AN1597
APPLICATION NOTE

HIGH CURRENT POWER MODULES FOR AUTOMOTIVE USING Max247™ PACKAGE WITH IMS SUBSTRATE

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1. ABSTRACT

Hybrid Electric Vehicles (HEVs) combine the internal combustion engine of a conventional vehicle with the battery and electric motor of an electric one. This combination offers the extended range and rapid refuelling that consumers expect from a conventional vehicle, together with a significant portion of the energy and environmental benefits of an electric vehicle.

The practical benefits of HEVs include improved fuel economy and lower emissions compared to conventional vehicles. HEVs are safety critical systems and demand high standards of safety and reliability. At the same time high power cost-effective power switches are required. But until now, the high power switch portfolio has not been well suited for automotive applications: cost is high and reliability characteristics are not the desired ones.

An innovative technique is proposed to design and manufacture power electronic modules, using high performances cost-effective IGBTs assembled in plastic package. This technique allows optimizing both the power switching devices and the converter, in terms of power handling, reliability and cost. This design is well adapted to mass production required by automotive applications.

2. Introduction

The serious deterioration of urban air requires cleaner cars. HEVs will reduce smog-forming pollutants over the current average. However, hybrids will never be true zero-emission vehicles because of their internal combustion engine. But the first hybrids on the market will cut emissions of global-warming pollutants by a third to a half, and later models may cut emissions by even more. More efficient cars can make a big difference to society in terms of environmental benefits.

The ecological objectives include fuel economy improvement, green house effect reduction, polluting gases emission reduction and pure electric mode within town centers. Additional targets for improved driving comfort are: stopping and starting the motor at traffic lights, increasing the electric power when the vehicle starts or changes gear, and applying continuous torque to the wheels.

Figure 1: Basic Architecture of a Parallel HEV

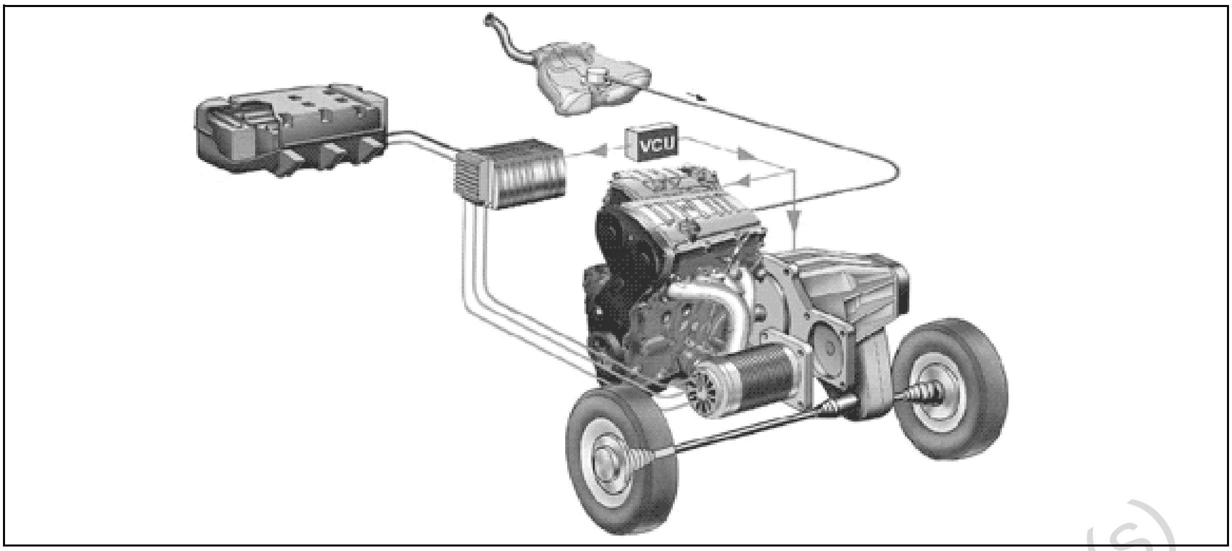
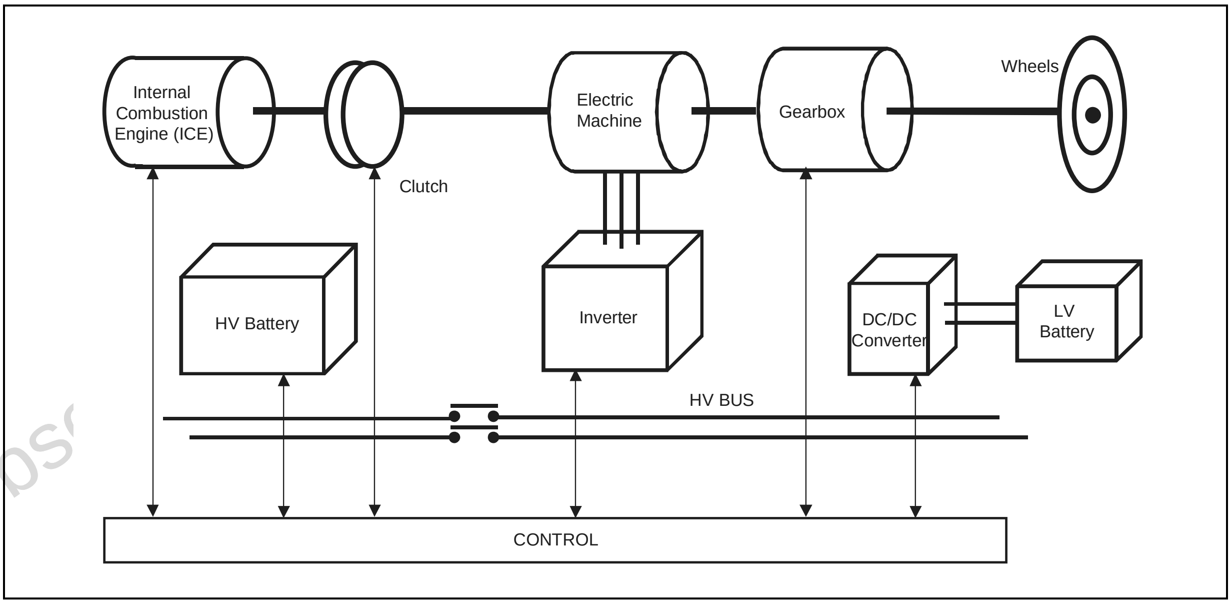


