ISSN: 1863-5598

ZKZ 64717
09–23

Bodo´s Power Systems®

Electronics in Motion and Conversion

September 2023

The DIPIPM Family: Our Technology, Your Comfort

The requirements for reliability, compactness and energy efficiency on electric drive systems are constantly increasing. Competition is particularly tough for applications in volume markets. For such volume-market applications (e.g., air conditioners, washing machines, heat pumps or industrial drives) severe cost pressure is an additional challenge. DIPIPM™ addresses the increasingly demanding technical requirements while the framework conditions in terms of costs are taken into account. In those applications, DIPIPM is an enabler for maximum competitiveness and customer satisfaction.

By Akiko Goto, Mitsubishi Electric Corporation, Fukuoka, Japan
Eugen Wiesner, Eugen Stumpf and Nils Soltau, Mitsubishi Electric Europe B.V., Ratingen, Germany

Introduction

Mitsubishi Electric's product family DIPIPM (Transfer-molded package Intelligent Power Module) stands for highly integrated and cost-effective power modules. DIPIPM modules combine power semiconductors, gate drivers, control ICs, sensors and protection circuits into one insulating, high thermal conductivity transfer-mold package. Thereby, power-electronic converters become more compact, reliable and cost effective due to lower number of parts and higher level of integration as shown in Figure 1.

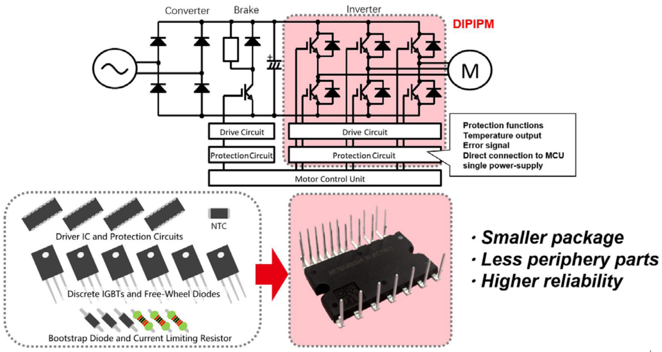


Figure 1: The DIPIPM concept

The DIPIPM concept has been initially introduced on PCIM 1997 [1]. It has targeted low power three-phase motor drive systems. Particularly house-hold appliances such as air conditioners or washing machines have been in focus. Afterwards, additional DIPIPM products have been continuously developed by using new chip technologies or package formats. Today a DIPIPM uses latest-generation CSTBT™ (Mitsubishi Electric's trench-gate IGBT technology), reverse-conducting IGBTs or SiC MOSFETs. Also, various package outlines are available for different application requirements. Figure 2 gives an overview of the continuous development of DIPIPM.

Today, more than 1 billion DIPIPM devices have been produced since their launch in 1997. Field experience and reliability data are accordingly satisfactory. Washing machines and air conditioners are still among the target applications. But also heat pumps and industrial servo drives are using DIPIPM today to become more compact, more reliable and more cost effective.

This article explains the technical details of DIPIPM and according development highlights. Furthermore, it describes how different applications benefit from DIPIPM products.

Chip Set

CSTBT (III)

The majority of DIPIPM power modules utilize all advantages of 7th generation IGBT chips using CSTBT (III) (MITSUBISHI ELECTRIC's trench-gate IGBT technology) structure. The CSTBT is a trademark of MITSUBISHI ELECTRIC. The CSTBT technology is to be considered as improved technology of trench structure of IGBT. The

