

Current Shunt Resistors integrated in IGBT Power Modules for Medium Power Drive Application

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Current sensors are required to measure an electric current in an output phase of an IGBT inverter. Depending on the IGBT inverter output power, several solutions are well known today. Shunt resistors, placed on the printed circuit board (PCB) in an inverter design, are popular due to the low system cost and exact current measurement. Due to the losses in the current shunt resistors during operation this solution is limited. Therefore other solutions have to be used for higher power. With a technology that allows placement of current shunt resistors on the base plate in an IGBT module these shunt resistors are as close as possible to the heat sink. In the range up to 35kW shunt resistors may be used for current measurement.

A different and in fact exciting solution is to use the advantage of current shunt measurement in a higher power range where current transducers are utilised today.

To obtain a voltage from the current

Fundamentally a current shunt resistor is a simple component. An electric current flows through a resistive material and an electric voltage drops across the resistance. This voltage is a perfect image of the current which is flowing through the resistor. Of course only if the resistance is constant throughout the temperature range. This is unfortunately not the case.

Not only an electric voltage is formed by the current through the resistance but also power losses are generated in this resistor. The power losses for a DC current are simply calculated as $P=I^2 \cdot R$.

As simple as the DC losses may be to calculate as difficult is it dissipating the heat from a current shunt resistor with rising current. Also losses increase the temperature and with this the resistance. In a nutshell: Shunt resistors able to conduct higher currents have to be cooled.

Therefore the usefulness of current shunt resistors in power electronics applications was technically limited or simply not cost effective.

Current Shunt resistors in IGBT Modules

In power electronics applications, especially in the wide field of frequency- and vector controlled inverters, current measurement is essential. Firstly to detect an over-current or short circuit current and secondly, this current information is necessary for the controller.

While drive inverters below 5,5kW use shunt resistors on the PC-board mainly, inverters with higher power use mainly current transducers to get the current information. The concept to bring the shunt resistors onto the heat sink to dissipate the power losses is not new. But it is realized for the first time in the medium power range in a standard IGBT module package.

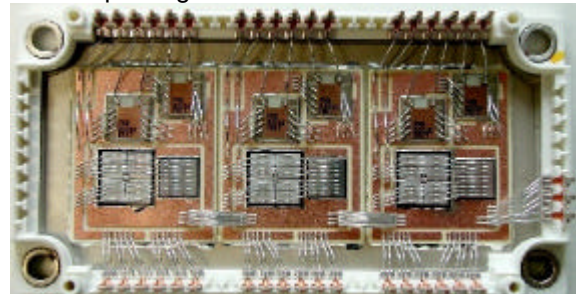


Figure 2: 150A IGBT module with embedded shunt resistors.

The main advantages of these IGBT modules are:

- Shunt resistors for current measurement are placed directly on the heat sink.
- Cost reduction by consistent accuracy of current measurement.
- Save space on PC-board
- Using world wide standard IGBT module package EconoPACK™.
- An optimized heat spread guarantees effective thermal management.
- Equal thermal voltage over all resistors inside the module further improves the accuracy of phase current measurement
- The integrated optionally NTC allows easy and efficient thermal protection
- IGBT³ Trench field stop chip

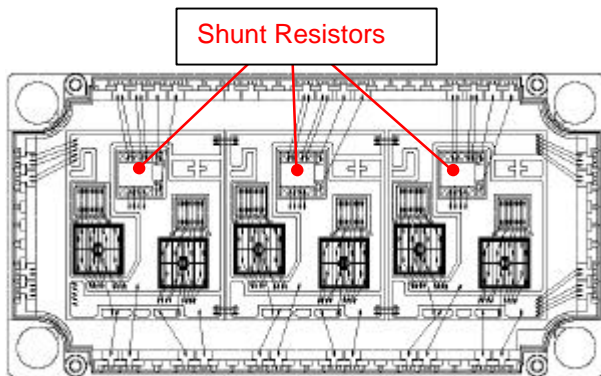


Figure 3: Internal layout of EconoPACK™ Shunt

Precision Resistors:

The shunt resistors used in these IGBT modules are precision resistors with a Kelvin connection.

The resistor elements consist of a solid Manganin foil. This Manganin foil is glued to a copper substrate with an epoxy adhesive. Nickel pads on the surface of this foil allow an electric connection.

The reverse side is covered with 0.2µm gold. Later the reverse side of the resistor is fitted to the IGBT module substrate by a soldering process. This layer composition allows a good thermal contact to the heat sink in order to dissipate the heat from the resistor.

