New 2-Pack IGBT Module with Spring Contacts

Fuji Electric Device Technology has designed a new IGBT module with the height of common Econo-Pack IGBT module and a spring contact for the connection to the gate control terminals. The main screw type terminals, divided in DC input and output terminals, are located on each side of the module. Besides the latest IGBT chip technology with a U4 chipset, a totally lead-free solution has been applied. As a result of the new solder material, the reliability and especially the power cycling capability has been improved. But the main advantage of this new package is the eased assembling process at the customer site, due to no soldering to the PCB, easy attachment to the printed circuit board and simple exchange of the modules for maintenance purposes. **Thomas Heinzel, Manager Application Engineering, Fuji Electric Device Technology, Offenbach, Germany**

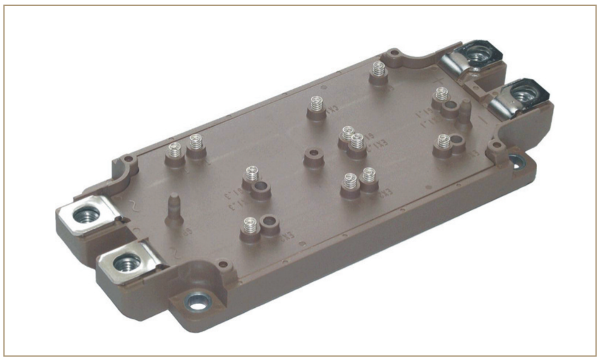


Figure 1: Econo-Dual 2MBI450U4J-120

The intention of this new package (Figure 1) is to provide a new alternative design option in the range of the standard 62mm packages from 200 to 400A at 1200V. Basically, the main design features are following the idea of the well-established Econo+ modules with a low profile of 17mm height and a separation between the DC input side and the AC output.

Application advantages

Compared to the Econo+ this new package offers several advantages, such as lower power loss density by distribution of the phase modules; more flexibility for various circuit topologies (H-bridge, parallel connections); easy attachment of the gate drive unit by spring connections; reduced assembling cost, quick exchange of the gate drive unit (GDU) for maintenance; individual NTC thermistor per each phase module; and access to each individual IGBT gate.

The biggest challenge for this new module design was, of course, the new contact system between the gate and emitter of the IGBT to the printed circuit board (PCB) with the driver board. As can be seen in Figure 2, the modules consist of three separate direct-bonded copper (DBC) substrates, which are symmetrically arranged and connected in parallel. Each group of IGBT and free-wheeling diode (FWD) chips has its own spring terminals, which will provide the gate control contact to the above attached PCB.

Compared to other solutions on the market, our springs will have just one pressure contact to the PCB, because internally the spring is soldered to the DBC substrate. This property will avoid any contact problems inside the power modules, even though we have to guarantee a proper contact to the customer's PCB. For this reason, a suitable spring material and shape have been selected, which will realise a proper contact