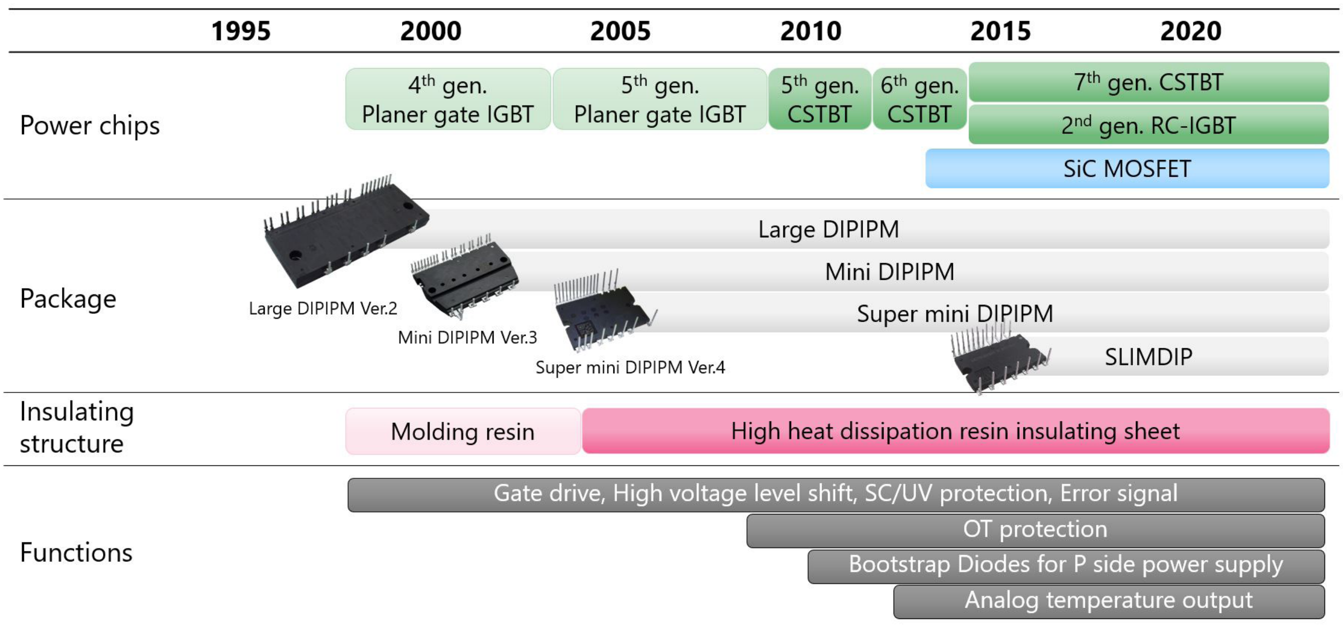


Figure 2: The continuous development and improvements of DIPIPM

trench architecture in power devices is introduced by MITSUBISHI ELECTRIC in 1994 allowing reduction of ON-state voltage and endurance property for latch up vs. planar IGBT [2]. The main gain by using of trench IGBTs is elimination of the parasitic JFET resistance. This technological step in combination with LPT (light punch through) technology allows significant drop of $V_{CE(sat)}$ value in IGBT. The CSTBT forms the n-layer under p-base between trenches, the n-layer stores carriers; as result, the carrier distribution of the CSTBT becomes that of the diode. The density of minority chargers increases, allowing recombination, allowing further reduction of steady state loss [3]. Figure 3 presents the differences between conventional trench technology and CSTBT proposed by MITSUBISHI ELECTRIC. The semitransparent n-buried-layer increases the concentration of minority charges in n-layer. The CSTBT (III) development is further improvement of CSTBT technology with focus on turn-off loss reduction and uniformity of characteristics like $V_{GE(th)}$ distribution [4]. This improvement allows further utilization of Si material before substitution by SiC power devices.

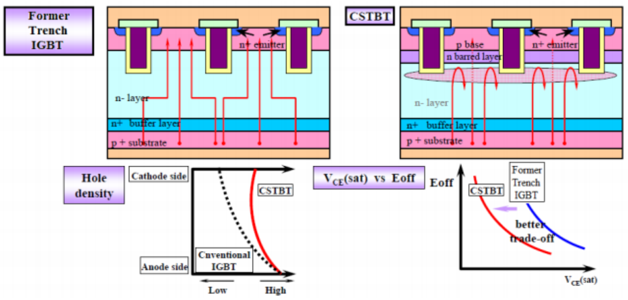


Figure 3: Cross sectional view of CSTBT in comparison to former trench-gate IGBT

RCIGBT

For package shrinking, for increasing cost efficiency the Reverse Conducting IGBT (RCIGBT) was introduced in SLIMDIP™ IPM. Today second generation of RCIGBT chip is utilized in commercially available products. The structure of RCIGBT is about integration of IGBT and FWD into one chip. Table 1 presents different technologies utilized in RCIGBT in order to increase technical and commercial performance. The area ratio between IGBT and FWD is most important parameter influence performance of IGBT and FWD. Additionally, tradeoff between voltage drop in diode and its recovery behavior is optimized in order to avoid current concentration in certain spot. The layout of chip regions is optimized in order to avoid hot spots and increase I_{FSM}. Thickness of wafer is an additional tool for decreasing of power loss [5]. In order to reduce cost and variation of electrical characteristics the life time control is not applied. All these steps allows reduction of package by 30% [6].