20W load condition capacity per resistor is possible. Depending on the chosen cooling

system a maximum resistor temperature of +140°C is acceptable.

The tolerance of the resistor value is 1%. The inductance of the resistor is less than 10nH (10mΩ value).

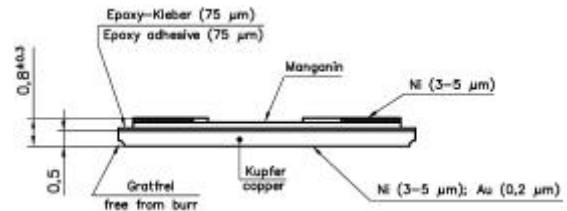


Figure 4: Layer composition of precision shunt resistor

Temperature Coefficient of Resistance (TCR):

The TCR of a shunt resistor is an important parameter when accuracy is required. The TCR of Manganin is not linear and can be either positive or negative for higher temperatures, as shown in Figure 5.

The reference temperature for R₂₀ is 20°C as shown as rated resistance in the datasheet.

The temperature coefficient of resistors is specified in units as parts per million per Kelvin "ppm/K".

A formula may be helpful to translate this accurately.

$$\Delta R(\%) = (T_{\text{operating}} - T_{\text{reference}}) \times \text{ppm}/10^6 \times 100\%$$

The Manganin shunt resistors have a temperature coefficient of <30 ppm/K in the range between 20°C and 60°C.

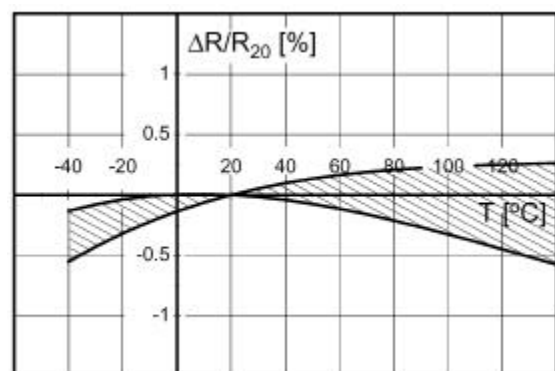


Figure 5: Temperature dependence of the electrical resistance of Manganin-resistors.

Four- Wire Measurement (Kelvin Connection):

In addition to the TCR of the shunt resistor element, copper traces and bond wires in the IGBT Module also have a TCR. The TCR of copper is approximately a hundred times higher than that of Manganin (+3900ppm/°C). A simple two wire measurement is not possible when accuracy is required.

The value of the applied shunt resistors is between 1.2mΩ and 2.4mΩ. The resistance of the bond wires and copper traces inside the IGBT module is in the range of 2mΩ. Connections to IGBT module such as cables and the load like an electric motor have also a resistance which changes with the temperature.

A four-wire Kelvin resistor solves this problem.

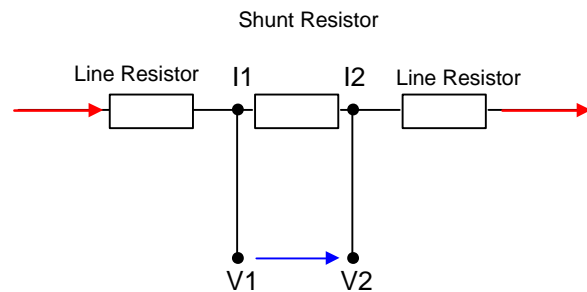


Figure 6: Four-wire resistor with Kelvin sense leads.

As shown in figure 6 and 7 the load current is flowing through the shunt resistor points I₁ and I₂. Two extra connection points V₁ and V₂ are for the voltage measurement. A measurement system with a high impedance connected to the sense leads V₁ and V₂ guarantees that only the measured voltage drop of the resistive element is measured. With this solution shown in figure 7, only the TCR of the shunt resistor determines the voltage measurement.

