Aspects of increased power density with the new 5th generation IGBT demonstrated by application relevant measurements

Raghavan Nagarajan, Infineon Technologies AG, Max-Planck-Str. 5, D-59581 Warstein, Germany , raghavan.nagarajan@infineon.com

Dirk Brieke, Infineon Technologies AG, Max-Planck-Str. 5, D-59581 Warstein, Germany dirk.brieke@infineon.com

Abstract

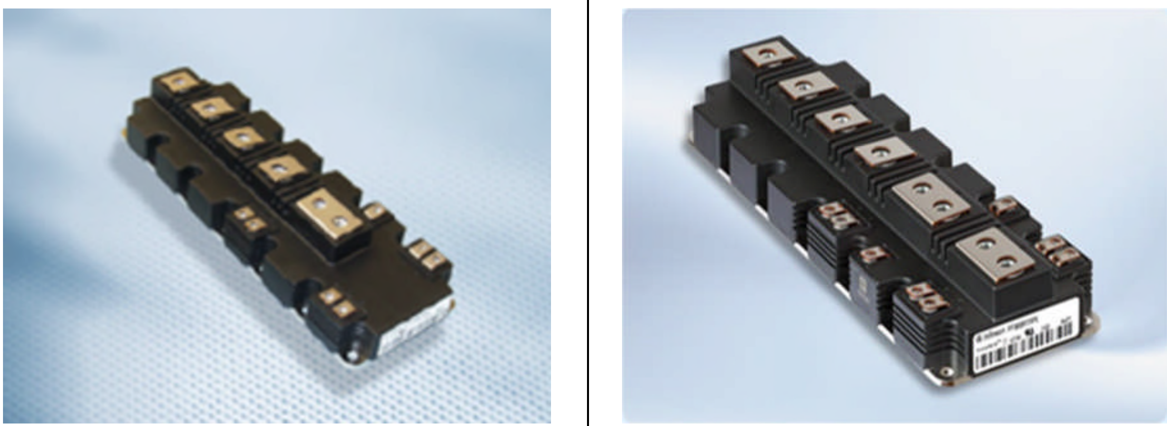
The objective of this paper is to illustrate the measurement results of a high power density water-cooled power stack demonstrator with the new 5th generation power semiconductor (IGBT5) operating at 175°C junction temperature. At the same time, all other surrounding system components such as capacitors and driver boards are maintained at acceptable temperature levels. This paper consists of two sections namely the design of a new power stack with IGBT5 having a maximum operating junction temperature of 175°C and secondly the comparison of the stack with the existing 4th generation power semiconductor stack. Key application oriented parameters such as the heat sink temperature, bus bar temperature and AC terminal temperature are measured and compared. The achievable increase in power density using this new device is illustrated. Finally, some guidelines are suggested which the designer should take into consideration while utilizing the new 5th generation power semiconductor's increased operating junction temperature.

1. Introduction

An introduction of a new generation of IGBT modules mainly comes along with the increase in power density on the base of a new technology [1, 2]. In this new 5th generation power semiconductor, increase in power density is enabled through new interconnection technologies [3] and it is introduced in PrimePack™ 3+ power module package.

The PrimePack™ 3 power module housing introduced in 2006 has become a standard for power module housing in the megawatt power range. Owing to its success it is self-evident that the launch of the new 5th generation 1700V IGBT will take place in the PrimePack™ 3+ housing [5, 6]. At present, the maximum available current rating in the PrimePack™ 3 housing in a half-bridge configuration is 1400A. With the introduction of this new 5th generation IGBT half-bridge module, the module nominal current rating is pushed to 1800A. To enable this increase in module current, the present PrimePack™ 3 package is modified. It now contains two AC terminal connectors instead of one AC terminal. The outer dimensions of PrimePack™ 3 package are retained without any modification.

Fig.1a shows the existing PrimePack™ 3 module and new the PrimePack™ 3+ module with two AC terminals is shown in Fig.1b.



(a) (b)

Fig. 1: (a) FF1400R17IP4 in a PrimePack™ 3 package, (b) New 5th generation IGBT, FF1800R17IP5 in PrimePack™ 3+ package

The increase in power density using IGBT5 is illustrated with an application correlated measurement of power loss and temperature rise. To obtain the measurement, a demonstrator based on the well-known STACK platform [7] with a 5th generation device FF1800R17IP5 was built. To bring to light the difference of this new 5th generation device in the demonstrator, a comparison of the new device with an existing IGBT4 demonstrator using FF1400R17IP4 was carried out. Also, the heat sink's temperature is measured and the junction temperatures of the chip are estimated under defined operating conditions.