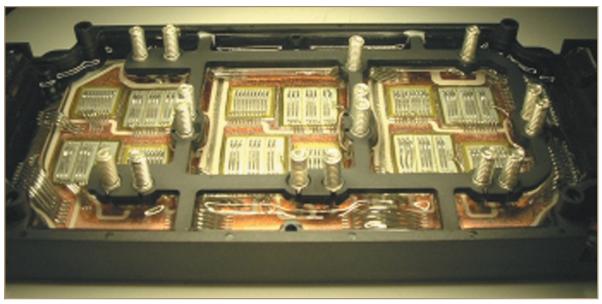


Figure 2: Internal layout of the Econo-Dual module

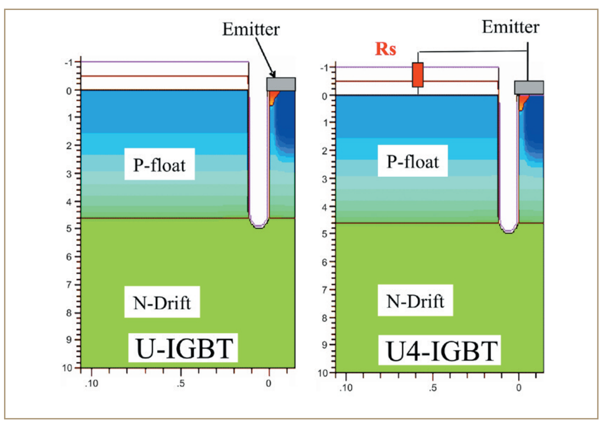


Figure 3: Cross-sectional view of U and U4 IGBTs

under all environmental conditions for the gate currents and also low current measurement signals such as NTC. Many different reliability tests have been carried out to proof this behaviour.

U4 chip technology

Since the beginning of this decade, Fuji Electric introduced the 5th IGBT generation (U-series), featuring a trench gate structure and a field stop (FS) layer at the back side of the IGBT chip. This technology led to a drastic reduction of the saturation voltage in combination with low turn-off switching losses. Unfortunately this U-series chip set did show some problems in some applications, because the turn-on speed of the IGBT is not very much controllable and thus the recovery behaviour of the corresponding FWD at low load appears to be a bit snappy. As a result, the radiated EMI noise could be a problem for some designs.

Consequently this IGBT series has been improved and all disadvantages are eliminated. The new U4 device (Figure 3) shows a slight modification of the production process, leading to an easy controllable and low switching loss IGBT. The different characteristics can be seen in Table 1.

		U	U4
Chip structure	IGBT	FS-Trench	new FS-Trench (mod. U)
	FWD	Epi-FWD	FZ-FWD
Vce(sat) @125°C [V]		2.0	2.1
VF @125°C [V]		1.7	1.75
VF distribution		about 0.5 V	more narrow (< 0.3V)
Eon @125°C		U-series	30% less than U-series
Eoff @125°C		U-series	same as U-series
Err @125°C		U-series	same as U-series
Radiation noise		U-series	lower noise (5-10 dB reduction)

Table 1: Comparison of basic characteristics between U and U4 series

Besides the improvement of the IGBT chip, the structure of the FWD has also been changed to achieve an adequate switching behaviour (soft recovery) and reduce the distribution of the forward voltage (V_f) spread in production. The new FWD is using the same FZ-wafers as the IGBT chips and can be realised without applying any life time control procedure. Thus, the V_f spread can be reduced to similar values as the IGBT die (Figure 4).

Such a small deviation between IGBT and FWD characteristics will also improve the internal parallel connection of several chips (e.g. three chips for this Econo-Dual package). Thus, the temperature deviation between the different chips will be very low and a high life-time in the application can be expected. The most significant challenge could be made regarding the EMI noise radiation of this new chipset, due to lower di/dt at turn-on and softer recovery behaviour of the FWD (Figure 5).

Reliability issues of soldering

Some years ago, several committees were discussing an environmentally friendly future and, as a result the RoHS and WEEE directives, were becoming active for electronic equipment and parts. Even if not applicable for some power electronics applications, Fuji Electric has recognised this requirement and will comply for all new product developments, as well as changed some existing products to RoHS conform devices.

For all our IGBT products, we had already changed towards a lead-free direction by replacing the former lead type solder material between the chips and the DBC substrate. As a next step, we had to change terminal nuts and metal rings at mounting holes from Chrom-6 to Chrom-3, lead solder surface of the solder pins to lead-free surface, and lead solder type between DBC and base plate to a lead-free solder type.

Besides the main target of a RoHS compliant product, we had to confirm or improve product reliability at the same time. The new surface plating of the metal parts could be verified by some salt spray tests, which were not showing a big difference between the two surface finishes.

Removing the lead content from the solder terminal plating is basically not a big problem, but a new lead-free plating has to proof a good solderability under several conditions. Wave soldering conditions (soldering profiles) for a lead solder bath with up to 235°C and new lead-free conditions up to 265°C especially have to be verified to guarantee a proper solder joint. Solderability test according to IEC 68-2-54 and whisker test at 85°C and 85% relative humidity for 1000 hours have been performed successfully.

