New PrimePACK™ package to lever IGBT5

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Abstract

The 5th generation IGBT and emitter controlled diode from Infineon Technologies allow for an increase in output current in the range of ≈30% on the same module footprint at a junction temperature of $T_{\mathrm{vj,op}}$ = 175°C [1,2]. In order to achieve the demanded module lifetime under these conditions, the new PrimePACK™ module generation makes use of the .XT technology [1,3]. Expanding the power range to this extent, the maximum current is limited by the ampacity of the existing internal bus bars. Improvement in the new PrimePACK™ 3+ package is implemented using a second AC bus bar and AC power terminal. This solution leads to a strong reduction of the maximum internal temperature at 30% increased current and 25 K increased chip temperature with respect to the PrimePACK™ 3. The influence of the new AC-bus bar geometry on the current distribution and current flow in the bus bars is investigated. An inverter test demonstrates the benefit of the improved thermal management under real application conditions.

1. Expanding the power range

Currently, the maximum current rating available for the PrimePACK™ housing in half bridge configuration is 1400 A. Employing the new 5th generation IGBT and diode technologies from Infineon Technologies, the maximum module current can be increased by approximately 30%, expanding the current rating for the PrimePACK™ 3 footprint to 1800 A at a chip temperature, $T_{\mathrm{vj,op}}$, of 175°C [1,2].

Figure 1: Expanding the power range. Using the new PrimePACK™ 3+ package in conjunction with IGBT5 and emitter controlled diode 5, the current rating on the PrimePACK™ 3 footprint can be extended from 1400A to 1800 A.

Such increase in current density turned out to be feasible only with an optimization of the module design with respect to its thermal management. Figure 1 shows the new PrimePACK™ 3+ module, which allows levering the full potential of the 5th generation 1200 V and 1700 V chip technologies in high power applications.

The new module has the same footprint as the well-established PrimePACK™ 3. The most prominent change is the additional AC power terminal. The benefits resulting from this design are in the focus of this paper. In addition, the PrimePACK™ 3+ comes with a further auxiliary collector terminal for the low side IGBT closely located to the low side gate control terminals, which is advantageous for advanced gate driver designs.

1.1. Thermal analysis

To evaluate the maximum ampacity of different module designs, thermal simulations using ANSYS workbench™ have been performed. In these simulations, the IGBTs/diodes are operated so that $T_{\mathrm{vj,op}}$ = 175°C is reached. The resulting temperature profile determines the temperatures of the points connecting the module bus bars to the substrates. The temperature of the module power terminals is fixed to 105°C.

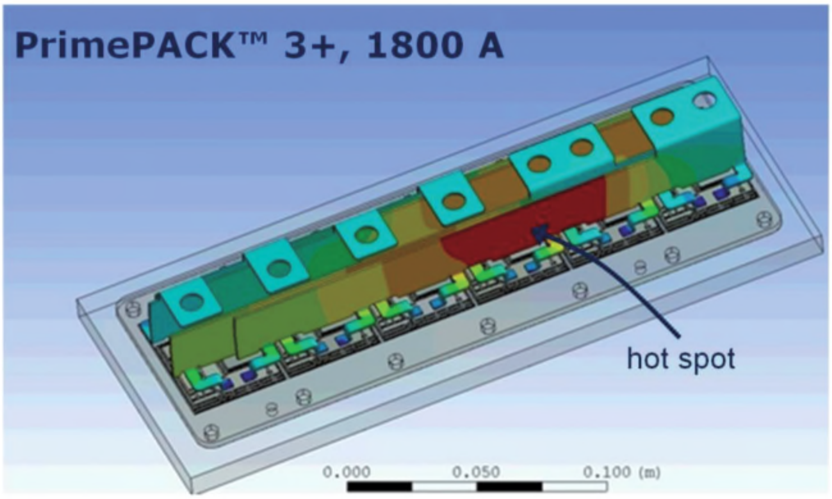

Figure 2: Simulated temperature distribution in the module bus bars for a PrimePACK™ 3+, module. The simulation has been performed for 1800 A RMS output current and a chip temperature of 175°C.

Now, a variable current can be forced through the bus bars assuming homogenous distribution between the six substrates of the module. In Figure 2, the temperature distribution along the bus bars is shown for the PrimePACK™ 3+ module operated at 1800 A, namely the FF1800R17IP5, equipped with IGBT5 and .XT technology. As can be seen, the hottest area is located on the AC-bus bar. The second AC-bus bar leads to massive improvements in this thermal bottleneck. Even at the increased current density with respect to the PrimePACK™ 3 and in spite of the 25 K increased chip temperature, the maximum temperature for the bus bar is kept well within the temperature limits of the materials surrounding the hot spots. With this enhancement, the PrimePACK™ 3+ is well-suited to lever the full potential of IGBT5. Utilizing the .XT technology, the new module fulfills the requirements concerning lifetime even at the increased current density and higher thermal stress. It should be noted that the module is designed for AC operation. When operated in DC mode, which has not been investigated in the course of this work, the DC terminals may become a thermal bottleneck not allowing for an operation at 1800A_{DC}.

