Application Focused Power Semiconductor Module Design for Hybrid Electric Vehicles

According to market surveys, the market share of hybrid electric vehicles in 2020 is predicted to be between 5 and 18%. Drivers for the different scenarios are environmental issues and energy concerns, as well as technological improvements. Only by developing more efficient components (batteries, motors and power electronics) will it be possible to grow the market for hybrid electric vehicles above 10%. Advances in power semiconductor modules, as well as application focused designs, are a key success factor. This article discusses the requirements for different hybrid systems and how they are addressed in the design of Infineon's HybridPACK family. **M. Münzer, Dr. M. Thoben, A. Christmann, A. Vetter, B. Specht, Infineon Technologies, Germany**

The term hybrid electric vehicle (HEV) describes a vehicle which uses a combustion engine in combination with one or more electric motors for the propulsion system. To distinguish different types the level of hybridisation and the system architecture can be used (Figure 1). The level of hybridisation describes the function that can be fulfilled with the electric motor. It has a direct influence on the necessary power levels, as well as the suitable system architecture. The system architecture describes how the hybrid function is realised. Which solution is suited best depends mainly on the size of the vehicle and the drive cycle. For passenger cars micro parallel, mild parallel and full power split types are state of the art.

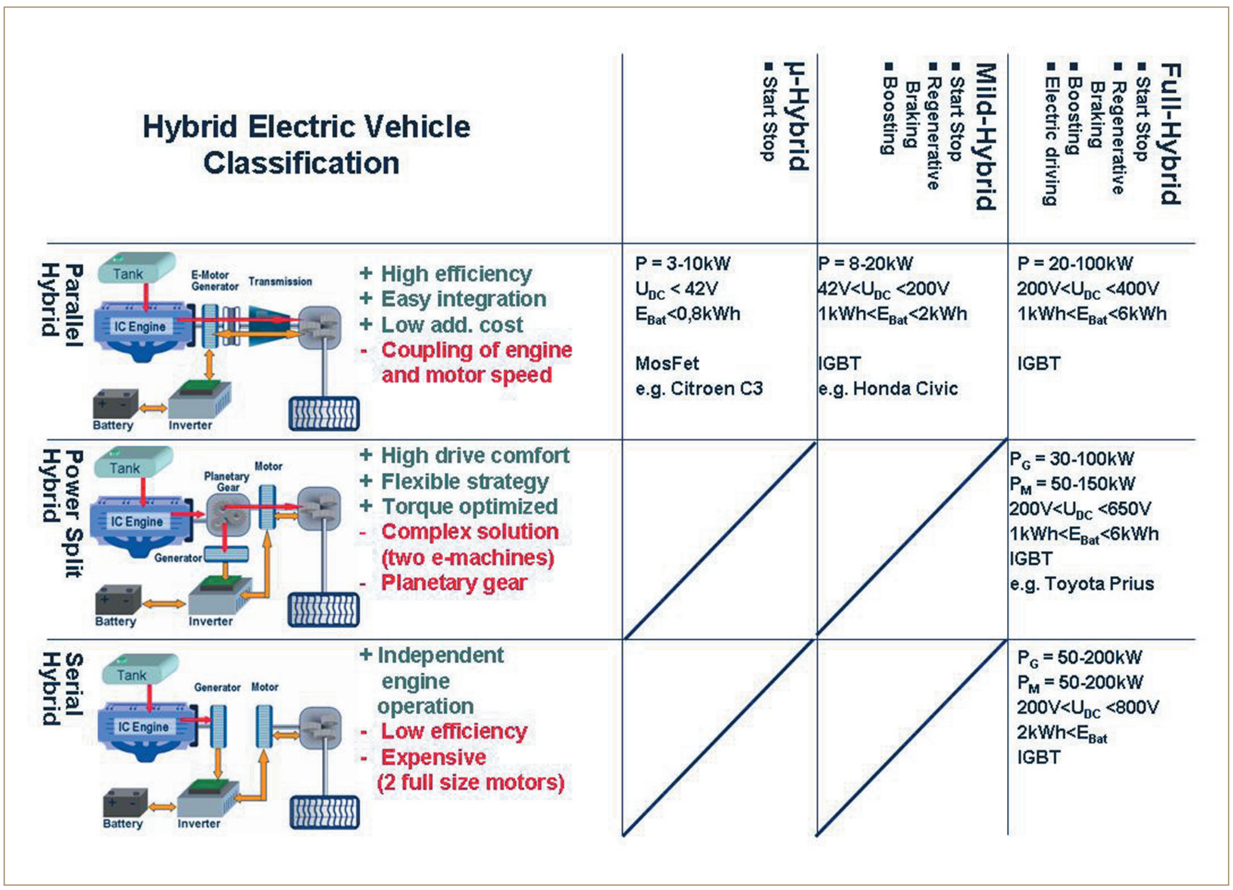

Figure 1: Classification of hybrid electric vehicles

	Mild Hybrid (Trunk mounted air cooled)	Full Hybrid (Transmission mounted liquid cooled)
Power rating	15-20kW	60-80kW
System voltage	80-220V	280-420V
Ambient temperature	-40 – 85°C	-40 – 125°C
Coolant temperature	-40 – 65°C	-40 – 105°C
Thermal shock	High	Very High
Power cycles	Medium	High
Mechanical Shock	50g	400g
Vibration	5g	20g
Cost pressure	Very high	High
Infineon Solution	**HybridPACK1**	**HybridPACK2**

Table 1: Requirements to power electronics for different hybrid electric vehicle systems

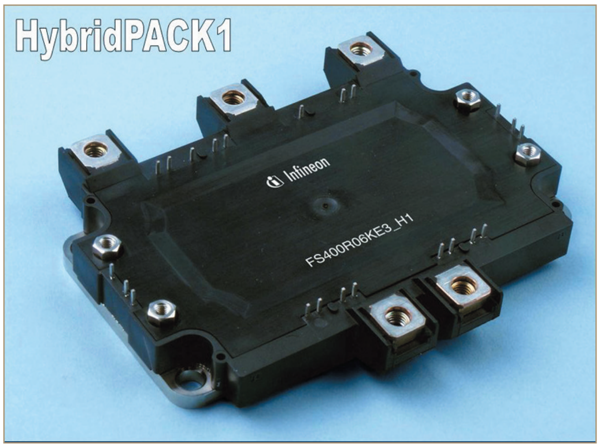

Figure 2: HybridPACK1 for mild hybrid electric vehicles

