

Implementation of low inductive strip line concept for symmetric switching in a new high power module

Georg Borghoff, Infineon Technologies AG, Germany

Abstract

The low inductive strip line concept offers several benefits regarding the switching behaviour of IGBT modules. But for the implementation in real packages a lot of boundary conditions have to be considered, such as standards, available material, manufacturing methods and the connectivity to the inverter system. This work shows a possible implementation for high power modules. Constrictions will be shown and possible solutions presented.

1. Introduction

1.1. Commutation path within module

The influence of a low inductive and symmetric concept on clean switching is already shown in several publications [1] [2]. The design of the internal conductors, the arrangement of the chips and the connection of the internal conductors, either to the insulation ceramics or to the external bus bar system, is highly contributing to the stray inductance and to the symmetry of the module.

During the IGBT and diode switching event the stray inductance of the internal IGBT module design are creating an overvoltage at the module terminals. With the reduction of the internal stray inductance, this overvoltage can be reduced. If additionally chips are paralleled inside the module, it is important to have the same inductance from each chip to the terminals. In this way oscillations and unsymmetrical current distribution are avoided.

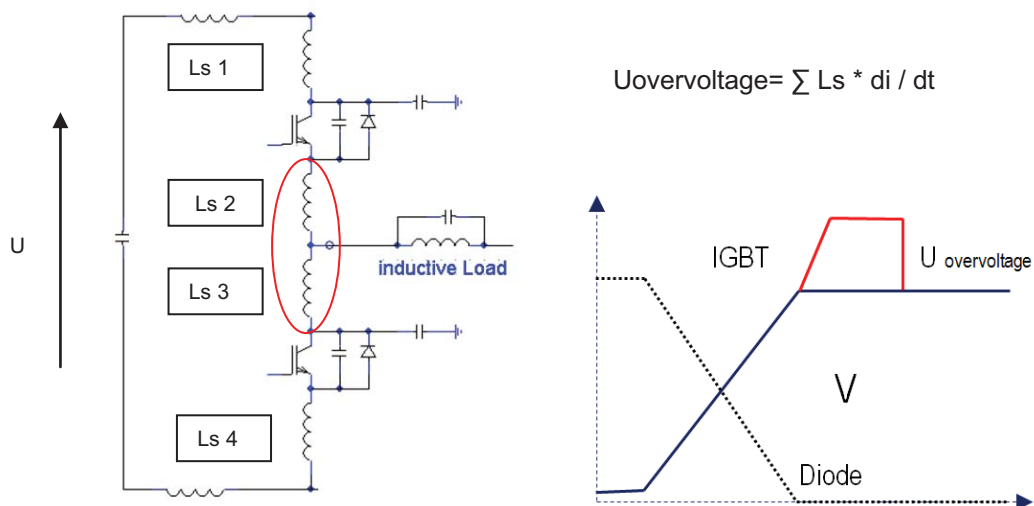


Fig. 1 half bridge circuit diagram with upper and lower switch. Internal inductances in the commutation loop between upper and lower system are shown in red circle, Ls1 and Ls4 are the conductors from the terminals to the chips.

The best concept for a low inductive design is the use of half bridge IGBT modules. They offer the possibility to keep the commutation path between upper and lower switch very short by implementing both switches on insulation ceramics with only internal, low inductive connections.

1.2. Strip line design of the main terminals

The internal conductors from the outside terminals of the DC terminals to the IGBT's and diodes are preferably designed as strip lines. The inductance of two strip line conductors carry the same current in opposite directions as shown in figure 2.

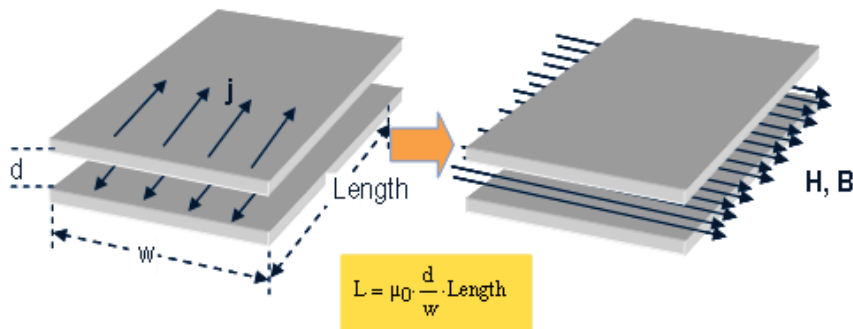


Fig. 2 strip line concept, 2 metal sheets with opposite current flow

From the above formula it seems to be very easy to generate a low inductance design: keep the connectors short, make them very wide and reduce the distance as much as possible.

