Reverse Conducting IGBT for Drives

RC-Drives

Cost-Optimized IGBT

for Consumer Drive Application

Application Note

System Application IGBT

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1. Short Description

As a further evolution of the TRENCHSTOP™ in the price-sensitive Consumer Drive market, Infineon has released a new product family in the 600V voltage class. Purpose of this note is to illustrate the key features of the new technology, highlight the potential benefit for the customer as well as advantages over existing solutions, and to provide recommendations for the utilization in an inverter motor drive circuit.

RC-Drives Product family

Part number	Package Type	Max Inverter Output Power	Heatsink needed	BVces	Ic@25C	Ic@100C	$V_{ce(on)}$ @ 175C Typical	Ets @ 175C Ic@100C Typical	Tsc	Vgeth
		[W]		[V]	[A]	[A]	[V]	[mJ]	[usec]	[V]
IKU04N60 IKD04N60	IPAK DPAK	200	NO	600	8	4	1.85	0.40	5	5
IKU06N60 IKD06N60	IPAK DPAK	600	YES	600	12	6	1.85	0.56	5	5
IKU10N60 IKD10N60	IPAK DPAK	1000	YES	600	20	10	1.85	0.93	5	5
IKU15N60 IKD15N60	IPAK DPAK	1500	YES	600	30	15	1.85	1.25	5	5

The product family can be used in a wide range of applications:

- Appliance Motor Drives
  - Air Conditioning Compressors, Fan
  - Washing machines
  - Refrigerator Compressors

- ☐ Vacuum cleaners
- ☐ Dishwashers
- ☐ Ventilation Fans

- General purpose Motor Drives
- Pumps

2. Technology Overview

Infineon has pioneered over the last 20 years the Trench Field Stop IGBT Technology (TRENCHSTOP™), combination of Field Stop concept in thin wafer technology and ´trench gate, with voltage classes spanning from 600V to 6500V. The RC-Drives technology is based on the established Trench Field Stop IGBT platform and tailored to the needs of the low-cost high-volume consumer market: the freewheeling diode is monolithically integrated in the IGBT chip, thus achieving substantial Si area saving:

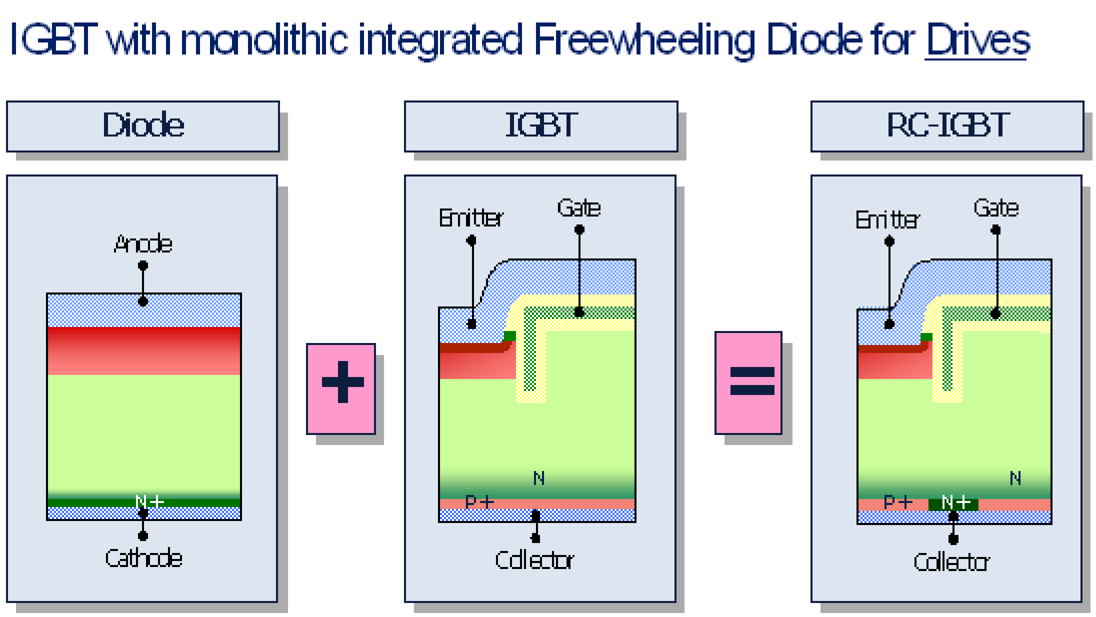


Figure 1: Reverse Conducting IGBT construction

The chip construction is similar to the previously released RC-H IGBT (Reverse Conducting for Induction Heating), however the integrated diode had to be improved in order to sustain hard switching conditions typical of inductive load in motor drive applications. This is realized by engineering the carrier profile inside the chip:

- Reduction of anode efficiency to reduce Q_{rr}, I_{rr}
- Lifetime killing process to speed-up depletion of the base from free-carrier
- Increase of cathode n-emitter efficiency to increase diode softness.

Thanks to these modifications, Q_{rr} and I_{rr} during reverse recovery are reduced, insuring reduced power dissipation at IGBT turn-on in half bridge hard-switching voltage source inverters typical of motor drives.

Beside Si area saving, additional advantages of the RC-Drives technology are:

- Reduction of wafer testing costs
- Reduction of assembly costs (single pass in chip bonding)
- More degrees of freedom in package layout
- Small „diodes“ can still be bonded with „thick“ bond wires
- Low thermal resistance of the diodes thanks to wider conduction area

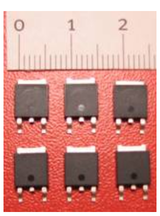
3. Chip shrink and power density increase

Thanks to the reduced total chip size, packages of reduced footprint can be used for the same current rating of equivalent DuoPAK Products, thus allowing a substantial power density increase:

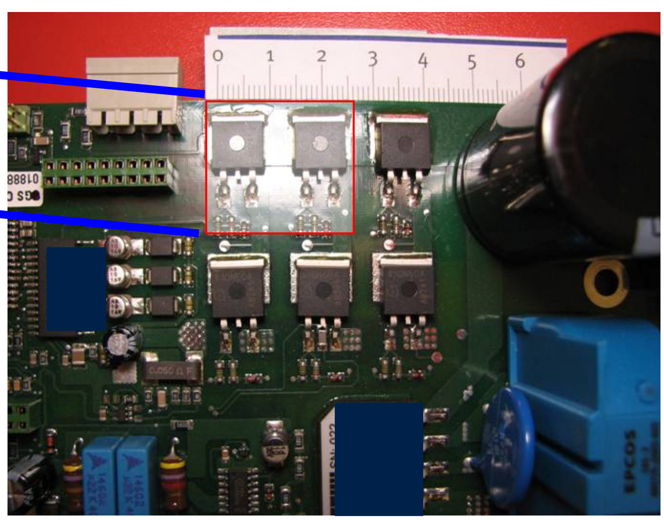
Conventional technology	Footprint [mm2]	Height [mm]	**RC-Drives**	Footprint [mm2]	Height [mm]	Footprint reduction	Height reduction
TO-220	157	4.5	**IPAK**	39	2.3	**-75%**	**-49%**
D²PAK	106	4.5	**DPAK**	39	2.3	**-63%**	**-49%**

Note: To keep the T_j below 175°C, additional cooling effort may be needed. As a reference, refer to options provided in Chapter 7.