Item	Technology	Purpose
1	Optimization of the area ratio of the FWD region	Reduce the power loss.
2	Review of the structure of the FWD	Improve the trade-off between V_F and recovery.
3	Improvement of the layout of the IGBT and FWD	Optimize the heat radiation from FWDs.
4	Thinning of wafers	Reduce the power loss using the seventh-generation process.
5	Manufacturing method without lifetime control (Selectable depending on the application)	Reduce the variation in the characteristics and cost.

Table 1: Technologies utilized for RCIGBT

Package of DIPIPM (Maximum Junction Temperature)

The heat resistance improvement in 7th generation IGBT chip and transfer mold resin has resulted in an expanded operating junction temperature range. This technology is adopted for Super Mini DIPIPM Ver.7 and Mini DIPIPM Ver.7. The average junction temperature ($T_{j(ave)}$) can now reach up to 150°C (with $T_c \leq 125$°C), and the maximum junction temperature (T_{jmax}) is capped at 175°C (with $T_c \leq 125$°C), as depicted in Figure 4. The maximum junction temperature is set based on short-term temperature rise considerations. This extension in temperature range enables an increase in the instantaneous overcurrent capability during overload operations, such as motor lock conditions in servo drive applications.

Figure 4 illustrates the differences between T_{jmax} and $T_{j(ave)}$. The repetitive temperature variation, denoted as ΔT_j, resulting from motor locking, can impact the power cycle's lifetime. Therefore, when designing systems for safety and prolonged operation, careful consideration should be given to the frequency of motor lock conditions. This helps to ensure reliable performance and durability over time.

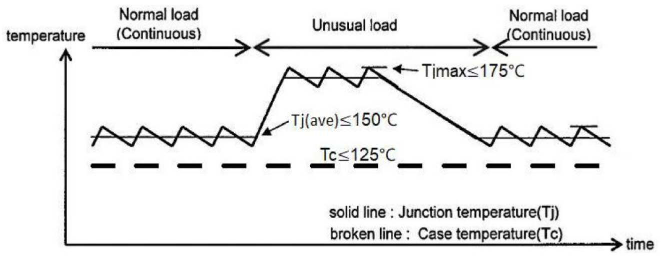
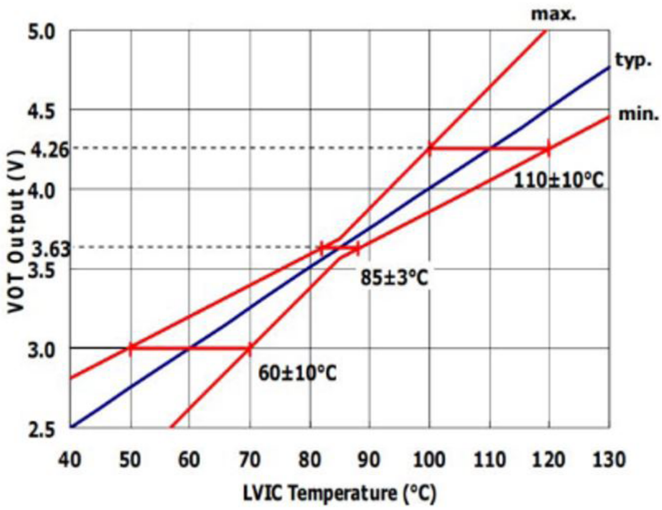
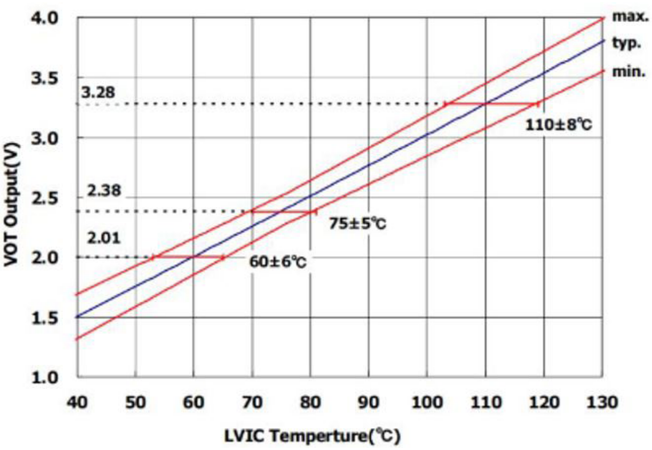