In the micro parallel hybrid, the starter and alternator of the vehicle are replaced by an integrated starter alternator. As only the start-stop function has to be realised, the influence of the hybridisation on the vehicle is minor. The fuel consumption of the vehicle, however, can be improved by up to 10% with a micro hybrid system. A mild parallel hybrid is also capable of boosting and regenerative braking. To realise these functions, more power and therefore higher voltage is necessary. In addition, the brake system, as well as the whole power train, has to be adapted. A mild hybrid system can improve the fuel economy of a vehicle by 15%. To enable electric driving, it must be possible to mechanically decouple the engine from the wheel. This, and the fact that the electric machine can be dimensioned differently for generating and motoring mode, led to the development of the power split architecture. Fuel consumption can be reduced by 25% with a full hybrid.

Requirements of power electronics in hybrid electric vehicles

For the end customer of a vehicle, it is important to have the same performance at lower total cost of ownership when buying a hybrid electrical vehicle compared to a conventional vehicle. The cost calculation is influenced by the additional vehicle costs, oil prices, average mileage per year, fuel consumption and its improvement. When analysing the cost performance data, it becomes clear that for big vehicles a higher price can be paid to achieve the maximum gain in efficiency. For smaller vehicles, the additional costs have to be kept at a minimum as the improvements in efficiency will not pay for these.

Besides cost and performance, quality is a major topic for HEV power electronics. Although expected quality level and lifetime are the same for all components, the environmental stress that determines the requirements for each component might be very different. As with most automotive components, the requirements for power semiconductors vary between different mounting places and cooling conditions. A power semiconductor module that is mounted on a forced air-cooled heatsink in the trunk will experience less vibration and thermal cycles over the expected lifetime than a transmission mounted power semiconductor module that is cooled by the engine coolant. In terms of thermal resistance, liquid-cooled systems show significantly better behaviour than air-cooled systems. Due to the low losses, mild hybrid systems can still be cooled with forced air-cooling. Full hybrid systems need liquid-cooling to dissipate the power. Table 1 compares the requirements of the power electronics for a trunk-mounted air-cooled mild hybrid system and a transmission mounted engine coolant-cooled full hybrid system.

