Power Modules for Onboard Chargers

Electric vehicles (EVs) are rapidly becoming state of the art in passenger cars, substituting combustion engine vehicles. Initially, one of the main challenges was the maximum distance covered by EVs in a single charge. Now, modern EVs can cover distances between 400 to 600 kms in a single charge due to increased Li-ion battery capacity, elevated nominal battery voltage of 800 V, and wide bandgap semiconductors.

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To accommodate the full potential of this increased battery capacity, high speed charging becomes inevitable. For AC charging in passenger cars, onboard chargers (OBCs) are required. Earlier, the most common power rating of OBCs was in the range of 3.6 kW to 7.2 kW. However, with an increase in the battery capacity, the popularity of OBCs with rated powers of 11 kW and 22 kW will also increase.

Increased power rating and production volumes pose some challenges for modern OBC designs. For instance, despite the fact that the power rating of OBCs increases, the available installation space for the OBC stays nearly unchanged due to the limited space in EV. Therefore, an OBC with 11 kW or higher power rating will require a higher power density (W/l) compared to former OBC solutions. Additionally, as the power density of an OBC increases, the cooling of semiconductors in the OBC also becomes more crucial. This makes an optimized thermal connection between the semiconductors to the heatsink, essential.

Another challenge that modern OBCs need to address is fast and robust manufacturing. To meet the increasing production demands, OBCs need to be designed such that their production can be realized through automation. Additionally, to reduce costs at system level a vertical integration of components, for example, in the form of power semiconductor modules is also required. In short, to meet the increasing demand for EVs equipped with OBCs of 11 kW or higher charging power, design and manufacturing processes need to be optimized.

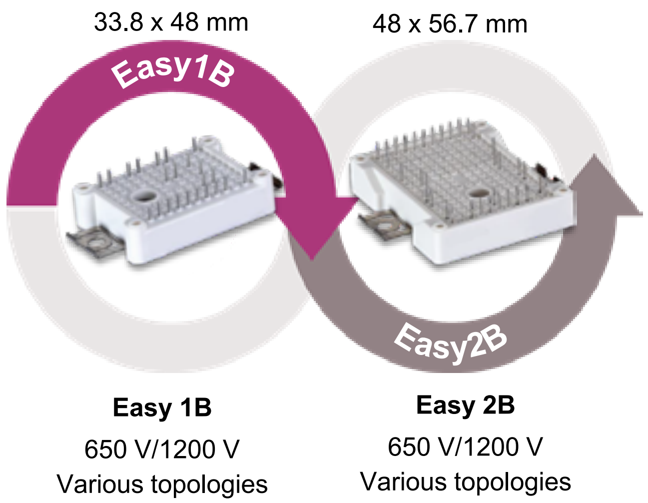

Figure 1: EasyPACK family with AQG324 qualification for OBCs

Here, EasyPACK™ modules offer the right-fit solution. As one of the industrial module standards set by Infineon Technologies, EasyPACK modules are well known for usage in applications such as EV chargers, general purpose drives, solar inverters, air conditioners, and many more. The two sizes of EasyPACK modules with AQG324 qualification, as shown in figure 1, provide the optimal area required for the semiconductors to realize a compact OBC solution.

A typical OBC consists mainly of a power factor correction (PFC) stage, and the primary and secondary sides of a DC/DC converter. For example, a 22 kW OBC solution can be easily achieved by using an EasyPACK 2B and an EasyPACK1 B. The EasyPACK 2B can utilize, for example, 12 pieces of 33 mOhm 1200 V CoolSiC™ M1H MOSFETs, allowing the PFC stage and the primary side of the DC/DC to be realized, as shown in figure 2 (a). Additionally, a negative temperature coefficient (NTC) resistance can be integrated in the module to monitor its internal temperature. On the secondary side of the DC/DC converter, the EasyPACK 1B can accommodate four pieces of 33 mOhm 1200 V CoolSiC M1H MOSFETs. However, EasyPACK 1B offers enough area to house the primary side of a high voltage to low voltage (HV/LV) DC/DC converter as well as an NTC, as shown in figure 2 (b). Using an EasyPACK 2B and an EasyPACK 1B the area required for semiconductor switches of a 22 kW OBC on the heat sink can be reduced to 43.4 cm². This design not only enables a very high power density, but also reduces the heat sink area providing more design flexibility.

