the resonance frequency can be investigated. Finite element (FE) simulations are carried out to compare different module package designs to ensure the highest possible ruggedness. Figure 2 shows a part of these results where the calculated and measured amplification factor of an external excitation on the package is compared. The most important point is the resonance frequency at which the maximum amplification occurs. The target of the design is to increase it above 1000Hz – significantly above the typical field conditions.

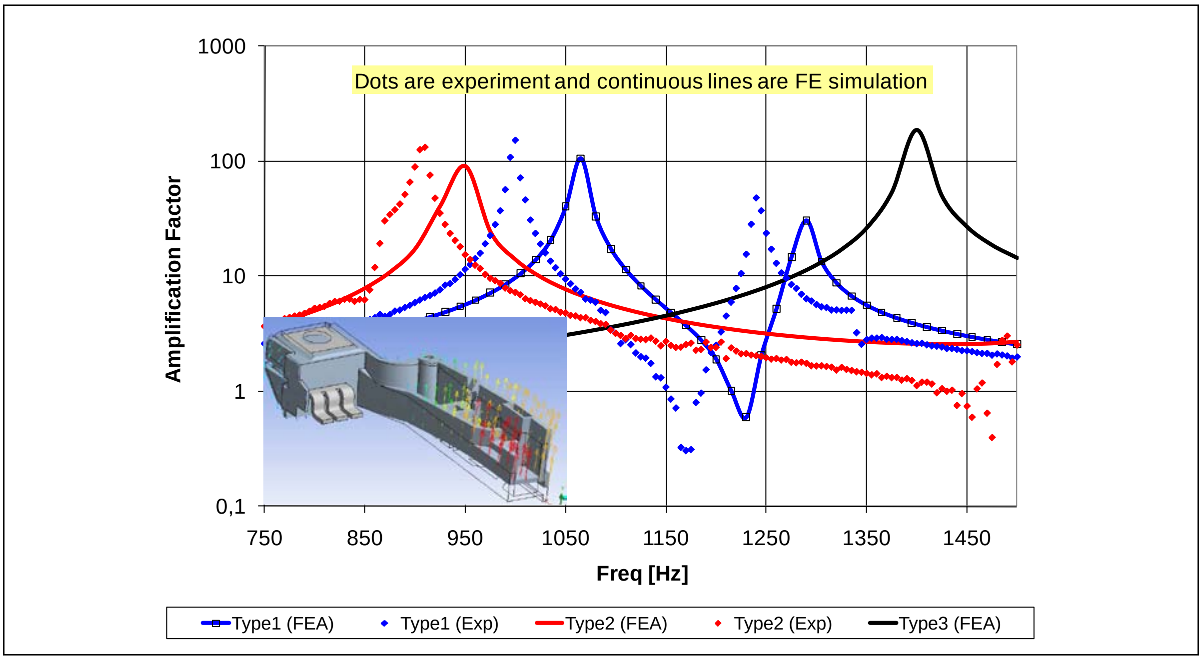

Fig. 2. Amplification factor of different designs, calculated and measured

In addition to the externally applied mechanical static- and dynamic stress, the frame has also to withstand stress caused by thermal changes. This stress is addressed by the Thermal Shock Test (TST). This reliability test is a two chamber test which applies as an accelerated test an extremely hard temperature cycle to the devices under test (DUT). In the two different chambers the DUT is stored for a period of time at T= -40°C and T=+125°C. This test has to be passed without failures at least 50 times.

2.2. Inherent advantages of ultrasonically welded joints

Higher mechanical robustness and lifetime as well as power density is a result of an innovative design of the electrical contact technology. For one decade of EconoPACK™ + history, power contacts consisted of aluminum bond wires with their well known behavior. Driven by the ongoing increase of the power density of silicon dies combined with rising junction operating temperatures T_{vjop} [2], engineers strive for other joining technologies. Today's lifetime limitations of power contacts have to be replaced by new technologies on the way to higher power density. In high current applications, the limitations of aluminum bond wires become obvious. Paralleling multiple wires is needed to manage the temperature, see figure 3. To achieve a high current capability a robust and highly reliable power contact technology is needed. Ultrasonic metal welding (USW) contacts are able to handle all these requirements. The USW technology was described detailed in [3].