Figure 4: Using T_{jmax}≤175°C for overload situations



(a) Large DIPIPM Ver.4



(b) Large DIPIPM Ver.6

Figure 5: V_{ot} characteristics of Large DIPIPM Ver.4 and Ver.6

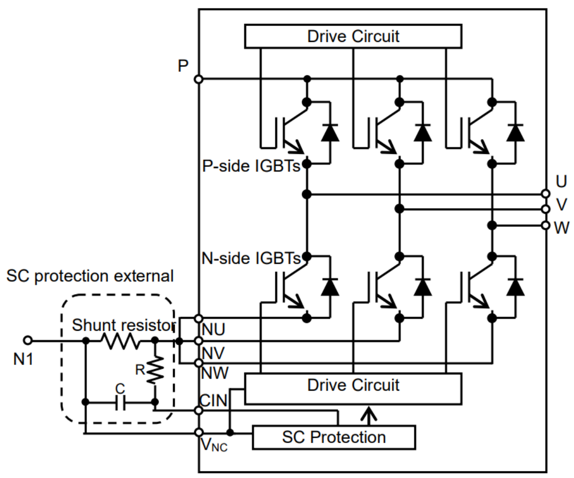
Protection Functions

During the early stages of DIPIPM history, the component already featured several integrated functions, including gate drivers for low and high side switches, undervoltage, and short circuit protections. Around 2008, an over-temperature protection was added and integrated into the LVIC. Subsequently, in 2010, bootstrap diodes with limiting resistors were integrated into the DIPIPM to simplify the power supply for the high side IC. Then, around 2012, DIPIPM featured the integration of an analog temperature output function into its design. These integrated functions are continuously under the improvement that can be demonstrated on analog temperature output and short circuit functions.

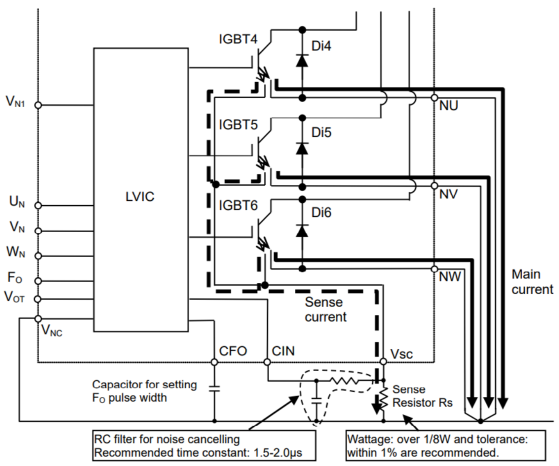
V_{OT} Function (Analog Voltage Output of LVIC Temperature)

An integrated LVIC (Low Voltage Integrated Circuit) employed in various DIPIPM product families includes a temperature sensor with an analog temperature output function, referred to as the V_{OT}-function. This function enables the sensor to deliver an analog voltage output, accurately representing the LVIC temperature (T_{ic}), via the V_{OT}-pin. In many instances, T_{ic} closely corresponds to the DIPIPM case temperature (T_c). This advantageous characteristic opens the possibility of reducing system costs by eliminating the requirement for an additional thermistor.

Figure 5 illustrates the V_{OT} voltage vs. LVIC temperature characteristics of the Large DIPIPM Ver.4 and Ver.6 as an example. In the latest version, Ver.6, the precision and linearity of the V_{OT}-characteristic have been improved by laser trimming technology. As a result, it becomes feasible to utilize the device with the IGBT junction temperature closer to its maximum limit. [13]



(a) Mini DIPIPM Ver. 7



(b) Large DIPIPM Ver.4/6

Figure 6: Short Circuit Protection for (a) Mini DIPIPM Ver. 7 and (b) Large DIPIPM Ver. 4, Large DIPIPM Ver. 6.

