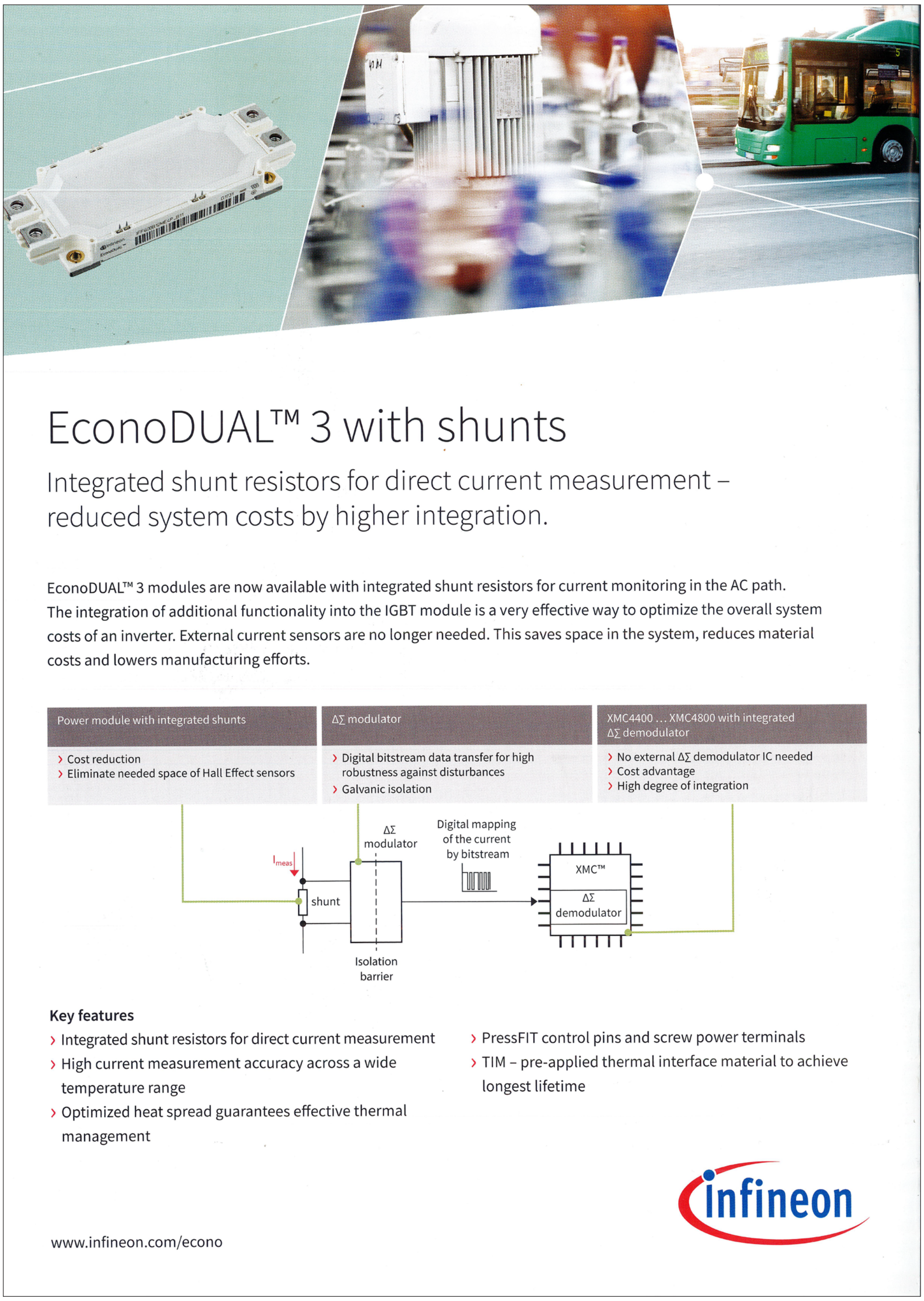
APPLICATION NOTE // SHUNTS INTEGRATED IN IGBT POWER MODULES



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ISABELLENHÜTTE

Innovation by Tradition

1. BASIC TECHNOLOGIES OF CURRENT SENSING

1.1 Passive measurement - Hall effect (open/close-loop)

Two basic technologies of sensing current compete today in the market and are fundamentally different in functionality and operation with their pros and cons. Hall effect sensors or current transducer are used for indirectly or passive current measurment based on magnetic flux caused by a current flow and convert in a analogue signal for futher processing. The converter outputs a voltage that is proportional to the primary current.