Fig.1 depicts the basic architecture of a parallel HEV. Parallel means that the mechanical power of ICE and that of the electric motor are added in parallel to provide torque to the wheels. For a short distance, pure electric mode is possible. For a long distance, ICE provides the necessary autonomy. When a peak transient torque is required to boost the vehicle, the two torques are added.
Fig. 2 reports the functional schematic.

Figure 2: Functional Schematic of a Parallel HEV



The suggested improvement has been obtained in the inverter block which houses the active switches required to drive the electric motor.

Main goals for power electronic equipment in electric vehicles are: low cost, high reliability and low total volume. It is a true challenge. In terms of cost and reliability, there is a huge gap between low-cost and highly reliable standard discrete plastic packages for power transistors and costly high power modules. These modules usually exhibit lower reliability due to complex assembly and low volume production.

For surface mount devices, this gap is even larger. Particularly for low-cost applications, module techniques are not suitable. On the other hand high-volume automotive applications require an AQL (Average Quality Level) of < 1 ppm and extremely low-cost devices.

A new surface mount plastic package, using mass-production tooling able to house large dies (ca. 300 x 400 mils^2), will dramatically reduce the package cost. In addition, surface mounting will bring additional cost reduction by lowering the labor cost for assembly and will increase reliability by improving the process control. This assembly technique is modular and gives more independence from module suppliers.

In this paper we show a new module using surface mount technology. The module has been realized thanks to a new specially designed IGBT housed, together with a high-speed diode, in a high-power plastic package. This solution realizes a complete bi-directional current switch component with high reliability and low cost mass production. The complete module, realized with IMS technology using 2 x 8 Max247™ in parallel,it is a 400A, 600V power arm bridge unit for automotive applications.

This work has been developed within the INMOVE (Integrated Modular electric propulsion system for parallel hybrid Vehicles) project founded by EC BRITE EURAM.

3. Overview of the Device Technology

The elemental devices are punch-through IGBTs (PT-IGBTs) with a breakdown voltage of 600V (50 A rated current). The devices belong to the last IGBT generation which are manufactured in the mesh overlay technology, i.e. a strip-based concept realized from a p-doped mesh structure (the body of the IGBT) where directly diffused n+ doped strips substitute the cells, and represent the emitter of the IGBTs.

This particular technological solution allows the IGBTs to be easily made with a reduced on-state voltage drop through a reduction of the on-state resistance (up to 20%). Moreover, the presence of a deep body p+ avoids the trouble of static latch-up, as the resistance of the body extending under the n+ source is reduced.