But the most severe modification and

Figure 4: Forward voltage distribution of U4 IGBT and FWD

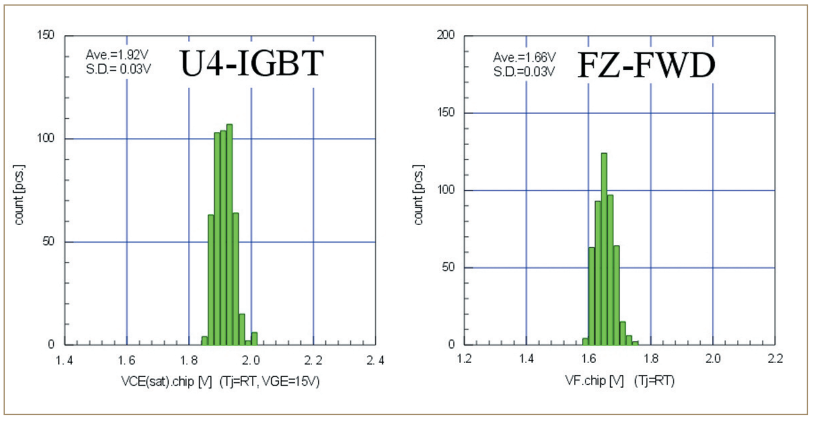
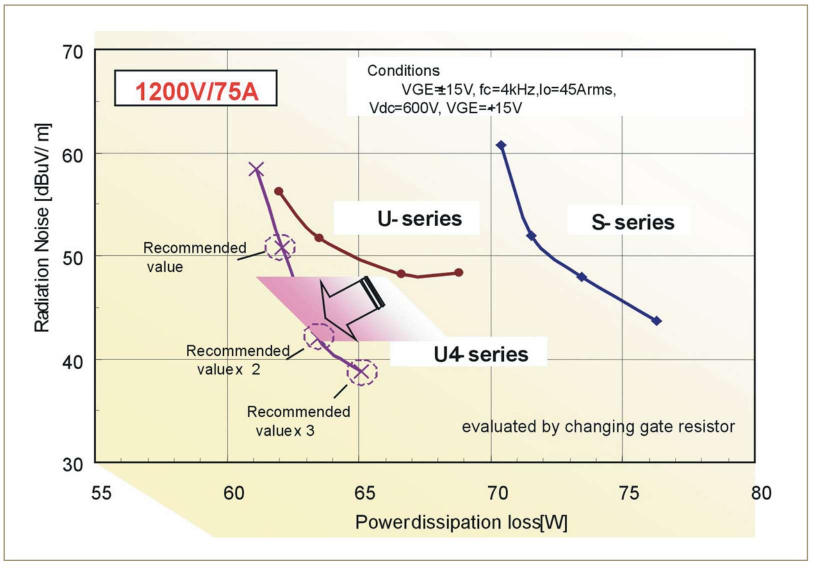


Figure 5: EMI radiation noise comparison



biggest impact to the module reliability was expected by the modification of the solder material between the DBC substrate and the baseplate.

The main target of a proper solder junction between the large area of a DBC to the base plate is to achieve a good thermal contact without any voids during the soldering process and a long lifetime at power cycling or heat cycling conditions. High power cycling capability will be limited by cracks of this solder joint due to heat cycling conditions between the two material layers. Several new lead-free solder materials have been evaluated for their heat cycling properties and the change of the base camber at the soldering process. Figure 6 is showing the solder material compositions and their behaviour of the base plate. If the melting temperature of the new composition will be much higher than before (Sn-Pb), the deformation of the baseplate after the soldering process will increase.

Regarding heat cycling capability of the new solder material the behaviour has been confirm by a heat cycling test for several solder compositions (see Figure 7). As can be seen, conventional SnAg solder type would lead to some initial cracks at the edge of the DBC area already from 100 thermal cycles. The former SnPb solder as well as the new SnAgIn solder will not show any change in the solder connection under thermal cycling conditions. Even a higher number of cycles will not have a negative impact on this joint, due to higher mechanical strength of the new solder material.