There are two main types of Hall effect sensors. The open-loop mainly used in standard applications with lower performance and less circuit efforts but shows significant disadvantages in terms of dynamic bandwith, off-set voltage and drift over temperatur. For higher requirements the close-loop hall effect sensors are used which are much faster and more precise. The drawback of close-loop sensors is a higher circuit complexicity and higher price caused by the feedback winding to null the flux in the core.

Fig. 1: Schematic diagram of an open-loop hall effect sensor // Copyright by LEM

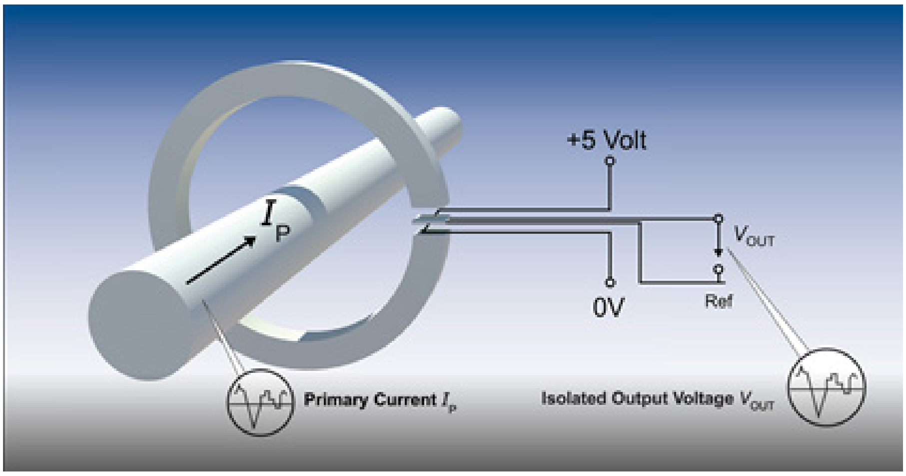
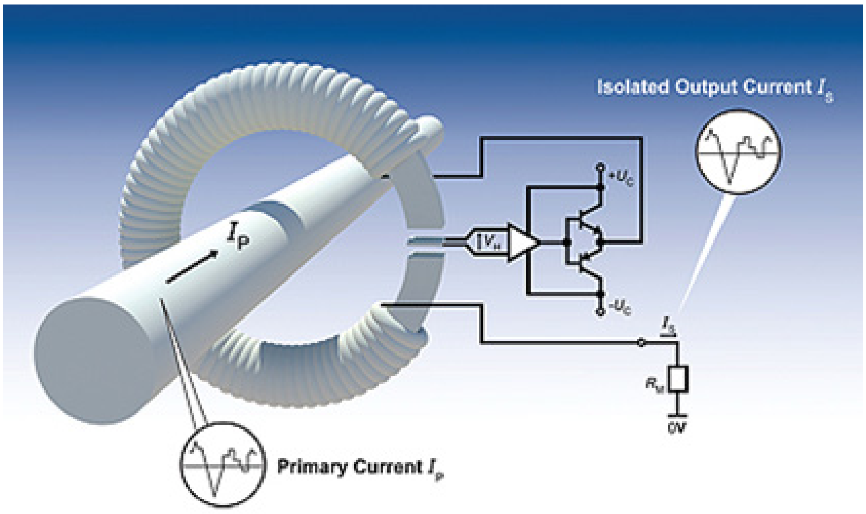


Fig. 2: Schematic diagram of a close-loop current hall effect sensor with feedback winding // Copyright by LEM



1.2 Disadvantages of Hall-effects

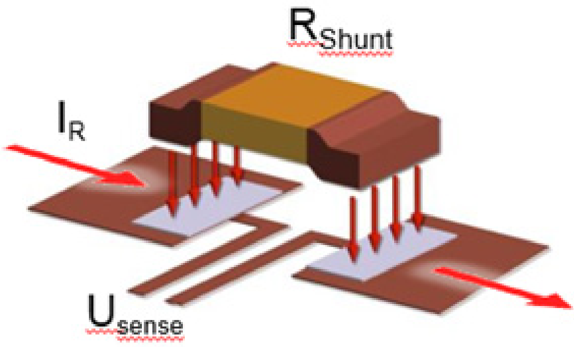
Depending on certain current level an adaption to different current ratings requires different sensors with corresponding magnetic core and housing which makes Hall effect sensors bulky and heavy. Conditioned by these circumstances an integrated into systems is related with increased efforts and costs. Further their operation temperature is limited and possible thermal drift (±0,05%/K) and does not guarantee a reliable current detection.

