Application note

On board charger design with ACEPACK DMT-32 modules

Introduction

An on board charger (OBC) for electric vehicles (EVs) is a very peculiar application, with specific requirements in relation to size and weight, as both requirements have a direct impact on driving range or autonomy. Efficiency was initially only important for the heat generation, and therefore cooling needs; a stationary EV does normally not have its water-cooling system engaged. With the onset of bidirectional use, as in V2G, V2H, etc., efficiency becomes more important, as energy could go through the OBC twice, before it is used; but still not an important factor for driving range, only for general power conversion efficiency.

The OBC is only required in situations where the vehicle gets charged by a wall-box, with limited power capabilities, and thus normally not being used when driving. The power range of OBCs is limited between 3.6 and 22 kW, which is normally communicated by the supplying charger. The actual limit is defined by the fuse rating of the outlet; in mainland Europe, a 16 A fuse is very common at 230 Vac, which results in 3.6 kW for a single phase, and 3 x 32 A for a 3-phase scenario. When using a cable box, which can be plugged into a standard AC-outlet, power is normally reduced to 1 or 2 kW, and can often be adjusted to comply with the power capability of the outlet.

As highlighted before, most new OBC designs employ bidirectionality. This allows the user to use the EV as part of an energy storage system, particularly useful with the (often) lacking or aged infrastructure; the battery can be charged during the night, or by solar or wind, and can offer its energy during peak hours where the electrical energy normally is less available, and thus more expensive. Future smart infrastructures support energy-on-demand. Having a smart microgrid is already feasible and beneficial in many occasions where solar or wind is available.

With the growing number of electric vehicles, it is now feasible to use them as additional energy storage, and as such the OBC becomes part of a solution for our electrical infrastructure, rather than a functional part of an EV. The requirements for these OBCs will now have to incorporate the requirements for energy supply and should be able to allow communication to be manipulated by a smart grid supervisor. The EU has published an EV charging infrastructure rollout with further details.

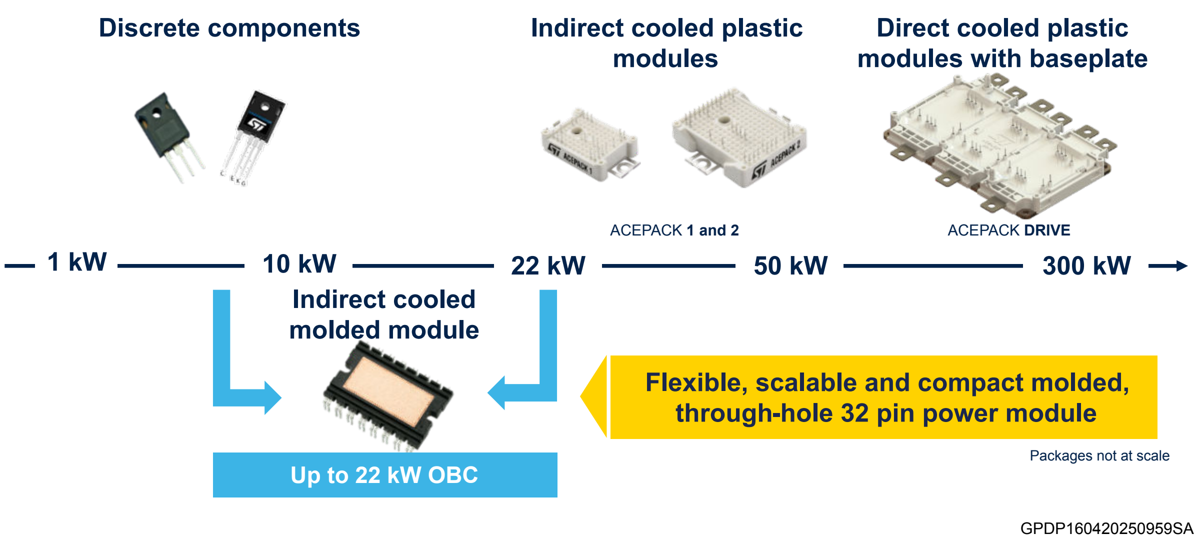
1 Design choices

The introduction explained that size and weight are important characteristics of the OBC, hence the power density is a key driving factory for the selection of power components. Higher power density can be achieved by fundamental choices at the beginning of the design process.

