A Novel Family of 1200V Transfer Mold Converter - Inverter - Brake (CIB) Modules driven by a new 1200V High Voltage Integrated Circuit (1200V HVIC)

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Abstract:

Transfer mold manufacturing technology has been successfully applied to Intelligent Power Modules (IPM) for the 600V range for more than 5 years now. Further improvements of the internal module construction, e.g. leadframe and heatspreader optimization as well as significant improvements in IGBT chip technology resulting in the availability of Carrier Stored Trench Bipolar Transistor (CSTBT), provide a cost efficient, reliable and thermally well performing power module technology. Recent 600V DIP IPMs are capable of driving up to 3,7kW. This paper presents the next pioneering step of transfer mold technology, a 1200V CIB module rated from 10A up to 25A/1200V driven and protected by a newly developed 1200V HVIC. The features of the DIP CIB module and the functionality of the dedicated 1200V HVIC are explained in detail in this paper. Thus the complete power stage for up to 3.7kW inverters including 3~ input rectifier, brake chopper and 3~ inverter as well as a NTC for the temperature sensing of the baseplate has been "transfer molded" into one compact package well respecting the minimum creepage and clearance distances required from UL and IEC.

1. Introduction

Transfer mold technology has been widely used to manufacture reliable power modules for power ranges starting from a few hundreds of Watts to up to more than 4 kW. This technology is well suited for large scale IGBT module and IPM production. The advantages of transfer mold technology over competing packaging technologies are mainly the dual use of the cupper lead frame as electrical conductor as well as an excellent heat spreader. Furthermore this advanced packaging technology allows to employ bare chips of IGBT, FwDi and control ICs instead of pre- packaged components omitting additional preparation and handling before the manufacturing process of the transfer mold IGBT module or IPM.

Since 1998 this packaging technology has been improved particularly with regard to the thermal resistance of the module.

The newly developed 1200V converter inverter brake module (CIB) employs this state-of-the-art packaging technology in conjunction with latest IGBT (CSTBT™) technology providing a highly reliable, efficient and compact solution for drives ranging from 1,5kW and up to more than 4kW. A new 1200V high voltage integrated circuit (HVIC) has been developed to drive the converter inverter brake module. This HVIC contains all necessary functions to drive and to protect the DIP CIB in compact drives. Finally this paper presents a reference design to show a PCB space efficient solution to apply the 1200V DIP CIB along with its dedicated 1200V HVIC in a 4kW class evaluation power stage.

2. Mechanical construction

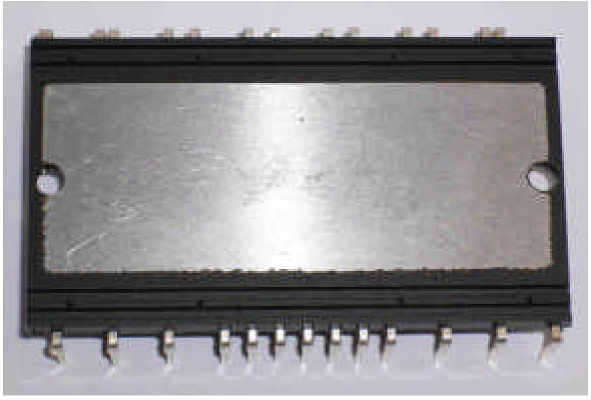


Photo 1: DIP CIB from heat spreader side

Photo 1 shows the DIP CIB and its employed aluminium heat spreader, which is isolated from the semiconductors. A guaranteed isolation voltage of 2500Vrms for 1 minute matches with the standard isolation voltage requirements for industrial drives of this power segment. The heat spreader efficiently avoids thermal hotspots and reduces the thermal resistance Rth(j-c).

A more precise impression of the compactness of the DIP CIB can be derived from figure 1 showing the dimensions of the package as well as the approximate position and dimensions of the employed heat spreader.

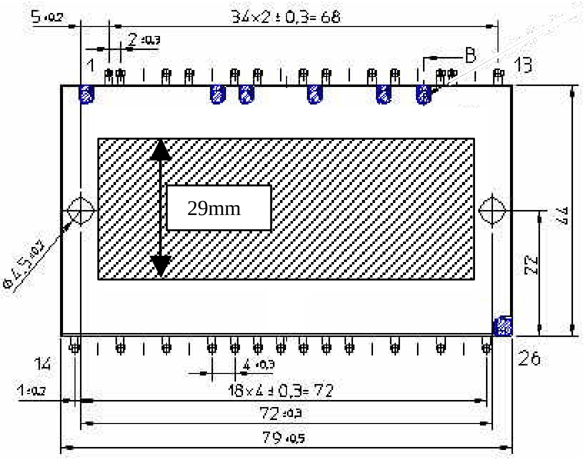


Figure 1: Outline drawing of the DIP CIB module

The module is fixed to the heat sink by just two 4mm screws. The stability and flatness of the heat spreader ensures a well defined thermal interface between the module and heatsink utilizing a small amount of thermal grease.