Smaller package means less board spacing and compact system design. Although board spacing is normally not an issue in House Appliances, newer generation of Products could take advantage of a reduced board real estate for the power section: for example washing machines with increased drum size that must maintain the external outline, Industrial fan of Refrigerator compressors were the inverter board is mounted directly close to the motor.



DPAK 3-phase



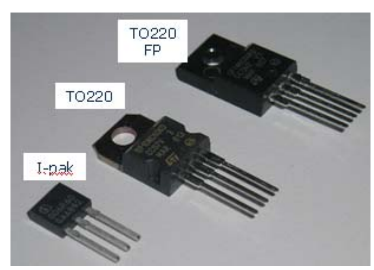


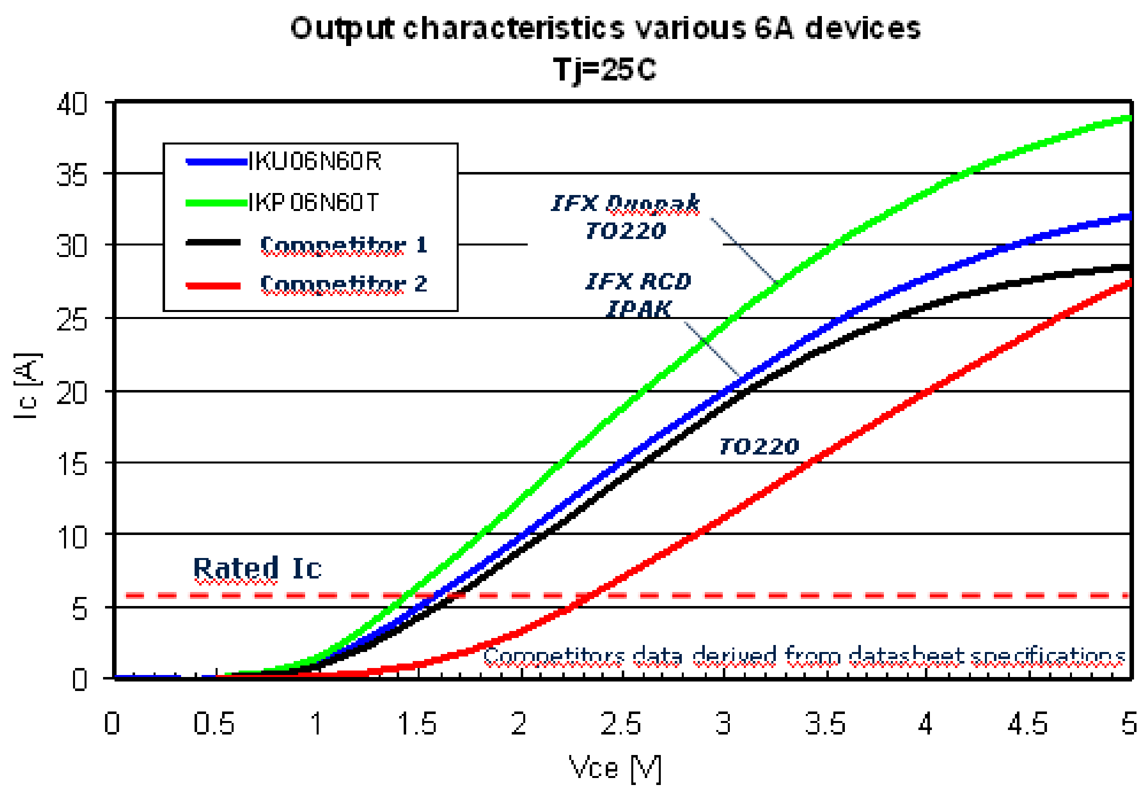
Figure 2: example of board space saving from RC-Drive in DPAK and IPAK package comparison

4. Static and Dynamic Behaviour

4.1 Static Behaviour

The RC-Drives IGBT is optimized for low V_{cesat}, because the conduction losses are dominant in the switching frequency range typical of motor drive application (4~16 kHz). Low V_{cesat} allows:

- Reduced losses and improve system efficiency
- Reduced number of devices in parallel for high power systems
- Reduced heatsink size



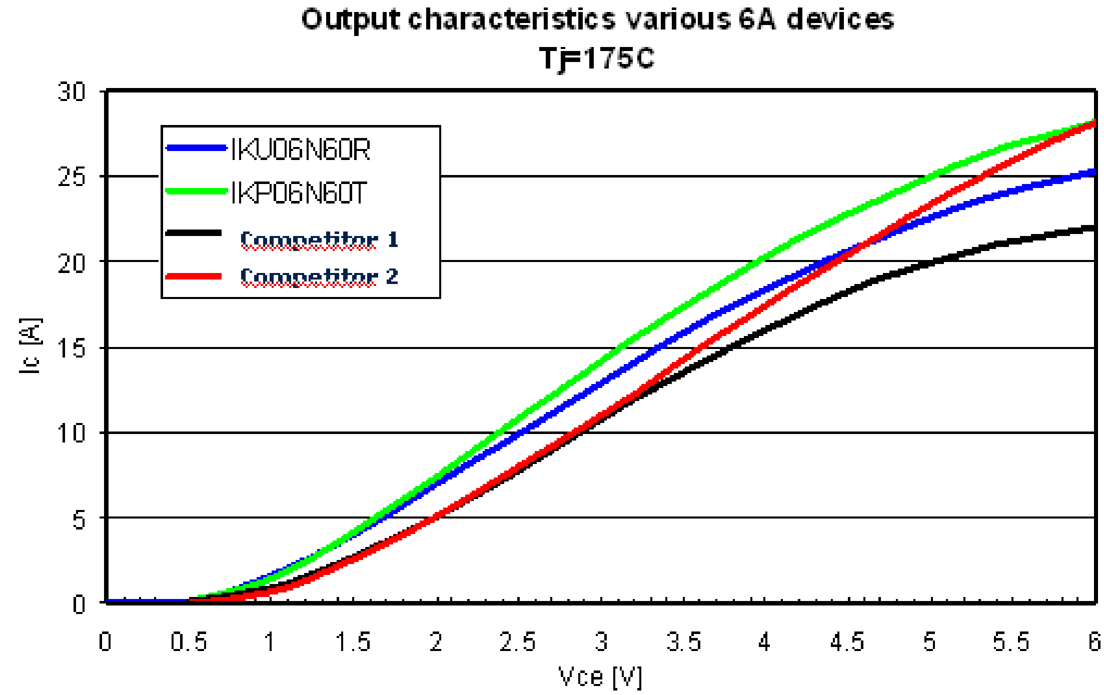


***Figure 3: Output characteristics of RC-Drives IGBT*.**

4.2 Dynamic Behaviour

Due to the optimization for low V_{cesat}, the RC-Drives tends to show long tail currents at turn-off (Figure 4).