Short Circuit (SC) Protection

Mini DIPIPM Ver.7 and Large DIPIPM Ver.4/6 employ different SC (short-circuit) protection methods, as illustrated in Figure 6. In the case of Mini DIPIPM Ver.7, SC protection is achieved by inserting an external shunt resistor into the main emitter current path. This approach follows the conventional method and is employed by other DIPIPM families. On the other hand, Large DIPIPM Ver.4/6 adopts a multi-emitter structure for the N-side IGBT, where a small current in the range of several milli amps is taken from the main emitter current to provide SC protection. As a result, a small sense resistor is utilized instead of a larger shunt resistor used in the conventional method. Compared to the conventional approach, the multi-emitter structure offers several advantages. Firstly, the smaller size of the sense resistor reduces parasitic inductance, enabling suppression of surge voltage between the NU/NV/NW terminals and the V_{NC} terminal. Secondly, it enhances the flexibility of circuit board design. Thirdly, it eliminates power losses associated with the shunt resistor. [13]

Dedicated Applications

Servo Drives

Just recently, VDMA (German Mechanical and Plant Engineering Industry Association) reported growth of the German robotics and automation industry by 13% increase in sales to 16.2 billion euros in 2023. Driven by the transformation trend to make European production more competitive and to compensate the over-demand of skilled workers [7], this trend will also require more reliable and cost-effective servo drives.

Servo motors bring particular challenges to an industrial drive inverter. The motors operate at high speed as well as at standstill (f_O = 0 Hz) for positioning tasks. The motors are usually driven dynamically requiring high switching frequencies in the range of tens of kilohertz. Due to the high output speed of the motors, output frequencies of up to f_O = 600 Hz are not uncommon. The operation at standstill causes large chip-temperature variations and high thermal stress on the semiconductor chips. At the same time, drives makers are under market pressure to drive down component costs.

For such applications like servo drives, MITSUBISHI ELECTRIC offers Super Mini DIPIPM Ver. 7 and Mini DIPIPM Ver. 7 [8]. Both product families are shown in Figure 7 and Figure 8 respectively. As introduced above, both feature a maximal operational junction temperature of 175°C. This is especially helpful during overload situations. The inherent short-circuit protection of Super Mini DIPIPM Ver. 7 and Mini DIPIPM Ver. 7 improve servo-drive reliability. Both power modules also feature over-temperature detection, which saves the servo drive in case of blocked filter, fan malfunction or degradation of thermal grease. Finally, the integration of the boot-strap diode and current limiting resistor into the Super Mini DIPIPM Ver. 7 or Mini DIPIPM Ver. 7 module further reduces device count, saves cost and improves reliability.

Both, Super Mini DIPIPM Ver. 7 and Mini DIPIPM Ver. 7, are perfect candidates for performant, reliable and competitive servo drives.

Table 2 shows the lineup of both series.

Series	Super mini DIPIPM Ver.7	Mini DIPIPM Ver.7	
V_{CES} / I_N	600 V	600 V	1200 V
5 A			X
10 A			X
15 A	X		X
20 A	X	X	
25 A			X
30 A	X	X	
40 A	X		
50 A		X	