The entire surface of the module is 79mm x 44mm = 34,8cm², but the "visible" portion of the heat spreader just covers 29mm x 72mm = 20,9cm² which is equal to 60%.

Thermally it is not necessary and electrically it is not desired to expand the heat spreader area more, because the distance from a heat sink connected to earth and the terminals of the DIP CIB linked to high voltages are limiting the creepage distance. The same considerations are valid for the direct distance through air from terminals of the DIP CIB to the heat sink. The minimum distances for both parameters are an important safety issue and those are well defined and restricted for the voltage classes and pollution degrees by UL508 and IEC664-1

During the design of the package special care has been taken to ensure that such a UL and IEC compliant drive design can be achieved simply. The area between the edge of the aluminium heat spreader and the terminals has been shaped with additional grooves to extend the creepage distance. This detail is shown in photo 2.

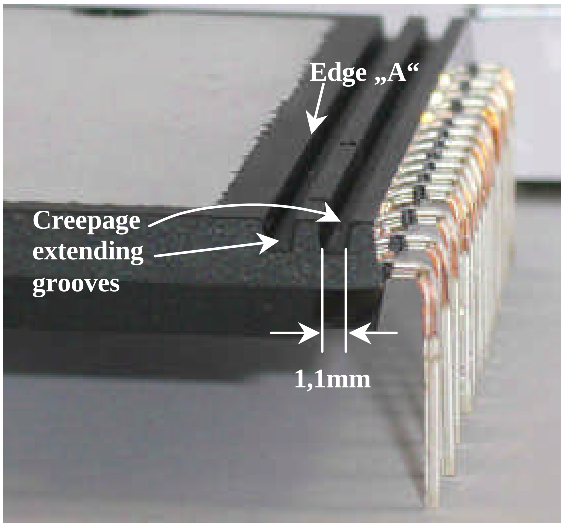
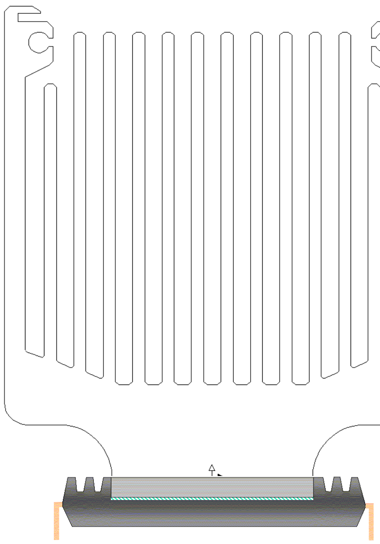


Photo 2: Creepage distance extending grooves of the DIP CIB's case surface shape:

Benefiting from this special shape a creepage distance from the top of the terminal of the DIP CIB to edge "A", as shown in photo 2, is more than 12,9mm. This calculation implies that the creepage distance is not compromised by the heat sink attached to the module. A suitable heat sink design faciliates the compliance with required minimum creepage distance and sets the necessary clearance distance at the same time. A simple approach to achieve both design targets and to maximize the clearance distance is shown in figure 2:



Such a suggested heat sink shape can be manufactured by extrusion or by high pressure aluminium cast in case the heat sink is integrated into the total case design of the drive to achieve a high degree of mechanical integration. Besides the proposal of figure 2 there are more degrees of freedom in the design of the heat sink when the clearance distance is reduced to values indicated by the previously mentioned standards.

