Power Semiconductor Solutions for Micro-Hybrid Systems

Current CO_2 discussion and the need for the higher efficiency lead to the highly growing market share of the hybrid automotive systems. One of the significant agenda points is so-called micro-hybrid cars. In those cars, the alternator is used also as a starter and the braking energy, or at least some part of it, is recuperated by the battery. The belt-driven micro-hybrid systems operating on a 14V board net are easy to integrate into the existing cars, both mechanically and electrically. The most important task in the alternator mode of operation is to maximise the efficiency of the electrical energy generation. Modern generators have typical efficiency of around 70%. Diodes in the classical rectifier bridge cause 38% of generator losses. **Dr. Ing. Dušan Graovac (Senior Staff Engineer, Automotive), Benno Köppl (Principal Engineer, Powertrain Systems), Frank Auer (Director, Powertrain Systems), and Michael Scheffer (System Expert Powertrain Systems), Infineon Technologies, Neubiberg, Germany**

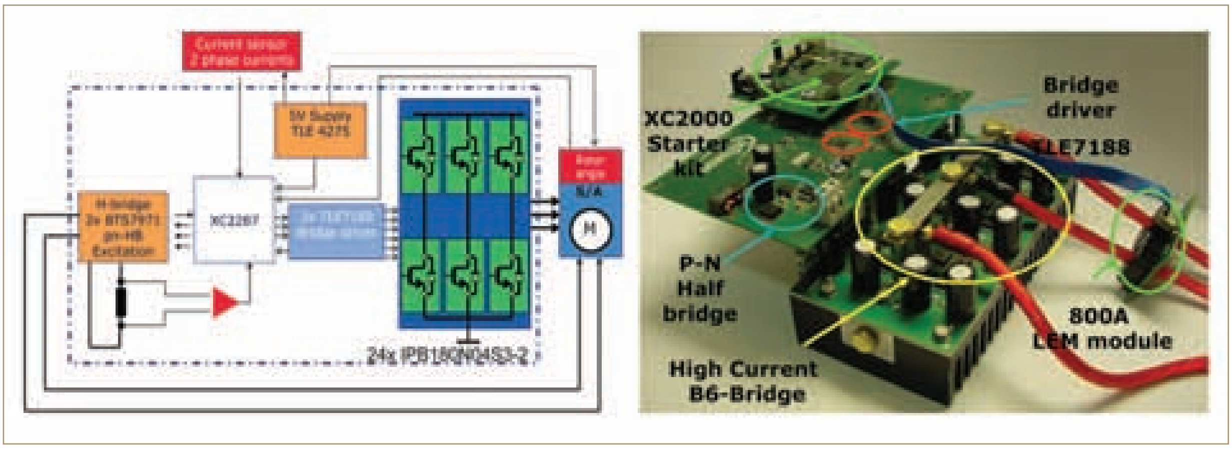


Figure 1: **Infineon's solution for a micro-hybrid ECU**

A simplified block diagram of a belt driven starter-alternator electronic control unit (ECU) and the appropriate system demonstrator are shown in Figure 1. It consists of the Lundell alternator, three- or six-phase inverter with power MOSFETs and a bridge driver, micro-controller for motor control during both starting and generation mode, H-Bridge for excitation control and different sensors.

Compared to a classical alternator with diode rectification, the efficiency of the complete system, including generator, is improved for at least 6%. With alternator modifications efficiency improvements of more than 10% are realistic. Another significant advantage is the increase of the available generator current at low speed of around 40%.

Figure 2 illustrates a load dump behaviour of the proposed alternator control in a so-called 'loss of battery' situation. It can be seen that when dumping the 100A load, the over-voltage peak remains below 25V and has a very short duration of below 5ms. Compared with classical load dump condition, which vary between 32 and 45V for 400ms, this concept brings significant advantages.

Application requirements on power semiconductors

The hardest requirements in a micro-

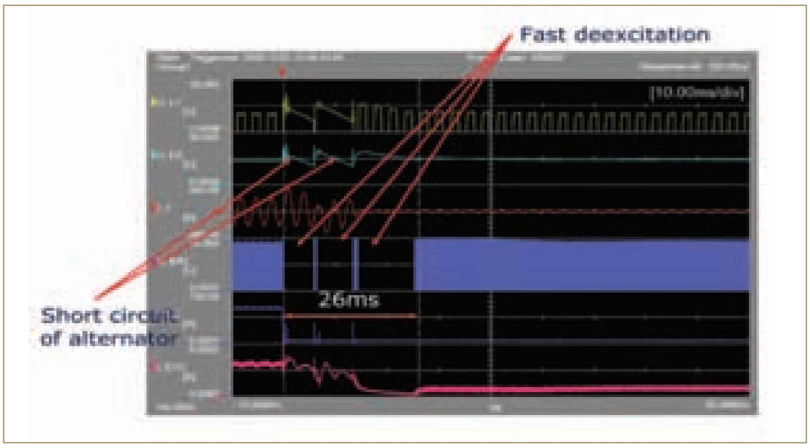


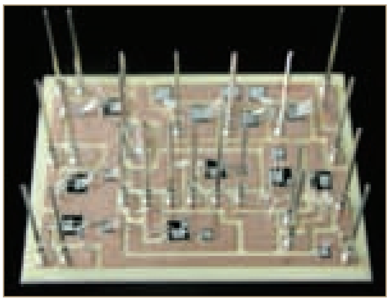
Figure 2: **Load dump minimisation**

hybrid system are set for power MOSFETs and modules. Very high currents (600A) and the need for low voltage drop and high efficiency require very low R_{dson} value and also low values of both the gate-charge (important for the bridge driver current capability) and gate-to-drain charge (important for the minimisation of the switching losses). Modern low voltage MOSFETs are based on trench cells. The Infineon trench concept, compared to the classical trench, enables further reduction in R_{dson}, gate-to-drain charges, gate resistance and is more robust against the parasitic turn-on which could be triggered with high du/dt transients. New 40V generation introduces first sub milli-ohm MOSFET ($R_{dson\_}max<1m\Omega$). In order to achieve high currents using standard 7pin D²PAK, a PowerBond bonding technology is used. This approach enabled achieving of a true 180A DC current capability of a D²PAK with the package resistance reduced to 0.3mΩ only.