An improved ruggedness, useful for paralleling connections, has been reached by means of the ballast resistance technique, by using an "H" type layout structure. The cross section of the manufactured device with the ballast resistance is shown in Fig. 3.

The extension of the p+ layer over the metallic contact increases the path of the electron current, thus creating a ballast resistance Rb. During conduction condition, the current through the source of the MOSFET causes, through Rb, a negative feedback on the gate-source voltage, and the gain is consequently reduced.

Figure 3: Cross-section of a robust IGBT with ballast resistors.

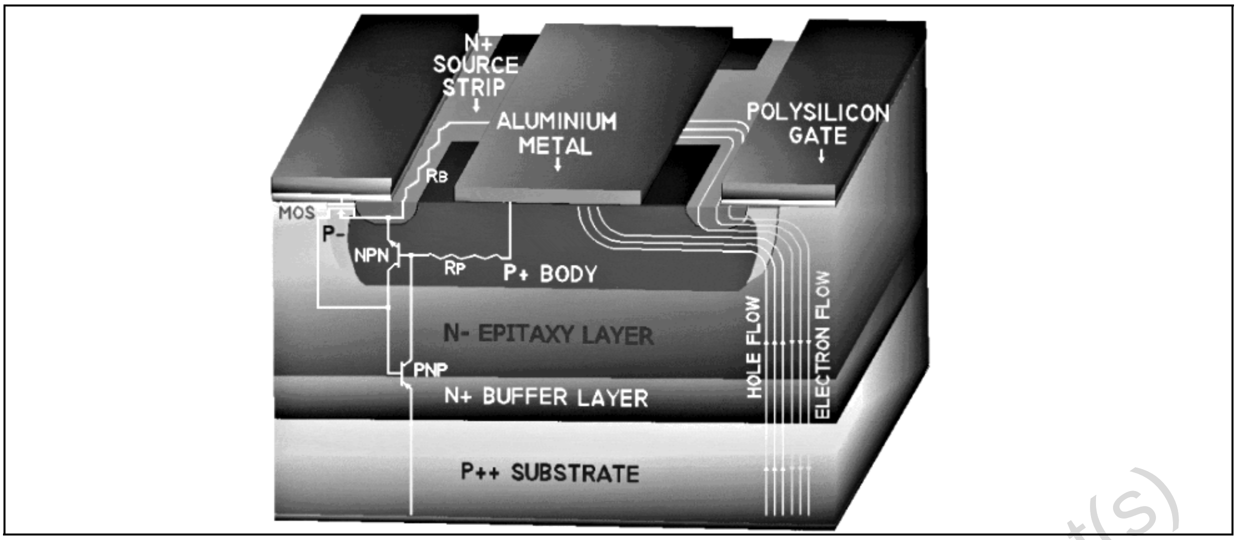


Table 1 summarizes the typical static and dynamic performance of the complete switch (IGBT + Diode) measured at room temperature.

Table 1: STGY50NB60HD typical values

BVdss @ 250µA	650V
Vth @ 250µA	3.5V
Vcesat @ 50A	2.1V
Vfec @ 50A	1.55V
rise time @ 480V,50A	50ns
fall time @ 480V,50A	150ns
Eoff @ 480V,50A	1.1mJ
Irm	7A
trr	60ns

4. 400A Module Design

During the INMOVE project a 600V, 400A power module was designed and built for the converter of the electric propulsion unit according to the guidelines suggested by the investigation carried out on efficiency, reliability, total volume, cooling requirements and cost.

The topology of the inverter is a conventional hard switching B6-configuration consisting of three half-bridges with an internal free wheeling diode. Each half-bridge must be capable of handling up to 600V and 400A.

A viable way to obtain high current switches is to connect in parallel several rather small devices. The design of a power switch able to handle 400A peak current needs the paralleling techniques to be used at different levels: devices, connections (electric, thermal and mechanical), driving circuit. The practical manufacture of such a switch needs various problems to be solved in terms of active switches characteristics, stray inductance equalization, power terminal connections and heat transfer.

The design of a power switch module for 400A, using paralleled devices, needs to determine:
- Selection criteria of devices working together in the same module to obtain a good current and losses share between each component and this for the whole range of the functional area.
- Module structure (switch, bridge-arm, full-bridge) to minimize the parasitic effects due to the paralleling topology.
- Technological elements (electrical isolation, thermal requirements, mechanical ruggedness).

