The Standard Module of the 21st Century

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Abstract

Standard IGBT modules, above 100A six-packs at 1200V, still use similar packaging to the Bipolar Darlington Modules, which they have progressively displaced from most applications over the last decade. A need for improved standard modules in the higher power range has been identified in order to simplify inverter construction, reduce the diversity of part numbers an inverter manufacturer needs to purchase and stock, and take full advantage of the IGBT characteristics. This paper introduces two new packages, which are expected to become the new standard in IGBT modules within the next years, the LoPak4 and LoPak5 packages
These new standard modules place demanding requirements on the IGBT and diode dies, which they use. The paper introduces a new 1200V IGBT chip-set from ABB Semiconductors, which will be used in these modules. The new chipset demonstrates ruggedness, low-losses, good parallelabilty and high noise immunity. In addition the chip layout has been carefully designed to allow very efficient and simple module construction without the need for internal chip paralleling resistors.

Introduction

Over the past decade the AC drive has grown to dominate most areas of the variable speed motor control market. Over this same time the Darlington Bipolar Transistor Modules, used in the main low-voltage drives market, have been displaced by IGBT solutions. Initially this change of technology was limited to the Silicon. The packaging used in the Bipolar modules was reused for the IGBTs. This led to a number of standard modules, which are available from several suppliers, but not necessarily optimised for the use of IGBT technology. These standard modules are relatively non-specific to any particular inverter market segment and as such have found wide acceptance in applications outside of AC drives. Examples are UPS, welding, power supplies, elevator drives, electric vehicles, wind power, etc.

Fig. 1 LoPak4 and LoPak5 Packages

Since the mid-nineties there has been a great diversification in packaging, particularly in the low power range, with the suppliers introducing new concepts with higher levels of integration, usually aimed at particular parts of the market. By introducing more functionality into the devices suppliers are not necessarily able to produce a standard module in two senses of the word “standard”. Firstly the additional functionality limits the area of application of the module. For example a Power Integration Module (or CIB) is a suitable device for single stand-alone inverters but not for inverters operating from a common DC bus or for many other applications. Secondly the standardisation required by most users, namely multiple-sourcing, is more difficult to achieve between suppliers with different technology platforms. For example the IPMs offered by a number of suppliers are not generally interchangeable, not only due to differences in mechanical layout or the IGBT characteristics but also due to the differences in the control / protection circuitry operation and interfacing.

In the market for low current modules (6-pack devices up to 50A 1200V) there was little consistency, in terms of packaging mechanics, between suppliers of Bipolar modules and no clear standard emerged. The Econopacks have filled this gap and are now reaching the definition of a standard module: manufactured by more than one supplier and used by many customers (2). However until now this new generation of standard modules, designed specifically for use with IGBT technology, has stopped at the 1200V 100A 6-pack.

By generating a standard module specification in co-operation with many potential manufacturers ABB Industry has enabled the process of reaching the new standard module by ensuring that the device will be multiple-sourced. (1)

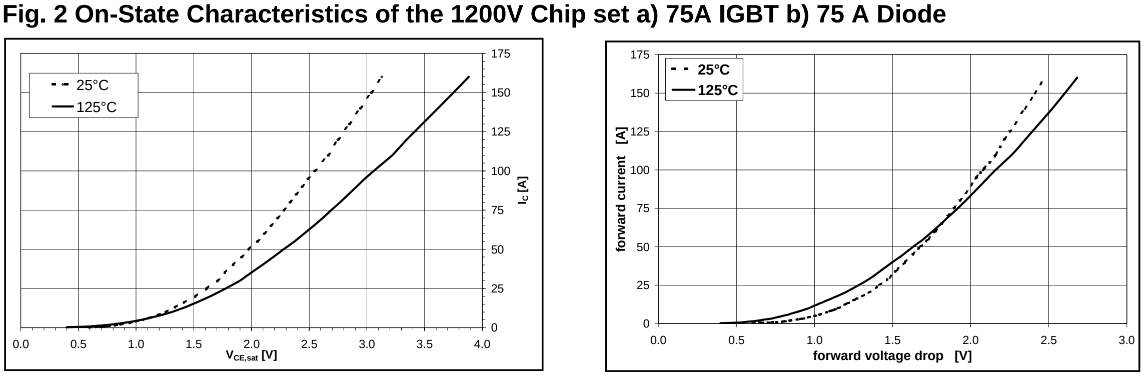
This paper introduces two new packages, which extend the range of standard modules up to 6 * 300A in 1200V and are designed to be parallel-connected in order to serve requirements for low-voltage inverters into the multi-MW range.

