RC-Drives, RC-Drives Fast and RC-Drives Automotive

RC-Drives IGBT for consumer and automotive applications

Application Note

About this document

Scope and purpose

This application note describes a cost-optimized discrete IGBT solution in order to address to the price-sensitive consumer drives market. Furthermore, a comparison will be made between the two technologies RC-Drives (RC-D) and RC-Drives Fast (RC-DF) IGBTs. The RC-D device is optimized for low conduction losses while the RC-DF device is optimized for low switching losses.

Intended audience

This document is intended for design engineers who want to improve their high voltage consumer drive applications.

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1 Introduction and short description of the product family

The RC-Drives IGBT technology was released by Infineon at the end of 2009 as a cost-optimized solution to address the price-sensitive consumer drives market. This basic technology provides outstanding performance in BLDC motor drives adopting block commutation–type of modulations, where one or both IGBT in the half-bridge are left conducting for 120° of the motor electrical angle (Dae-Woong Chung et al., IEEE TRANSACTIONS ON INDUSTRIAL ELECTRONICS, VOL. 46, No. 3, June 1999). Due to the low conduction losses of both IGBT and integrated diode, the overall losses are drastically reduced. This type of control is commonly found in fridge compressors: by limiting the hard switching events the dv/dt and dI/dt commutation slopes are avoided, therefore the harmonic content injected into the motor windings (hence the EMI) is reduced. Below we have a typical example of this type of commutation found on a 100 W commercial fridge compressor:

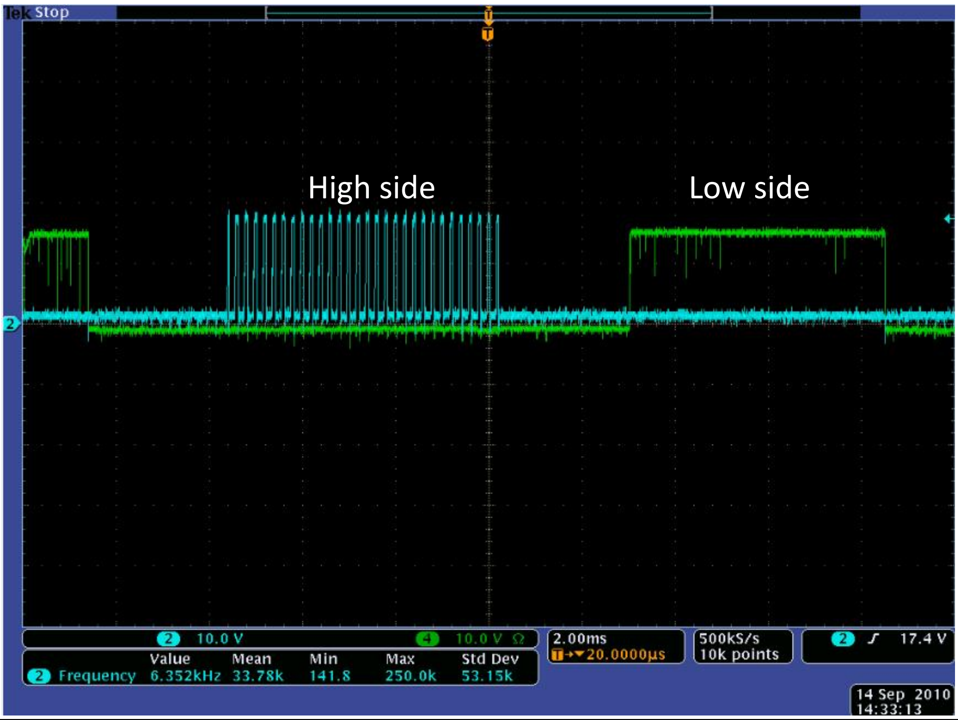


Figure 1 High side and low side gate signals for 120° PWM commutation switching

Another application that benefits from the low on-state losses or the RC-Drives is found in domestic aircon systems: the ~1.5 kW BLDC compressor is driven by IGBTs switched by full sinusoidal PWM hard switching at moderate switching frequencies of 5 to 8 kHz. Again in this case a device optimized for low conduction losses provides an overall loss reduction.

However, the trend observed in low power drives for outdoor and indoor fans of domestic aircon systems as well as industrial fans and pumps up to ~200 W is to increase the PWM switching frequency. The reason is two fold: on one side the size of the output filter can be reduced by keeping the same current ripple. On the other side, in small motor drives adopting sensor-less FOC (Field Oriented Control), where a high dynamic control (torque and speed) of the PMSM motor is required, the higher switching frequency allows to increase the sampling rate of current and hence the accuracy of reconstructed rotor position.