Semiconductor devices in the micro-hybrid application are placed in the engine compartment with an additional goal of integrating both the power electronics part, as well as the control circuitry into the alternator. Thus, they have to deal with both severe temperature cycles and high junction temperatures. An ECU has to withstand 600,000 internal combustion engine (ICE) starts over 17 years without failure, together with additional thousands of operating hours in generator mode.

Although it is possible to design an ECU based on discrete MOSFETs mounted on insulated metal substrate (IMS), as done previously with the system demonstrator, very high current and power densities, integration in the generator housing and reliability/lifetime requirements can be achieved only by using the power module with a ceramic substrate (DCB – direct copper bonding). Compared to IMS, DCB offers lower thermal resistance (R_{th}) by the factor of 2 to 4.

Figure 3: **Cost savings through modules without a baseplate**



The classical build-up of a power module with a copper baseplate, from automotive point of view, is bulky and expensive for micro hybrid vehicles. For that reason, power modules without a baseplate are often used in automotive applications. One module of this type is shown in Figure 3. To withstand high electrical and thermo-mechanical stress, interconnections inside the power module have to be as strong as possible. The failure mechanisms for standard modules due to thermal load changes are bond wire lift-off, delamination of the upper side copper layer, and solder cracks.

The main cause of these failures is different heating of the individual areas/layers and the different thermal expansion coefficients of the materials used in the inside the power module. This also shows the importance of the proper material choice for the module lifetime.

The driver IC is the interface between the microcontroller and the MOSFETs. As the microcontroller delivers the control signals, the driver IC level-shifts, amplifies, and buffers the control signals to provide the necessary gate charge for the power stage. In addition, the driver IC incorporates protection functions and functions to reduce the external part count and cost. It also allows operation at very low battery voltages during ICE starting. In addition to that it should be noted that over-current, shoot-through, under-voltage and over-voltage protections are necessary.

Future outlook

In the power MOSFET technology, further minimisation of both R_{dson} and gate charges is expected, together with the increase in temperature capability. Changing the maximum allowable junction temperature of the power semiconductor will directly change the thermal stress on the interconnection of the chip surface. A typical wear-out effect at the chip surface is the wire bond lift off. To test this interconnection, power cycling tests are performed. The number of cycles that a device survives is related to the temperature swing, the maximum temperature and the slopes. The wire bonding process for power modules has already been improved from standard wire bonding to the Infineon new generation wire bonding (Figure 4). For future designs results of the low temperature joining process (LTJT) are very promising. Further innovation comes from the field of drivers, microcontrollers and sensors. In the development, there is a rotor position sensor based on iGMR (integrated giant magneto resistance) technology.

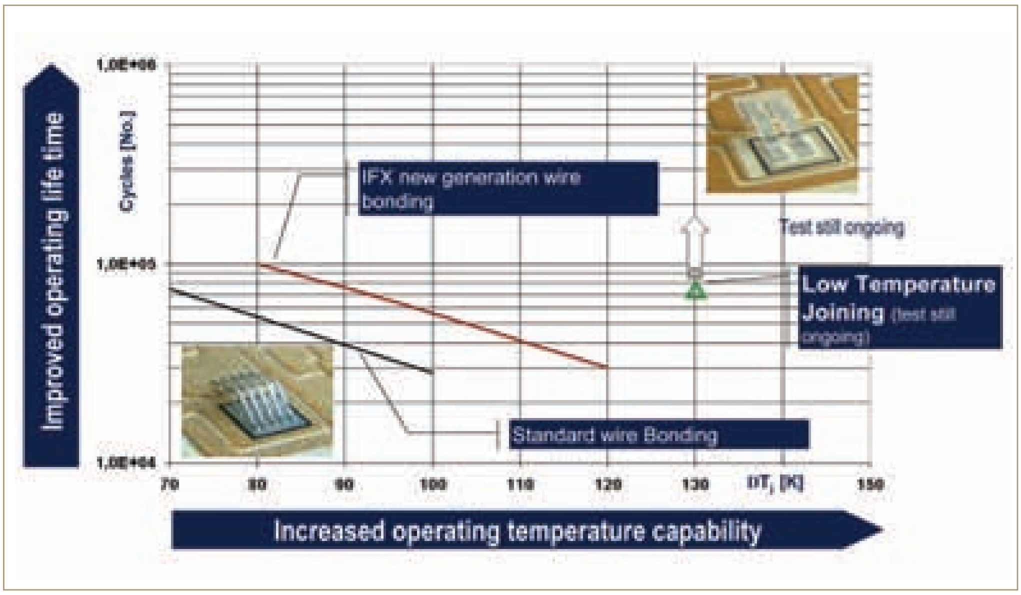


Figure 4: **Improvement of power cycling capability as a result of new interconnection technologies (LTJT)**