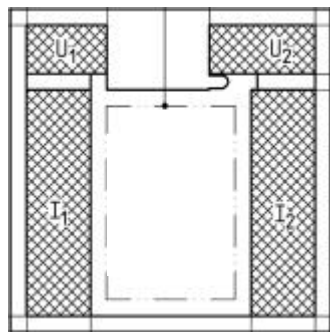


Figure 7: Surface view of current shunt resistor

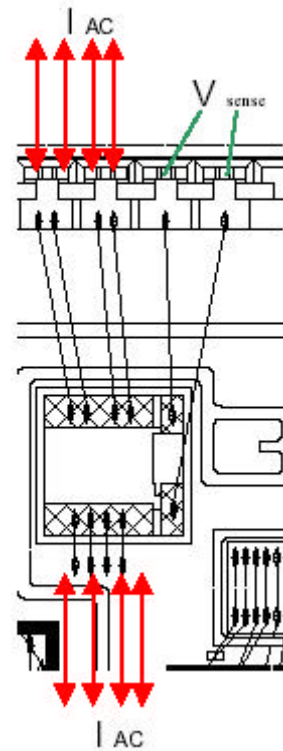


Figure 8: Four-wire shunt resistor with Kelvin sense leads connected in the EconoPACK™ Shunt IGBT module.

Paralleling Four-Wire Resistors:

As shown in Figure 2, the 150A IGBT module contains two shunt resistors per leg. These two shunt resistors are connected in parallel. This is needed to distribute the heat when sensing high currents.

To avoid significantly higher currents in the sense lines than expected, ballast resistors must be used in the sense lines.

Referring to the schematic of Figure 9, and remembering that the whole point of the Kelvin connections is to counteract the variability of the contact resistance, without the ballast resistors, unequal currents through the contact resistances could equalize in the sensing elements by flowing through the interconnected sense lines. These are typically not designed for high currents.

The lower the Kelvin resistor value is, the higher will be the error introduced by mismatched connections.

The value of the ballast resistor should be in the order of 1000 times the shunt resistance and can have a low power rating since its presence insures that any currents in this path will be quite low.

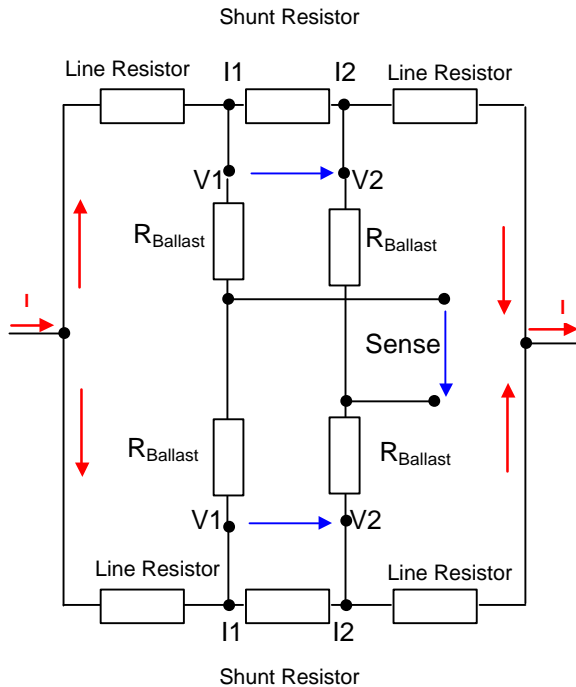


Figure 9: Paralleling four-wire shunt resistors by using ballast resistors .

In practice by using this 150A IGBT module the user has to connect the ballast resistors externally. Therefore this IGBT module has separate sense lines for each shunt resistor. Figure 10.

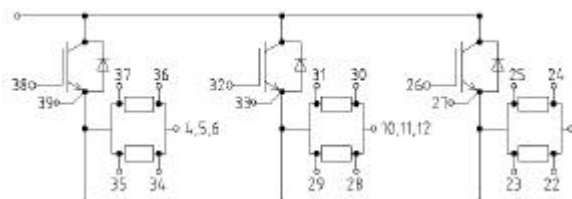


Figure 10: Schematic of the 150A EconoPACK™ Shunt Module

Using Shunt Resistors in Motor Drive Application:

Figure 10 and Figure 11 shows that the current shunt resistors are placed in the output phase line of each IGBT half bridge. This has advantages and disadvantages for the

complete motor drive inverter. The advantage is to measure the motor current directly in each phase. Also the stray inductance of the shunt element and the stray inductance of the IGBT module internal connection in the output phase is not critical. On the contrary it will help to form the current. It is also possible to detect a overload current and a short circuit current in the load cable or directly in the load. The disadvantage, is that the current shunt resistors are working at floating potential. Due to the alternate switching of IGBT's and diodes the current shunt resistors will either see the DC-Bus plus voltage or the DC-Bus minus voltage.