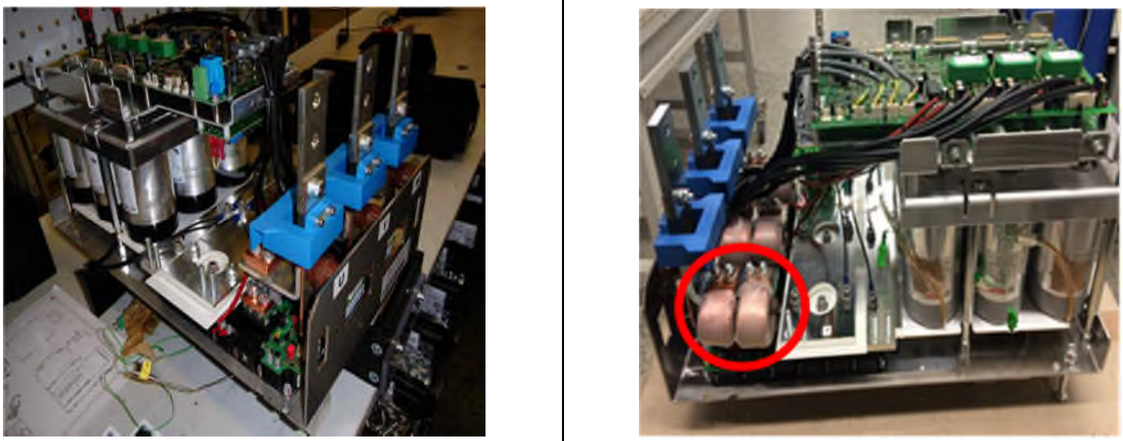
The impact of higher operating junction temperature of the new generation IGBT on the surrounding peripherals such as DC bus bar and AC terminals is evaluated through measurements. From these measurements the list of critical thermal design considerations of the system is derived, enabling the designer to focus on these points when using the IGBT5 device.

2. Hardware Demonstrator

Two hardware demonstrators were built, one with 3 half-bridge modules FF1400R17IP4 and one with 3 half bridge modules FF1800R17IP5 as shown in Fig. 2. The driver board for both demonstrators are identical and contain of three dual channel EiceDRIVER™ 2ED300C17-ST. The value of the turn-on and turn-off gate resistors for both the demonstrators are identical as listed in Table 1.

The main difference between the two demonstrators is that the FF1800R17IP5 features two output AC terminals instead of a single one. In the newly built demonstrator, the additional AC terminal has been taken into consideration and the mechanical construction of the

system is adapted accordingly. The dimension of the module adapter board is modified to fit the new PrimePack™ 3+ package. This arrangement is explicitly marked with a circle as depicted in Fig. 2(b).



(a) (b)

Fig. 2: Photo of the two demonstrator Stacks built: (a) Stack with FF1400R17IP4 (b) Stack with FF1800R17IP5

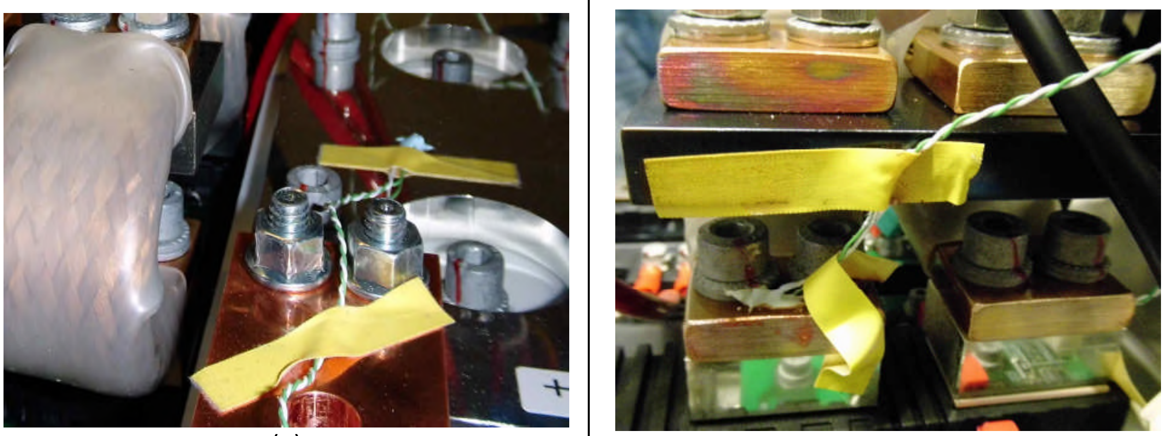
Each hardware demonstrator consists of a 3 phase inverter having one module in each leg. The DC link consist of a 3.6mF DC bus capacitor and the output AC terminals of the demonstrator have three Hall effect current sensors of nominal current rating of 1200A, as depicted in Fig. 2.