For use in these packages ABB Semiconductors introduces a new 1200V IGBT and diode chip set. These dies have been designed to be easy-to-use and easy to parallel and are therefore well suited to the new standard module range.

A New 1200V Chip Set

ABB Semiconductors introduces a line up of 1200V IGBT and diode chips intended for application in modules in motor drive, UPS and general purpose inverter applications. The IGBT is based on the thin wafer NPT structure giving the well-known advantages of ruggedness, low temperature dependence of switching characteristics, and a positive temperature coefficient of on-state voltage. The on-state of the IGBT can be seen in Fig. 2a). The device demonstrates a positive temperature co-efficient over the entire current range. In addition a very narrow spread of characteristics has been achieved due to the design itself as well as the tight process control in the wafer fab.

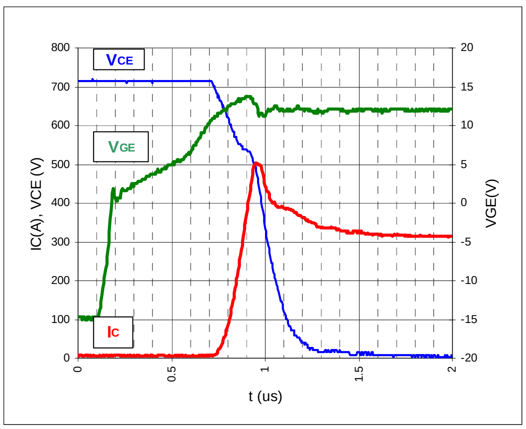
Fig. 2 On-State Characteristics of the 1200V Chip set a) 75A IGBT b) 75 A Diode



The philosophy behind the design was to design a "chip set" where the diode is considered as an equal partner in the IGBT module, rather than an afterthought. To this end very close attention has been paid to the performance of the diode when used in combination with the IGBT. In order to develop a module capable of easy paralleling, and to take advantage of the benefits offered by the narrow distribution of parameters and positive temperature coefficient of the IGBT, it was considered necessary to develop a diode with similar characteristics. The resulting device has a positive temperature coefficient of on-state below nominal current rating (as shown in Fig. 2 and by the application of special lifetime control schemes achieves a similarly low spread in characteristics.

Careful optimisation of the IGBT design has produced an exceptional trade off of on-state and turn-off switching losses combining the best of a low sat. and a high speed device in one (2.7V and 11mJ at 125°C, 100A, 600V). It was an essential part of the design of the LoPak4 & 5 packages that IGBTs were available with a low loss density in order to be able to make relatively compact packages, where the useable current was not unreasonably limited by the module thermal performance. This low loss density has been achieved without the use of expensive trench technology and in this way the ruggedness of the device has also been maintained.

Fig. 3 Turn-on and Turn-off Waveforms 300A 1200V LoPak5 on 700VDC link, 125°C.