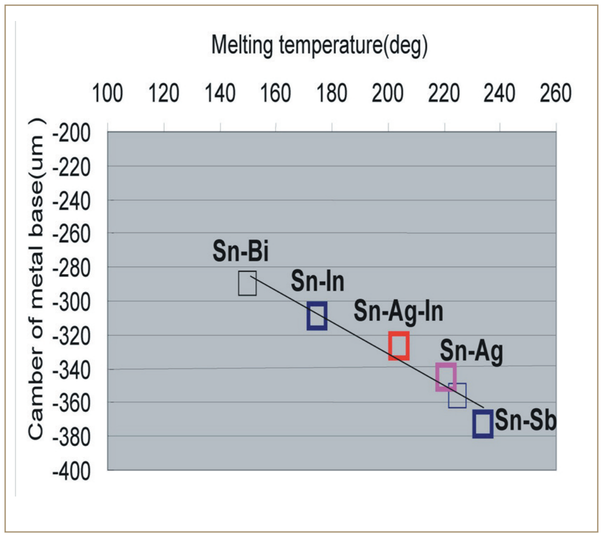


Figure 6: Properties of solder materials

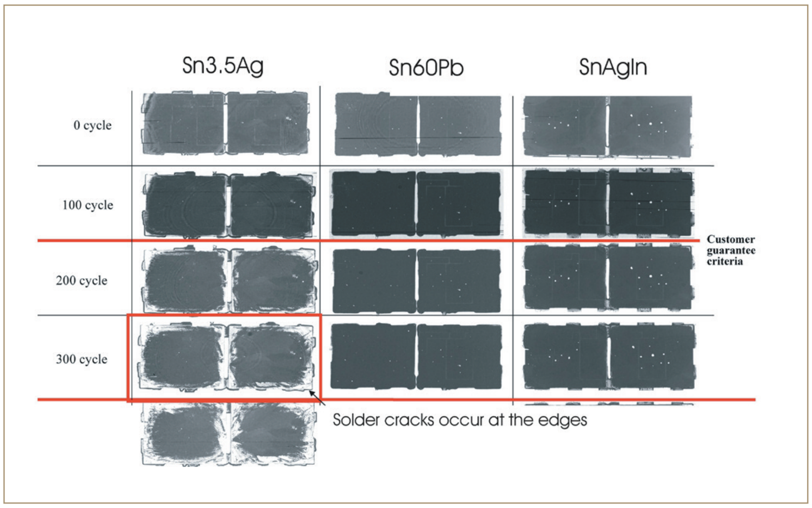


Figure 7: Heat cycling capability of DBC solder materials

Spring contact reliability

As the spring for the control terminals is a new contact structure for our IGBT modules, many evaluations to define the best material for the spring and the contact area of the PCB have been carried out. Under consideration for the spring materials were beryllium copper, phosphor bronze, and stainless steel. After comprehensive tests, a spring of phosphor bronze with a silver plating and additional coating has been chosen. Not only the spring material is important for the long-term reliability of this contact; furthermore, the contact surface of the related pad on the gate drive PCB has to fit. In actual PCB production processes, various surface finishes are known and used, thus we have specified some suitable surface materials such as chemical Sn, HAL (hot air levelling) Sn, nickel-gold (Ni ≥ 3μ; Au ≥ 20nm), and SnPb. Particularly for new RoHS compliant processes, the first option with a chemical tin surface seems to be the favourite solution, because of good electrical properties and good cost position.

Besides those requirements, the contact resistance at low current conditions, like NTC temperature measurements or DC voltage detection, can be very important. Therefore, Fuji Electric has defined an additional test to verify the contact resistance at low currents and severe environmental conditions, like PCT (Pressure Cooker Test) or H^2S gas. As a target, most applications will require currents of less than 1mA for a DC voltage detection. Down to values of approximately 10μA the contact is keeping an ohmic behaviour and thus, a proper contact, even for such low currents can be guaranteed. Similar results can be confirmed for the corrosive gas atmosphere, even if a discoloration of the spring surface happens, the contact area will keep a good and low resistivity (see Figure 8).