Table 1 lists the important parameters of the demonstrator developed:

Topology	B6I
Application	Inverter for Drives & Wind energy converters
Load type	Resistive, Inductive
DC link capacitor	3.6 mF
Heat sink	Water cooled
Thermal resistance heat sink to ambient per switch – $R_{th,ha}$	30.2K/kW
Sensors	Current, Voltage, Temperature
Driver signals to the IGBT	Electrical
Rg_on	1.0 ohm
Rg_off	0.68 ohm

Table 1: Important parameters of the demonstrator

To measure the temperature of the system in detail, apart from the standard temperature measurements, further temperature sensors are included in the test set-up. K-Type thermocouples are placed on the DC bus bar and at two locations in the V-phase AC terminal as depicted in Fig. 3.



(a) (b)

Fig. 3: Additional thermocouples for temperature measurement: (a) on the DC bus bar (b) on the module's AC terminal

1. Test bench set-up

Two stacks were tested under identical conditions in the same test bench. The load test was carried out at different switching frequencies with an inductive load of 0.1mH. The DC bus voltage was maintained at 1100V. The main purpose of such a test arrangement is to compare Stacks based on IGBT5 and IGBT4 under identical operating conditions and to obtain the relevant temperature rise of the surrounding components such as DC bus bar and AC terminals.

The parameters of the test setup are listed in Table 2:

Load	Star connected inductive load, 0.1mH
DC bus Voltage	1100V
DC link capacitor	3.6mF
Cooling condition	Water cooled with a flow rate of 17L/min
Water Inlet temperature	37°C
Humidity	23%
Output frequency	50Hz

Table 2: List of important test parameters

2. Measurement results:

The two stacks were tested at two different test conditions as listed in Table 3:

Module type	Output current @ 2000Hz	Output current @ 2500Hz
FF1400R17IP4	780A	660A
FF1800R17IP5	1020A	860A

Table 3: Results achieved using different switching frequencies

The IGBT's virtual junction temperature T_{vj}, the case temperature T_c and the heat sink temperature T_{hs} were estimated using IPOSIM [4]. The DC bus bar temperature and the AC terminal temperature were measured directly using an isolated K-Type thermocouple measurement set-up.

