Comparative Study on Common-mode EMI between Two IGBT Package Layouts

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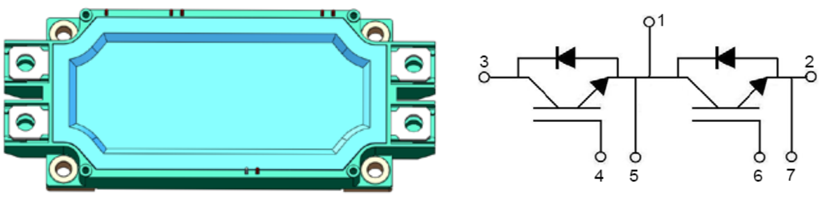
Abstract

The high *dv/dt* of IGBT module during switching transients is an important source of common-mode (CM) electromagnetic interferences (EMI) in most power converters. Different internal layout of IGBT module generates different *dv/dt* even if all other conditions keep unchanged. A system-level CM EMI model based on chip-level equivalent circuit for three phase power converter was proposed in this paper. The CM EMI emission of the two frequently-used IGBT modules with the same package was investigated in detail. Comparative analysis demonstrated that one is superior to the other, which suggests that the EMI performance should be taken into careful consideration while designing a new package of IGBT modules.

1. Introduction

With the rapid development of power electronics technique, the switching frequency goes higher and higher, and the switching time becomes shorter and shorter. One noticeable advantage of those improvements is that much higher efficiency and higher power density can be obtained. At the same time, the so-called EMI problem become more and more prominent and sometimes it could become a fatal bottleneck when putting a new product on the market. EMI standards have become the top non-tariff barriers for the export of many products.

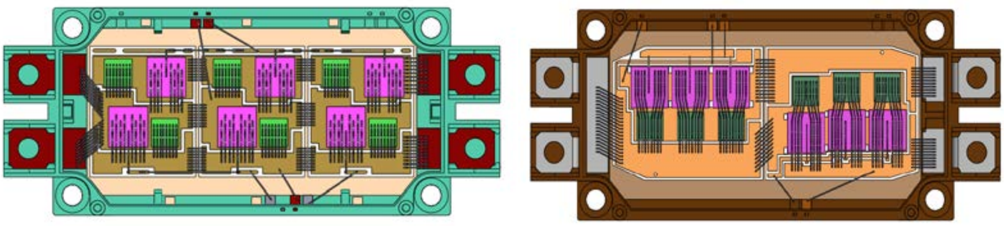
A great deal of effort has been made in this area to reduce the EMI emission[1-5], including adding input/output EMI filter, taking proper grounding, or improving the control algorithm such random PWM and SHEPWM, etc. Strictly speaking, the high *dv/dt* should be responsible for the CM electromagnetic disturbance, which is to be known as sources of CM EMI. And the propagation path also plays an essential role in this effect. So far, a lot of researches have focused on the power converter level design and modification [1-3]. Very few studies can extend to power module level [4-5], that's to say, to study the effect of the internal geometry inside the module, mainly, the interconnection between direct-bonded-copper (DBC) and chips, on the *dv/dt*. One IGBT with an external package size of 62mmX150mm is one of the most commonly-used power modules in practice, as shown in Fig. 1(a). Different power module manufacturing companies has different name for this kind of package. The circuit of this module is shown in Fig. 1(b).



(a) Outline (b) Circuit topology

Fig. 1 The IGBT module of 62mmX150mm

There are two typical internal layouts for this kind of module, as shown in Fig. 2 (a) and (b) respectively. They will be named as type A and type B in this paper for convenience of comparison. Generally speaking, type A represents a conventional style package which came into being more than 10 years ago, while type B stands for a novel package which just emerged several years ago.