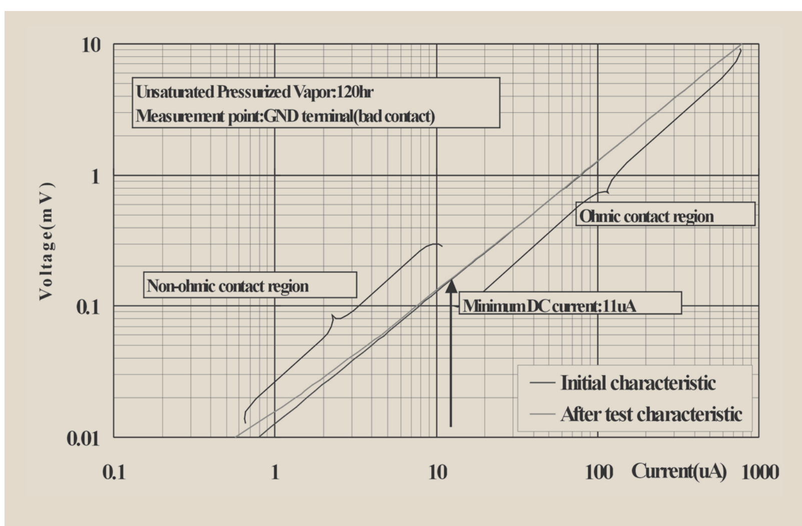


Figure 8: Low current resistance of spring contact

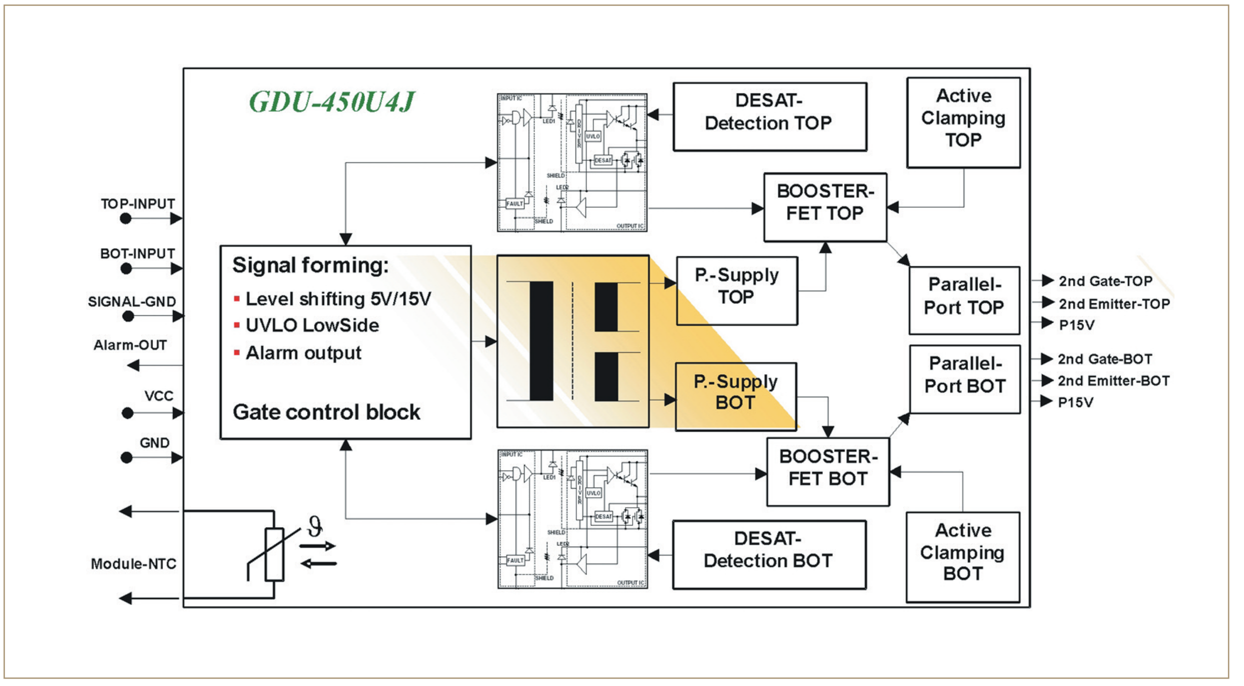


Figure 9: Block diagram of GDU for Econo-Dual modules

Gate drive unit and applications

Basically, this kind of spring type module can be used with a single driver board directly attached to the top of the module or a common PCB for a three-phase inverter, because the tight tolerances of the spring alignment and a sufficient pad size will avoid any mechanical problems. To get easily started with a design of an inverter and the evaluations of this new module, Fuji Electric has designed a gate drive unit (GDU) for a single phase (Figure 9).

This PCB will be screwed directly on top of the module and all connections to the control board will be made via a simple connector and a fully isolated interface (Figure 10). This isolation barrier fulfils all requirements of a safety isolation according to IEC 50 178 and only a single supply of +15V will be necessary. The output buffer of the GDU has a quite high pulse current capability (24A peak), which is not absolutely required to drive one phase of these modules up to 450A. On the other hand, this gives the