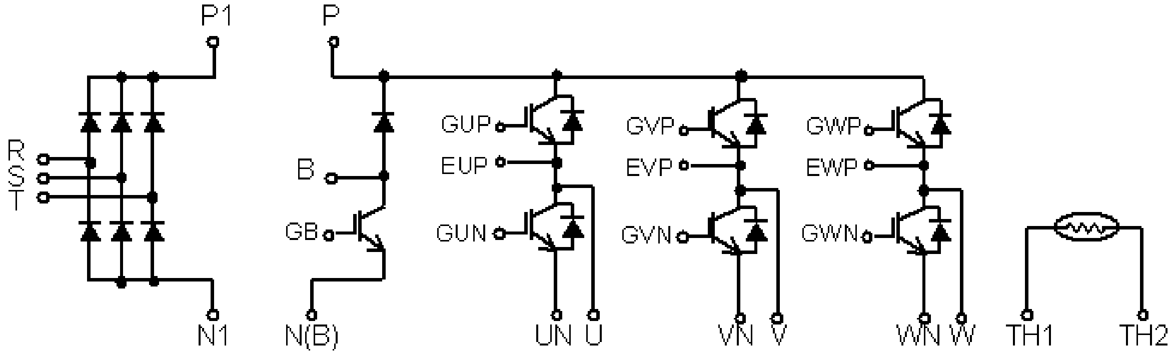


Figure 3: Internal circuit of the DIP CIB

3. internal circuit

As shown in figure 3 the CIB module comprises the input 3~ rectifier, a brake IGBT including the corresponding free- wheeling diode and the output inverter stage. For the temperature measurement of the heatsink a NTC has been integrated into the DIP CIB, too. The NTC is not linked to any potential and it is isolated from the heat spreader. The rugged transfer mold construction protects the NTC from losing its isolation capability in case of the worst case electrical failure of the output inverter - in case of an explosion.

The input rectifier is separated electrically from the brake and inverter part to allow connect the DC-link capacitors and their charging circuit. All Emitters of the N-side IGBTs have been left open and linked to individual terminals to provide the possibility to connect individual shunt resistors for sophisticated control strategies. The P-side IGBT have separated power and control Emitter terminals. Referring to the pin layout of the DIP CIB module, the control terminals of the P- and N- side IGBT, Gate and Emitter, are adjacent for all three phases U, V and W, which leads to simple PCB routing. The dedicated driver HVICs which are discussed later have been optimized with regard to their pin out to match the DIP CIBs terminal assignment for the shortest connection between these two components.

The NTC has got 2 separate terminals and is placed on the lead frame at a location where electromagnetic disturbances are considered to be low for a high reliability of the associated over temperature detection circuitry.

The value $R_{NTC} = f(\vartheta_{heat\ sink})$ is shown in figure 4.

The graph results from a simulation based on R25 = 10kΩ and B = 3450K as parameter of the employed NTC:

$$R_{NTC} = 10\,k\Omega \cdot e^{3450K \cdot \left(\frac{1}{J_{heat\sin k}} - \frac{1}{298{,}15K} \right)}$$

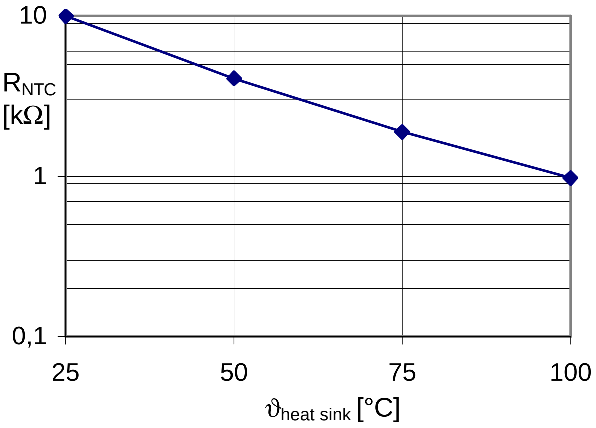


Figure 4: $R_{NTC} = f(\vartheta_{heat\ sink})$ for the built-in NTC

4. Leadframe construction

The leadframe of the DIP CIB is shown in photo 3. Bare chips of rectifier diodes, free-wheeling diodes and IGBTs are soldered directly on the lead frame.

The thickness of the lead frame of 0,8mm provides a very efficient heat spreading for the chips and decreases heat concentration effects.