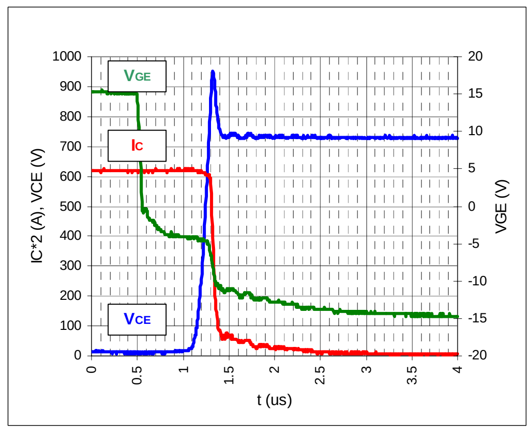
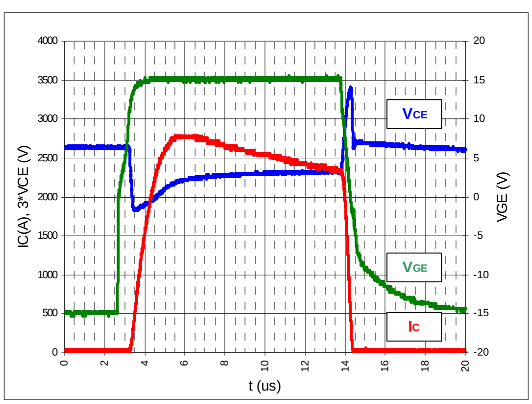
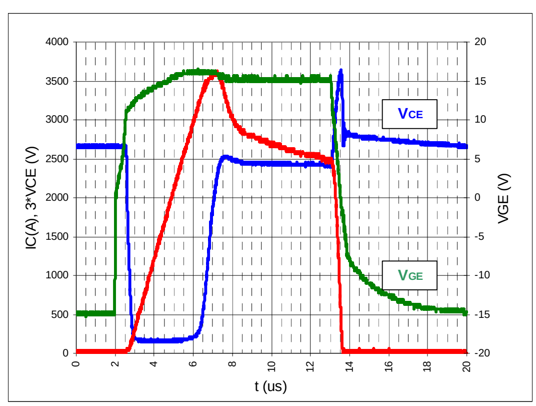


Fig. 3b shows the turn-off of the IGBT with the typical NPT tail, which is relatively constant with temperature. A soft voltage waveform is achieved with a relatively low overshoot. Fig. 3a shows similar conditions at turn-on. Dynamically the diode has an exceptionally soft recovery characteristic even under low current and low temperature conditions, allowing the IGBT to be switched on with an unusually high dI/dt, minimising switching losses and deadtime requirements.