2. Constraints in reality

2.1. General requirements from IGBT module size

Total width of strip line

As shown above, the stray inductance is mainly a function of the dimension of the used conductor sheets. So the outside dimensions of the module mainly determine the design of these parts.

For ideal switching behavior it is favorable to arrange all chips in a single row. In this case the number of chips define the width of the module. But in reality this would lead to a very long narrow construction that will not fit all requirements for a minimized system size. So the width of the internal strip line is limited by the size of the paralleled dies.

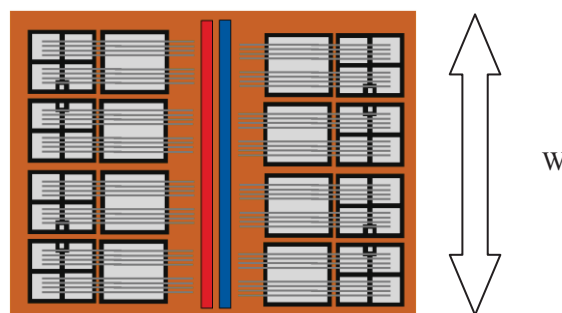


Fig. 3. Arrangement of IGBT's and diodes in 4 rows

For this study a chip layout as shown above was chosen. With this layout a nominal current of 700 Amps for upper and lower system can be implemented. The width of the module is approximately 80mm. If we take into account that we need additional space for a housing and clearance for assembling, the maximum possible usable width is smaller than the module width.

Length of the strip line

Especially with higher blocking voltages, e.g. 3300V and above, the IGBT package has to fulfill the standards for clearance and creepage distances. Within the IEC 60664-1 the required distances for insulation coordination are described.

Minimum distances are depending on the voltage classification and the housing material. A way to fulfill the creepage distances and minimize the clearance between the terminals is the implementation of grooves and a housing material with a high CTE. In this example a minimum required creepage distance of 28mm leads to spacing between the terminals of 14mm.

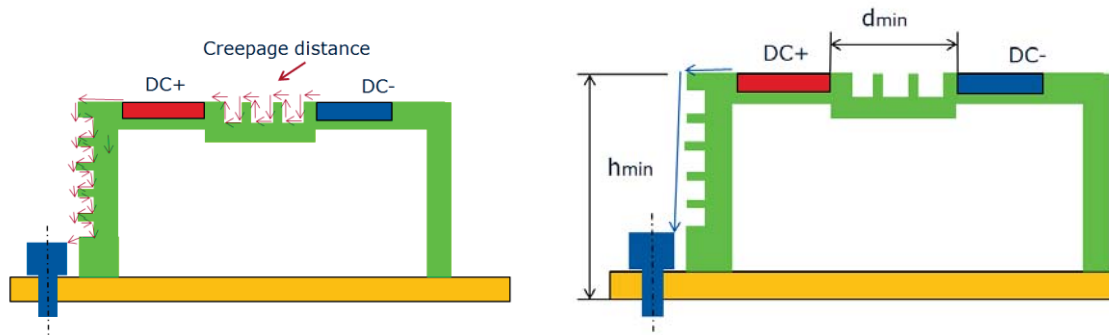


Fig. 4. (left) required creepage distances on IGBT module level (right) minimum clearance

In our study we consider feeding the DC current into the middle of the IGBT module (see Fig. 3).

Driver mounting directly on the module offers the possibility for a low inductive connection to the driver. For half bridges with auxiliary collector contacts there are 3 different voltage levels on the driver board that require certain spacing. With DC terminals kept in the middle, the space for the driver PCB is split in two areas.