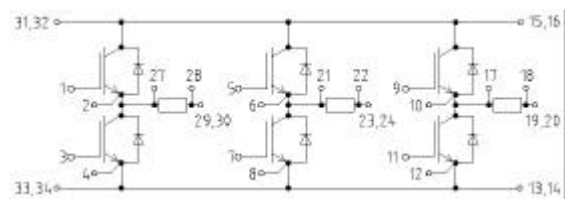


Figure 11: Schematic of the 75A and 100A EconoPACK™ Shunt Module

An isolated signal transfer is needed to obtain the current information. This is possible with a linear amplifier. The transmission can be magnetic, capacitive or via light like an opto-coupler. The common way today is to use analogue to digital converters (ADC) or analogue to analogue converters (Sigma-Delta converter) like the HCPL316J from Agilent. It transforms the analogue voltage signal into a digital code and transmits this via an opto-coupler. Finally the digital signal is converted back to an analogue signal. Figure 13.

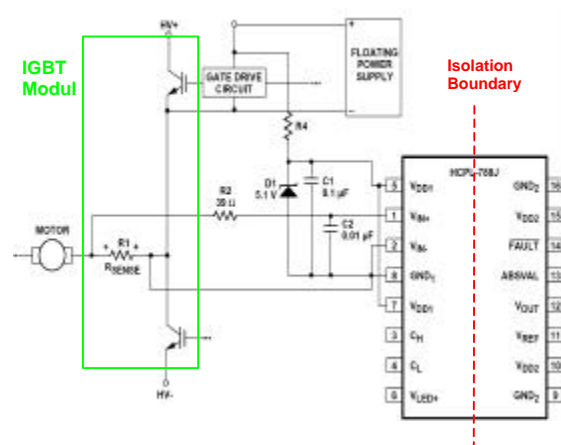


Figure 12: Current measurement with HCPL 788J and EconoPACK™ Shunt

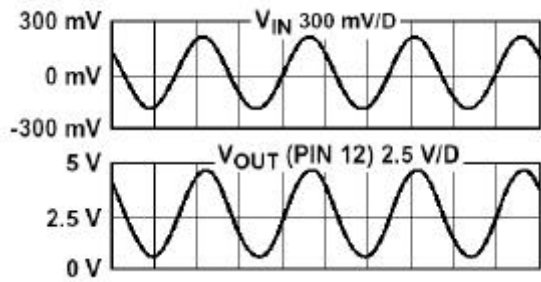


Figure 13: Sigma-Delta converter, input voltage output voltage

First Motor Drives with IGBT- Shunt- Modules :

For the first time IGBT- Shunt- Modules "EconoPACK™ Shunt" are used in the new motion drive family SINAMICS S120 from the Siemens Company³.

This Motor drive inverters are able to drive 16kW until 36kW electric Motors for a line net voltage from 380V_{AC} to 480V_{AC}.

Current measurement and protection function like over current and short circuit current is realized by using the IGBT module integrated shunts.

The compact and cheerful PCB design of the SINAMICS S120 is shown in Figure 15.



Figure 14: New Siemens³ SINAMICS S120 Motor module.
Left : 60A Device. Right: 30A Device.

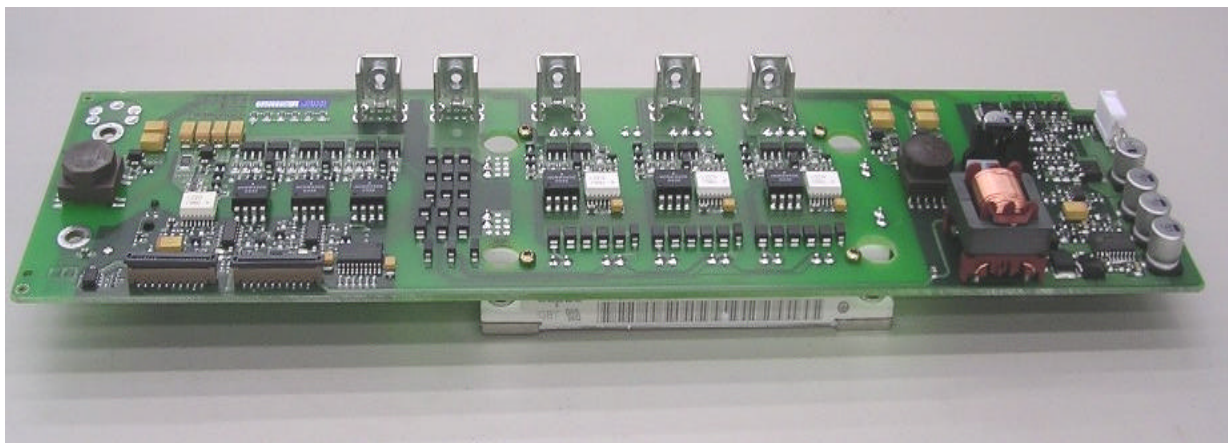


Figure 15: Power PCB of 16kW SINAMICS³ Motor Drive with IGBT- Shunt- Module.