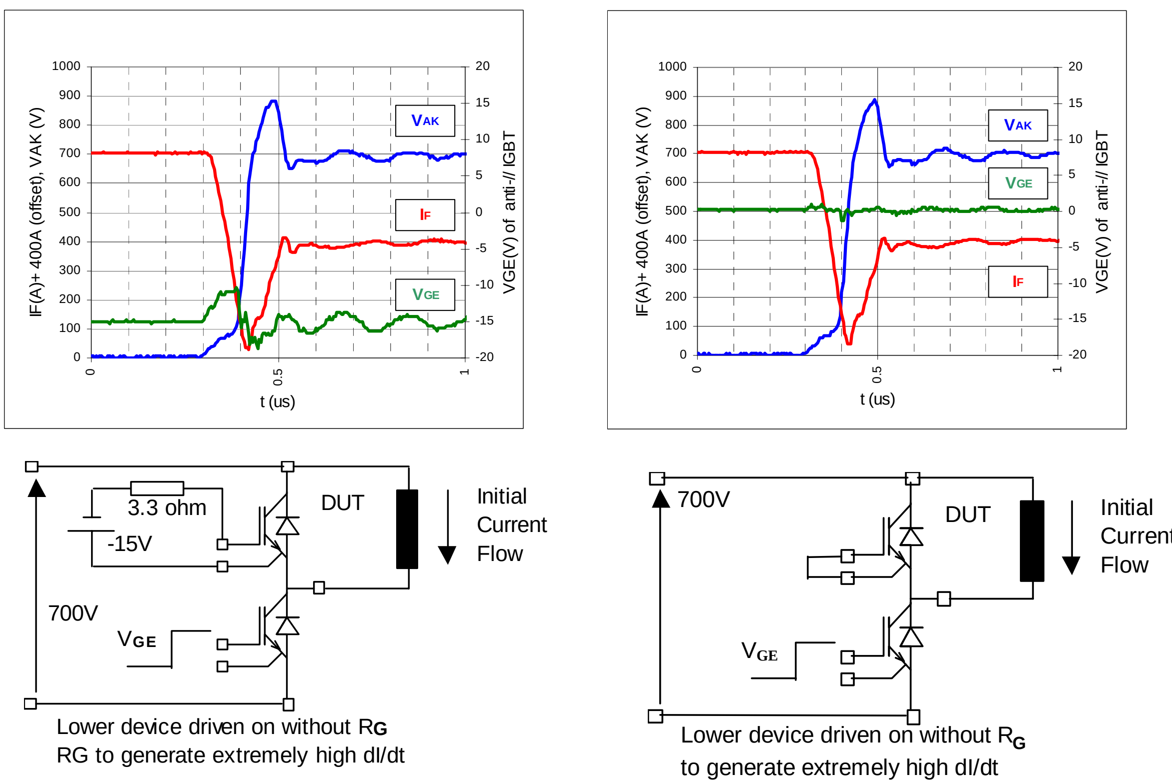
Fig. 4 300A 1200V LoPak5 under short circuit conditions on 900VDC link 125°C.
a) Phase-leg short circuit. b) Short circuit with small load inductance





The waveforms in Figs. 4a) and 4b) show the 300A 1200V LoPak5 device on a 900V DC link in short circuit with small series inductance and with significant load inductance respectively. The first waveform is representative of the case when one IGBT element in a phase leg fails or when there is a malfunction in the gating / control circuitry so that both devices in a leg are switched on simultaneously. Practically the short circuit with some load inductance (Fig. 4b) is more likely to happen in a real application. Unfortunately this is usually also the more severe case. As can be seen the short circuit current rise is limited by the load inductance until the IGBT begins to come out of saturation. As the voltage across the IGBT begins to rise charge is pumped through the reverse transfer (or Miller) capacitance of the device and begins to lift the gate voltage above the normal 15V level. The waveform shows that the gate reaches around 17V in this case, although internally on the IGBT side of the internal sharing resistors and gate inductance, it is likely to, be higher. The increased gate voltage drives the IGBT harder on, further increasing the short circuit current., up to 12 times nominal rating in the figure. The cell design of the ABB IGBT allows for an exceptionally high ratio of input- to reverse transfer- capacitance, so that this IGBT is particularly insensitive to this effect and therefore easier to use in this critical short circuit mode.

Fig. 5 300A 1200V LoPak5 noise immunity test. Room temperature, 8kA/µs, 16kV/µs, 700V DC
a) DUT gated to –15V through 3.3 ohm. b) DUT gate shorted to emitter at terminals.
Spot the difference?



In addition to superior short circuit capability the ratio of capacitances improves the noise immunity of the device. The waveforms in Fig. 5 are tested under unrealistically severe conditions in order to demonstrate this noise immunity. In both figures the same test circuit