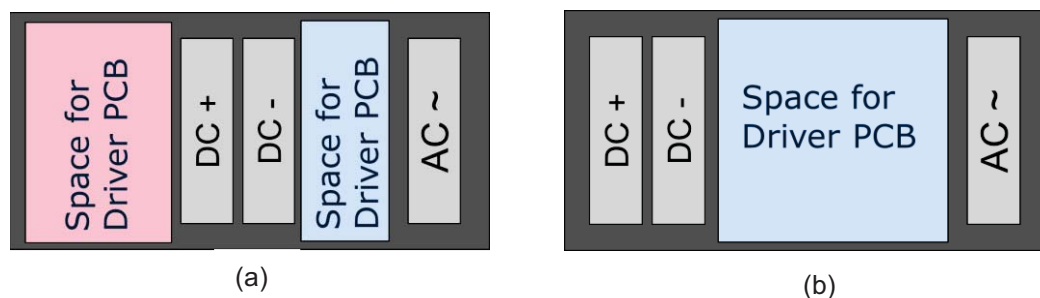


Fig. 5. arrangement of terminals on the outside design

The red marked area will be underneath the external bus bar and is therefore not fully usable. For maximizing the area for a driver board, it is favourable to move the DC terminals to the edge of the power module and utilize the space in the middle.

Unfortunately this will increase the length of the internal conductor. A possible solution is a sloped design. The length of the conductors can be reduced compared to a solution with perpendicular bends.

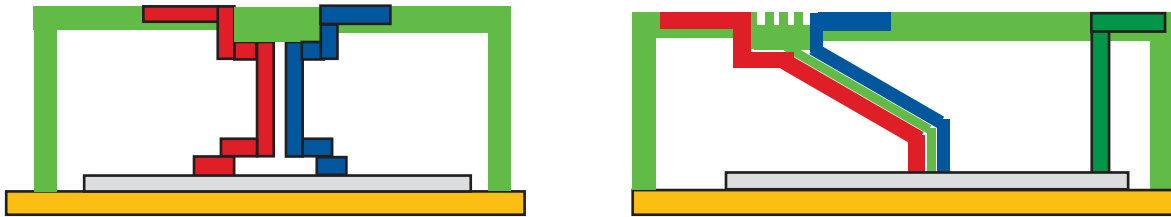


Fig. 6. arrangement of terminals, possible internal design

2.2. Distance between the conductors

To separate the potential between DC + and DC – conductors, an insulation layer in between is needed. In order to achieve a low inductance the thickness of this material has to be kept thin.

One possibility is the use of very thin heat resistant foils. With Polyimide or Teflon foils a thickness of 0,2mm and less could be possible on the basis of the insulation stability.

The difficulty of using foils is the manual assembly and the need to keep it safe in place. This is possible with insertion into an injection mold and embedding the conductors with plastic. The disadvantage is a costly process and possible delamination in thermal cycling conditions.

With conventional injection molded spacers a typical thickness of the plastic material without having the risk of pin holes or other defects is ~1mm.

In the overall design the effect of the thickness of the insulation layer was calculated in simulations of different variants.

The result is shown in the following diagram:

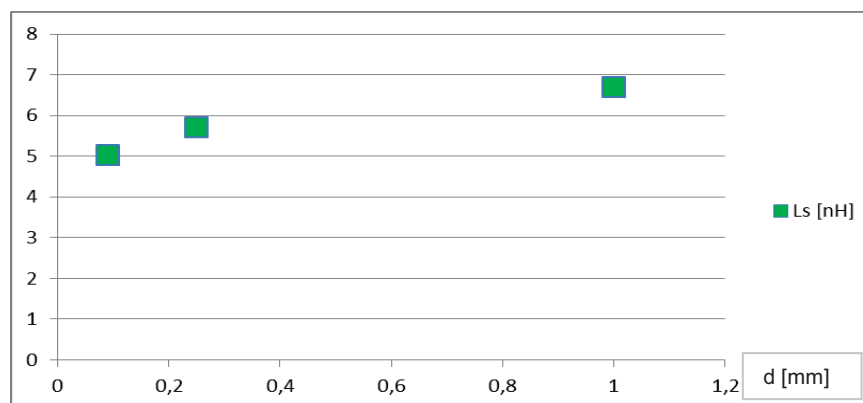


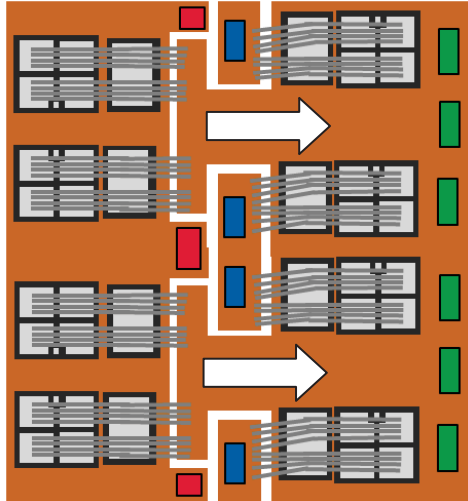
Fig. 7. Module stray inductance as a function of insulation thickness

For a 0,1mm foil the inductance could be as low as 5 nH.

Based on the above described boundary conditions, the use of a plastic spacer is preferred and leads to a stray inductance below 7 nH.

2.3. Connection to the chip

If we take a closer look to the connection of the conductors to the ceramic substrates, unfortunately there is no way to connect in a “line”. With a placement of the leads in between high side and low side IGBT’s there has to be a separate potential for the commutating current. In the next figure possible points for connections are shown. Instead of using one single point, several connections as wide as possible to the outside were made.



On the left side the IGBT’s and diodes of the upper switch, on the right side the lower switch. The red areas show the connections to the DC + conductor, the blue areas determine the position of the DC – potential. The white arrows describe the area where the commutation current is flowing.

The green areas show possible positions for the AC terminal

Fig. 8. half bridge layout with sketched up connection points for the DC +/DC- terminals

2.4. Connection to the external bus bar system

Another important interface of the IGBT module is the connection to the DC bus bar. The bus bar itself is an ideal strip line concept with wide conducting plates and a thin insulation sheet. This concept has to be given up at the connection points, especially when screw terminals are used. These short interruptions of the strip line have a big input on the overall outcome.

As already shown [2], for low and medium power devices the connection to the DC link can be realized with press fit pins and a PCB with reinforced copper layers. Paralleling with multiple connection points reduces inductance in this area.

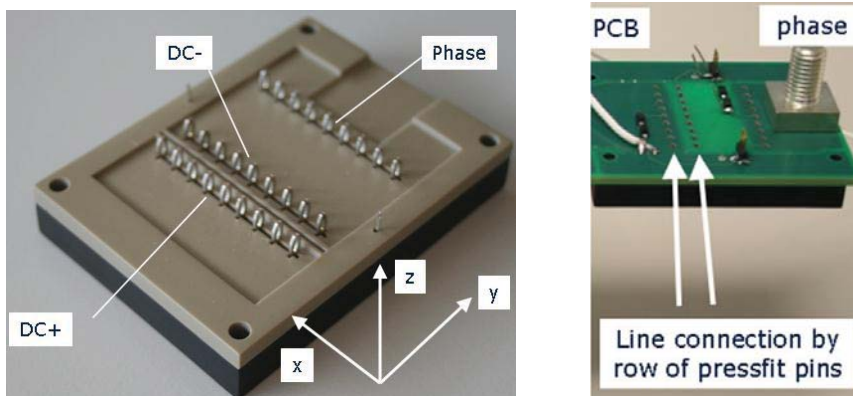


Fig. 9. Connection to PCB with press fit pins for medium power module

In high current and high voltage applications the contacting of the IGBT module to an external bus bar system is usually realized with screws connections. The bus bar system is made of laminated metal sheets of copper or aluminum. To realize a reliable connection with little losses, screws are the most common connectors. They offer high contact forces that reduce contact resistance. Furthermore, they are easily available and can be assembled with standard equipment. As shown above with press fit pins, also with screws the use of multiple, paralleled connections reduce the negative effect of interruptions to the stray inductance. One issue is the area where the lower bus bar sheet has to be fastened. The upper sheet has to have large holes to allow the screw to pass through and ensure sufficient clearance. In this area the reduction of the available current carrying section and the required clearance and creepage distances have to be considered. Therefore, an optimum of the number of screws has to be found to achieve a good balance between stray inductance and current carrying capability.