(a) Type A (b) Type B

Fig. 2 Two internal configurations of 62mmX150mm IGBT module

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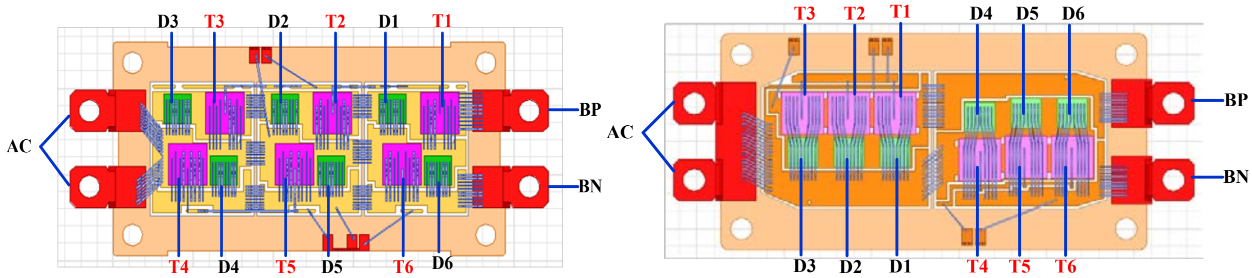
As can be seen from Fig. 2, there are three identical DBCs used in type A, while two DBCs with minor differences used in type B. The whole DBC-chip configurations are totally different between type A and type B, and therefore different fixtures are needed to finish the soldering process. And for the wire bonding processing, except the wires for control signals, there are 22 and 12 rounds of wire bonding in the two types of modules respectively. Less bonding rounds will help to improve the production efficiency. What's more, type B can reduce the imbalance of current sharing among chips connected in parallel, which will be discussed in another paper. But the topic of interest in this paper is about CM EMI, what will be the comparison between the two types in this aspect? The following sections will deal with this problem step by step.

2. Parasitics extraction for the electrical interconnections of chips

For both types, there are 3 IGBT/FRD chips connected in parallel to increase the current capacity for medium-high power applications. The static/dynamic electrical behaviors of the three chips not only affect the power density of the module, but also affect the EMC performance. In order to accurately evaluate the electromagnetic behaviors especially the CM EMI for the two types of configurations, it's necessary to create a precise equivalent circuit model for each, and this model must contain frequency-dependent RLCG parasitics.

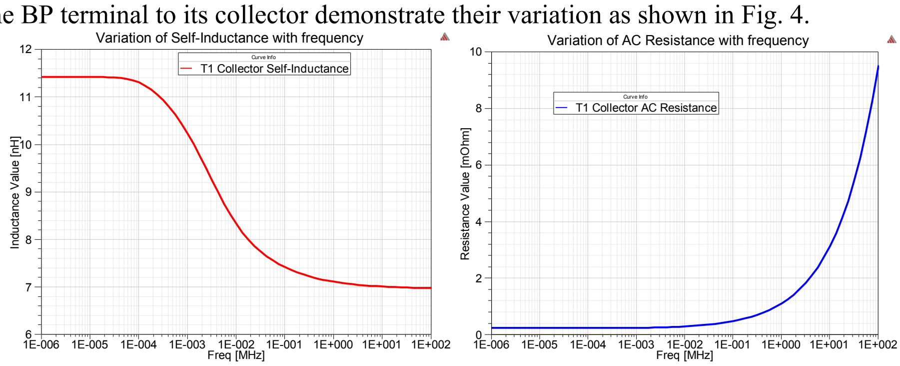
The typical rising/falling time of current for this kind of module is approximately 80ns, and correspondingly the effective bandwidth of the electromagnetic emission is no more than 5MHz, the corresponding wavelength is 60 meters. The maximum size of this module is no more than 20cm, so it can be treated as a typical quasi-static field while conducting electromagnetic field analysis. In practice, the Q3D Extractor was chosen to serve this purpose. The Q3D models for both types are displayed in Fig. 3 respectively. T1~T6 are IGBT chips and D1~D6 are FRD chips. For the sake of simplification, the plastic shell was removed during the Q3D computation.