A higher switching frequency, for example, results in smaller magnetic components, like inductors and transformers; which also have less weight. With the introduction of new power semiconductors, like silicon carbide (SiC) and gallium nitride (GaN), such increase in switching frequency is feasible. Their fast-switching capabilities and therefore reduction in switching losses, in comparison to established technologies like IGBTs and MOSFETs help to support high switching frequency designs.

Another choice for a higher power density is the type of integration and packaging of the power semiconductors. STMicroelectronics has developed several power modules to achieve the higher power density that is needed for applications such as on board chargers. In the power range of 22 kW STMicroelectronics can offer several solutions, one such solution stands out in the ease of design-in; the ACEPACK DMT-32.

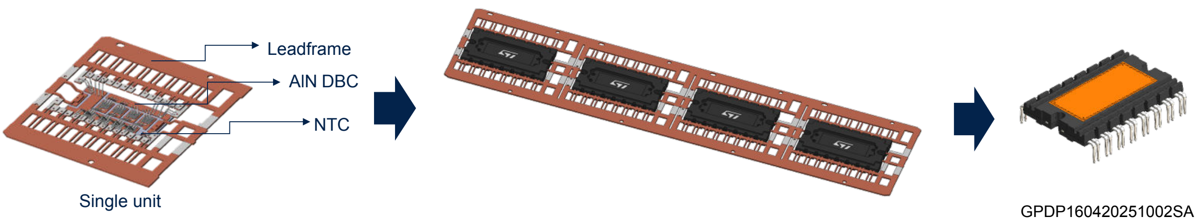
Figure 1. Module positioning from ACEPACK DMT-32



The ACEPACK DMT-32 is a molded power module designed to integrate power devices with different nature. Using a power module simplifies the design and increases reliability while optimizing PCB size and system costs.

Thanks to its compact package, the ACEPACK DMT-32 can be easily incorporates in the design of a power board, reducing the development time and effort. Its top-side cooling facilitates mounting of a heat sink, and the compact pa. The isolated ceramic substrate ensures higher thermal conductivity and therefore very low thermal resistance, enabling a cost effective cooling system design.

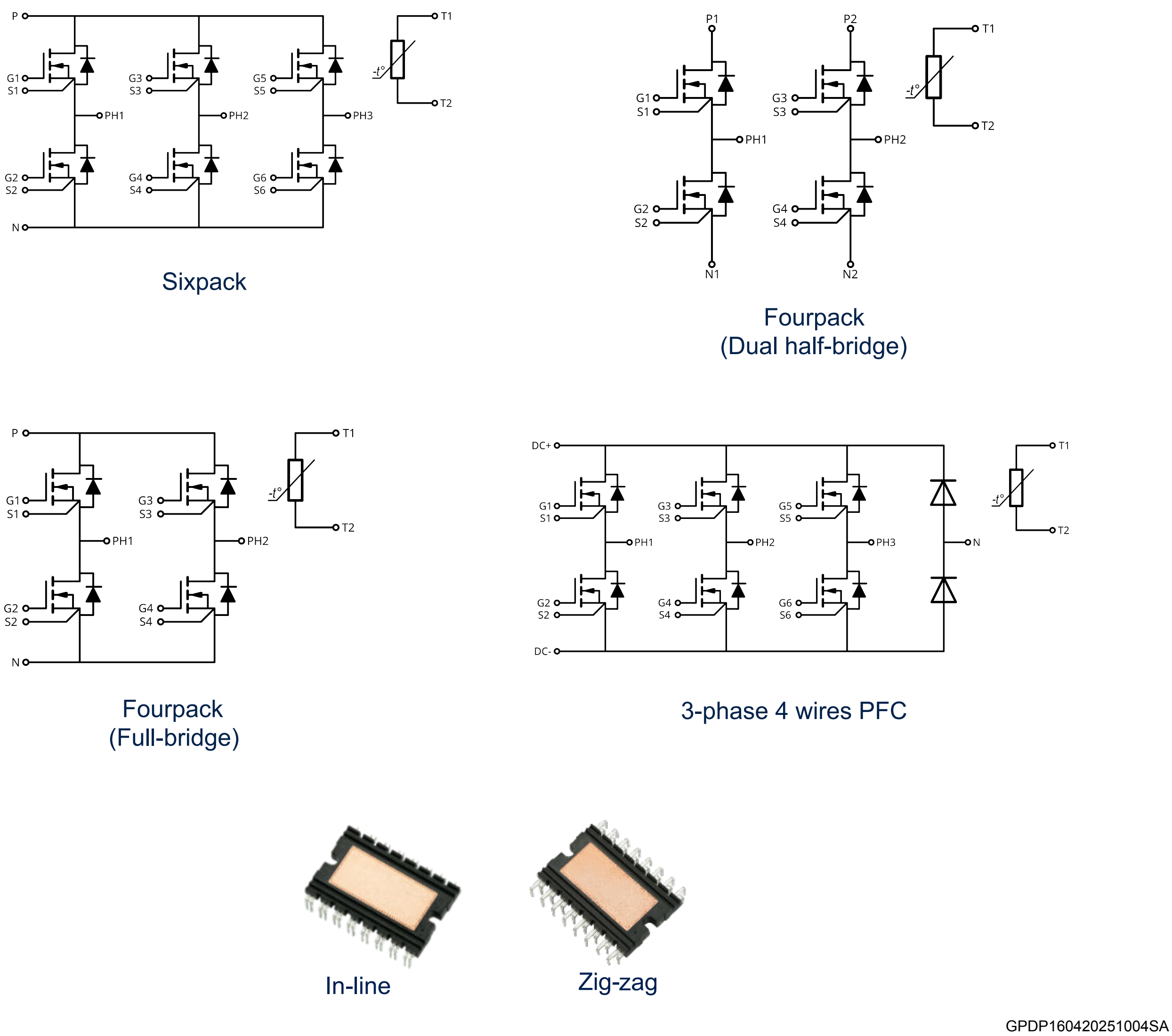
Figure 2. Internal configuration of the ACEPACK DMT-32