Parameters like linearity (±0,5% of IN), magnetic-offset and hysteresis can influence the signal and has to be considered which is often associated with significant disadvantages and limitations for the application.

2. ACTIVE MEASUREMENT - PRECISION AND POWER RESISTOR (SHUNT)

The Shunt technology in the opposite is an active measurement which can be integrated in the circuit layout very easy with positive effects fulfilling higher requirements in terms of precision and smart solution for low price.

Fig. 3: Active measurement with shunt



2.1 Benefits of integrated shunts

- Very good accuracy and long-term stability over a wide temperature range
- High power level on shunts while improved cooling over module base plate
- Very effective way to optimize the overall system costs
- Low complexity and easy integration with delta-sigma modulator/demodulator to µC
- Save space, reduce material costs and assembly costs compared to Hall effects sensors

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Fig. 4: Overview of the main advantages of Shunt vs. Hall sensor (open/closed-loop)

	Shunt module + ΔΣ modulator	Hall Effect Sensor Closed Loop	Hall Effect Sensor Open Loop
Accuracy	high	high	medium
Cost	low	high	medium
Physical Space required	low	very high	high
Assembly/ Mounting effort	Very low Some parts on PCB	high mounting, cable & plug connection	high mounting, cable & plug connection
Isolation	reinforced via ΔΣ modulator	reinforced w/o additional measures	reinforced w/o additional measures

An important feature of the shunt is the temperature stability that enables a current measurement with excellent liniarity over a wide temperature range and its easy system integration.

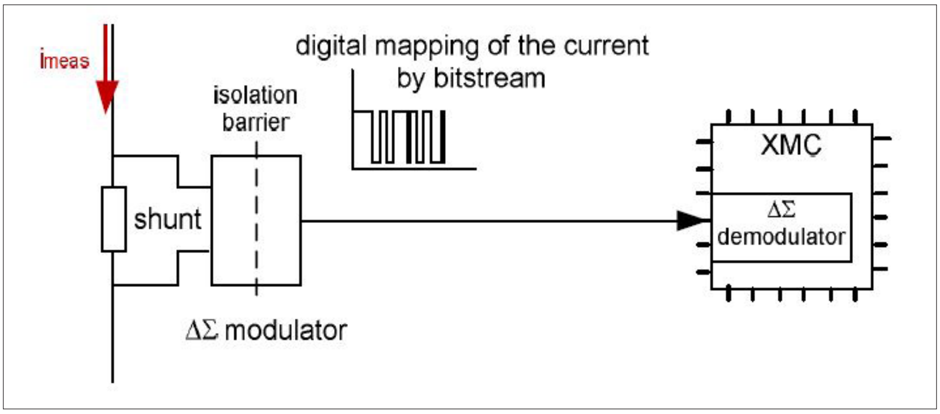
3. SIGNAL PROCESSING WITH DELTA-SIGMA-MODULATOR

There are many ways to process and amplify the voltage drop of a shunt resistor. The simplest and cost-effective solution is an operational amplifier with discrete components. However the electrical isolation from the main current path to the control side and further circuit complexity and costs to convert the analog signal into a digital increase circuit complexity and costs.

With the widespread adoption of a shunt-based current measurement, about 10 years ago, delta-sigma converters appears on the market, which were able to amplify the small analog voltage signal and output as a bitstream isolated to a demodulator or directly to a µC.

This sigma delta modulators worked in the past with an input voltage of ±250mV and required higher resistance values to generate such voltage drop which leads to higher power loss across the shunt. This in turns led to an additional heat source in the application.
The development of new sigma delta modulators (e.g. XMC 4400) enable to operate with an input voltage of ±50mV and allows the use of up to 5 times lower ohmic shunts to achieve higher current rate and less power dissipation through the shunt.