(a) Type A (b) Type B

Fig. 3 Q3D models for parasitic extraction

Obviously there are 12 chips (including both IGBTs and FRDs) all together inside the IGBT module. In order to obtain the full-wave model, proper stimulus and boundary conditions should be assigned to the model. After a long time calculation, a complex solution matrix will be obtained. As stated above, the parasitic inductance and parasitic resistance (RL) parameters varies with frequency greatly, a single set of parasitic at certain fixed frequency point will not satisfy both the steady state and the switching transients at the same time. Take the chip T1 of type A for example, the RL value from the BP terminal to its collector demonstrate their variation as shown in Fig. 4.



(a) Self inductance (b) AC resistance

Fig. 4 Variation of RL with Frequency

From 1Hz to 100MHz, the self inductance has decreased by about 40%, and the AC resistance has increased more than 47 times. The RL in other branches abides by the similar rules. Taking all RLCG parameters into account, the high frequency equivalent circuit model can be exported into a box shown in Fig. 5.

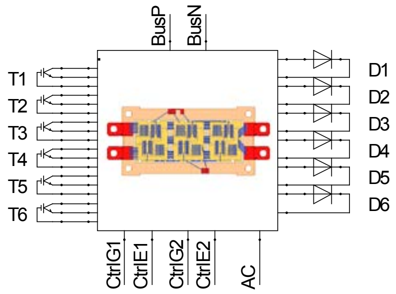


Fig. 5 Full-wave equivalent circuit of the IGBT

In Fig. 5, T1~T6 are the same physics-based IGBT chip-level model, and D1~D6 are the same physics-based FRD chip-level model. The combination of accurate chip model with a full-wave frequency-dependent parasitic can be used to simulate most electromagnetic-related phenomena for IGBT module.

3. System-level modeling and CM-EMI Analysis

3.1 Construction of the system-level model

Based on the model in Fig. 5, a system-level equivalent circuit was established to model the CM EMI, as shown in Fig. 6. Several critical parts, including DC-link capacitors, busbar, and three phase RL load are modeled in this schematic. CM leakage current flows through the hidden "GND" net in both IGBT and busbar models. A regular V-type linear impedance stabilization network (LISN) is used to sense the CM disturbance voltage. The main simulation conditions are as follows: VDC=300V, using SHEPWM control methods with a modulation of 0.8, the output frequency is 50Hz and the switching frequency is 1kHz, the dead time between phase leg control signals is 2.5us. For comparison, IGBT module-level of Type A and Type B are used separately to conduct the simulation while all other conditions remain the same.

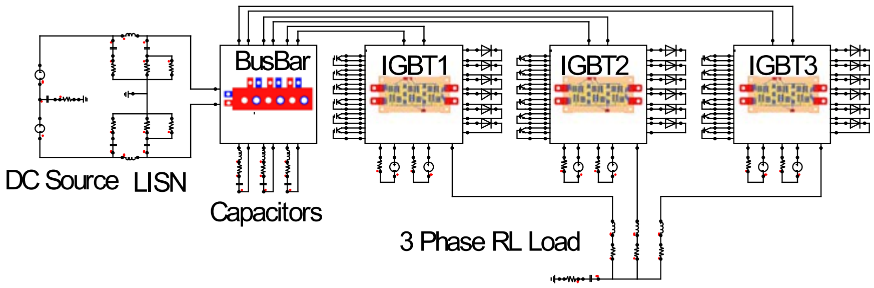


Fig. 6 System-level simulation of CM EMI

3.2 Simulation and Analysis

This kind of simulation is very time-consuming. After a long time, the steady-state three-phase load current is shown in Fig. 7. Type A and Type B module have almost the identical results.