Chip technology and power module outline

To improve the efficiency of a hybrid drive, it is important to reduce the losses in the power semiconductor. HybridPACK1 and HybridPACK2 are equipped with the newest generation of 600V IGBT^3 and EmCon Diode. Due to the trench fieldstop, concept these chips generate significantly lower losses than other power semiconductor chips of equivalent size. Besides the influence of the losses on the efficiency of a hybrid drive, they also directly influence the cost of the system especially the expenses for cooling and necessary silicon area.

The losses generated in the silicon heat up the device. To keep the chip temperature below the maximum allowable junction temperature, a significant effort in cooling has to be spent. To minimise the cooling effort, not only the losses can be reduced ,but it is also of interest to increase the maximum allowable junction temperature. With the introduction of 600V IGBT^3, the allowable junction temperature has been raised by 25°C to 150°C operational and 175° maximal.

HybridPACK1 and HybridPACK2 have the same basic construction. The chips are soldered onto a metallised ceramic substrate. To connect the top side of the chips, an improved wire bonding process that enhances the power cycling capability by a factor of two is used. The substrates are soldered to the baseplate and a plastic frame applied for external connections. The power terminals are designed for screw connections, while the auxiliary terminals are of the solder type. For easier inverter design, the DC inputs and AC outputs are placed on opposite sides of the module. The driver board can be placed on top of the module (see Figure 2).

To enable a 20kW mild hybrid application on a forced air-cooler HybridPACK1 can be equipped with a maximum of two 200A dies per switch (FS400R06A1E3). Each phase is built up on its own DBC. For over-temperature protection, an NTC is placed on the middle one. Due to the high cost pressure for mild hybrid applications, expensive materials had to be avoided. Utilising a new improved Al_2O_3 substrate material in connection with a dedicated solder process which uses spacers to guarantee a homogenous and optimised solder thickness, HybridPACK1 can fulfill the thermal cycling requirements of the application with a 3mm stamped copper base plate. The smallest possible form factor (baseplate size 139mm x72mm) in combination with low cost materials makes HybridPACK1 a cost optimised solution for mild hybrid applications which are based on low coolant temperatures.

HybridPACK2 (see Figure 3) is

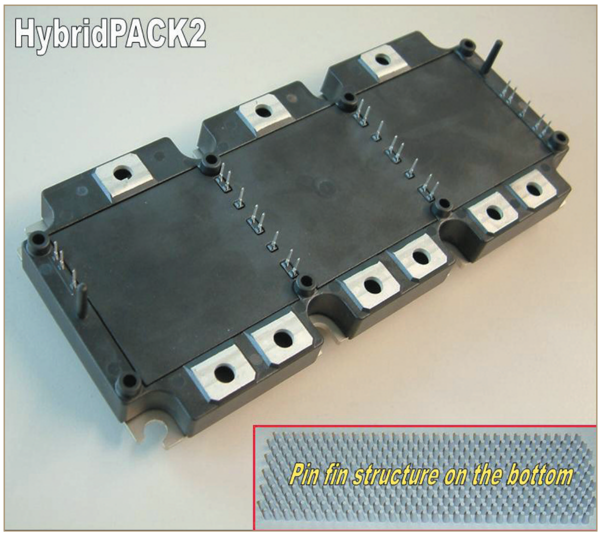

Figure 3: HybridPACK2 for full hybrid electric vehicles

designed for liquid-cooled full hybrid applications. To avoid an additional coolant loop, the losses generated in the silicon have to be dissipated into the engine coolant. The maximum coolant temperature, as well as the severe cycling, asks for different solutions than those of HybridPACK1. To minimise the thermal resistance between the dies and the coolant, a pin fin baseplate for direct liquid cooling was chosen. The increased thermal cycling requirements for HybridPACK2 can be met with a combination of AlSiC baseplate and Si_3N_4 DBC. With up to four 200A dies per switch (FS800R06A2E3) in the HybridPACK2 housing, it is possible to build an 80kW inverter based on a liquid cooler with engine coolant.

Conclusion

With the introduction of the HybridPACK family, Infineon has developed two new power semiconductor modules which have been specifically designed for hybrid electric vehicle applications. Variations in the requirements for mild and full hybrid applications have been taken into account for each design. HybridPACK modules, therefore, support cost optimised inverters with the highest efficiency at the smallest form factor for the individual target application.

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