Fig. 5: Schematic of shunt and Delta Sigma Modulator with integrated demodulator µC

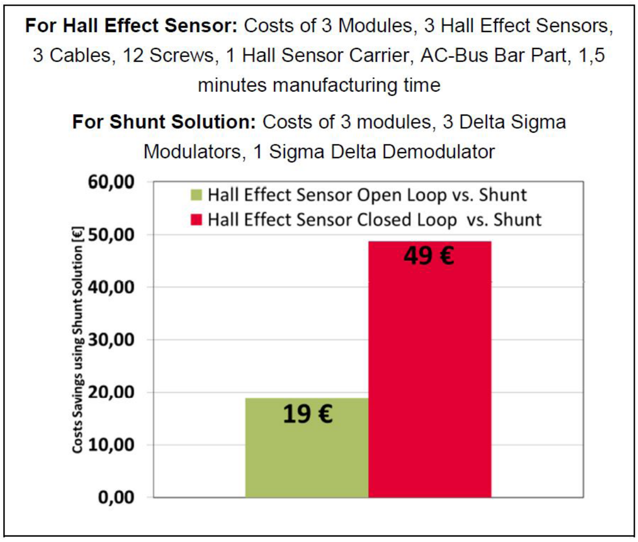


4. EFFECTIVE SAVING ASPECTS

Hall-effect sensors, especially the closed -loop type are, as mentioned are very expensive compared to shunt resistors. But not only the price difference of the components itself are taken into account. Also “the total cost of ownership” like the assembly cost, equipment like cables to connect the sensor with the PCB, bus-bar and screws to mount the sensors in the application.

Although the initial-cost of designing the PCB with shunt measurement requires increased circuit complexity and additional components on PCB, this are only one-time cost respectively almost negligible compared to the costs which can be omitted in the BOM (Bill of material) when using a shunt solution. This will reduce the final inverter costs and improve the system reliability in combination with a smart and compact solution.

Fig. 6: The right figure shows the possible cost savings using shunts in IGBT module instead of Hall-Effects // Copyright by Infineon

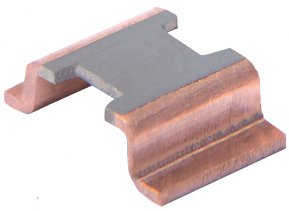


5. ISA SHUNTS INSIDE IGBT-MODULES

Infineon is using Isabellenhütte shunt type BVZ in the MIPAQ™ and EconoPACK™ IGBT Modules.

ISA-WELD® // PRECISION RESISTORS

BVZ // Size 4026



Features

- Heavy copper connectors
- Excellent long-term stability
- Ideal suited for mounting on DBC / IMS substrate
- Max. solder temperature up to 350 °C / 20 min. (with hydrogen under vacuum)
- RoHS 2011/65/EU compliant

Applications

- Current sensor for power hybrid applications
- High current applications for the automotive market
- Frequency converters
- Power modules

The following BVZ-Types are currently available:

Type	Value [mΩ]	R_{thi} [K/W]	TCR [ppm/K]	$P_{100\,°C}$ [W]	$P_{70\,°C}$ [W]
BVZ-Z-R000525	0.525	8	<320	5	9
BVZ-M-R00077	0.77	12	<230	5	7
BVZ-I-R001	1.0	8	<150	4	6
BVZ-I-R0015	1.5	12	<110	4	6
BVZ-I-R0024	2.4	20	<60	3	5
BVZ-I-R003	3.0	21	<60	3	5