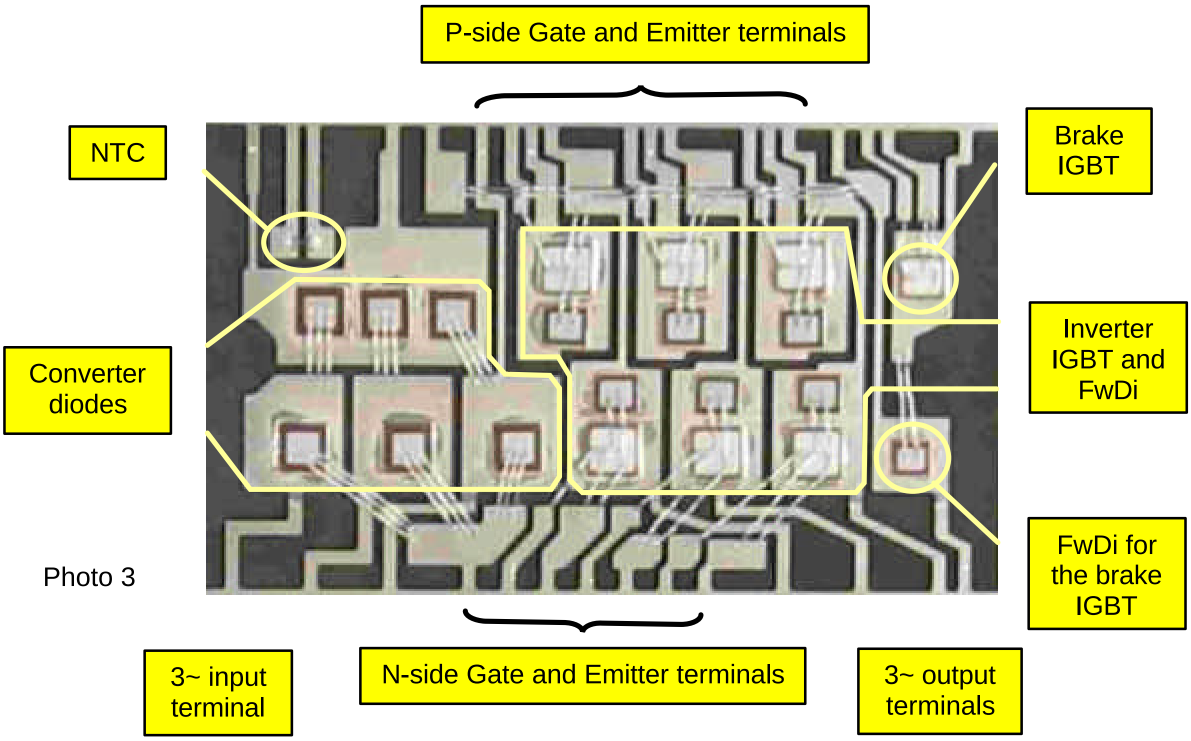


Photo 3

The leadframe assembly is shown above just before the final injection molding process that provides the encapsulation of the chips and gives the module its final form. The island for the semiconductors have been designed in large scale to make maximum use out of the thick cupper material for the reduction of the thermal resistance.

5. 1µm CSTBTÔ

The performance of Carrier Stored Trench IGBTs (CSTBT™) has been widely proved in industrial application like motor drives UPS etc. IGBT modules ranging from 50A/1200V up to 1400A/1200V or 1000A/1700V have been manufactured using this 1µm CSTBT technology in the past 2 years. Analysing the superior performance of CSTBT™ over conventional trench or planar IGBT technology, it is obvious that today's CSTBT™ technology is the key for further improvements of the trade off between switching loss and DC loss. So far the IGBT module range below 50A/1200V was restricted to planar IGBT technology, but in order to reach state-of-the-art loss performance today, CSTBT™ technology has been adopted for the DIP CIB to drive 400VAC …460VAC motors.

The test results of a 25A/1200V rated DIP CIB module (CP25TD1-24A) utilizing CSTBT™ technology are shown below:

Parameter	Conditions	Value	unit
$V_{CE(sat)}$	I_C=25A, T_j=125°C, measured at the terminals	1,98	V
Eon	R_G=13Ω, T_j=125°C, Vcc=600V, L=1mH	2,2	mJ
Eoff	R_G=13Ω, T_j=125°C, Vcc=600V, L=1mH	1,85	mJ
Rth(j-c)		0,9	$^K/_W$

Table 1: Parameter of a first lot random sample of the 25A/1200V DIP CIB module CP25TD1-24A.

The indicated test data may give a first indication of the module's capability. However this random sample alone cannot fix the specification.

Therefore it is recommended to use the performance curves in the design process to determine a suitable module.