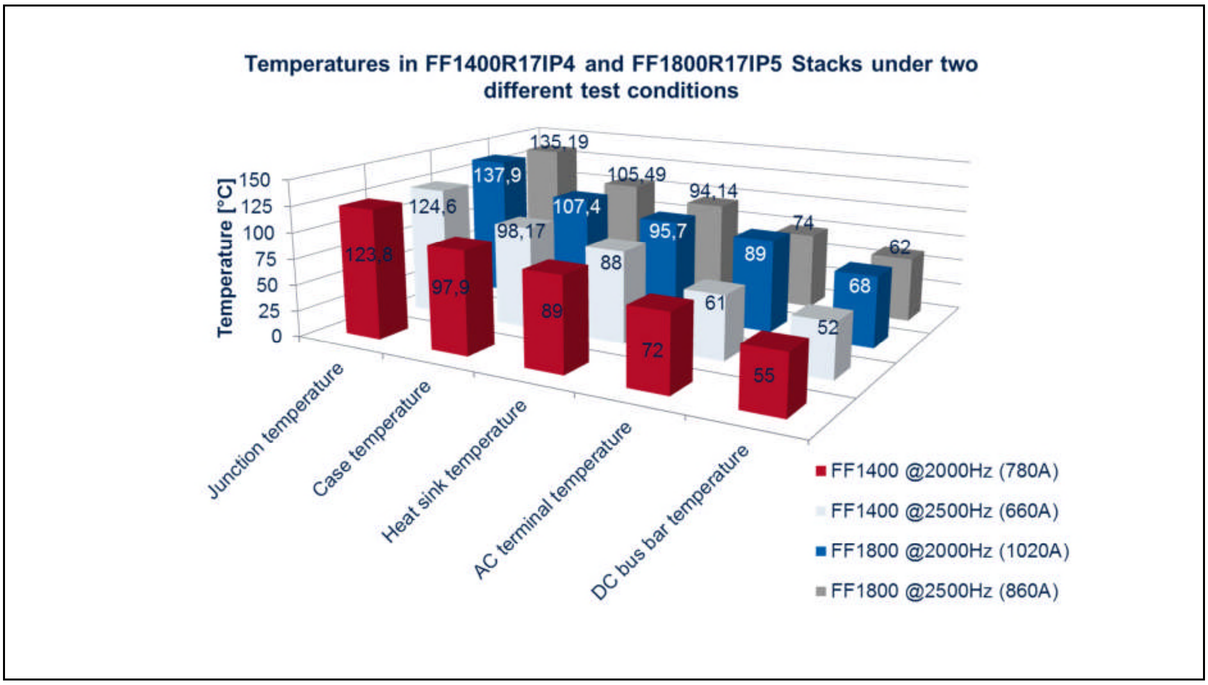


Fig. 4: Temperatures in FF1400R17IP4 and FF1800R17IP5 Stacks

From Fig. 4, it can be seen that for the FF1400R17IP4 based stack at a switching frequency of 2000Hz, the junction temperature reaches 123.8°C, the case temperature reaches 97.9°C and the heat sink temperature reaches 89°C. Also it is seen from Fig. 4 that the DC bus bar reaches a temperature of 55°C and the AC terminal reaches a temperature of 72°C.

The measured temperatures and IPOSIM based estimations of the junction temperature of the FF1800R17IP5 stack is also shown in Fig. 4. It can be seen that the junction temperature of the FF1800R17IP5 based stack at a switching frequency of 2000Hz reaches 137.9°C, the case temperature reaches 107.4°C and the heat sink temperature reaches 95.7°C. It can be derived from the Fig. 4 that the DC bus bar reaches a temperature of 68°C and AC terminal reaches a temperature of 89°C.

Fig. 5 depicts that when IGBT5 is used, the designer would be able to obtain a 30% increase in current at marginally increased junction temperature of the chip. The junction temperatures in Fig. 5 are estimated using IPOSIM for the operating conditions mentioned in Table 2 and Table 3.

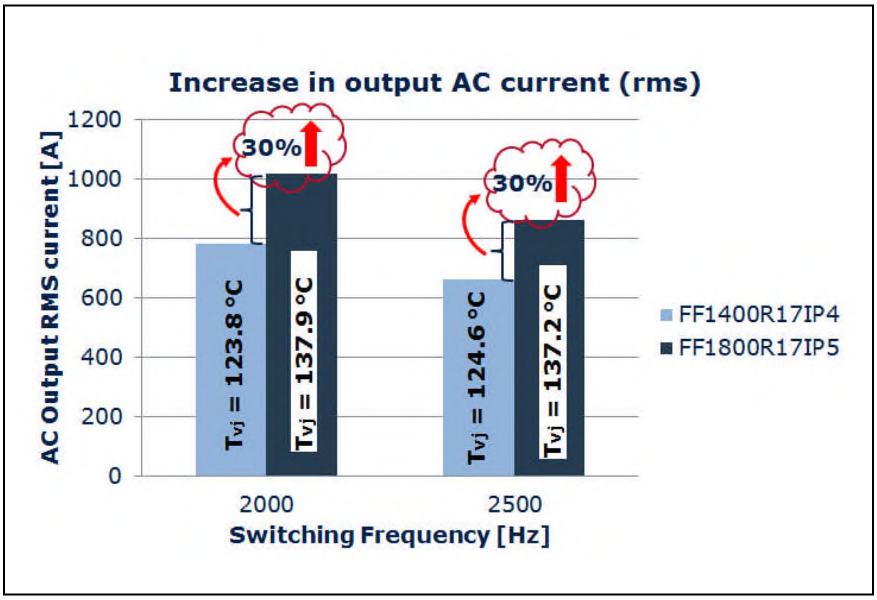


Fig 5: Change in current and corresponding junction temperature between IGBT4 and IGBT5

Fig. 6 depicts the comparison of the AC terminal temperature at two different switching frequencies. A difference in the AC terminal's temperatures can be expected due to the difference in the module design and local current densities.