In figure 3, a simulation of an US welded terminal compared to a power terminal solution with aluminum wires is given. The simulation was made under the same boundary conditions. The results show a significant advantage of the ultrasonically welded terminal leading to an even reduced temperature down to approx. T=120°C.

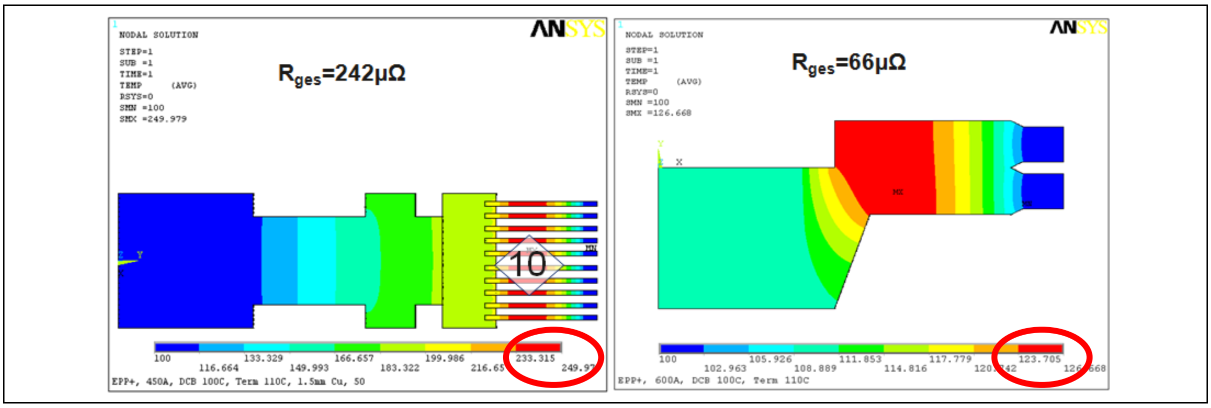

Fig. 3. Simulated temperature distribution with aluminum bond wires vs. an US-welded terminal

This massive temperature reduction by ultrasonically welded terminals offers the opportunity to prepare the module for an increased current capability and thereby also for future chip generations. Figure 4 presents the temperature distribution of the EconoPACK^{TM} + power terminal at two different conditions derived by simulation.