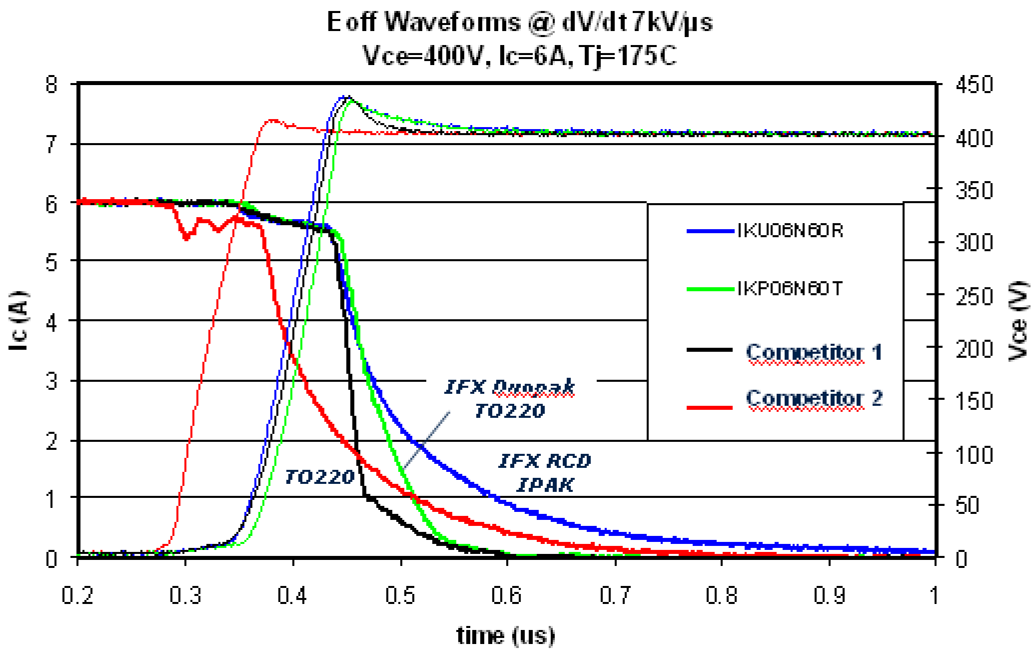


Figure 4: Turn-off Transient Waveforms

The turn-off losses at same dV/dt are higher compared to the DuoPAK (IKP06N60T) and to Competitor 1. These devices show however some non linear dI/dt characteristics that would generate harmonics of the radiated EMI noise (see next chapter). Competitor 2 shows similar turn-off current waveform resulting in similar turn-off losses as the RC-Drives. A trade-off chart V_{cesat} - E_{off} is summarized in Fig. 5.

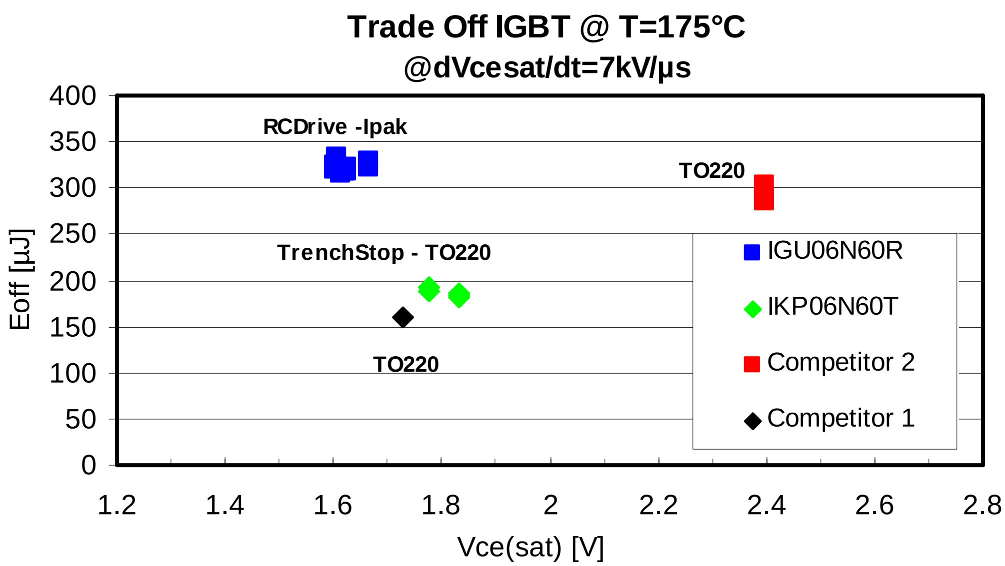


Figure 5: Trade-off V_{cesat} ***-*** E_{off}

4.3 Short Circuit Capability

The monolithic integration of the antiparallel diode does not degrade the short circuit capability in comparison with the TRENCHSTOP™. The RC-Drives is rated at t_{sc}=5usec at T_j=150°C, V_{ge}=15V, V_{cc}=400V.

The destruction mechanism is thermal run-away after successful turn-off (Figure 6), confirming the robust latch-up free Trench cell design. The failure mechanism of thermal destruction was validated by electro-thermal simulation: for long enough SC pulses, the device cannot dissipate the energy of the pulse, the Junction temperature increases and the Ices leakage is running away.

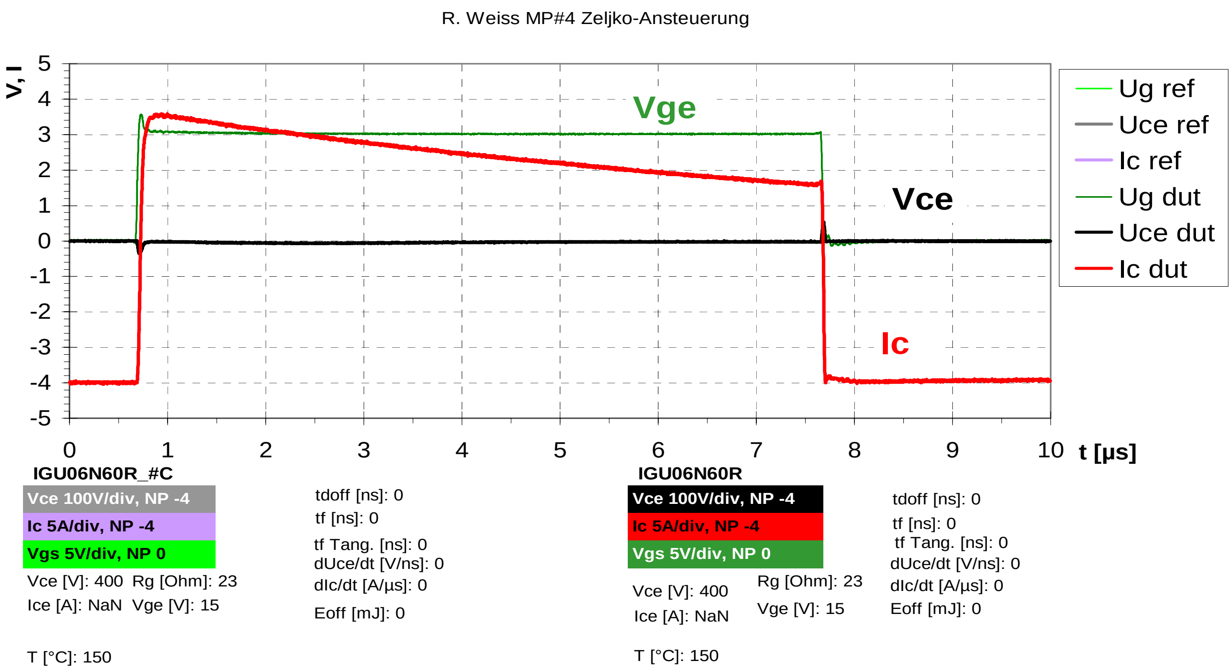


Figure 6: Typical short circuit waveform of a failing device. Thermal failure is happening well after turn-off. V_{ge}=15V, V_{ce}=400V, T_j=150°C.