Table 2: Super Mini DIPIPM Ver. 7 and Mini DIPIPM Ver. 7 Lineup

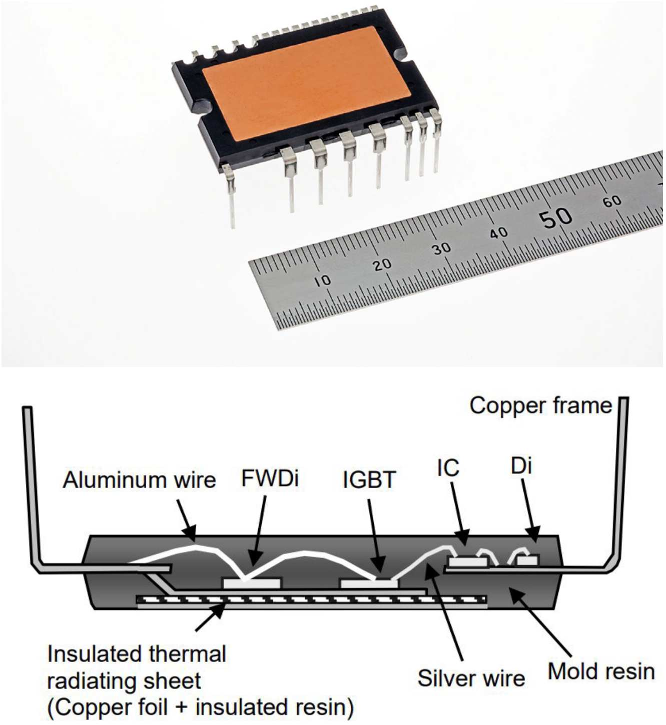


Figure 7: Photo and cross-section view of Super Mini DIPIPM Ver. 7

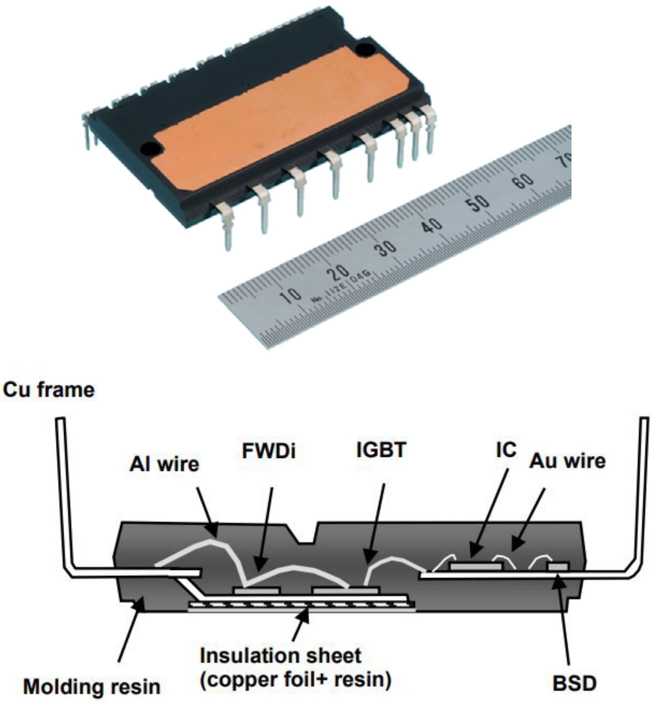


Figure 8: Photo and cross-section view of Mini DIPIPM Ver. 7

Air Conditioning

One of the popular applications for power electronics is air-conditioning (AC). The total number of installed AC systems can be estimated as around 2 billion. The main of this amount is used in countries like USA, Japan, China, South Korea. According to the International Agency of Energy, IAE, the number of air conditioning units worldwide is expected to increase to 4.6 billion units in 2050 and by then, the power consumed by air-conditioners is expected to be comparable to the total power consumption of China today. The trend of AC using would have a self-acceleration effect – the more installations, the more CO2 produced, the more CO2 produced, the more environmental heating, the higher the air temperature, the higher the demand for air-conditioning and so on [9]. Restriction of AC using is not a solution, because AC is not a luxury. The 2016 study by A. Barreca et al. (cf. [10]) shows that the utilization of residential air conditioning resulted in 75% reduction in the rate of mortalities caused by high temperatures in the USA after 1960. The most realistic solution today is to increase the efficiency of air-conditioners by utilizing power electronics containing power devices developed with the very latest materials. For such a solution SiC can be offered. MITSUBISHI ELECTRIC has launched a power module in its DIPIPM family which incorporates MOSFETs based on SiC material.

The product portfolio of MITSUBISHI ELECTRIC contains two dedicated SiC power modules with current/voltage ratings 15A/600V and 25A/600V. The corresponding type names are PSF15S92F6-A6 and PSF25S92F6-A6. Power loss comparison in a mode to keep room temperature constant of air conditioning is presented in Figure 9. Reduction of power loss by 75 % is proven which would increase of AC about 2%.

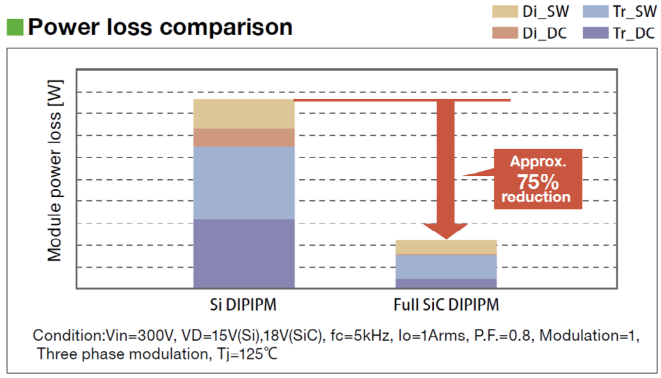


Figure 9: Power loss comparison of power module based on Si and SiC chip technologies