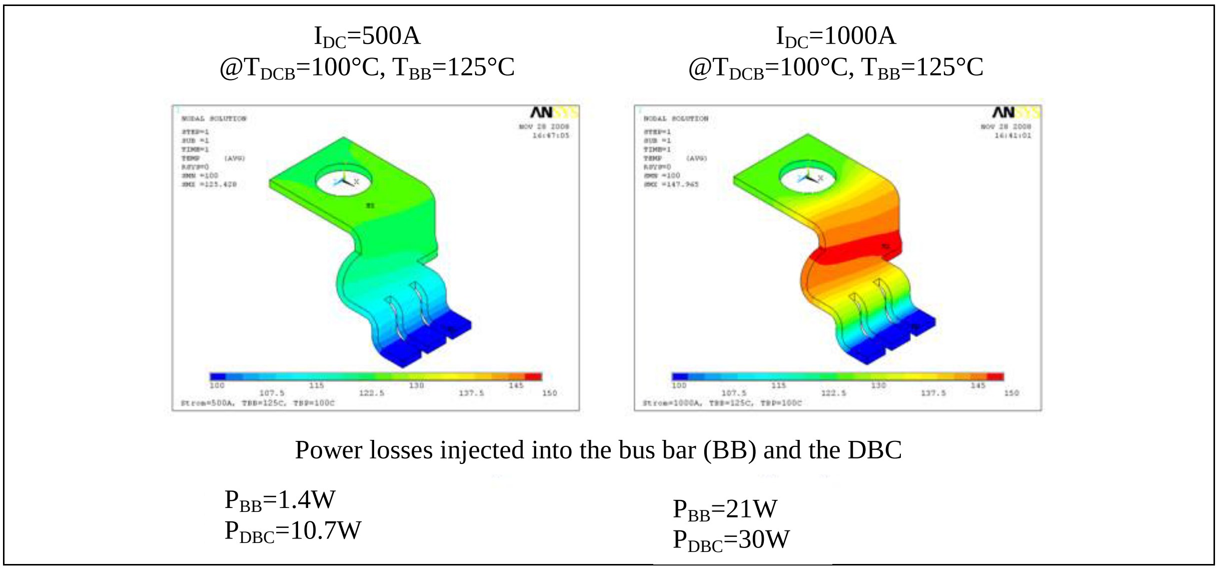

Fig. 4. Power losses and resulting temperature distribution in a terminal at 500A and 1000A

The simulation of US welded terminals under two different conditions, presented in figure 4, makes the advantages more obvious. For today's existing maximum DC current rating of the EconoPACK^{TM}+,

I_{Cnom}=450A, the new technology offers significantly reduced power losses in the terminal system itself and as a result of that a reduced operating temperature as well as lower mechanical stress in the device.

The previously given simulations are carried out to ensure the highest possible DC current under given conditions. In real applications the resulting temperatures especially at the power terminals are depending on the connected DC link design. A proper way for the investigation of a thermal behavior is the measurement of the temperatures utilizing Infra Red thermographic camera systems (IR).

To measure the temperatures the IR system needs a black painted surface to take the temperatures by an infrared image. The measurement in figure 5 compares USW terminals with wire bonded terminals, investigated by an IR system under identical load conditions. The result of the infrared measurement is exemplary given in figure 5. The hot bonds are clearly visible in comparison to the colder USW connections which adopt the same temperature as the substrates (DBC).

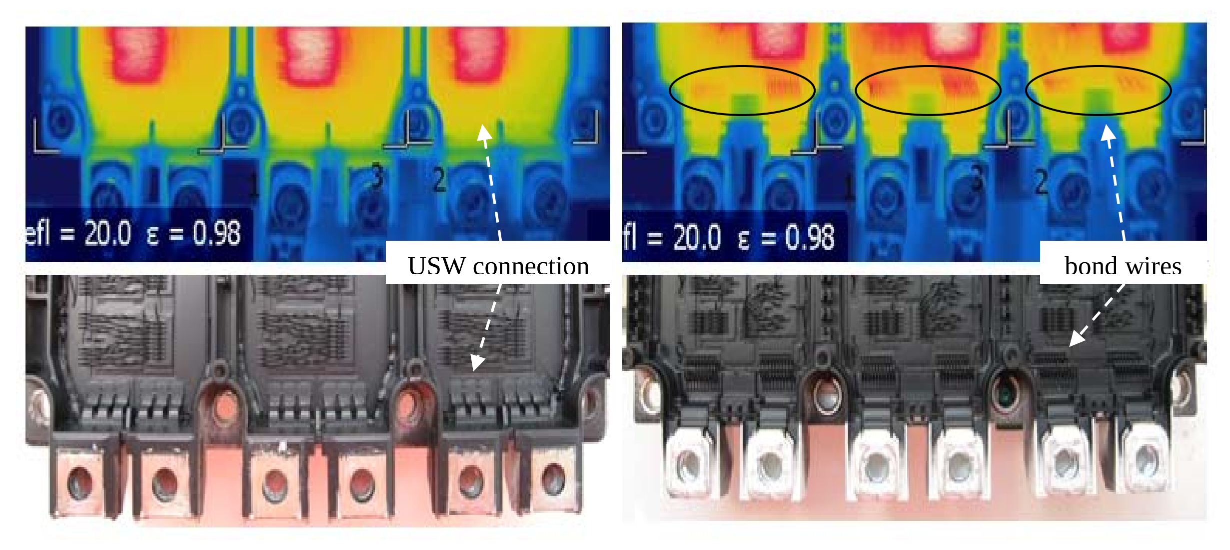

Fig. 5. Thermograph of the wire bonded module (right) and the USW module. The hot bonds are clearly visible in comparison to the cold USW connections which adopt the same temperature as the DBC.