2 ACEPACK DMT-32

Many different configurations are possible, currently four configurations are made available:

Figure 3. Available configurations of the ACEPACK DMT-32 module



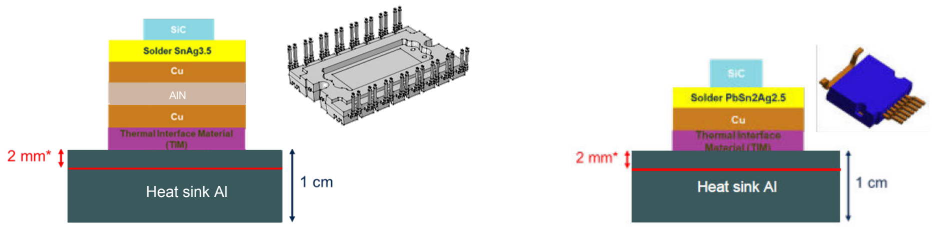
The pin type of the ACEPACK DMT-32 can be "in line" or "zig-zag". The zig-zag pins allow wider solder area and distance between the pin at PCB level.

3 ACEPACK DMT-32 vs HU3PAK thermal performance comparison

The ACEPACK DMT-32 power module features a DBC isolated substrate. At the same time the DBC enables optimal thermal performance, with AlN substrate offering further improvement vs cost-effective Al_2O_3 substrate. Thermal resistance between junction and heat sink (R_{thJH}) comparison between ACEPACK DMT-32 vs discrete solution SMD top-side cooling (TSC) could be done assuming 3 kVac / 60 s voltage isolation level by using the following thermal interface material (TIM) thickness for heat sink connection:

- Discrete top-side cooling (that is, HU3PAK): 600 µm TIM with 3.0 W/m·°C
- ACEPACK DMT-32 power module: 50 µm TIM with 3.0 W/m·°C as voltage insulation is matched thanks to ceramic substrate.

Figure 4. Heat sink assembly according to ACEPACK DMT-32



Based on R_{thJH} thermal simulation, the following comparison could be made:

- ACEPACK DMT-32 with AlN based substrate features a 58% reduction vs HU3PAK.

Thermal simulation conditions:

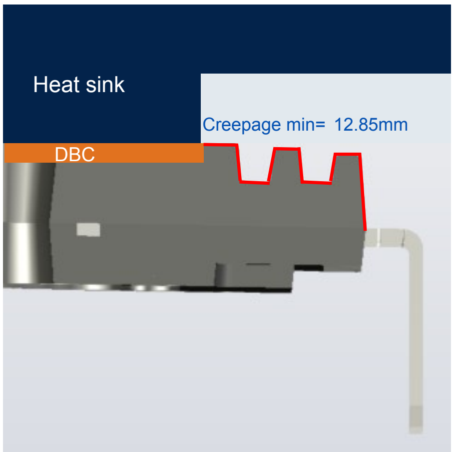
- Convection constraints: heat sink backside heat transfer coefficient: 10000 [W/m^2°C] (T_A = 50 °C).
- Heat sink: Al, x = 15 cm, y = 13 cm, z = 1 cm
- TIM λ = 3.0 W/m·°C
- Simulation tool: COMSOL Multiphysics 6.1
- Related power applied: value set to obtain T_J max. = 150 °C

4 Creepage and clearance

The creepage distance is defined as the shortest distance along the surface of a solid insulating material between two conductive parts. Thanks to the grooves specifically designed on the molded surface, the ACEPACK DMT-32 ensure higher creepage.