1.2. Current sharing between the AC-terminals

The introduction of a second AC terminal including a second internal AC bus bar raises questions concerning the current sharing between the two bus bars. In order to investigate the current sharing and the influence of different connection geometries for the two AC-terminals on the current flow, double pulse tests with a PrimePACK™ 3+ module in a laboratory setup have been performed.

The current sharing was experimentally determined using Rogowski coils. In Figure 3(b), the relative current mismatch is plotted during turn-on for four different AC connection geometries. The switching measurements were performed at room temperature with a DC-link voltage of 900 V and a current of 1800 A. The load inductance was 44 µH.

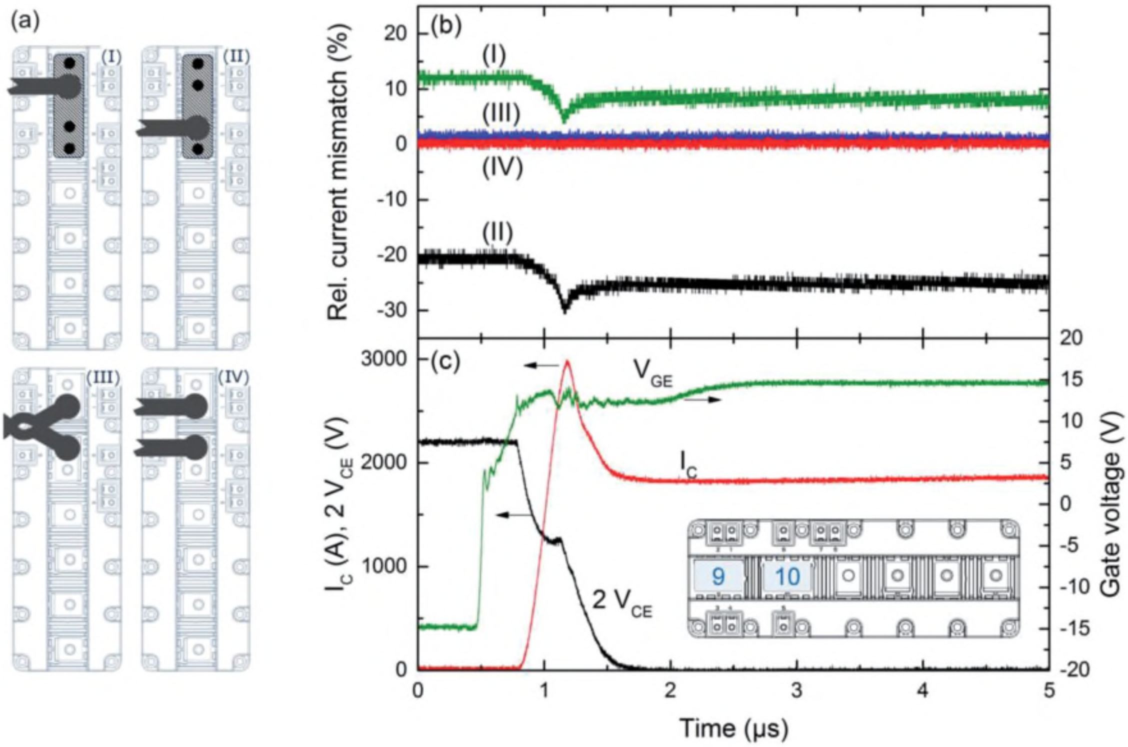

Figure 3: (a) AC terminal connection variations investigated. (b) Relative current mismatch between the two AC terminals of the PrimePACK™ 3+ for different AC connection geometries measured during turn-on and (c) according waveforms of collector emitter voltage, collector current, and gate voltage. The inset in (c) defines the terminals 9 and 10.