5. EMI consideration and R_g section

EMI is mainly driven by rate of change of voltage and current during switching events. Switching behavior as a function of R_g and Tj was investigated to assess the EMI performance in a real inverter circuit. Results for the RC-Drives are compared with the previous generation TRENCHSTOP™ and other competitors. Specifically the dV/dt behavior is plotted in Figure 7.

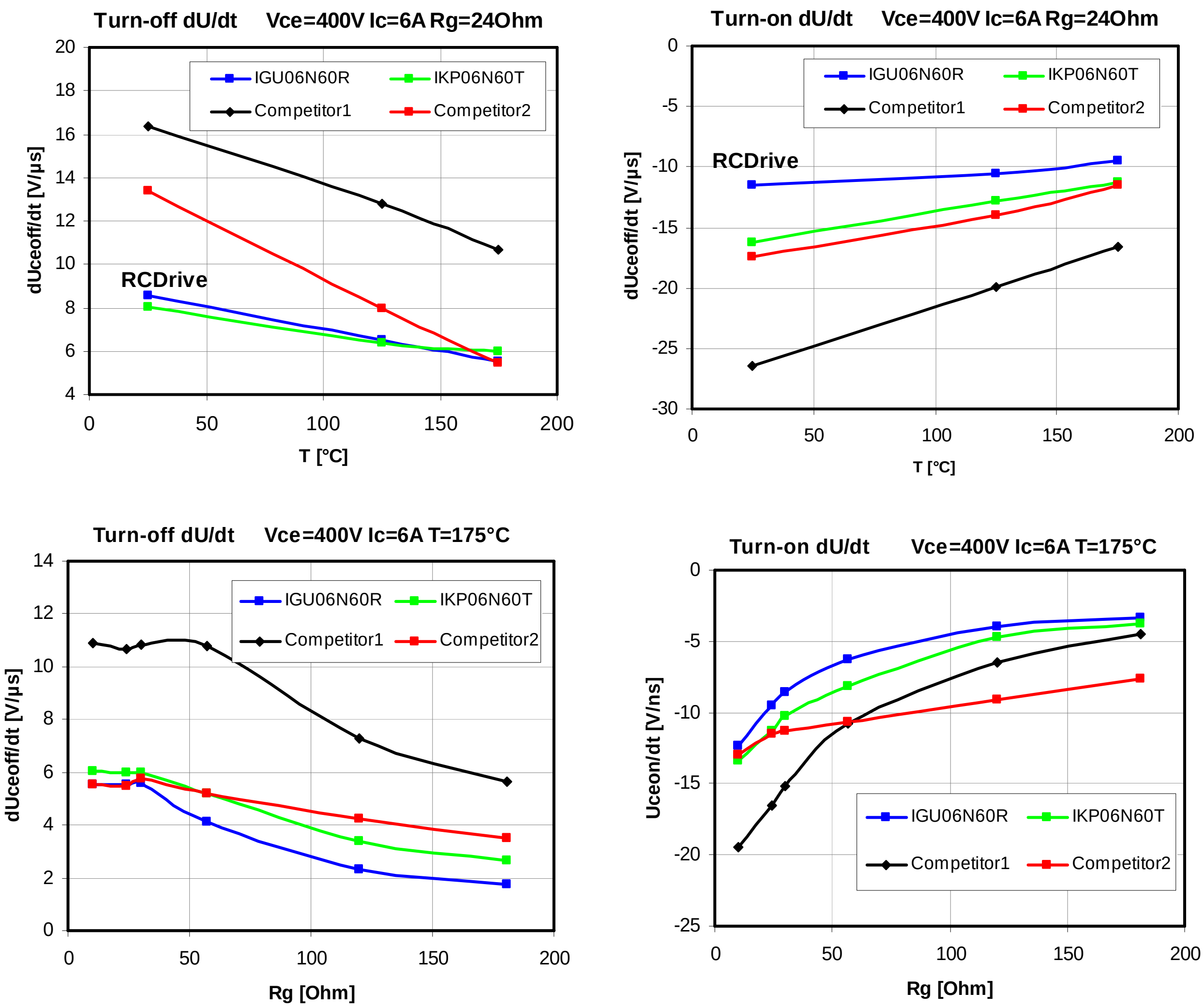
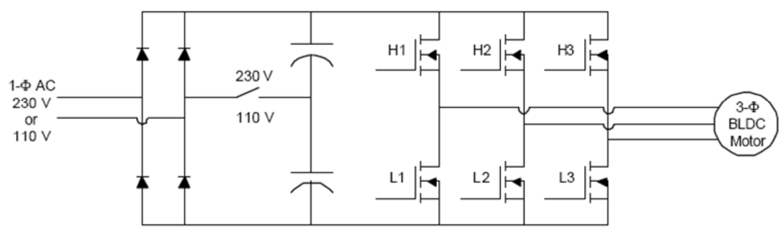


Figure 7: dV/dt as a function of Tj and R_g.

The RC-Drives show the lowest dV/dt over the entire temperature range that will translate in lower high frequency harmonics of radiated EMI noise. The R_g can be reduced in order to reduce switching losses still maintaining low EMI.

6. Power Losses in a BLDC Motor

On the basis of the measured conduction and switching losses, the power losses of a real 3-phase voltage source Inverter driving a BLDC motor were estimated. The modulation type is hard switching (Fig 8), were both conduction and switching losses are playing a significant role:



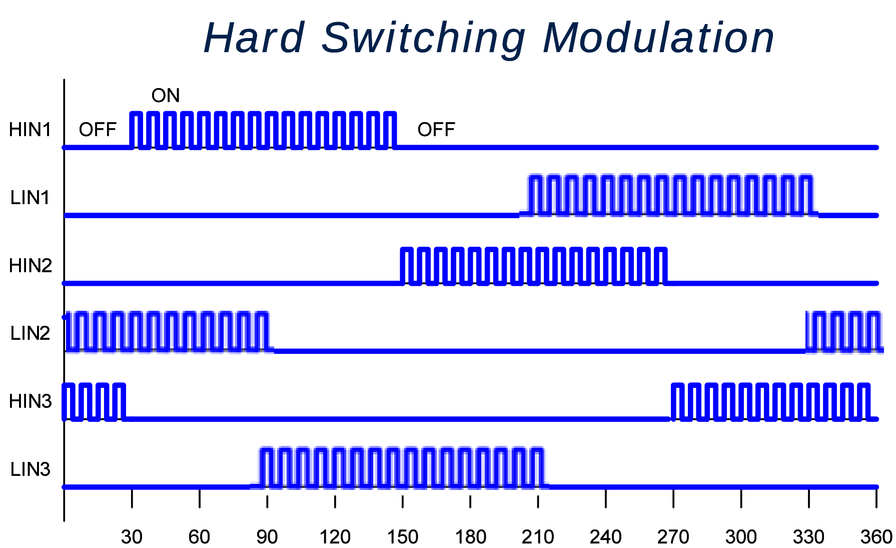
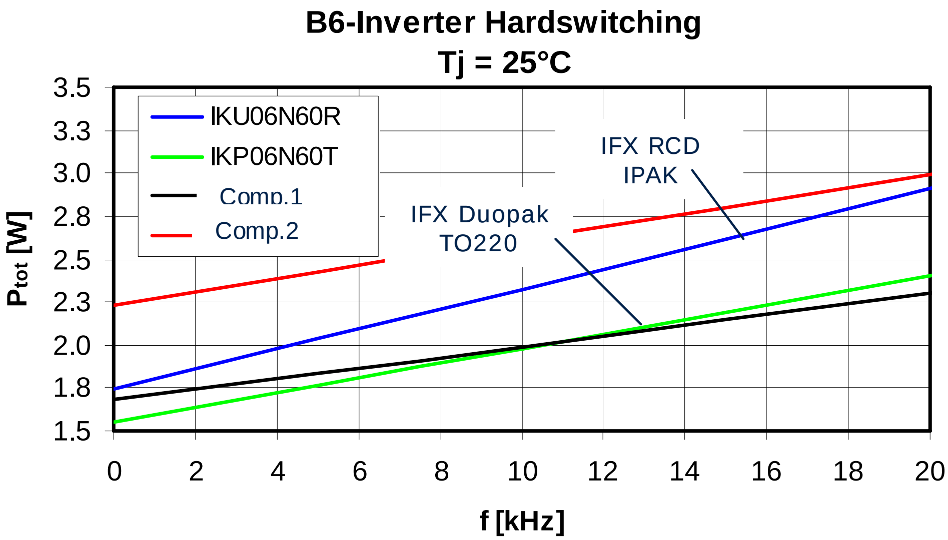
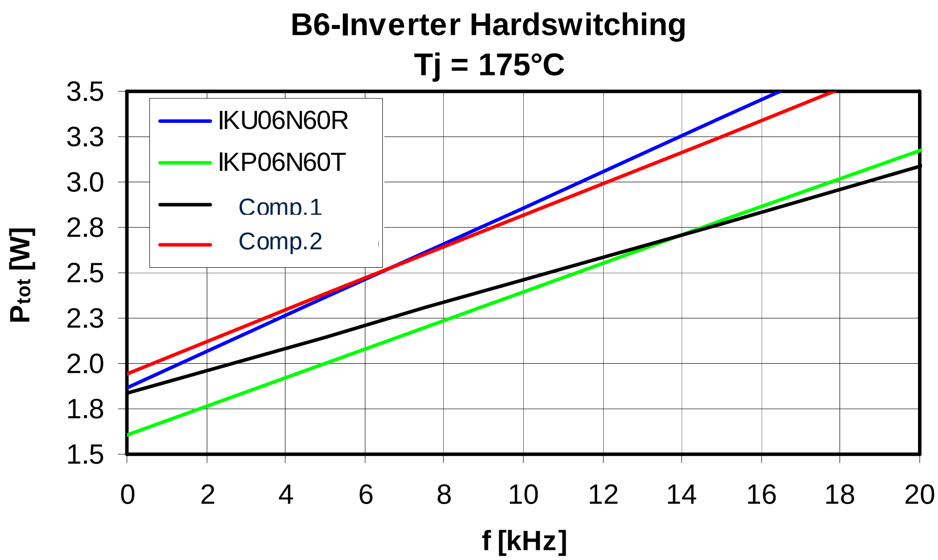


Figure 8: Hard switching of a 3-phase voltage source inverter

Vcc=400V, R_g =24 Ohm, Iout=6A. hard switching

Simulations results for the 6A RC-Drives in IPAK are shown in Fig 9. At 4 kHz the conduction losses are dominating the overall losses, and the RC-Drives show low power dissipation aligned with competitors devices in TO-220 package. At 16 kHz the switching losses are taking over, and the RC-Drives is penalized. R_g is set to 24 Ohm for all devices, a reduction of R_g for the RC-Drives would have reduced the power dissipation in this case. The TRENCHSTOP^{TM} in TO-220 package shows the lowest losses for fsw<15 kHz.





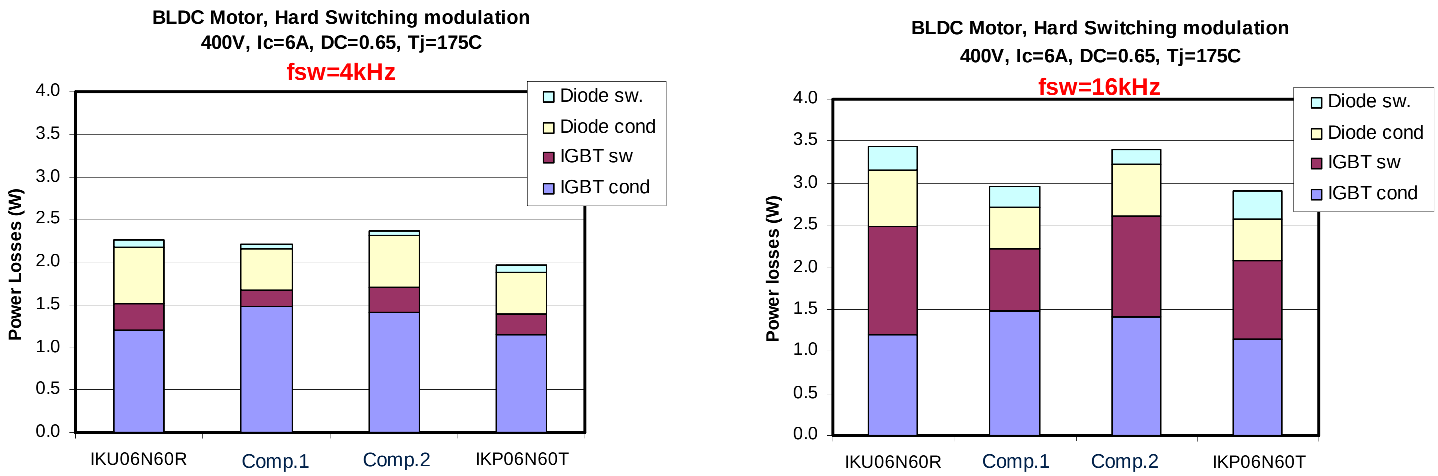


Figure 9: Power loss vs. switching frequency and loss breakdown for individual switch

7. Thermal Behaviour

7.1 Washing Machine Application Test.

In order to verify the thermal behavior of the RC-Drives, an application test was performed in a commercial AEG Washing machine. The original Electrolux board was equipped with TO-220 FullPAK device from competition. The HS and LS TO-220 FullPAK for one phase were replaced with RC-Drives in IPAK (Fig 10). Thermal foil was added to insulate the package from the heatsink.

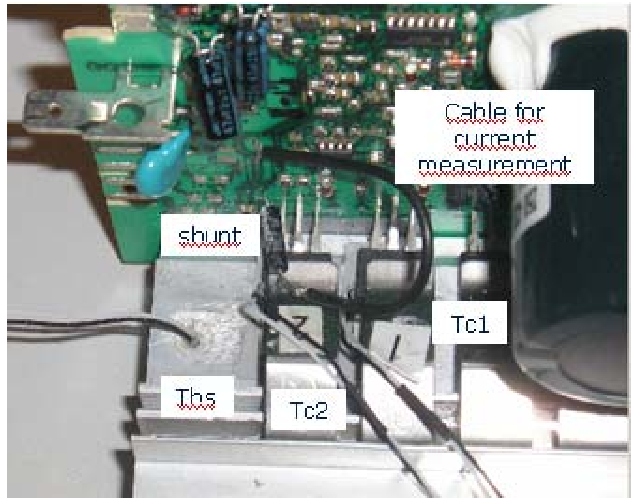


Figure 10: Application test set-up

For the case temperatures of the high side and low side IGBTs a thermocouple is inserted on a small hole drilled in the molding compound on the side of the package. The resulting temperature readings are very close to the junction temperature. For the heatsink temperature a small hole is also drilled in the heatsink in the vicinity of the low side device, and a third thermocouple is inserted. Temperatures are recorded during a “20 min” Washing-Rinsing-Spinning cycle with approx 5 Kg of load, 1200 rpm and 30°C water temperature (Fig11). The difference between junction and ambient temperature Tj and Ta is directly related to the power losses and thermal resistance:

$$T_j - T_a = (R_{thjc} + Rthcs) \text{ x } P_{tot} + R_{thsa} \text{ x } P_{tot} \text{ x } 6$$

Were P_{tot}= Average Power loss IGBT + Diode for one device.