The figure below shows the minimum creepage of 12.85 mm, defined as the minimum distance guaranteed and to be considered as a reference for the heat sink positioning. The creepage distance is depicted with the red line.

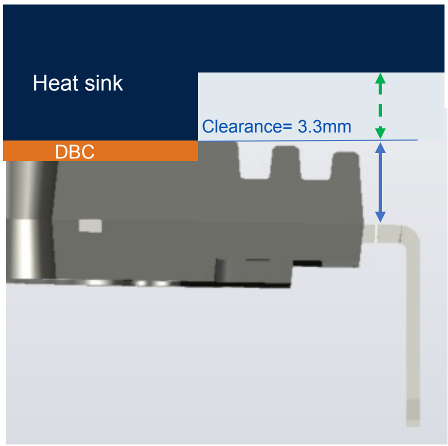
Figure 5. Creepage distance allowed



The clearance distance is defined as shortest distance in air between two conductive parts. The clearance distance, referred to the shoulder of the pin and the top of the groove is 3.30 mm, considered as typical value. This represent the typical distance at which a generic heat sink can be located.

In the figure below it is highlighted the typical clearance can be guaranteed, considering the surface of a heat sink on the top of the DBC substrate. This is represented by the solid arrow in blue. Additional clearance distance can be achieved by specific design of the heat sink, that is as indicated in the figure below by the dashed green arrow.

Figure 6. Clearance distance allowed



5 Mounting instructions for the ACEPACK DMT-32

When attaching a heat sink to an ACEPACK DMT-32, make sure not to apply excessive force to the device for assembly. Drill holes for screws in the heat sink exactly as specified. Smooth the surface by removing burrs and protrusions of indentations.

Table 1. Recommended mounting instructions

Item	Condition		Min.	Typ.	Max.	Unit
Mounting torque	Mounting screw: M3	Recommended 7 kgf·cm	4	7	8	Kgf·cm
		Recommended 0.69 N·m	0.39	0.69	0.78	N·m
Device flatness	See TN1393 - Figure 1. Device flatness specification		0		+120	µm
Heat sink flatness (1)	See TN1393 - Figure 2. Heat sink flatness specification		-20		+20	µm

1. *In case of mounting torque of 0.69 N·m, the related heat sink flatness min. and max. values are -30 µm and +30 µm.*

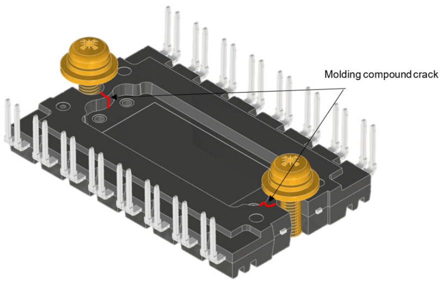
ACEPACK DMT-32 is an indirect cooled molded module.

To attach the power module to a heat sink, it is recommended to follow the following steps:

1. Apply thermal-conductive grease over the contact surface between the module and heat sink, also useful for preventing the contact surface from corrosion.
2. Tighten the screws in two steps, avoiding cracking of the ceramic or molding compound, following the recommended torque and speed of 200 rpm max.
   – Temporary fastening both screws by applying a mounting force of 0.2 / 0.3 N·m.
   – Permanent fastening by applying a mounting torque of 0.69 N·m.

   Since the thermal pad is isolated, an electrical isolation may not be necessary; Thermal interface material (TIM) often increases the thermal resistance to the heat sink.

Figure 7. Molding compound crack



All mounting screws should have washers and spring washer for best mounting results. It is recommended to use SEMS screw (included spring/plain washer M3) as shown in the following figure.