Forward- Looking

Today's market offers few sigma-delta converters for safety isolation below 1000V. The alternatives are in a manageable amount. But more and more companies are working on alternatives and new technologies. eupec is working on an IGBT driver and an ADC concept based on CLT (Coreless Transformer) technology too.

As it can be seen from Figure 16, a complete chipset consisting of IGBT Driver Chip 2ED02012-F and ADC chips will support IGBT modules with integrated current shunt resistors in the future.

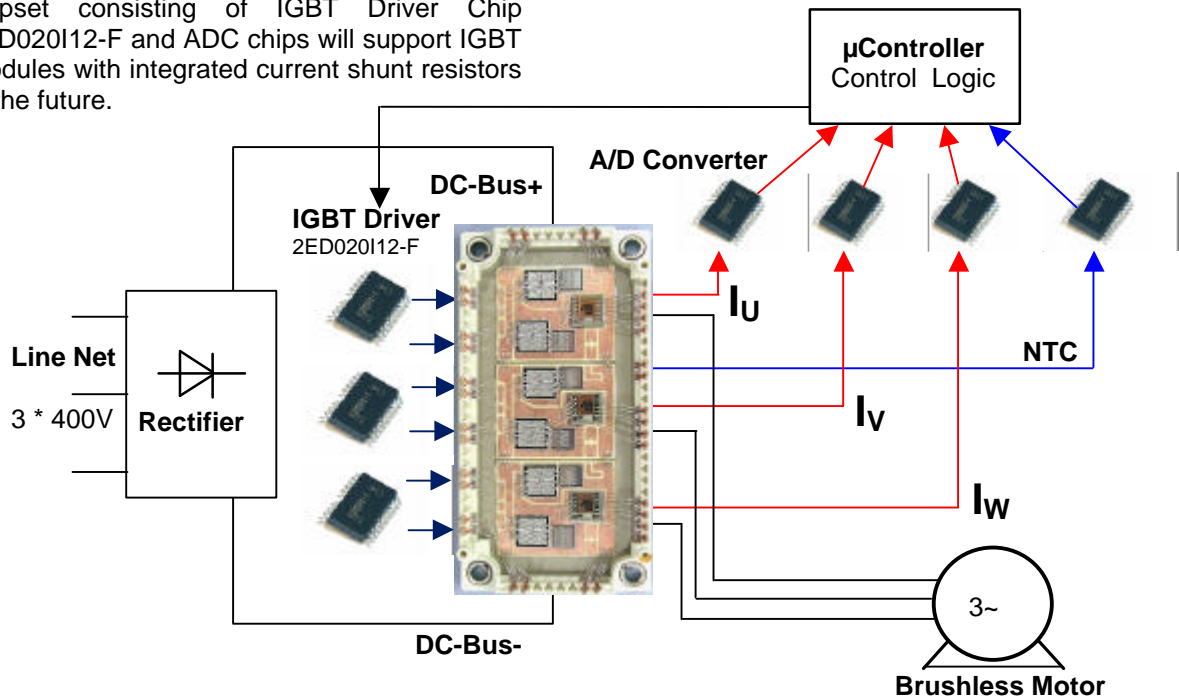


Figure 16: System solution with EconoPACK™ Shunt IGBT module and CLT (Coreless Transformer) chipset technology.

References:

1. ISABELLENHÜTTE Heusler GmbH, Präzisions- und Leistungswiderstände (Das mΩ- Konzept).
2. ISABELLENHÜTTE Heusler GmbH, ISA-PLAN® -Precision Resistors
3. R.Dillig / A. Hoge
Siemens AG A&D SD RD PE2
4. Bob Mammano, Current Sensing Solution for Power Supply Design, Texas Instruments
5. eupec GmbH, technical information FS75R12KE3_B3, FS100R12KE3_B3, FS150R12KE3_B4,
6. Agilent Technologies, technical Data HCPL 788J , No. 5966-0001E.pdf
7. Mark Münzer, eupec GmbH, June 2003, Coreless transformer a new technology for half bridge driver IC's

Technical Information:

www.eupec.com
www.eicedriver.com