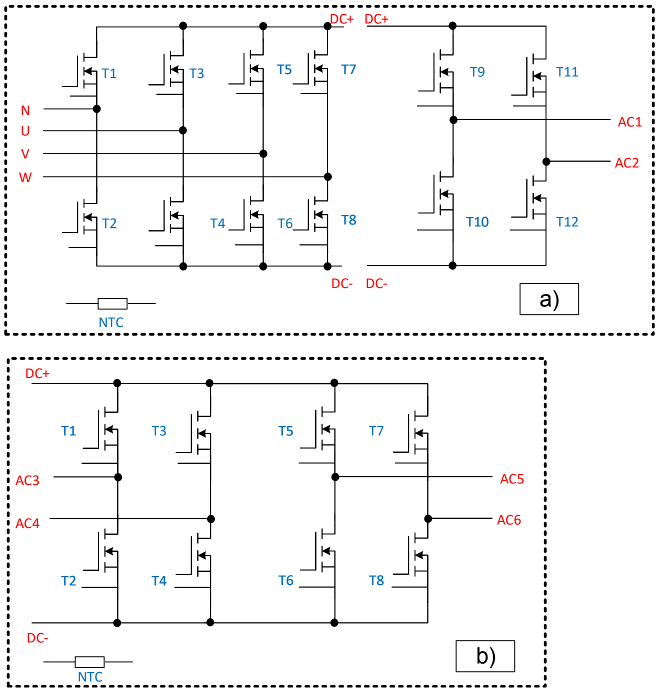

Figure 2: Common topology of OBC consisting of PFC (a) The primary side of DC/DC converter (b) The secondary side of DC/DC converter with integrated primary side of HV/LV DC/DC converter

The semiconductors in EasyPACK modules are placed on a direct-bonded copper (DBC) substrate. The layers of the DBC are shown in figure 3. On the top copper layer, the semiconductors are connected via soldering and wire bonding. The ceramic material between the top and bottom layer (can be either Al_2O_3, AlN, or Si_3N_4) isolates the high potential on the semiconductors from the ground. This eliminates the necessity of an additional isolation layer for the power semiconductors, which is an additional leverage for reducing the bill of materials and processing steps in production. One additional benefit of the DBC substrate, thanks to the ceramic layer, is stable isolation properties over its lifetime.

Another characteristic of EasyPACK is its very good thermal performance. EasyPACK modules are screwed directly onto the heat sink (see figure 5). This construction of the EasyPACK modules allows them to be fixed to the heat sink with a very low cavity. The resulting thickness of the thermal interface material (TIM) layer between the bottom side of the DBC and the heatsink is less than 100 µm. Such a thin TIM layer is sufficient to fill up the cavity and assure the connection of semiconductors with very low thermal resistance to the heat sink. For instance, a 80 mOhm 1200 V CoolSIC™ M1H in EasyPACK can achieve power losses of up to 30 W without exceeding the $T_{vj,max}$.

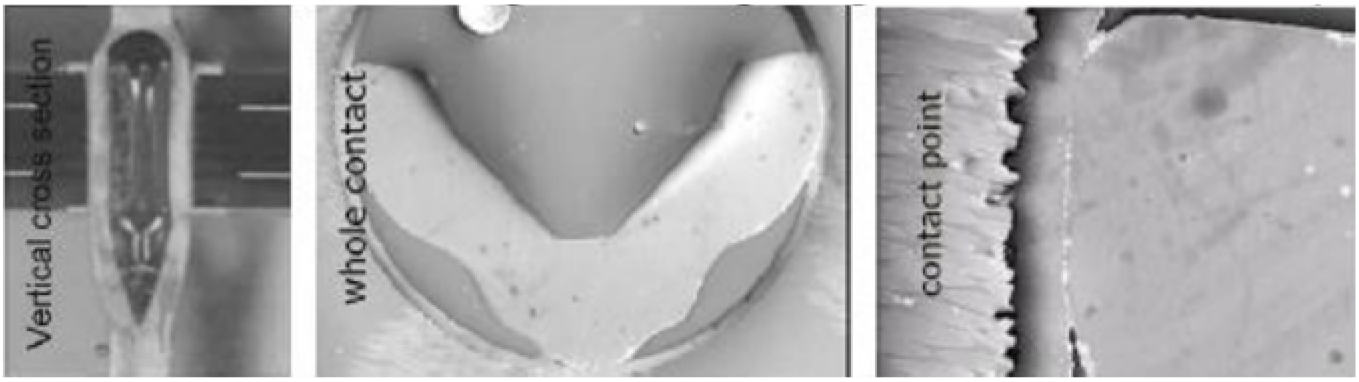

Figure 3: Cross sections of the PressFIT contact zones [2]