The result (Fig. 12) shows only 15 °C maximum increase in T_j of the RC-Drives in IPAK in comparison with the commercial solution in TO-220 FullPAK from competition, and 90°C of T_{jmax}. In a worst case of a max Ta in a real application of approx 70°C, the resulting T_{jmax} would be approx. 135°C, well within the T_{jmax} specification of 175°C.

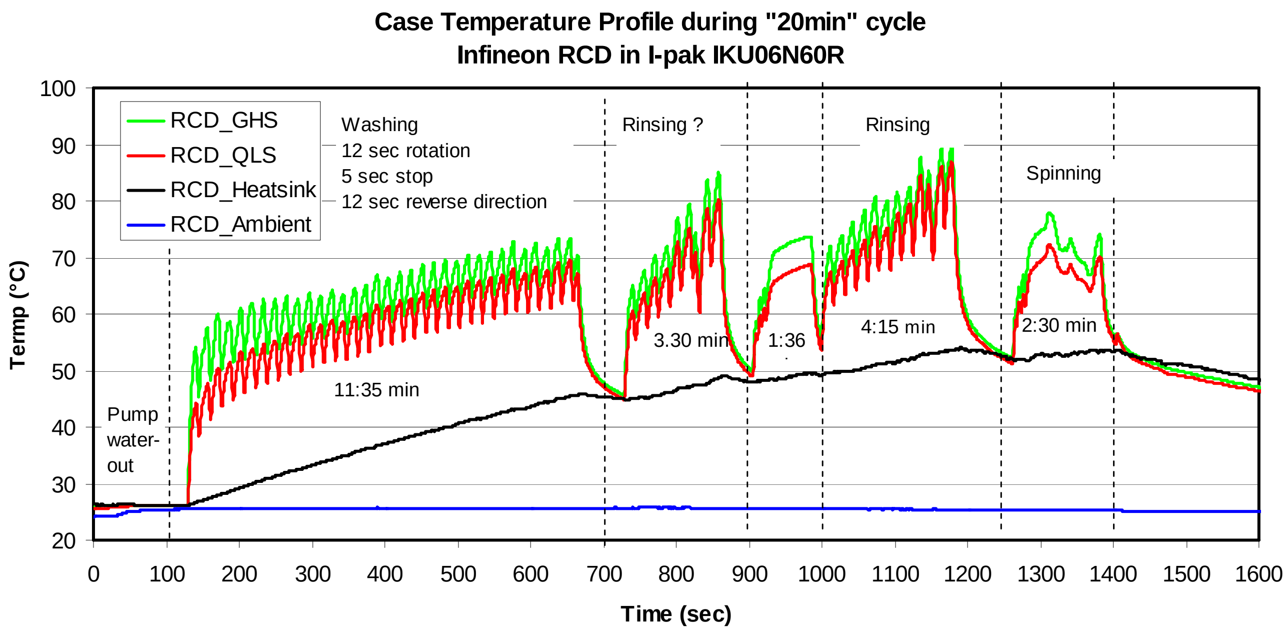


Figure 11

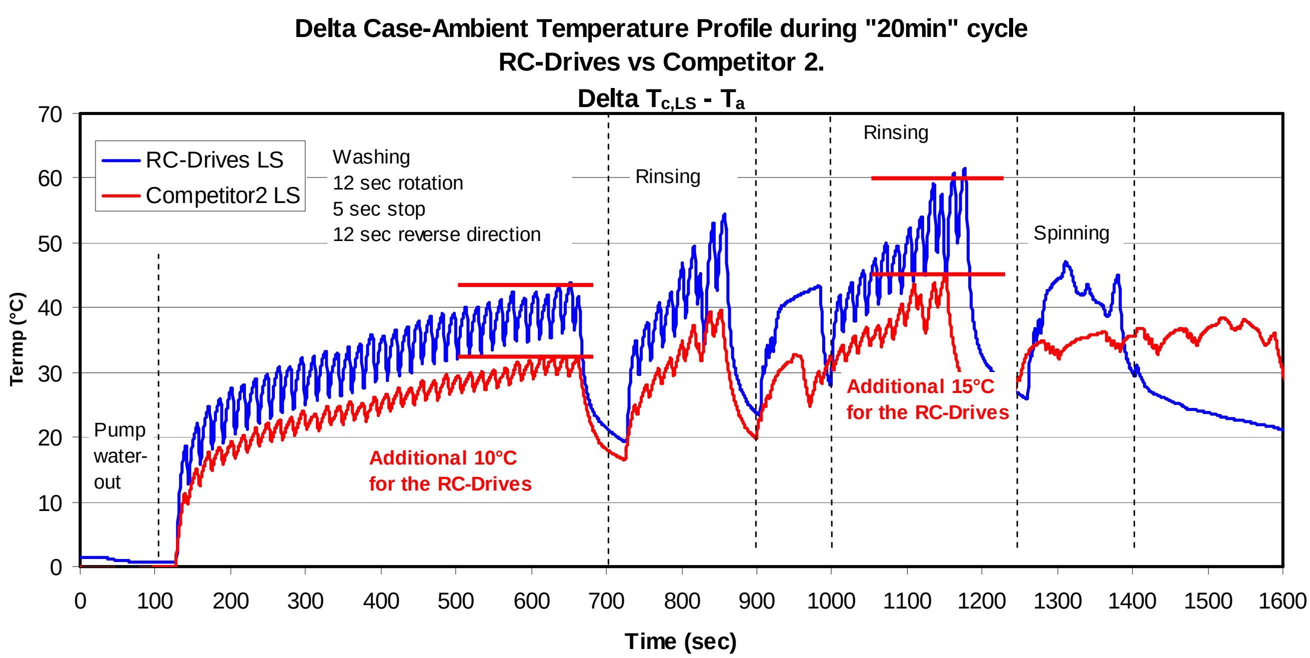


Figure 12

7.2 Mounting and Cooling Consideration

As a cost saving option for consumer drive, the RC-Drives are intended to be a replacement of bigger packages to provide good enough performance in the selected application. Below we provide examples of mounting options for both surface mount (DPAK) and straight leads (IPAK) versions.

7.2.1 Surface Mount

This package version is normally found in low power system (up to 300W), were simple surface mount assembly (soldering + reflow) allows a good cost saving for the power section of the inverter. Output power is limited by the thermal resistance of the package mounted directly on the PCB (T_{jA} up to 50 °C/W), and power dissipation / switch must be kept within 2W approx.