Figure 8. SEMS screw (size M3, spring washer 5.0Φ, plain washer 7.5Φ)

Related links

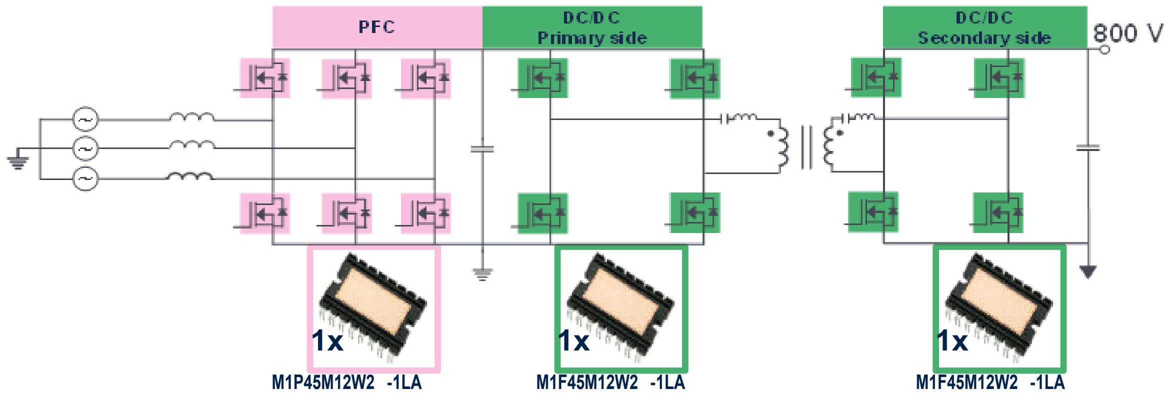
TN1393: Mounting instruction for STPOWER module ACEPACK DMT-32

6 Electronic design of an on board charger

There are many configurations available to reach the design goals of an OBC. Below is an example of a three-phase OBC, consisting of a three-phase power factor correction circuit (PFC), followed by a full-bridge CLLC DC-DC converter.

The PFC is implemented with a sixpack ACEPACK DMT-32, while the DC-DC converter has two fourpack ACEPACK DMT-32. All switches applied are 1200 V SiC MOSFETs with a typical $R_{DS(on)}$ of 45 mΩ. The sixpack and fourpack ACEPACK DMT-32, have a thermal resistance of R_{thJC} = 0.38 °C/W. These ACEPACK DMT-32 modules ease the design by replacing 14 discrete power switches by three ACEPACK DMT-32.

Figure 9. The modules placed in-line



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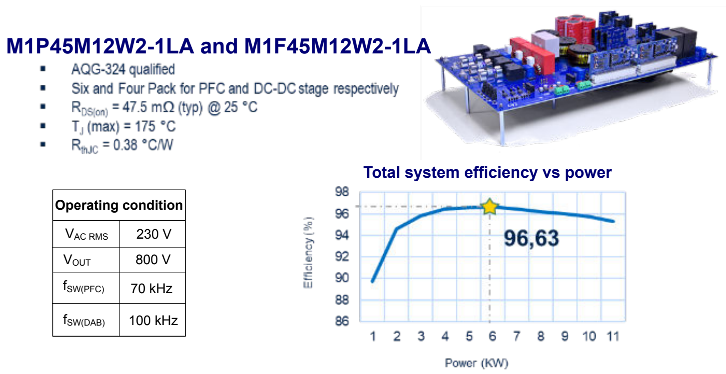
STMicroelectronics has developed a complete design example, based on this topology in STDES-BCBIDIR, which is available on www.st.com, and explored in the following pages.

Figure 10. STDES-BCBIDIR complete design



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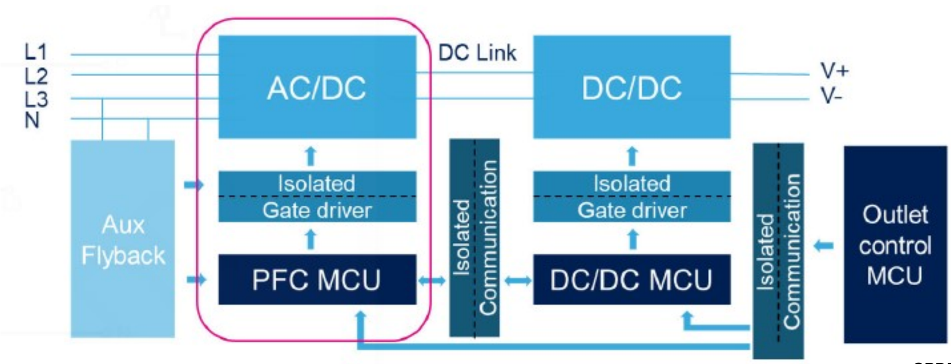
7 STDES-BCBIDIR

The STDES-BCBIDIR represents a complete bidirectional solution for high-voltage battery charging in both the industrial and automotive fields. The converter consists of two power stages: a PFC and an isolated DC-DC. The active front end (AFE) rectifier stage (PFC) is based on a three-phase full bridge. The DC-DC section can be configured as dual active bridge (DAB) or CLLC topology.