is used. Current is initially flowing in the free wheeling diode of an IGBT in a phase leg configuration. The gate of this IGBT is held off while the other IGBT in the leg is driven on as fast as possible (with zero gate resistance) in order to force the current carrying diode to recover. The waveforms show that this imposes a dI/dt of around 8kA/us on the diode, which recovers generating a dV/dt of around 16kV/us from a 700V DC link. The first point to stress is that this is a very soft recovery for such an extreme dI/dt under cold conditions, and that despite these unrealistically severe conditions the diode behaves cleanly and generates only around 200V of overshoot.
The extreme level of dV/dt imposed on the “off” IGBT in this test, couples charge through the reverse transfer capacitance onto the gate. Fig. 5B) shows the waveforms with the gate held off through the standard gate resistance of 3.3ohms to –15V. Fig. 5a) on the other hand shows the same conditions with the gate and emitter shorted together on the module auxiliary terminals. The extraordinary noise immunity of the device is clearly demonstrated by the fact that both voltage and current waveforms are identical. Typically it could be expected that the test with the gate short-circuited would cause the gates of the chips inside the module to be lifted to the point that the IGBT would begin to conduct during the high dV/dt phase of the commutation.
This feature makes it much easier to use phase-leg (half bridge) modules as choppers, without the need for additional circuitry to gate the IGBT permanently off. Although this is wasteful of silicon it can be an excellent solution to for users who buy large quantities of phase-leg or six-pack modules and also need relatively small volumes of choppers. In addition the uniquely high noise immunity margin of the ABB die significantly reduces the need for negative drive voltages.

Chipset Mounting Considerations

Fig. 6 IGBT Die showing corner gate pad and large emitter bonding area

Fig. 7 Two IGBT dies bonded together showing advantage of corner gate when parallel connecting dies

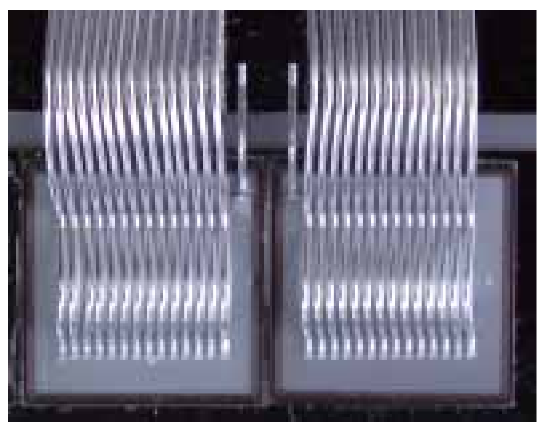


ABB Semiconductor’s experience in module manufacturing has been carefully applied to the chipset design, in order to optimise the application of the dies in an IGBT module. The gate pad is located in the corner of the die allowing easy access with the gate wire. This position of the gate pad has additional advantages. By rotating the dies, a flexible gate wiring in the module becomes possible which allows low inductance and low noise designs. For example when parallel-connecting 2 chips the gate pads can be adjacent. Since the corner of a chip runs at a slightly lower temperature than the centre, a better resistance of the gate bond against bond wire fatigue is expected. The large chips also have large gate pads which allows the modules to be built with only one thickness of

bond wire for gate and emitter connections. This avoids the use of a two-step bonding process.
Bonding is further simplified by the elimination of the commonly used gate fingers from the chip design. In this way almost the whole emitter area is available for bonding, rather than specific pads on the chip surface. The bonding tolerances are therefore relaxed, thus simplifying the process and allowing the module designer new degrees-of-freedom in his bonding patterning, such as bonding from different lateral angles.

Generally paralleling of IGBT chips requires the use of separate gate resistors to damp the resonant circuits created by joining the gates and emitters of two or more dies, and in this way ensure clean switching transitions with uniform transient current distribution. By integrating the necessary gate resistances into the dies themselves ABB has removed this requirement and dramatically simplified the cost and effort of assembling modules using paralleled chips. In addition the reduction of module internal parts count and bonding complexity is expected to positively impact module reliability.