Comparing the results summarised in Fig. 6, an increase of 17 Kelvin is measured despite a 30% increase in output current. This increase in AC terminal temperature is within the tolerable temperature limit of the AC terminals and this has a minor influence on the system design.

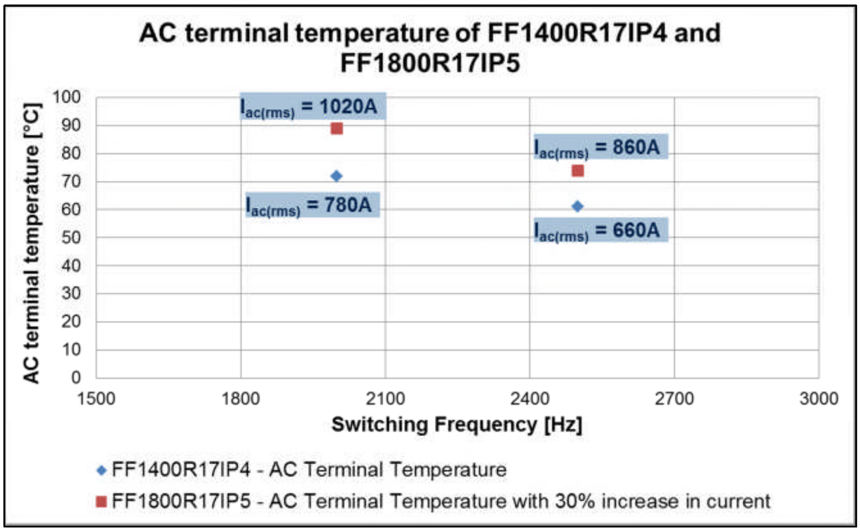


Fig. 6: Comparison of AC terminal temperatures of FF1400R17IP4 Stack and FF1800R17IP5 Stack.

3. Guidelines

Based on the observation of the measurement results, some guidelines are suggested for the designer when using a new 5th generation IGBT module.

- Consider the need for mechanical modification/adaptation of the AC terminal connection of the system.
- For a 30% increase in output AC current, the heat sink temperature is increased by 6.7 Kelvin. This is acceptable in most designs so there is no urgent need to change the heat sink or cooling arrangement of the system.
- The AC terminal temperature is increased by 17 Kelvin and therefore it is recommended to choose a current sensor with a suitable operating temperature range.
- Due to the new interconnection technology [1, 6], an increase in junction temperature for a 30% increase in output AC current is not an issue for the module lifetime.

4. Conclusion

Based on the comparison of the stacks with 4th and 5th generation IGBT it can be concluded that the temperature rise in the AC terminals is not a severe issue and this temperature rise can be easily handled. A 30% increase in output power under acceptable temperature rise for the surrounding peripheral components is obtained with the 5th generation IGBT Stack. The designer of the complete system needs to understand the impact of a marginal rise in temperature of the surrounding components to their lifetime and should follow the suggested guidelines for a sophisticated system design.

5. References

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

[2] K. Vogel et al.: IGBT with higher operation temperature - Power density, lifetime and impact on inverter design,
PCIM, Nuremberg, Germany, 2010.

[3] K. Guth et al.: New assembly and interconnects beyond sintering methods,
PCIM, Nuremberg, Germany, 2010.

[4] IPOSIM: IGBT power simulation,
www.infineon.com/IPOSIM

[5] M. Schulz: Power Semiconductor Development,
Bodo's Power Systems, February 2015.

[6] Andre R. Stegner et al: Next generation 1700V IGBT and emitter controlled diode with .XT technology
PCIM, Nuremberg, Germany, 2014

[7] Infineon ModSTACK™ HD Datasheet: 6MS10017E41W36775,
www.infineon.com