The connection of EasyPACK modules to the printed circuit board (PCB) is realized by PressFIT pins. The PressFIT pin has a press zone with galvanized tin that forms a cold-welding contact with FR4 PCBs. A cross section of welded parts is shown in figure 4. This interconnection provides consistent and continuous low electrical contact resistance (as low as 0.05 mOhm [1]). The cold-welded PressFIT contacts offer a very low failure-in-time (FIT) rate that according to [2] is a factor of six lower than that of automated soldered contacts.

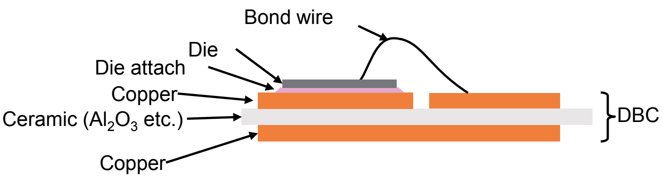

Figure 4: The layers of a DBC in an EasyPACK

Another benefit of PressFIT pins is the reduction in production complexity compared to selective soldering. Due to the height of the passive components and modules that need to be connected to the heat sink, the modules are located on the opposite side of the contact pins of the through-hole components. As the pins are pressed, only the side of the PCB, on which the contacts of through-hole components, such as capacitors, connectors and transformers are placed, needs to be selective soldered. Using the PressFIT pins to contact the modules to PCB, therefore, reduces processing time and handling complexity; thereby reducing production costs.

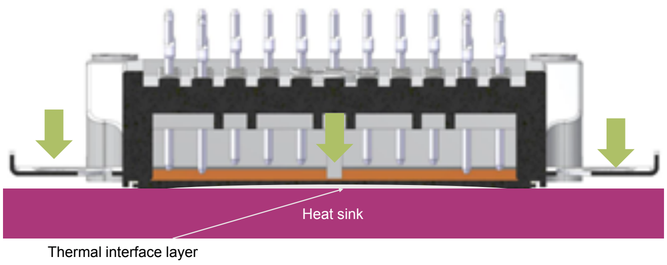

Figure 5: The construction of EasyPACK allows a low cavity between module and heat sink

Furthermore, the screwed EasyPACK in combination with PressFIT pins eliminates nearly all mechanical and assembly process related tolerances, and reduces the mechanical stress on the PCB.

Conclusion

The growing demand for OBCs with higher power ratings, such as 11 kW and 22 kW, necessitates higher vertical integration and easier manufacturing capability to increase productivity and achieve better economies of scale. These requirements can be easily fulfilled by using integrated power modules such as EasyPACK. For example, it is possible to concentrate power semiconductors in a 800 V 22 kW OBC within 43.4 cm² area using a single EasyPACK 2B for the PFC stage and primary side of the DC/DC, and a single EasyPACK 1B for the secondary side of the DC/DC. The utilization of the EasyPACK 1B for the secondary DC/DC stage can be further extended by integrating a H-bridge as primary side of a HV/LV DC/DC converter to bring the power density for combined systems to an even higher level.

High power density, integrated isolation, fast and robust manufacturing capability, and lower FIT rate due to PressFIT pins makes the existing EasyPACK module family with AQG324 qualification an excellent solution to meet the demands of OBCs with 11 kW and above power rating.

References

[1] AN-Automotive EasyPACK™-Assembly, revision 1.0, 7 Sept. 2021
[2] Siemens norm SN 29500-5 / Edition 2004–06

About the Authors

Koray Yilmaz has a power electronics (M.Sc.) and mechanical engineering (Ph.D.) background. As a technical marketing manager, he is responsible for the definition and application of EasyPACK modules in EV auxiliaries.

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