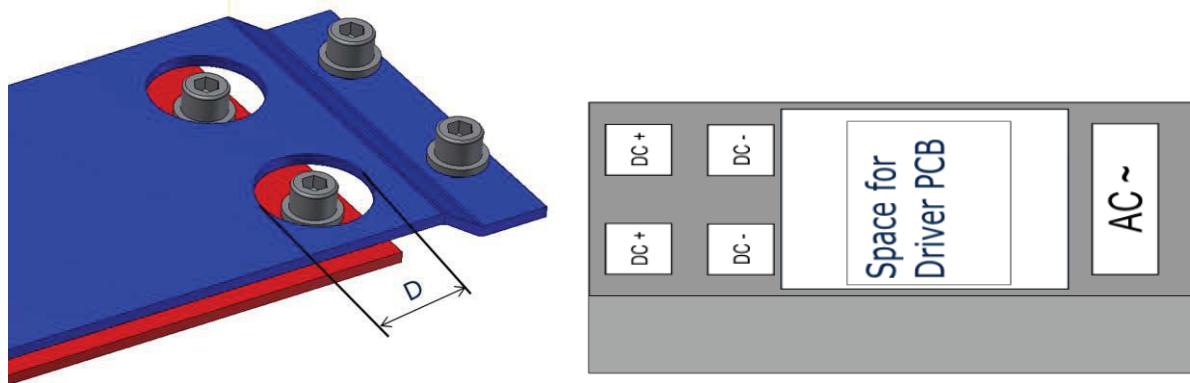


Fig. 10. Screw connection DC bus bar to IGBT module. 2 screws for + and – on the IGBT module

3. Conclusion

Also for high power modules with high blocking voltages and high output currents a low inductive design with the strip line concept is possible. Legal regulations and standards create several constraints that do not allow the implementation of an ideal solution. But nevertheless, an IGBT study with a stray inductance below 7 nH at a nominal current of 700 A was realized.

For future applications this will enable the use of fast switching devices. With reduced switching losses higher switching frequencies could be implemented.

The concept also allows an easy way to connect several IGBT modules in parallel with the use of one common DC bus bar. In a 3 module parallel configuration this will lead to 2 nH for a configuration with a nominal output current of 2100 A per system.

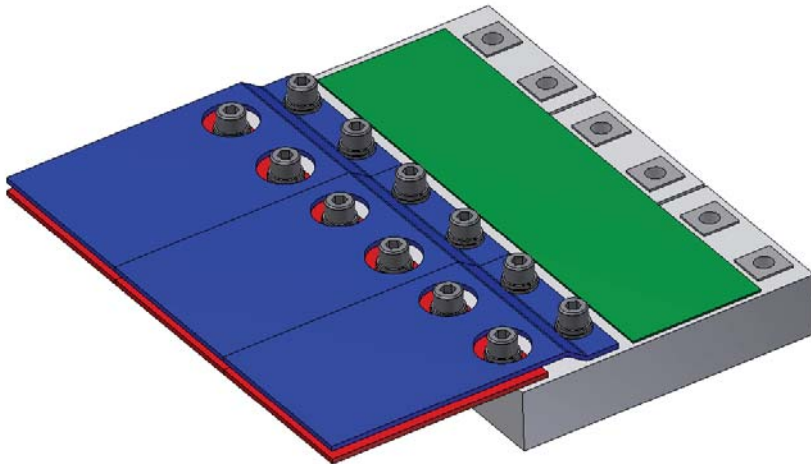


Fig. 11. Triple paralleling of IGBT modules or possible 3 phase inverter design

4. Literature

- [1] R. Bayerer, D.Domes: Power circuit design for clean switching, CIPS, 2010
- [2] R. Bayerer, D.Domes: Power circuit design for clean switching, ECPE, 2011