Figure 11. DC charging station



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The 3-phase input of 400 Vac, 50 Hz, goes through the active front end PFC and boosted up to 800 Vdc. Its power is rated for 11 kW. The achieved power factor is higher than 0.99, with less than 5% THD. The maximum efficiency, at 7 kW, is measured just above 98%, while being 97.8% at full load.

When used as an inverter, the efficiency is slightly higher, 98.1%, and 97.9% resp.

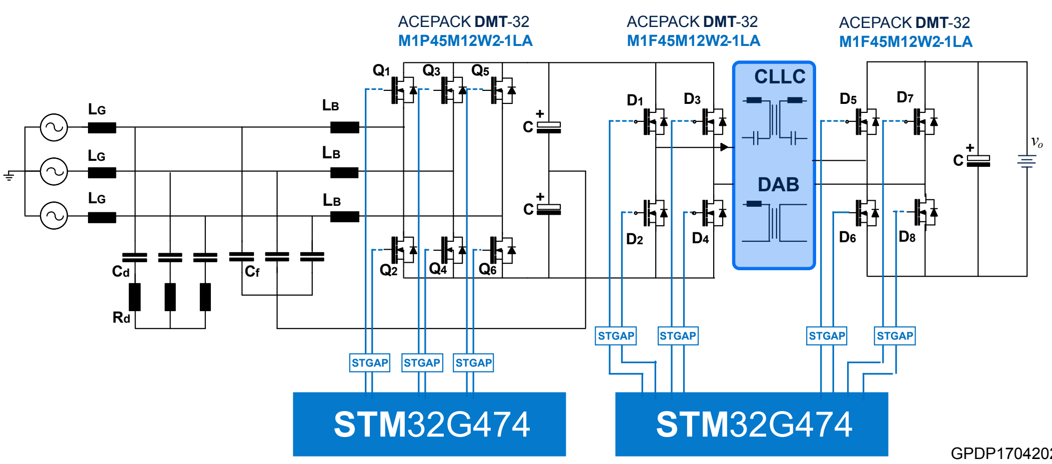
The switching frequency of the AFE is standard set to 70 kHz. This maximum limit is chosen to remain just below the minimum frequency of the mandatory conducted emissions measurements, according to the CISPR standards.

By default, the second stage is configured as a dual active bridge (DAB), which provides a 1:1 isolation between in- and output. Its switching frequency is set to 100 kHz, it is therefore advisable for the AFE not to come too close to this 100 kHz to prevent subharmonic interferences. Since the DAB is implemented as a symmetrical topology, the performances of forward and reverse operation are very close. The efficiency is designed to have its peak at 4 kW, at about 98.8%, while its full-load efficiency reaches 97.5%.

For the complete design, at 6 kW the measured efficiency was 96.6%, while 95% is achieved at full-load.

The complete power path is described in the following schematics:

Figure 12. Block diagram



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The AFE is implemented after some filtering, starting with boost inductors Lb, and a half-bridge. The three half bridges required for a three-phase front end, are implemented through a sixpack topology ACEPACK DMT-32, designated as M1P45M12W2-1LA. The module employs 45 mΩ / 1200 V, second-generation silicon carbide MOSFET switches.

The DC-DC converter part is covered by two fourpack modules M1F45M12W2-1LA. These modules also employ 45 mΩ, 1200 V, 2^{nd} generation SiC FETs.

Both modules are automotive qualified according to AQG 324, have a maximum junction temperature of 175 °C, and have an integrated NTC, to control the temperature. The isolation of the thermal pad is rated for 3 kV, and the main DBC structure is Cu-AlN-Cu to provide optimum thermal performance.

Related links

M1P45M12W2-1LA: Automotive-grade ACEPACK DMT-32 power module, sixpack topology, 1200 V, 47.5 mΩ typ. SiC Power MOSFET with NTC

M1F45M12W2-1LA: Automotive-grade ACEPACK DMT-32 power module, fourpack topology, 1200 V, 47.5 mΩ typ. SiC Power MOSFET with NTC

Revision history

Table 2. **Document revision history**

Date	Revision	Changes
15-Sep-2025	1	First release.

Contents

List of figures