Heat Pump

One of further rising stars in application world is heat pump application. Annual sales in Europe reached 3 million pieces showing annual growth of 38 % in 2022 [11]. Continues growth until 2030 is expected, reaching 10 million annually installed heat pump systems. The trend in heat pump application is integration, it is about embedded drive system. Power electronics is used in compressors,

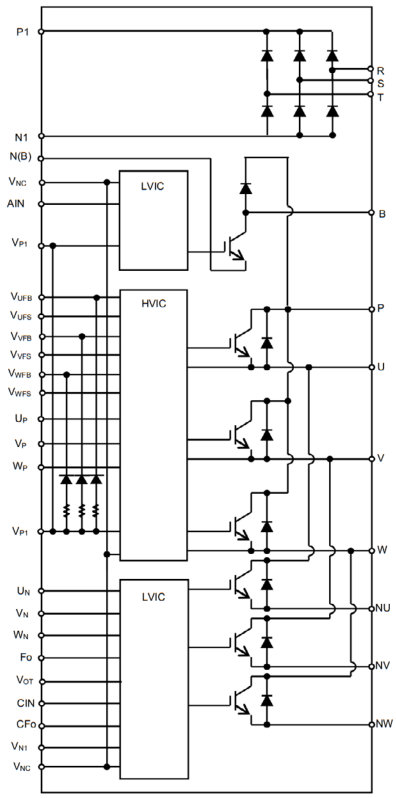


Figure 10: Internal circuit block diagram of DIPIPM+ with additional brake circuit

in pumps themselves and in ventilation. The efficiency requirement of pump itself is hydronic heat pump is the demanding one due to long annual operation time compared with compressor. In summer, liquid pump is in operation for cooling purposes, where compressor is used for preparing of service water only and not for heating. Efficiency is addressed by implementing of 7th generation IGBT [12]. Integration on power semiconductor level is performed through manufacturing of three phase rectifier converter and three phase DC-AC inverter in one package. This highly integrated package from DIPIPM family named DIPIPM+. Topology of DIPIPM+ is presented in Figure 10. The current rating of 1200V DIPIPM+ is between 5A and 35A (cf. Table 3). For the higher output power so called "Large DIPIPM+" is to be selected with rated currents 50A, 75A and 100A and blocking voltage capability of 1200V [13]. The higher current ratings and higher output power is realized by using larger package, larger volume. Comparison of footprint DIPIPM+ vs "Large DIPIPM+" is depicted in Figure 11.

Type name	Rated current	Rated voltage	Motor ratings	Brake	Isolation voltage
PSS05NC1FT	5A	1200V	0.75kW/440V_{AC}	No	2500Vrms
PSS10NC1FT	10A		1.5kW/440V_{AC}		
PSS15NC1FT	15A		2.2kW/440V_{AC}		
PSS25NC1FT	25A		3.7kW/440V_{AC}		
PSS35NC1FT	35A		5.5kW/440V_{AC}		
PSS50NC1F6	50A	600V	3.7kW/220V_{AC}		