Figure 3(c) displays the waveforms for the gate voltage, collector emitter voltage and total collector current. As the waveforms of the total collector current only reveal a negligible dependence on the AC connection, Figure 3(c) includes the curves for one connection option only. Curve (I) in Figure 3(b) represents the relative current mismatch during turn-on for connection geometry (I). Here, both AC terminals are connected with a 170 mm² copper bar directly at the module and a cable is attached to the outer AC terminal as schematically illustrated in Figure 3(a). For this type of connection, the current mismatch prior to commutation is approximately +12% of the total current. The higher current is flowing through terminal 9. During commutation, a redistribution of the current is observed resulting in a current mismatch of 8% after commutation. Curve (II) in Figure 3(b) has been obtained from a measurement using a geometry similar to (I) where the two AC terminals are connected with a 170 mm² copper bar. However, in the case of (II), the cable was connected to terminal 10 as depicted in Figure 3(a). For (II), a larger average current mismatch of approximately -21% and -25% is observed before and after current commutation, respectively. For connection types (III) and (IV), the AC terminals were individually contacted with two cables of the same length and the copper bar was omitted. In case of (III), the two cables where twisted, while this was not done for (IV).

In both cases, a much lower current mismatch of less than 2% and no repartition of current between the two AC terminals occurs during current commutation. The lowest current mismatch is measured for connection version (IV).

In Figure 4, the different AC connection geometries (I) to (IV) are compared for the IGBT turn-off in an analogous way as presented for the turn-on in Figure 3. As for the turn-on measurements, the DC-link voltage was 900 V and the current before turn-off was 1800 A. The results obtained are very similar to the results from the turn-on measurements. Version (II) exhibits the largest current mismatch, followed by types (I), (III) and (IV). A redistribution of approximately 4% of the total current occurs during current commutation for the options where the two AC terminals are bridged with a copper bar and the cable is only connected to one of the terminals. For all measurements of alternatives (III) and (IV), approximately 4% of the total current is redistributed from terminal 9 to terminal 10 during turn-on and from terminal 10 to terminal 9 during turn-off. The reason for the difference in the current mismatch between the on-state and the off-state can be understood considering the different d*i*/d*t* of the load current in these two situations. The minor difference between the inductances of the two AC terminals in combination with the inductance of the connecting copper bar, leads to a slightly different d*i*/d*t* in the two module internal AC bus bars. When the two AC terminals are individually connected by two cables (III) and (IV), the difference in the module's internal inductances is small compared to the inductance of the cables, which results in closer balance of the current sharing. The lowest current mismatch is obtained for an individual connection of the two AC terminals with two cables ideally of the same resistance and inductance.

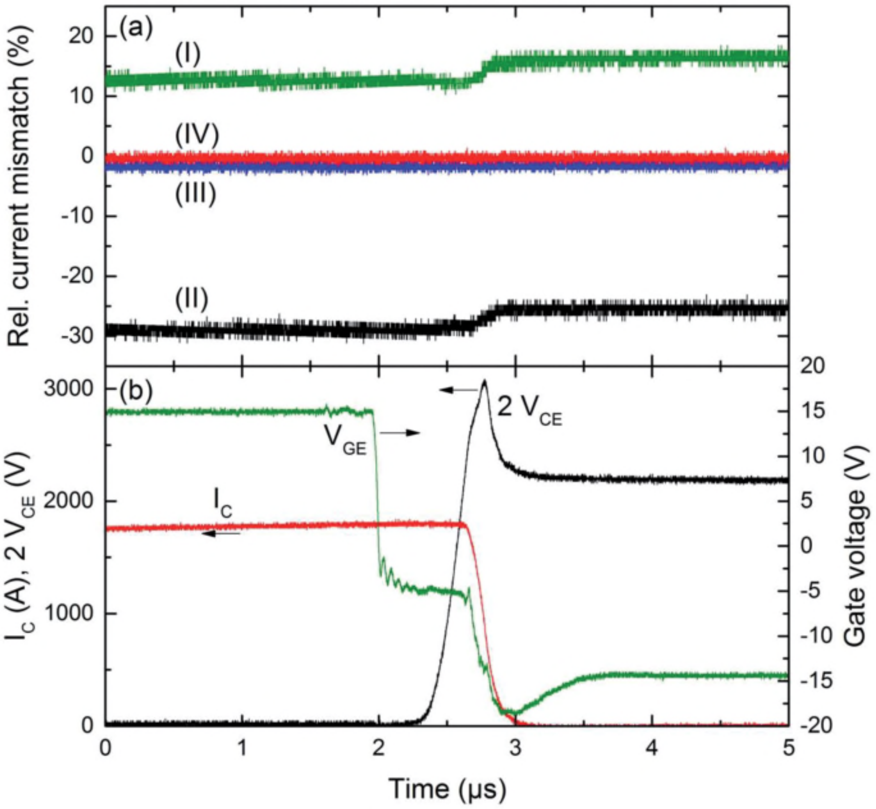

Figure 4: (a) Relative current mismatch between the two AC terminals of the PrimePACK™ 3+ for different AC connection geometries measured during turn-off and (b) according waveforms of collector emitter voltage, collector current, and gate voltage.