A detailed analysis of all these aspects is reported in Reference 5. The module has been realized according to the obtained results and using STGY50NB60HD devices connected in parallel and assembled on a low cost support like IMS (Insulated Metallic Substrate). Refer to Fig.4 for the electrical scheme.

The main characteristics of the final module are summarized hereafter:
- Size 150 x 83 x 18 mm
- Assembly on IMS substrate BERQUIST THERMALCLAD whose characteristics are:
    - Base layer 3.2mm Aluminium 6061 T6;
    - Dielectric layer 75µm
    - Circuit layer ED copper 140µm
    - Thermal Resistance 0.65 °C cm^2/Watt
    - Capacitance 70 pF/cm^2

- The active switch is the STGY50NB60HD. It is a 600V, 50A fast IGBT assembled with an antiparallel diode in a new Max247 plastic package. The devices are selected, at room temperature, according to ΔVcesat @ 50A < 150mV; ΔVf @ 50A<100mV; Idss @ 600V < 20µA.
- Power connections with screw terminals for each 100A arm, control connections with plug terminals
- An individual 10Ω series resistance is present for oscillation dumping, while a 10KΩ resistor with two 18V zeners, connected back to back, form the gate protection. An individual Kelvin path is required on the emitter for fast driving, while a desaturation sensing connection is used for device over-current protection.

Figure 4: Schematic of 600V, 400A IGBT Module

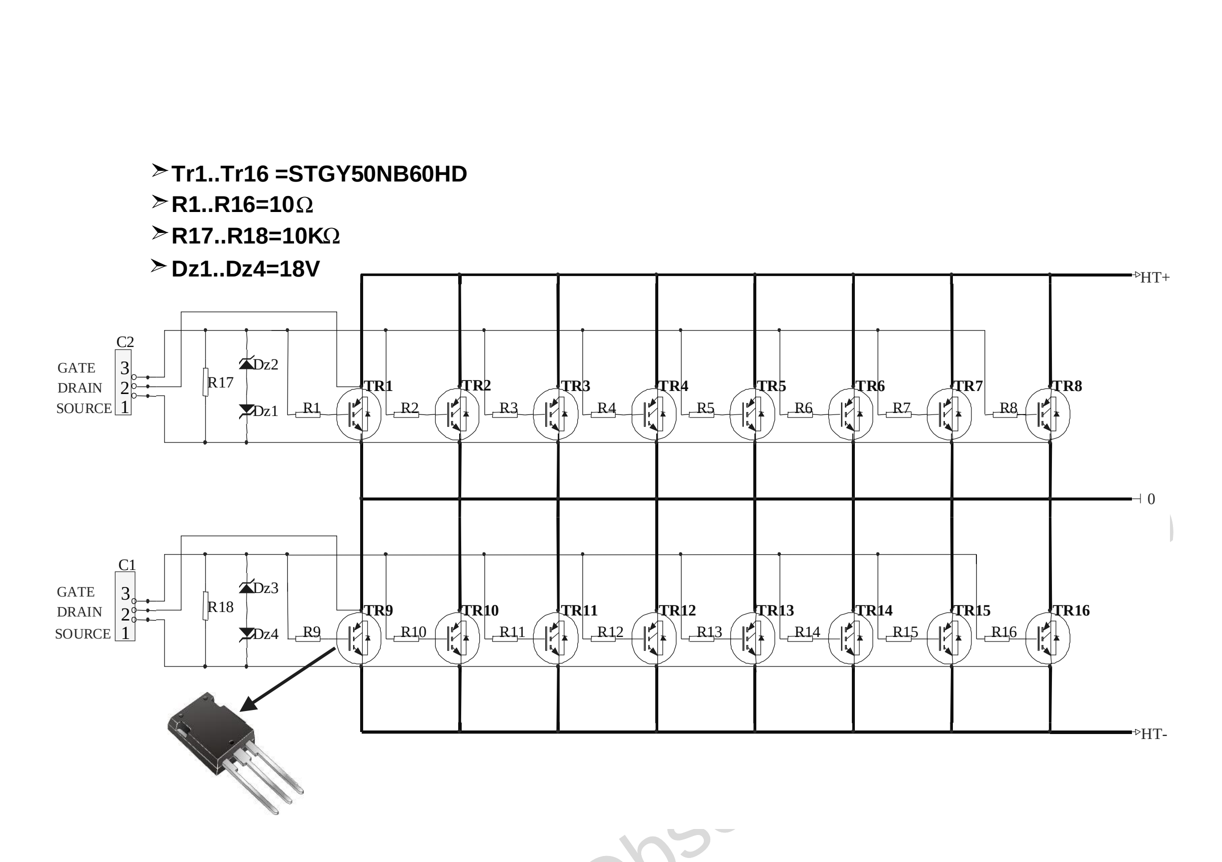


Fig. 5 shows the final assembly: the four 600V, 100A arms will be connected in parallel by a bus bar fixed by screw.