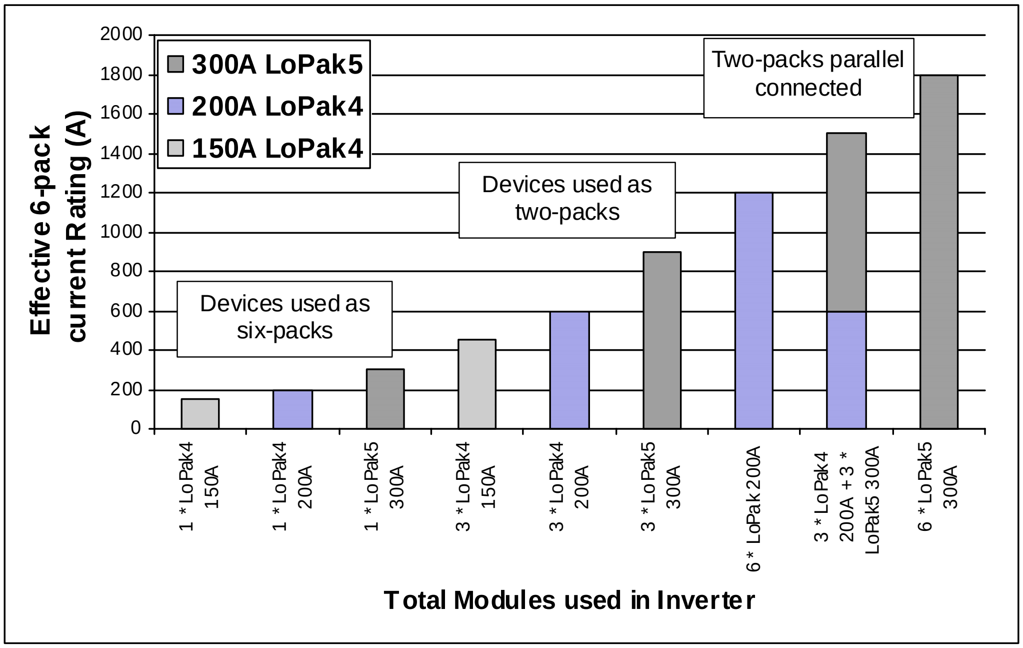
Standard IGBT Module Topology

The traditional standard IGBT module range starts with the full inverter configuration (or six-pack) at low current. As the required current rating increases then the inverter is split into three sub-unit, phase-leg (2-pack) modules. With further increase in the current required then single switches (1-packs) become the norm and finally these devices are paralleled to achieve the highest ratings. This results in a great number of different module packages in order to manufacture a line-up of inverters with a range of power ratings. Engineers must characterise, approve and build layouts for a wide range of modules. Supply management must control supply and inventory of many article numbers. Module manufacturers must produce relatively small quantities of a large number of different packages and purchase many different sets of diverse piece parts in relatively small volumes of each.

Fig. 8 LoPak4 and LoPak5 circuits and line –up

Package	Circuit	Voltage	No. of switches & Rating
LoPak4	Six–pack	1200V	6 * 150A
	Six–pack	1200V	6 * 200A
LoPak5	Six–pack	1200V	6 * 300A
LoPak4	Six–pack with user connected phase outputs	1200V	2 * 450A
	Six–pack with user connected phase outputs	1200V	2 * 600A
LoPak5	Six–pack with user connected phase outputs	1200V	2 * 900A
LoPak4	Six–pack	1700V	6 * 110A
	Six–pack	1700V	6 * 150A
LoPak5	Six–pack	1700V	6 * 225A
LoPak4	Six–pack with user connected phase outputs	1700V	2 * 330A
	Six–pack with user connected phase outputs	1700V	2 * 450A
LoPak5	Six–pack with user connected phase outputs	1700V	2 * 675A

Fig . 9 Example of an inverter line-up for 400V – 500V AC with effective module rating 150A –