Another general observation is that the absolute current mismatch of connection type (I) is smaller than the current mismatch for connection version (II). This can be explained by the fact that for option (II) the current path via terminal 9 includes a larger resistance than the current path via terminal 10 for set up (I).

1.3. Inverter Test

For the simulations discussed in 1.1, a constant terminal temperature of 105°C was assumed. Depending on the cooling conditions and the RMS output current, a certain thermal power has to be dissipated via the AC terminals in order to fulfill the boundary condition of a fixed terminal temperature. The simulations show that at an RMS output current of 1800 A and a chip temperature of 175°C, the total thermal power dissipated via the two AC terminals of the PrimePACK™ 3+ is only 4% larger than for the PrimePACK™ 3 operated at chip temperatures of 150°C and an RMS current of 1400 A.

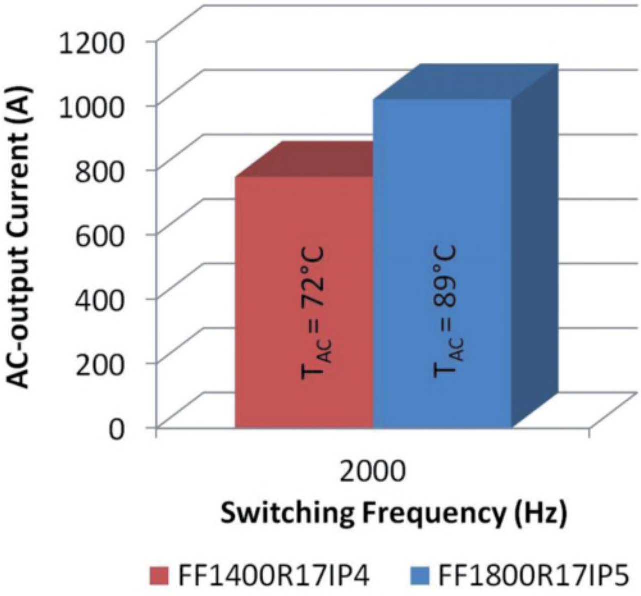

Figure 5: AC-output current and AC terminal temperature measured in thermal equilibrium for a PrimePACK™ 3 module, FF1400R17IP4, and a PrimePACK™ 3+ module, FF1800R17IP5. The output current of the PrimePACK™ 3+ was increased by 30% with respect to the PrimePACK™ 3 for a switching frequency of 2 kHz. No active cooling was applied to the terminals

In order to assess the thermal situation under real application conditions, the two modules have been compared in an inverter test. The experiment has been performed with a liquid cooled test inverter system. The two modules under test are the FF1400R17IP4, a 1700V, 1400A IGBT4 PrimePACK™ 3 module and the 1700V, 1800A IGBT5 PrimePACK™ 3+ module FF1800R17IP5. The AC terminals were connected with two 200 mm² copper cables forming a short loop to the connection terminal of the inverter. There was no active cooling for the terminals. Temperature sensors were attached to the AC terminal of the PrimePACK™ 3 and to the combined AC terminal of the PrimePACK™ 3+ module. In Figure 5, the results of the temperature measurements are displayed. The temperatures of the AC terminals were measured after thermal equilibrium was established. The PrimePACK™ 3 was operated at an RMS output current of 780 A at a switching frequency of 2 kHz, which resulted in an AC terminal temperature of 72°C. For the PrimePACK™ 3+, the RMS current was increased to 1020A at the same switching frequency, where an AC terminal temperature of 89°C was measured.

Notably, in spite of the 30% higher output current the temperature of the AC terminals of the PrimePACK™ 3+ is increased by only 17 K without cooling of the AC terminals.

2. Summary

In summary, the new PrimePACK™ 3+ package has been presented, which expands the current range of the PrimePACK™ series to 1800 A. The ampacity of the module is enhanced by a second AC bus bar, with large benefits for the thermal management of the module. An optimal current sharing between the two AC terminals is obtained when the two terminals are individually connected with two cables of the same resistance and the same inductance exceeding the inductance of the module’s internal AC bus bars. An inverter test demonstrates that a 30% increase in current density compared to the PrimePACK™ 3 leads to only 17 K increase in AC terminal temperature at a switching frequency of 2.0 kHz.

3. References

[1] A. Ciliox, et al., Next step towards higher power density with new IGBT and diode generation and influence on inverter design, PCIM, Nuremberg, Germany, 2013.

[2] A. Stegner, et al., Next generation 1700V IGBT and emitter controlled diode with .XT technology, PCIM, Nuremberg, Germany, 2014.

[3] A. Ciliox, et al., New module generation for higher lifetime, PCIM, Nuremberg, Germany, 2010.