Three different current ratings are planned to cover typical motor power requirements:

Type	Vces	I_C @ Tc=80°C	
		Inverter	brake
CP10TD1-24A	1200V	10A	10A
CP15TD1-24A	1200V	15A	15A
CP25TD1-24A	1200V	25A	15A

Table 2: Collector current rating of the new Transfer Mold DIP CIB family

6. 1200V halfbridge HVIC functions

Besides the general way to drive 1200V class IGBTs by photocoupler isolated drive circuits, HVIC technology became ready to enter this domain in 2001 with the release of the version 3 of the application specific IPM. Ever since 1200V HVIC technology has been applied to new Intelligent Power Modules (IPMs) such as the Transfer Mold 1200V DIP IPM. Provided that a functional isolation is sufficient between the microcontroller or DSP and the DIP CIB, the 1200V HVIC is the first choice especially when the absence of ageing effects is considered. With the help of HVIC technology and its associated low power consumption the P-side floating supply can be simplified by a simple bootstrap circuitry. Moreover the monolithic implementation of advanced protection functions and a driver stage for the L-side IGBT helps to reach a higher system integration and thus, leads to higher reliability of the entire system. The newly developed 1200V HVIC utilizing patented RESURF, MFFP and dual stage signal level shift technologies contains various protection functions such as an interlock circuit preventing that the IGBTs of one leg are on at the same time and an under voltage protection for the P-side floating supply to ensure proper drive conditions for the IGBT. The N-side portion of the HVIC contains a fast comparator which is connected to an internal fault logic. It is designed to detect an abnormal current through the voltage drop at a shunt connected to the Emitter side of the IGBT at a threshold level of typically 500mV. Figure 4 indicates the functional block diagram of the 1200V HVIC M81019FP:

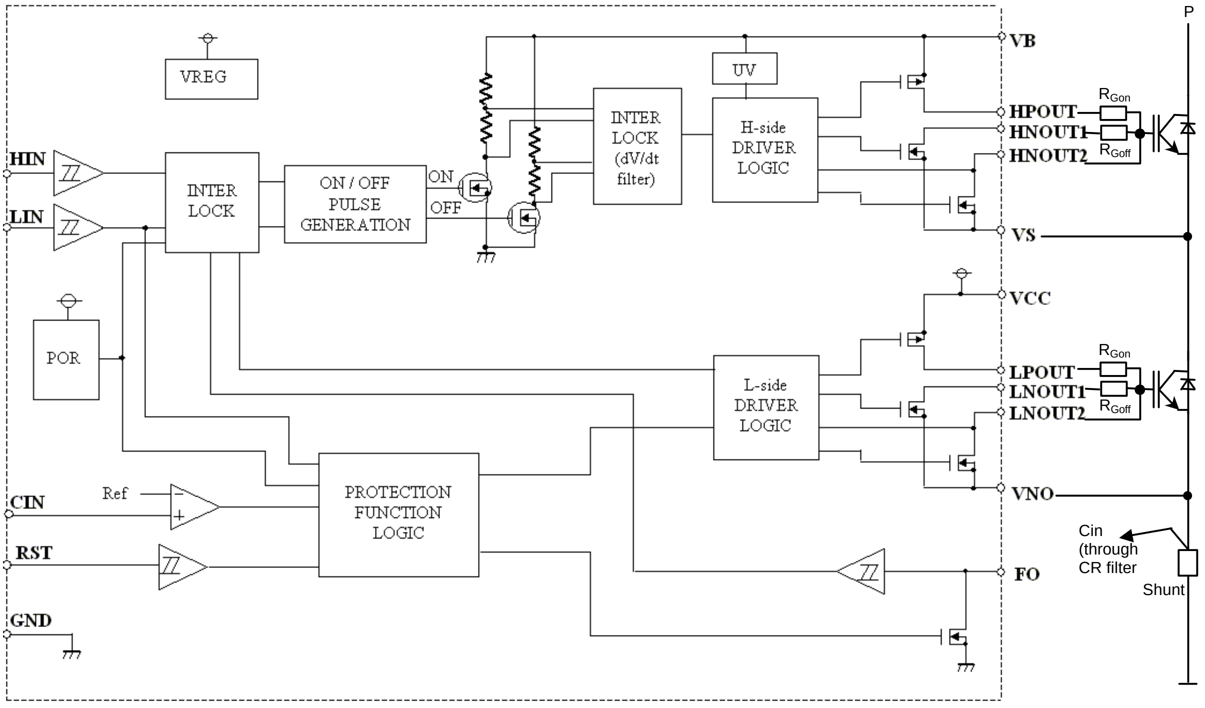


Figure 5: Functional equivalent circuit of the 1200V HVIC M81019FP

All control signal input indicated on the left side of figure 5 are dedicated 5 V logic inputs. The terminals Hin, Lin for the control signals of the P-side IGBT and respectively the N-side IGBT and the RST input contain an internal pull down resistor of approximately 5kΩ. The output stage of the P- and N- side driver is realized by three MOSFETs. While the *POUT and *NOUT1 terminals allow to connect a separate resistor to the gate of the IGBT to perform an independently optimized turn-on and turn-off behaviour of the IGBT and hence omitting an additional diode circuit, the terminal named *NOUT2 keeps the IGBT off by connecting the gate directly to the corresponding Emitter, when the gate voltage during the transition to turn off state has fallen below the internally fixed threshold voltage. This powerful MOSFET is keeping the IGBT in turn-off state especially when during a dV/dt a current through the C – G path is flowing. A solely turn-off gate resistor might not be able to keep V_{GE} below the threshold voltage of the IGBT, thus might not be able to keep the connected IGBT turned-off and avoid an arm shoot through situation under severe conditions.

The short circuit or over current detection utilizes the shunt resistors signal which is fed to the Cin terminal through a CR filter (not shown) blanking the recovery peak of the Free-wheeling diode and avoiding false tripping of the comparator.

Once a real fault condition has been sensed by the comparator and the N-side IGBT is turned on, the fault logic turns off both IGBTs and issues a fault signal at the fault output Fo. The Fo has a bidirectional function, it acts as a master when the fault logic has detected an internal fault condition and it operates in a slave mode when externally the signal was tied to ground. Operating three halfbridge HVICs in a typical 3~ application this feature ensures proper communication between the three separated fault logics and brings the inverter to a safe state when one of the ICs has detected a fault condition. To release this stored fault event, the fault reset input RST requires a high signal. The complete timing chart of the HVIC with regard to the short circuit or over current handling is shown in figure 6.

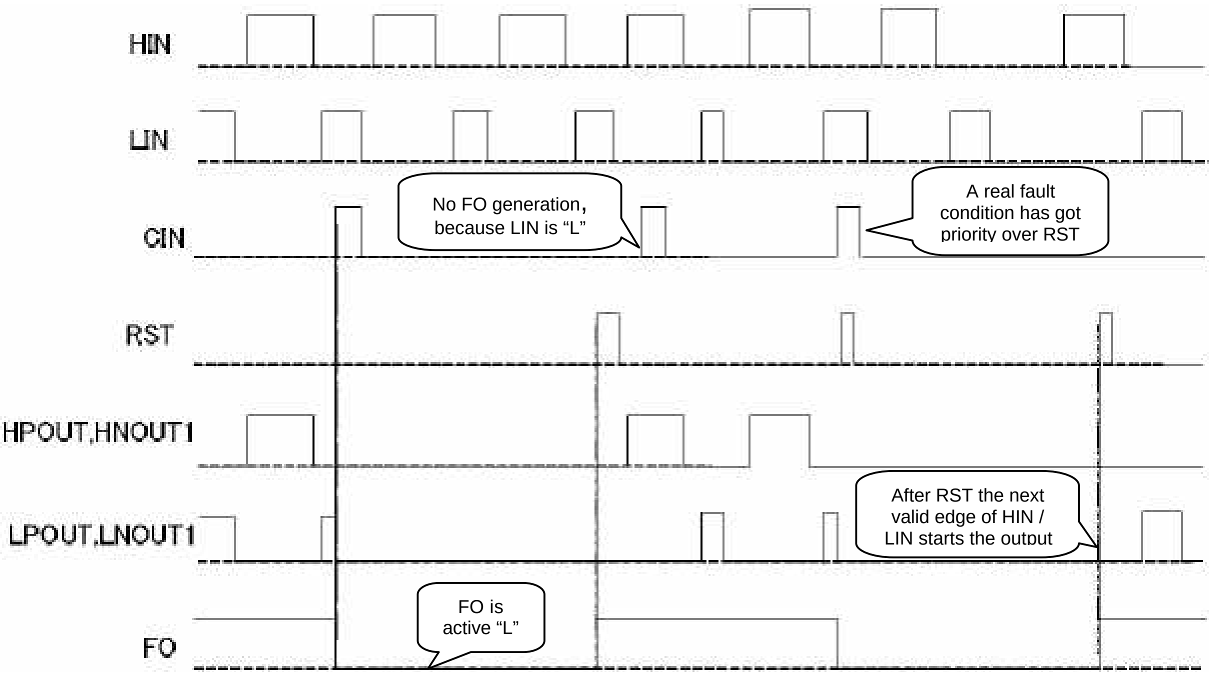


Figure 6: 1200V HVIC M81019FP timing chart and fault output generation

The pin assignment of the HVIC package has been optimized to be used with the previously described 1200V DIP CIB module. It allows simple routing of PCB tracks from the HVIC to the DIP CIB module. Moreover a clear mechanical separation of the floating P-side terminal pins of the HVIC from pin 1 to 12 (6) on one side of the HVIC and on the opposite side the N-side and control input pin terminal row from pin 13 to 24 (23) provides a large creepage and clearance distance.