possibility to drive several modules in parallel with one gate driver. For this purpose, an adapter board for all additional paralleled modules with individual gate resistors and the connectors for the link with the main gate drive board will be required. Even in parallel operation, switching frequencies above 12kHz are possible, depending on the number of paralleled modules and the gate charge of the chosen module.

Besides all standard functions like V_{ce} detection, under voltage lockout or an error feedback signal, this GDU also offers over-voltage protection by use of an active clamping circuit.

The Econo-Dual module can be used for all kind of converter applications where fast switching devices are required, but especially applications such as UPS, industrial and servo drives and elevators are the focus. For most of these applications, the Econo-Dual will be a replacement for the very common 62mm standard IGBT modules. Currently, three different types with 1200V blocking voltage and current ratings of 225, 300 and 450A are available; and the next step planned is for 1700V modules.

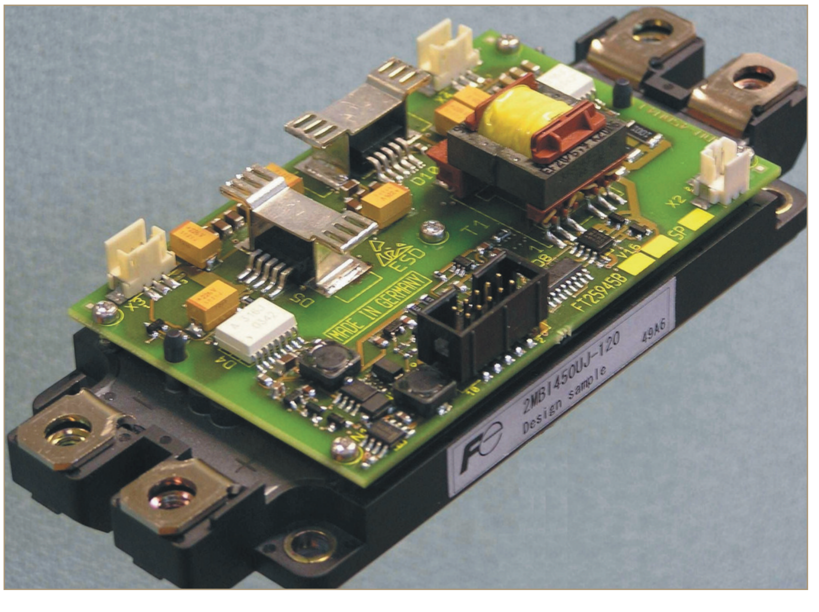


Figure 10: View of the GDU mounted on top of a IGBT module