1800A using only 2 packages and 3 article numbers

The LoPak4 and LoPak5 modules aim to address these issues by extending the currently available range of standard IGBT modules in six-pack topology from 100A 1200V to 300A. The modules are designed so that by parallel connecting the phase outputs the same device is then usable as a two-pack (phase-leg) at three times the current rating (up to a 900A in 1200V LoPak5 in this case). By further parallel connecting these “2-packs” multi-MW inverters can be realised. In this way a user can manufacture a complete range of inverters in 400V – 690V AC from 40kVA to perhaps 5MVA using only two packages, three 1200V article numbers and three 1700V article numbers. The footprint of the LoPak4 and LoPak5 modules is designed with replacement of existing standard modules in mind. The base of the LoPak4 is double the size of a traditional standard 1-pack or 2-pack. The LoPak5 footprint is three-times the size of such devices. In this way it is expected that users may be able to switch from the traditional standard modules to the LoPak4 and LoPak5 devices without major changes to the heatsinks used

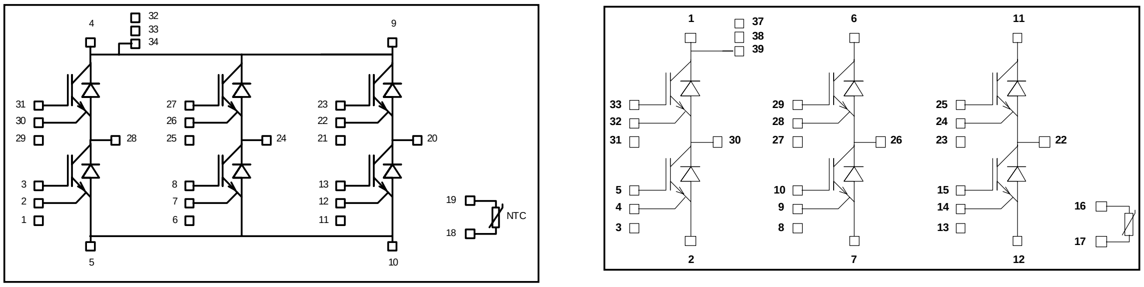
.

Degree of Integration

In order to achieve a module, which can be used as a global standard it is necessary to avoid integrating elements, which would make the module unacceptable to any of the major potential markets. In order to maintain this flexibility of application the six-pack topology was chosen. It was decided that integration of control elements into the package would not be advantageous. Firstly internal control limits the flexibility of use of the module and therefore the range of applications the module can fit. Secondly control circuitry housed inside the package is subject to relatively high temperature operation which may negatively impact the device reliability. Thirdly it was felt that parallel connection (which is one of the key features of the concept) of such modules would be rather difficult.

However it was decided to integrate a temperature sensor, which measures the baseplate temperature and gives a simple and efficient indication of overload or cooling failure. In addition pins have been provided for connection of auxiliary collector signals into the control circuitry. These can be used for short circuit detection and control or alternatively for active dV/dt control to optimise switching losses and EMC performance. Further auxiliary pins have been included in order to input the DC link voltage signal into the control circuitry. In this way the power- and control-circuit connections to the module are completely separated from each other.

Fig. 10. Module schematics of LoPak4 and LoPak5



Assembly of LoPak4 and LoPak5 in an Inverter

The concept behind the LoPak4 and LoPak5 modules is that the best place for the gating and control circuitry is on a PCB as close as possible to the IGBTs which it has to control. The module is designed to take a PCB, which snaps on top of it and needs no soldering to the module. A low-profile channel runs along the centre of the module long dimension, to allow for high PCB-mounted components, like capacitors and magnetics. The auxiliary connections are located as close as possible to the chips inside the module. This avoids unnecessary tracking inside the module, which would make it larger and therefore more costly than necessary. The user has the opportunity to place the low-impedance gate circuit loops of his drive circuit close to these pins, minimising the inductance between the real driver and the chips themselves. In this way the user can achieve gate circuitry with high noise immunity and optimise the switching of the device to his application.

The power connections to the module have been inverted when compared to a traditional standard module. Rather than a nut into which the user screws a bolt to locate his bus bar a bolt is provided. This has two major advantages. Firstly it is possible to achieve a much lower profile module, as the height needed by the bolt entering the module, can be subtracted from the module height. This means that the equipment can be more compact and, more importantly, the actual connection to the chips from the bus bar is significantly shorter than in the case of the higher standard modules, leading to lower inductance in the power circuit. Secondly the bolt connection allows a pre-built laminated bus bar to be simply located onto the terminals during inverter assembly. By contrast the assembly with traditional nut connections requires the bus bars to be held in place until at least two bolts have been screwed in to the module.