2.3. Base plate structure for an optimized thermal behavior

With increasing power density not only the temperature of the power terminals has to be considered. Even more important is the effectiveness of the cooling system. The module base plate has to provide the thermal contact to the heat sink as a part of the inverter assembly. To transfer the heat, generated by the power dissipation, the base plate has to be mounted as close as possible to the heat sink surface using a proper thermal interface material applied. Due to the bimetallic effect under working conditions the structure of the module`s base plate must be adapted to the DBC´s structure used internally.

Calculations based on Finite Elements (FE) are used to optimize the base plate`s shape, as depicted in figure 6. Assembly and operation conditions like mounting torque and temperature are discussed as boundary conditions.

The knowledge gained was part of redesigning the EconoPACK™ + package and is most obvious from the bottom side of the module.

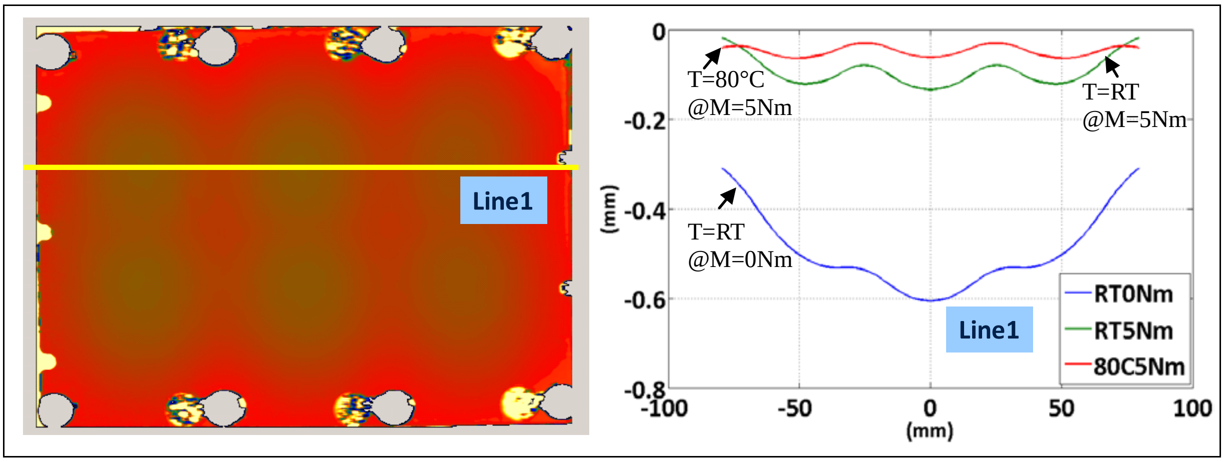

Fig. 6. Base plate shape measurement (left) and FEM calculation done at Room Temperature (RT) mounted and unmounted as well as 80°C mounted (right)

The optimized geometry of the base plate does not longer need any segments or slots – it´s one large plate as it is shown in figure 7.

With the optimized base plate structure six larger substrates instead of nine smaller ones per power module can be implemented. The reduction from nine DBCs down to six DBCs results in getting rid of one group of bond wire interconnections which will reduce resistive losses.