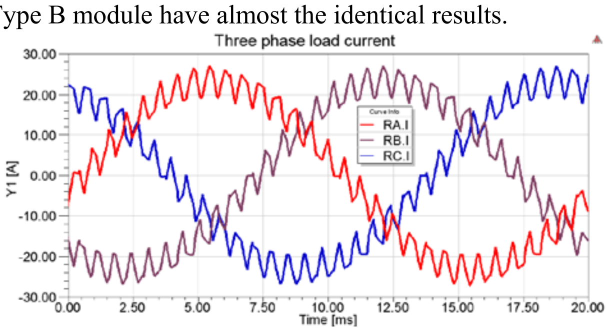
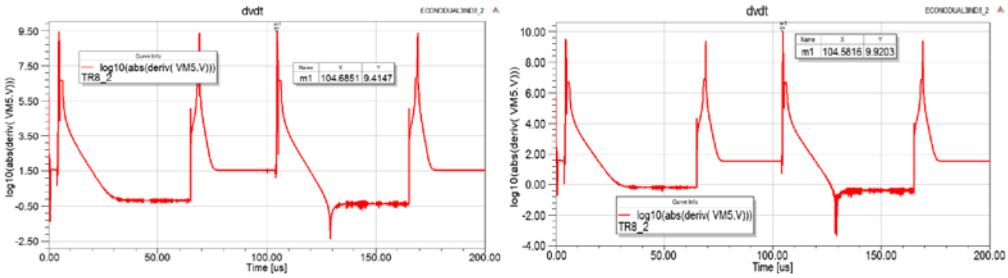


Fig. 7 Steady-state three phase load current

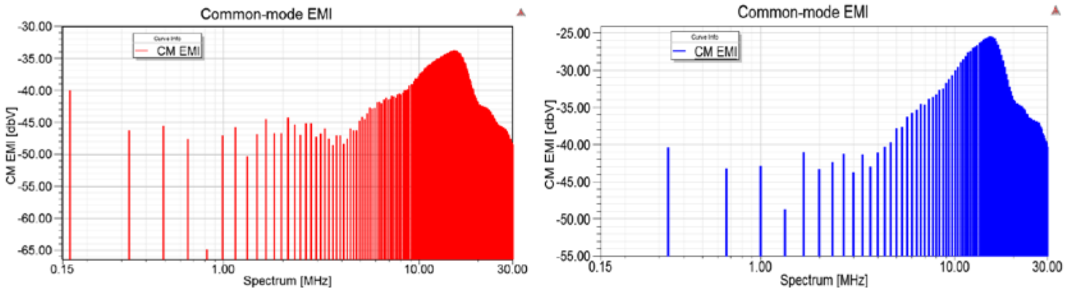
The *dv/dt* magnitude is mainly responsible for CM EMI. The phase-leg IGBT modules are taken as a whole to check this quantity. For the convenience of comparison, the *dv/dt* has been changed into absolute values and then taken the logarithm. When time ranges from 0 to 200us, there are altogether 4 switching operations occurred during this period. It's clearly observed in Fig. 8 that the *dv/dt* of type B is higher than that of type A at each switching transients, which predicts a more serious CM EMI in the three phase power converter using type B module.



(a) Type A (b) Type B

Fig. 8 dv/dt of two types of IGBT modules

For both cases, the CM EMI in frequency domain transformed from LISN-sampled voltage is shown in Fig. 9. As can be seen, the EMI spectrum has a similar envelope for both type A and B. The two figures demonstrates a minor difference from 0.15MHz~10MHz, and high likeness from 10MHz~30MHz. For type B, the highest magnitude of EMI occurs at frequency of 15.34MHz; For type A, the highest magnitude of EMI occurs at frequency of 14.93MHz. The difference between the two maximum values is about 8.3 dbuV.



(a) Type A (b) Type B

Fig. 9 CM EMI of the three phase frequency converter

4. Conclusion

Detailed modeling and simulation were given for CM EMI analysis for power converter using two types of IGBTs . Although type A and type B differs from each other just in the internal layout, they shows a relatively large differences in CM EMI performance. As a newly emerged power module, type B is superior to type A in many aspects except EMI performance. It reminds us that much attention should be given to EMC while designing a new IGBT module or using a new IGBT module in specific applications.

5. References

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