In the example below (Figure 13) we compare a commercial board for refrigerator compressors to a 200W RC-Drives demoboard developed in-house for compressors, fans and pumps:

Commercial 200 W compressor board – **D²PAK**   RC-Drive demoboard - **DPAK**

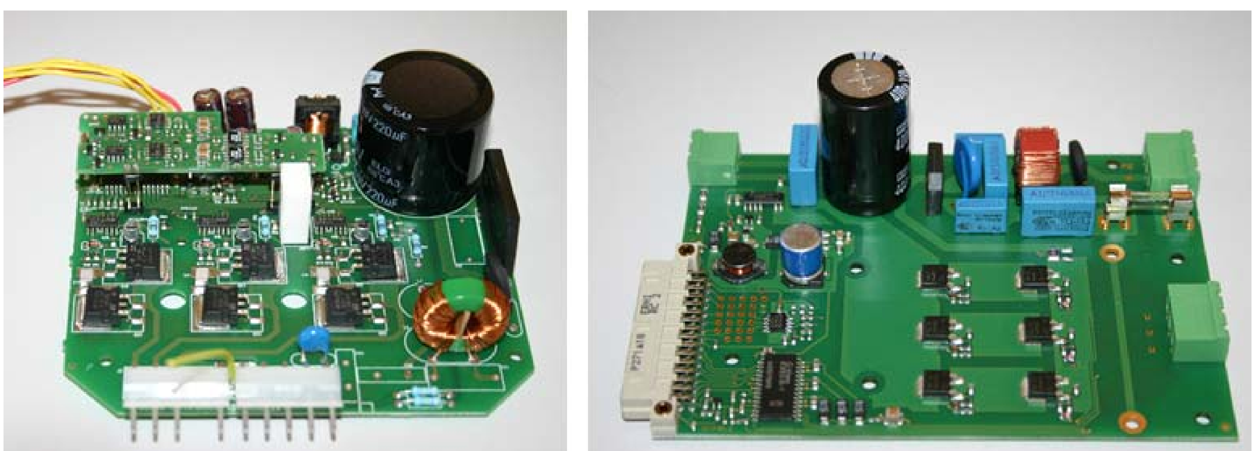


Figure 13

In order to improve the heat dissipation, thermal vias are realized in the PCB under the device case, in order to allow a better heat dissipation in case a heatsink is mounted on the opposite side of the board (Figure 14 and 15). The heatsink is insulated by Thermal foil.