The IC package counts 24pins, however not all of them are linked to the die. Figure 7 shows the pin assignment of the 1200V HVIC and figure 8 reveals the dimensions of the chosen compact SSOP24-P-300-0.80 package.

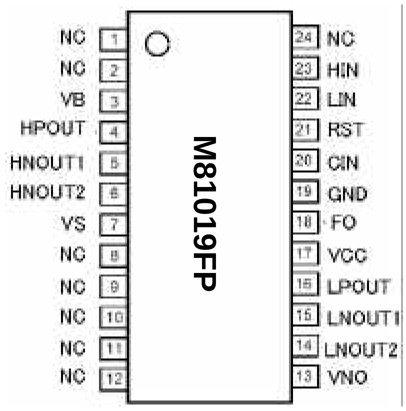


Figure 7: Pin assignment of the 1200V HVIC

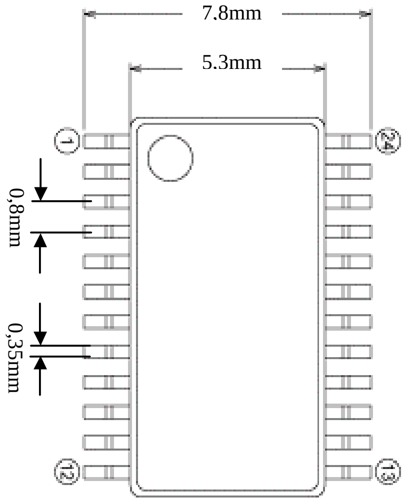


Figure 8: Dimensions of the 1200V HVIC

The following table summarized the most significant target parameter of the 1200V HVIC:

Item	Description	value
VB	Floating supply absolute voltage max	1224V
VS	Recommended max floating supply offset	<900V
Pd	Package power dissipation	0,89W
dVs/dt	Allowable offset voltage supply transient	±50V/ns
$Tj_{,min}$	Junction temperature minimum	-20°C
$Tj_{,max}$	Junction temperature maximum	+125°C
VIH	Logic “H” input voltage typically	3V
VIL	Logic “L” input voltage typically	1,5V
IOH	Output current (H-level), max	~-0,9A
IOL	Output current (L-level),max	~0,9A

Table 3: Target parameter of the 1200V HVIC

The power loss of the output stage has been simulated in conjunction with a CP25TD1-24 DIP CIB considering worst case conditions for the driver stage, e.g. $R_{G,on} = R_{G,off} = 0\Omega$.

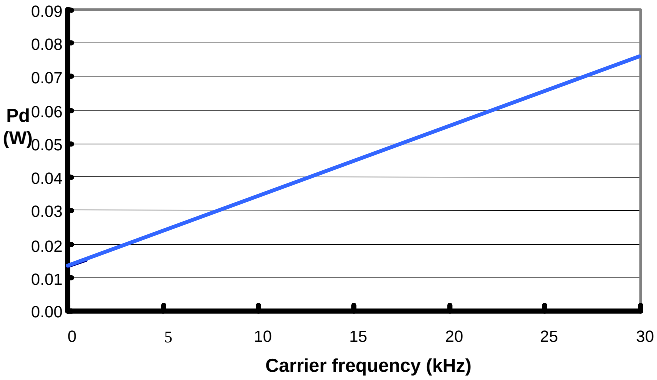
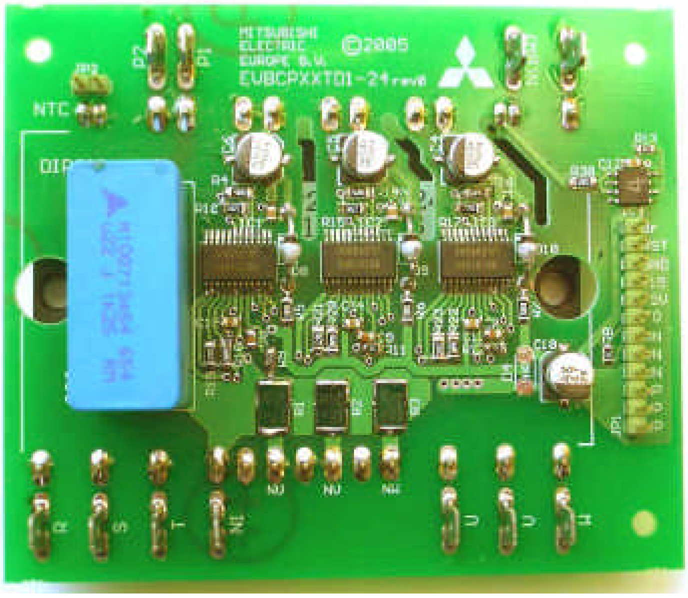