Material type I=ISAOHM®, M=MANGANIN®, Z=ZERANIN®

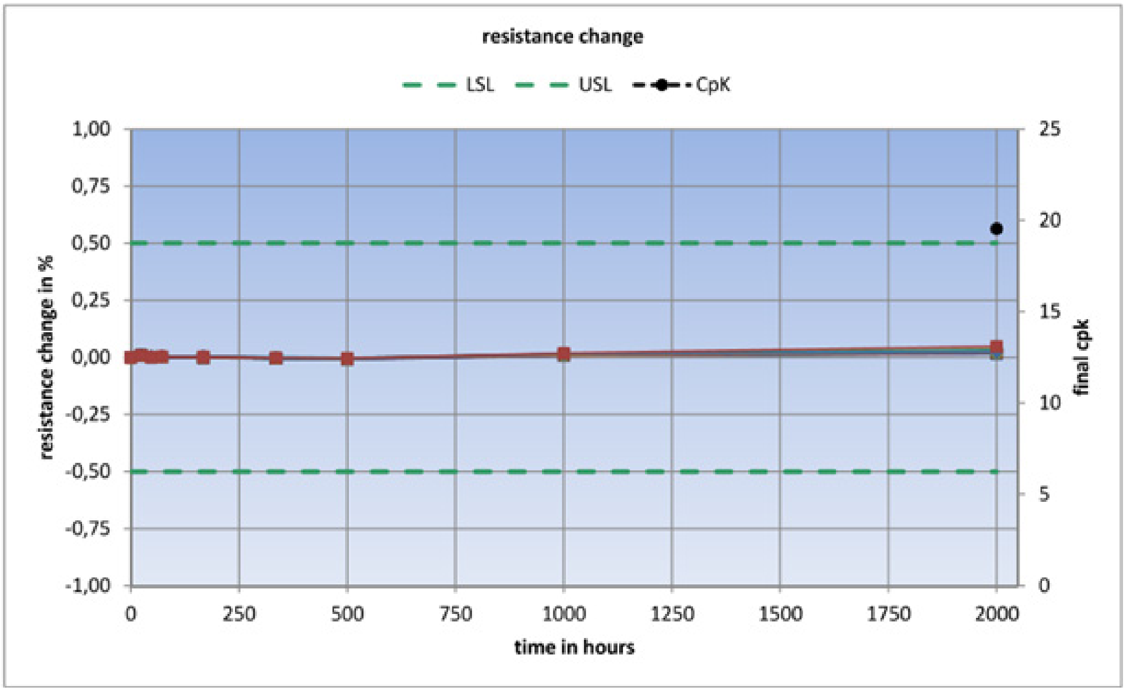
4.1 BVZ with ISAOHM® resistance material

The ISAOHM® resistance material that is used for the BVZ shunt resistor is an alloy that was developed has been optimized to fulfil the highest requirements even in high temperature environment.

Thermoelectric voltage has been adjusted to the Cu environment so that even very small voltages can be analysed and the Peltier and Seeback effect, which normally causes interferences, does not generates any errors. An special annealing and tempering process of the resistance alloy guarantee very good long-term stabilty.

The thick Cu terminals of the part guarantee good heat transfer from the resistor alloy via the solder joint into the substrate, which has equally good heat-conducting properties, so that it’s possible to achieve a very low overall heat resistance of 4,5 K/W.

Fig. 7: The following curve shows a tested BVZ-I-R001 with ISAOHM® resistance material, which is used in IGBT power modules with a temperature drift of less than 0.2% over 2.000h @140°C