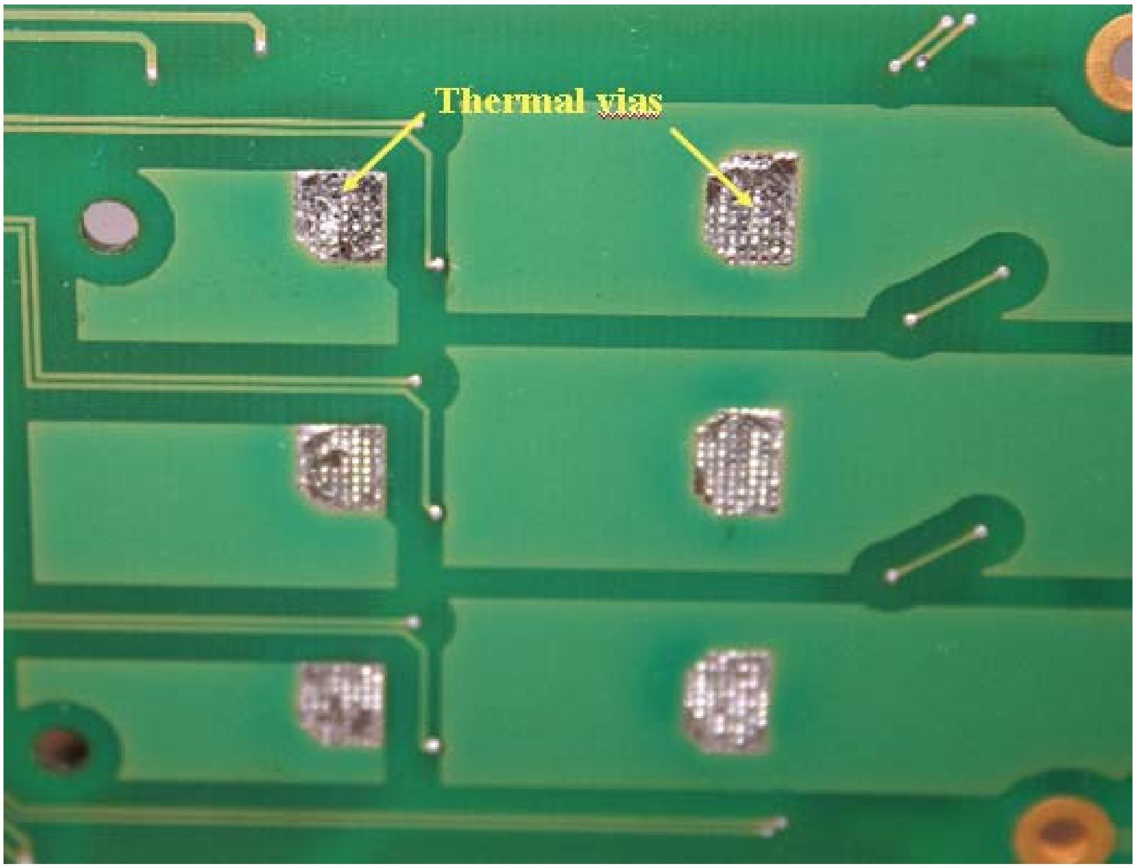


Figure 14: Thermal vias for an improved thermal design

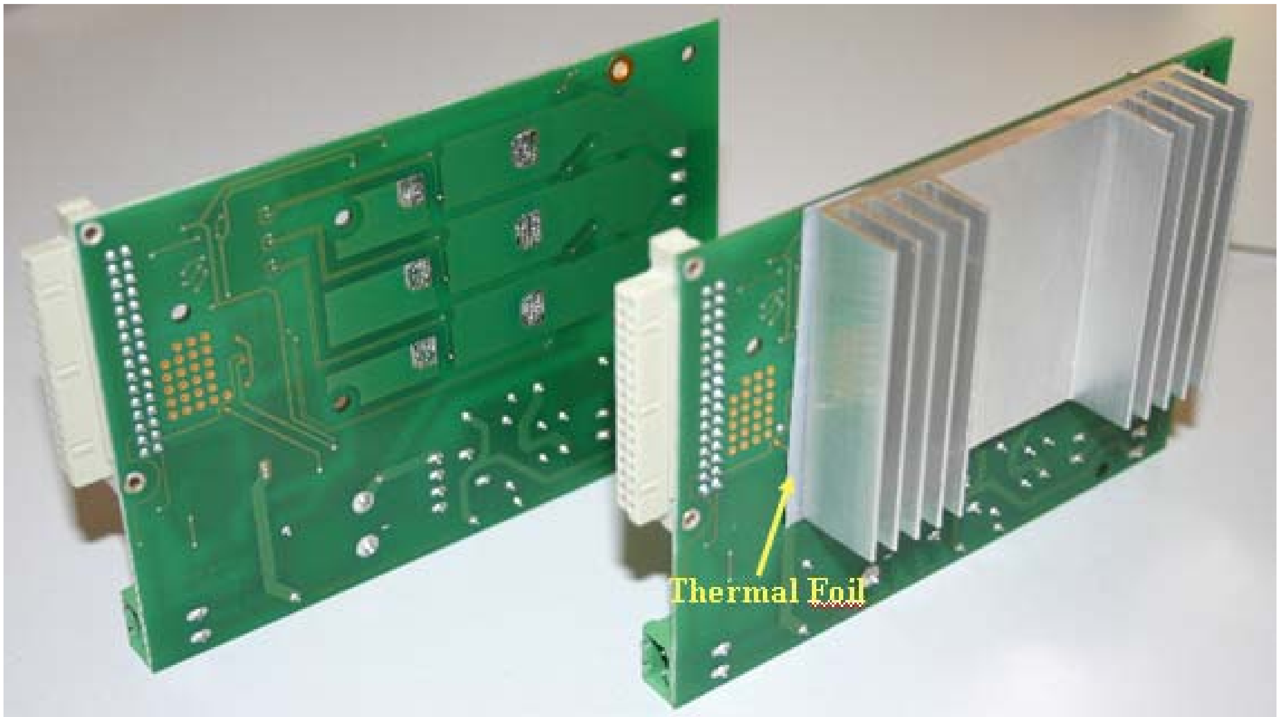


Figure 15: Example of heatisink mounting

7.2.2. Straight Leads mounting

Vertical insertion of straight leads packages are typically found in higher power systems (600~800W), were normally TO-220 FullPAK are used anchored to heatsink. Here the RC-Drives in IPAK can replace such packages, but an insulation foil has to be used because the drain of the DPAK is not isolated. An example is provided in Figure 16, were the Electrolux board of a commercial AEG Washing machine is used to test different IPAK mounting concepts.

Figure 16: Commercial board with TO-220 FullPAK + clips

To improve the mounting for the IPAK, the heatsink design was changed to allow clips screwing (Figure17). The angle of the clips is now optimized for the IPAK size and a uniform pressure of the device on the heatsink is achieved. Insulating foil is added. Against vibrations typical on a washing machine, bolts can be added to secure the clips.

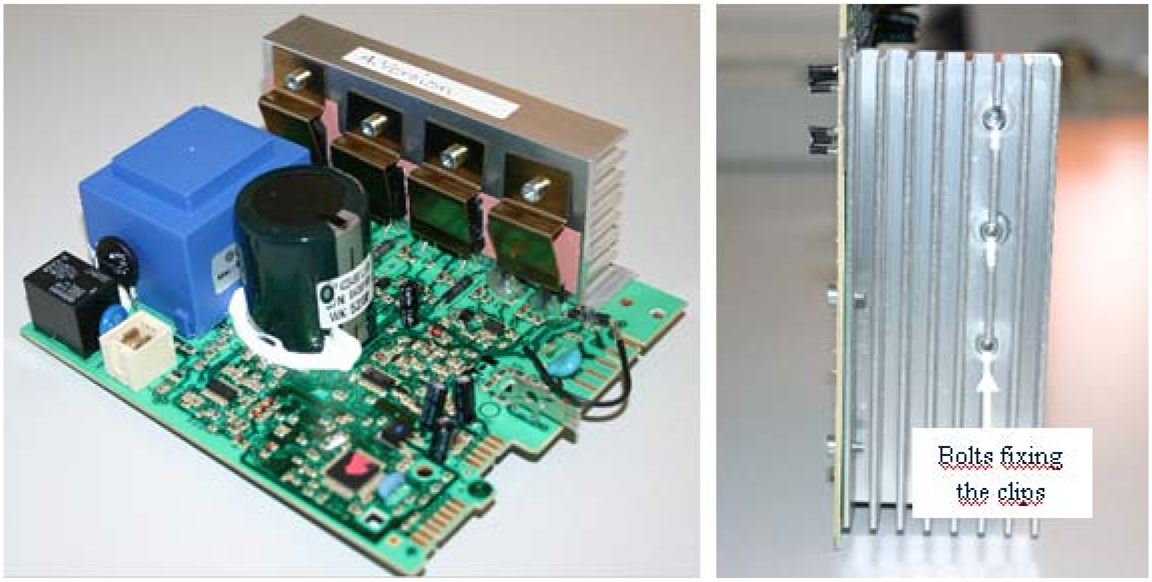


Figure 17: Mounting the clips with nuts and bolts.

Different heatsink / clips combinations are also showed in Figure 18 and 19:

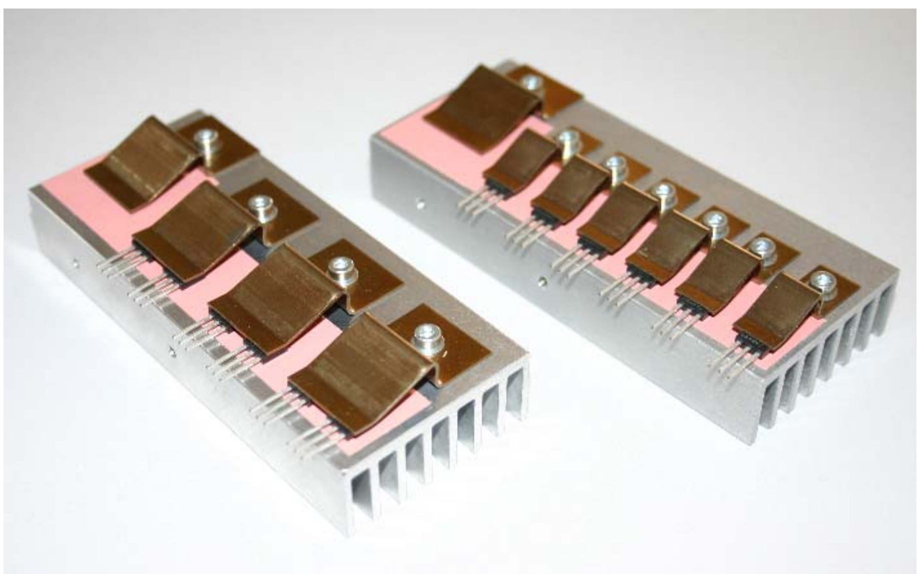


Figure 18: different Clips / heatsink / foil combination for mounting of the IPAK

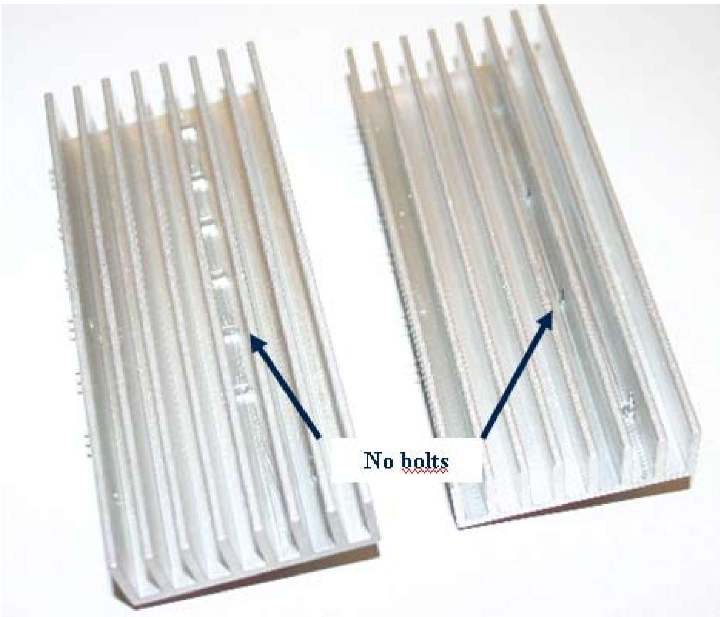


Figure 19: no bolts are used in this case, but direct screwing on the Aluminum heatsink.

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