Figure 9: loss simulation M81019FP per P-side / or N-side IGBT driving a CP25TD1-24 with $R_{G,on=off} = 0\Omega$

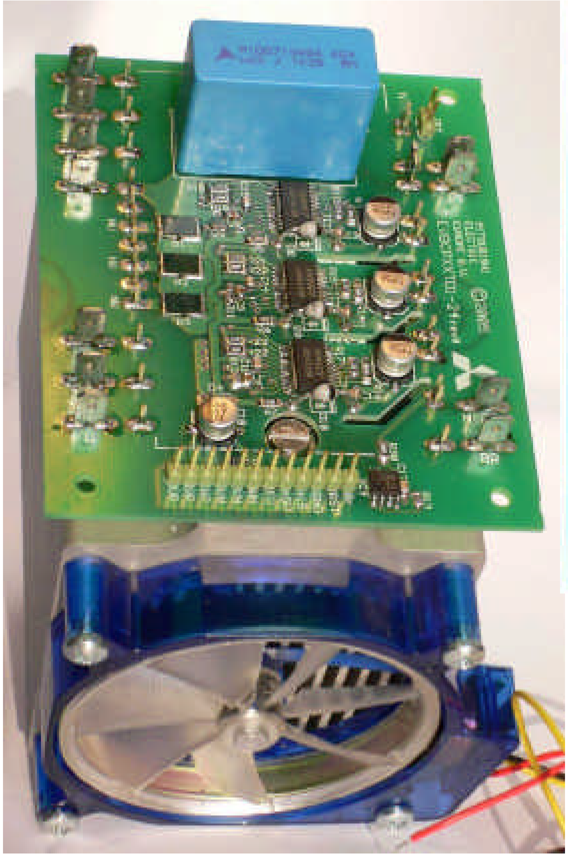
Drives in a 4kW class are mostly operating at switching frequencies around 8 kHz. At that operating point the power dissipation of one HVIC is in total 2 x 30mW = 60mW which offers sufficient margin with regards to the maximum package power dissipation indicated in table 3 as 0,89W.

7. Evaluation board test

An evaluation board for the has been manufactured to test the DIP CIB in conjunction with the 1200V HVIC. On this evaluation board 1200V HVICs including their bootstrap circuit utilizing 1200V fast diodes (trr = 75ns) and capacitors and 3 shunts to perform individual short circuit / over current protection are placed. Completing the evaluation board a 0,22µF/1250V snubber capacitor and the previously described separated Gate resistors $R_{G,on}$ and $R_{G,off}$ for the inverter IGBTs of the DIP CIB are populated. The brake function has been verified utilizing a dedicated driver LVIC M81716FP for the brake chopper IGBT. The evaluation board mounted on a heat sink shaped for maximum clearance distance is shown in photo 4. The evaluation board shown in photo 5 shows the possible advantageous compact construction of the inverter:



↑ Photo 5: Populated evaluation PCB for the DIP CIB and the 1200V HVIC



← Photo 4: The DIP CIB / 1200V HVIC evaluation board mounted on the heatsink which has according to chapter 2 a clearance distance optimized shape

8. Summary

A new transfer mold 1200V Dual Inline Plastic (DIP) Converter Inverter Brake (CIB) IGBT module utilizing latest CSTBT™ silicon chips and latest packaging technology for low thermal resistance has been developed. Its compact construction in conjunction with the suggested heat sink shape fulfils international safety standards such as UL508 and IEC664-1.

The newly developed 1200V HVIC with its dual level voltage shift circuit and the separate driver terminals for turn-on, turn-off and keeping off the IGBT offers a very reliable and rugged driver solution when a functional isolation between the controller and the CIB is required. Its complete protection functions for short circuit and under voltage has been tested in conjunction with the DIP CIB on an evaluation board.

9. References

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