5. APPLICATION EXAMPLE

5.1 Infineon IGBT-Type: IFS100B12N3E4_B31

1,5mOhm => Shunts Type BVZ-I-R0015-1.0

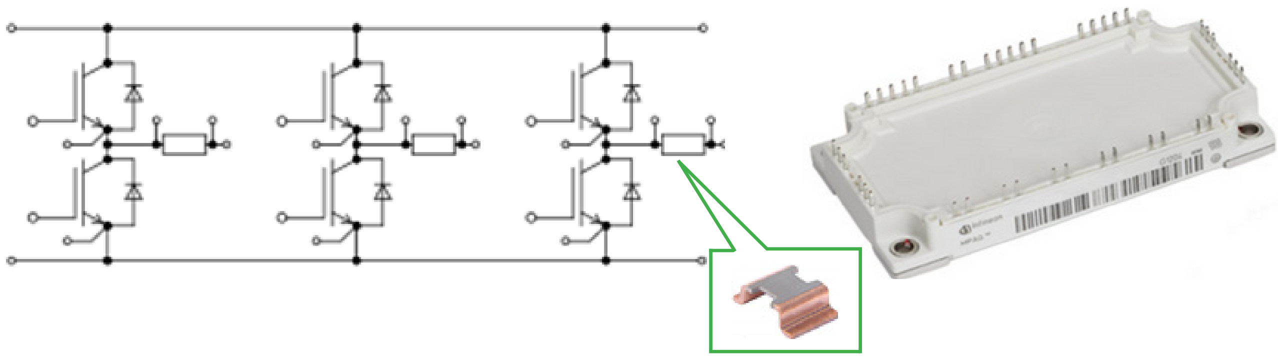
Strommesswiderstand / Shunt

			min.	typ.	max.	
Nennwiderstand Rated resistance	T_c = 20°C	R_{20}		1,50		mΩ
Temperaturkoeffizient Temperature coefficient (tcr)	20°C - 60°C			< 30		ppm/K
Betriebstemperatur Shunt-Widerstand Operation temperature shunt-resistor		T_{vjop}			200	°C
Wärmewiderstand, Chip bis Gehäuse Thermal resistance; junktion to case		R_{thJC}			8,7	K/W

V_{CES} = 1200V

$I_{C\,nom}$ = 100A / I_{CRM} = 200A

Fig. 8: Schematic diagram and picture of MIPAQ Module for 3-phase Motor/Servo Drives



5.2 Infineon IGBT-Type: IFF600B12ME4P_B11

0,26mOhm => 3 Shunts of type BVZ-M-R00077-1.0 in parallel-connection for better power distribution

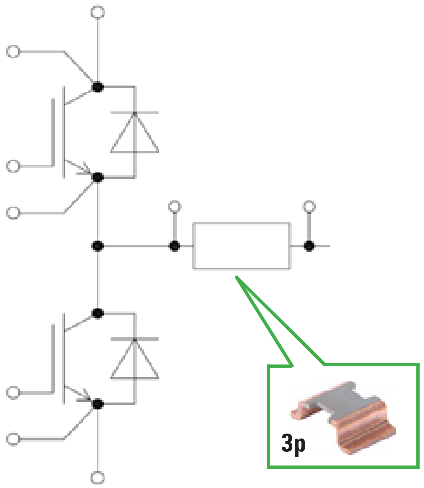
Strommesswiderstand / Shunt

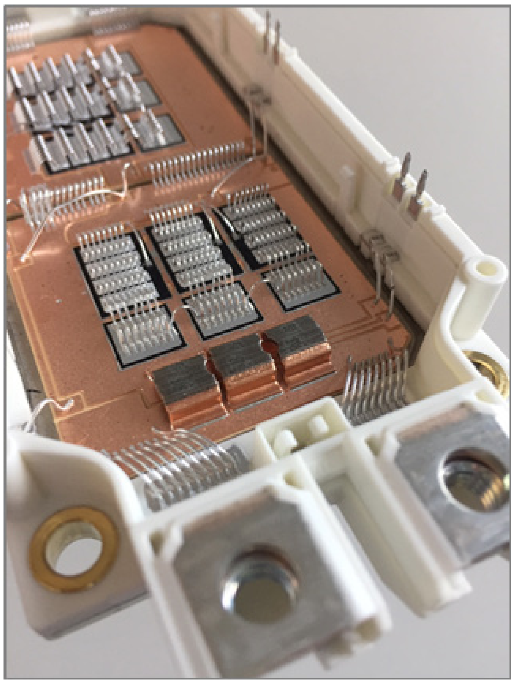
			min.	typ.	max.	
Nennwiderstand Rated resistance	$T_H = 20°C$	R_{20}		0,26		mΩ
Temperaturkoeffizient Temperature coefficient (tcr)	20°C - 60°C			< 30		ppm/K
Belastbarkeit pro Shunt-Widerstand Load capacity per shunt-resistor	$T_H = 80°C$	P			40	W
Betriebstemperatur Shunt-Widerstand Operation temperature shunt-resistor		T_{tvjop}			200	°C
Wärmewiderstand, Chip bis Kühlkörper Thermal resistance, junction to heatsink	pro Shunt-Widerstand / per shunt-resistor valid with IFX pre-applied thermal interface material	R_{thJH}			3,0	K/W

$V_{CES} = 1200V$

$I_{C\ nom} = 600A$ / $I_{CRM} = 1200A$

Fig. 9: Schematic diagram and picture of EconoDUAL Module for Solar/UPS with 3 BVZ Shunts in parallel connection for an uniform load distribution





Conclusive remarks:

Integration of power resistors in IGBT modules has been established since many years now and the benefits for the application are clearly obvious in terms of technical performance and accuracy but as well as in cost effective aspects.

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