Table 3: Product portfolio of DIPIPM+

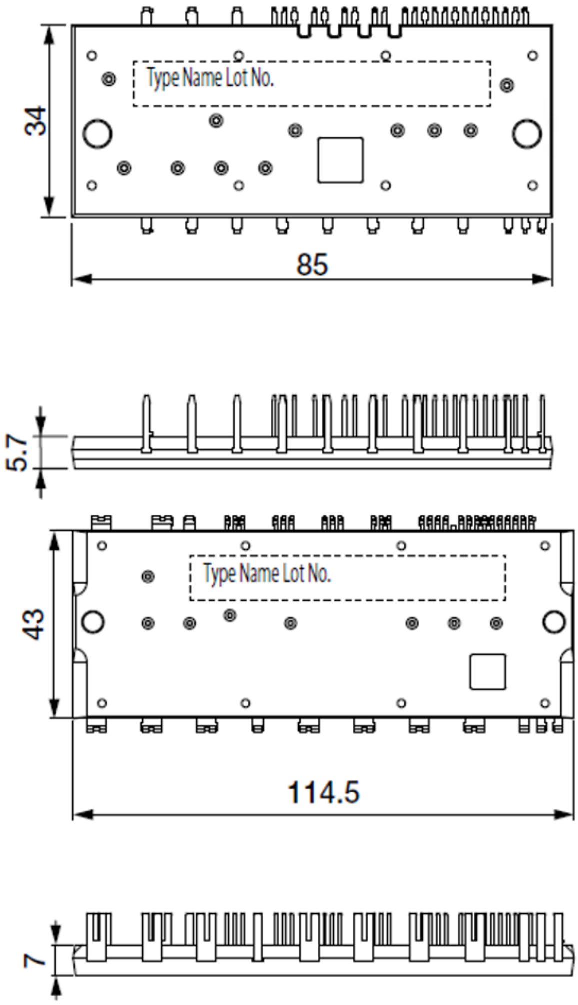


Figure 11: Layout of (a) DIPIPM+ and (b) "Large DIPIPM+" (in mm)

Conclusion

Especially in volume markets, increasing demands for reliability, compactness and energy efficiency on electric drive systems are tough. At the same time, cost pressure is immense.

MITSUBISHI ELECTRIC's DIPIPM family addresses the increasing technical demands while also taking the framework conditions in terms of costs into account. Today, DIPIPM is used in various applications such as air conditioning, heat pumps, washing machines or servo drives. Since its market launch in 1997, more than 1 billion DIPIPM units have been manufactured. The field experience and the proven reliability are correspondingly high.

References

[1] S. Noda, K. H. Hussein, S. Yamada, G. Majumdar, T. Yamada, E. Thal and G. Debled, "A Novel Super Compact Intelligent Power Module," in *Thrity-fourth International Power Conversion Conference (PCIM)*, Germany, 1997.

[2] M. Harada, T. Minato, H. Takahashi, H. Nishihara, K. Inoue and I. Takata, "600 V trench IGBT in comparison with planar IGBT-an evaluation of the limit of IGBT performance," in *6th International Symposium on Power Semiconductor Devices and Ics*, Davos, Switzerland, 1994.

[3] H. Takahashi, H. Haruguchi, H. Hagino and T. Yamada, "Carrier stored trench-gate bipolar transistor (CSTBT)-a novel power device for high voltage application," in *8th International Symposium on Power Semiconductor Devices and ICs. ISPSD*, Maui, HI, USA, 1996.

[4] T. Takahashi, Y. Tomomatsu and K. Sato, "CSTBT (III) as the next generation IGBT," in *20th International Symposium on Power Semiconductor Devices and IC's*, Orlando, FL, USA, 2008.

[5] T. Takahashi and T. Yoshida, "RC-IGBT Chip Technology for White Goods," *Mitsubishi Electric ADVANCE,* pp. 2-4, March 2019.

[6] S. Shibata, et al., ""SLIMDIP Series" Power Module Using RC-IGBT," *Mitsubishi Denki Giho,* vol. 90, no. 5, pp. 307-310, 2016.

[7] Mechanical Engineering Industry Association (VDMA), *Robotics and Automation expects all-time high,* 2023.

[8] S. Lu, R. Zhao and R. Tao, "DIPIPM Suitable for Middle Power Servo Drive," in *International Exhibition and Conference for Power Electronics, Intelligent Motion, Renewable Energy and Energy Management (PCIM Asia)*, Shanghai, China, 2022.

[9] "SIC DIPIPM for a Greener Tomorrow," *Bodo's Power Systems,* p. 14, July 2020.

[10] Barreca, A. et al., "Adapting to Climate Change: The Remarkable Decline in the US Temperature-Mortality Relationship over the Twentieth Century," *Journal of Political Economy,* vol. 124, no. 1, pp. 105-159, 2016.

[11] European Heat Pump Association (ehpa), "Annual report 2022," Brussels, Belgium, 2022.

[12] T. Radke and K. Masuda, " 7th Gen. IGBT and Diode Chipset Enabling Highest Performance Power Modules," *Bodo's Power Systems,* pp. 42-45, June 2015.

[13] MITSUBISHI ELECTRIC Press Release No. 3280, *Mitsubishi Electric to Launch Large DIPIPM+ Series,* Tokyo, Japan, 2019.

www.mitsubishielectric.com