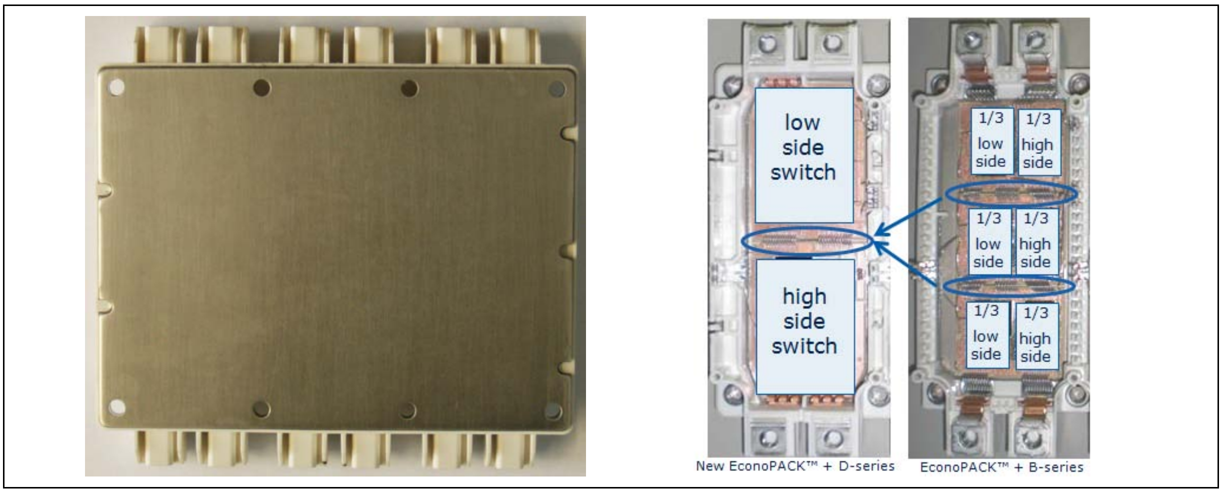

Fig. 7. Shape of the power module base plate, left picture and the difference of the system wire bonding between the EconoPACK™ + D-series and the old EconoPACK™ + B-series exemplary shown for one segment per module

The superior thermal properties of the EconoPACK^{TM} + concept are based on the design of the footprint and the new internal chip arrangement enabled by the changed DBC design. Enhanced spreading of the heat into the base plate and optimized thermal contact from the base plate to the heat sink are consequences of this redesign.

A further important aspect is the homogeneity of heat density across the base plate. The alternating placement of IGBTs and diodes is beneficial if the circumstance is taken into account that the losses are primarily produced in only one type of chip, either only IGBTs or only diodes, a condition that occurs for example in purely motor- or generative operation of an inverter.

Finally the arrangement of the two arms of the comprised half-bridge is done in a way that the Si-dies of each individual arm of the half bridge are also arranged to reduce a thermo coupling of the devices. In order to illustrate this feature the IGBTs in the high side (low side) arm are labeled by “+” (“-“) in figure 8.

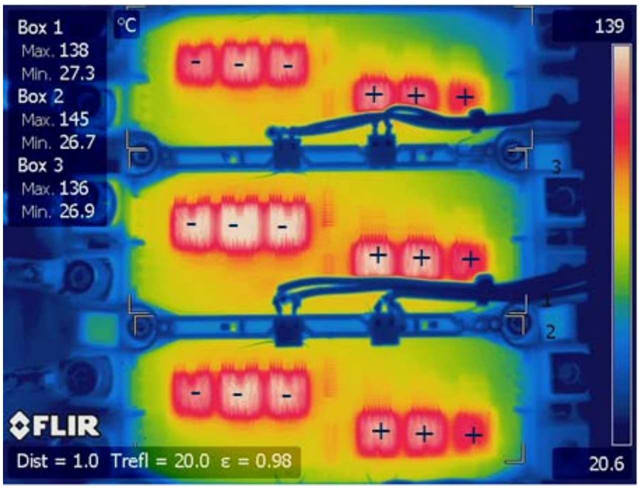

Fig. 8. Infrared image of the thermal measurement of the EconoPACK™ +

2.4. Reliable control connections

The innovative EconoPACK$^{\text{TM}}$ + redesign also takes care of the inverter system costs by providing reliable and solder less press in contacts with PressFIT [5] auxiliary terminals. The PressFIT contacts also provide the flexibility for a solder process, if required by the user.

3. Summary

The increase in power density within standardized power module designs can no longer simply be achieved by the introduction of higher performance IGBTs. Much more attention has to be paid on how the excess of performance can be made usable. The benefits of increased power density can only be achieved by an overall solution approach, including all functional groups within the module.

Higher reliability, higher current, future-proof design for upcoming chip generations and the integration of these features in a standardized footprint are the main challenges for a power module design. In this paper, possible solutions have been briefly addressed.

4. Literature

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[5] Reliability of PressFIT connection, T.Stolze, M.Thoben, M.Koch, R.Severin, PCIM Proceedings 2008, Nürnberg