The power module has been electrically characterized at different case temperatures. Table 2 summarizes the values of relevant parameters measured on typical devices. Table 3 reports the thermal resistance.

The application of these new 400A half-bridge power modules has been performed within a power inverter. This inverter controls and supplies a permanent magnet synchronous motor of 30 kW, which serves as additional traction drive for a hybrid vehicle.

Besides the reliability requirement of the automotive application, a cost optimization is also needed. Therefore, it is important to take advantage of the peak voltage ratings of a power module to achieve an economic utilization of device voltage current ratings.

In order to utilize the voltage ratings up to the limit, minus a certain safety margin, a low inductive design of the DC link is required to reduce voltage transients, caused by the IGBT switching, to a minimum. This has been performed by a compact design with short electrical interconnections and a plane busbar (parallel arrangement of two isolated copper layers), that distributes both potentials (+ and -) of supply voltage between buffer capacitors and all IGBT power modules. The inverter has been prototyped within an aluminium housing with integrated water-cooling system in the bottom part.

Figure 5: Photo of the 600V, 400A Power Module Prototype

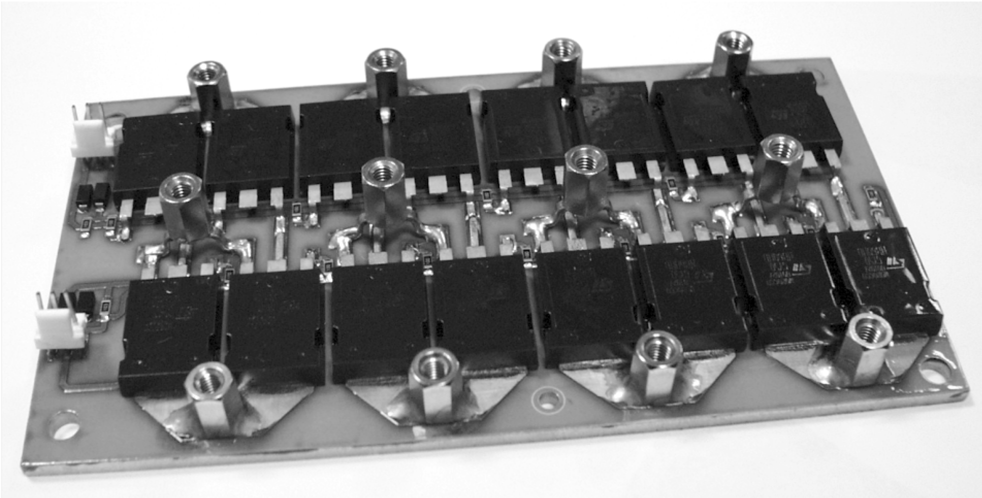


Table 2: Power Modules Relevant Parameters

	25°C	125°C
Vcesat@400A	2.2V	1.9V
Vfec@400A	1.6V	1.5V
Eon@300V,400A	9.8mJ	11.0mJ
Eoff@300V,400A	7.3mJ	14.4mJ

Table 3: Thermal Resistances

Rth	up	down
IGBT	0.107°C/W	0.111°C/W
Diode	0.137°C/W	0.127°C/W

5. Conclusions

In this paper we present a new possibility to realise power modules using standard plastic packaging devices associated in parallel with IMS technology. The main advantages of this new power module design can be summarized especially focusing on the automotive application:

- Low profile design.
- Increased reliability regarding automotive temperature levels (thermal fatigue)
- Vibration and shock requirements
- Flexibility in current ratings without significant tooling costs, (scaleable design: 50A, 100A, 150A,..)
- Cost reduction on custom specific redesigns

A first production cost estimation for quantities of ten thousand parts/year has not yet resulted in a competitive price level, if compared to conventional power modules. Improved reliability may result in slightly increased costs, but subsequent investigations should show cost reduction, especially if production processes for high quantities will be investigated in detail.

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