Fig. 11 Drawing of how bus bars and PCB attach to module

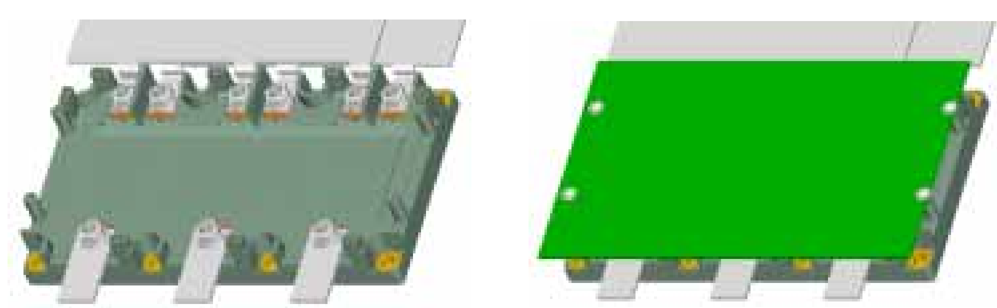
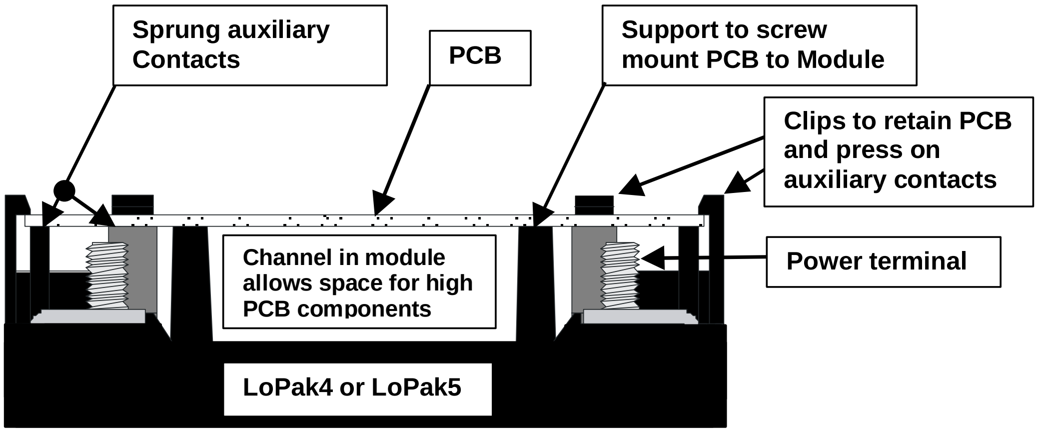


Fig. 12 Cross Section of LoPak4 / LoPak5 showing clip – in mounting of PCB



Conclusions

Two new standard IGBT module packages have been developed; the LoPak4 and LoPak5. These modules allow users to manufacture a range of drives in 400V – 690V AC from around 40kVA to up to 5MVA using only two packages and 6 article numbers. The packages are intended for use with a control PCB, which simply snaps on to the top of the package, allowing a very simple and efficient inverter construction. The compact and low-profile module construction allows extremely compact systems to be manufactured.

In parallel to the development of the LoPak4 and LoPak5 packaging a new 1200V IGBT and diode chip set has been introduced, which offers exceptionally low losses. Both diode and IGBT demonstrate positive temperature coefficient of on-state, soft switching characteristics, extreme ruggedness, and noise immunity. In addition the chip layout has been designed to make module layout simple and cost efficient, by the elimination of gate fingers and the use of a corner gate pad with integrated sharing resistor.

References

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