In order to meet the rising demands of the IGBTs for the low power motor drive consumer market, a new version of the RC-Drives IGBT is developed: the IGBT and diode losses are optimized to reduce the inverter losses at switching frequencies of 18~30 kHz. The new family is called RC-DF, and released in the current classes from 2.5 A to 15 A in DPAK packages.

Static and dynamic behavior of RC-D and RC Drives Automotive (RC-DA) devices are similar, therefore all characteristics for RC-D are valid also for RC-DA devices.

Table 1 Product specification for RC-D and RC-DFast

Part number	Package type	Power [W]	Switching frequency	V_{CE} [V]	I_C [A]		$V_{CE(sat)}$ [V]		E_{ts} [mJ]		t_{SC} [s]	V_F [V]		Q_{rr} [µC]	
					25°C	100°C	25°C	175°C	25°C	175°C		25°C	175°C	25°C	175°C
IKD03N60RF	DPAK	40-80	4-30 kHz	600	5	2.5	2.2	2.3	0.09	0.14	5	2.1	2.0	0.06	0.19
IKD04N60RF	DPAK	80-150	4-30 kHz	600	8	4	2.2	2.3	0.11	0.19	5	2.1	2.0	0.09	0.26
IKD06N60RF	DPAK	150-250	4-30 kHz	600	12	6	2.2	2.3	0.18	0.28	5	2.1	2.0	0.16	0.34
IKD10N60RF	DPAK	250-600	4-30 kHz	600	20	10	2.2	2.3	0.35	0.52	5	2.1	2.0	0.27	0.62
IKD15N60RF	DPAK	600-1000	4-30 kHz	600	30	15	2.2.	2.3	0.52	0.78	5	2.1	2.0	0.42	1.00
IKU04N60R	IPAK	80-150	DC to 5 kHz	600	8	4	1.65	1.85	0.24	0.4	5	1.7	1.7	0.22	0.52
IKD04N60R	DPAK														
IKU06N60R	IPAK	150-250	DC to 5 kHz	600	12	6	1.65	1.85	0.33	0.56	5	1.7	1.7	0.37	0.80
IKD06N60R	DPAK														
IKU10N60R	IPAK	250-600	DC to 8 kHz	600	20	10	1.65	1.85	0.59	0.93	5	1.7	1.7	0.56	1.22
IKD10N60R	DPAK														
IKU15N60R	IPAK	600-1000	DC to 8 kHz	600	30	15	1.65	1.85	0.9	1.25	5	1.7	1.7	0.76	1.7
IKD15N60R	DPAK														

Table 2 Product specification for RC-D Automotive

Part number	Package type	Power [W]	Switching frequency	V_{CE} [V]	I_C [A]		$V_{CE(sat)}$ [V]		E_{ts} [mJ]		t_{SC} [s]	V_F [V]		Q_{rr} [µC]	
					25°C	100°C	25°C	175°C	25°C	175°C		25°C	175°C	25°C	175°C
IKD04N60RA	DPAK	80-150	DC to 5 kHz	600	8	4	1.65	1.85	0.24	0.4	5	1.7	1.7	0.22	0.52
IKD06N60RA	DPAK	150-250	DC to 5 kHz	600	12	6	1.65	1.85	0.33	0.56	5	1.7	1.7	0.37	0.8
IKD10N60RA	DPAK	250-600	DC to 5 kHz	600	20	10	1.65	1.85	0.59	0.93	5	1.7	1.7	0.56	1.22
IKD15N60RA	DPAK	600-1000	DC to 8 kHz	600	30	15	1.65	1.85	0.9	1.25	5	1.7	1.7	0.76	1.7

2 Static and dynamic behavior

2.1 Static behavior

Due to the optimization for fast switching, the $V_{CE(sat)}$ of the RC-DF is increased compared to the RC-D. However for the target inverter applications in the range of ~100 W the RMS currents are usually limited below 1 A and here the $V_{CE(sat)}$ increase is limited to ~200 mV both at 25°C and 175°C. A negative temperature co-efficient of $V_{CE(sat)}$ is observed in this current range, contributing to a reduction of conduction losses in normal operating conditions, with junction temperature T_j typically ranging from 60 to 100°C.

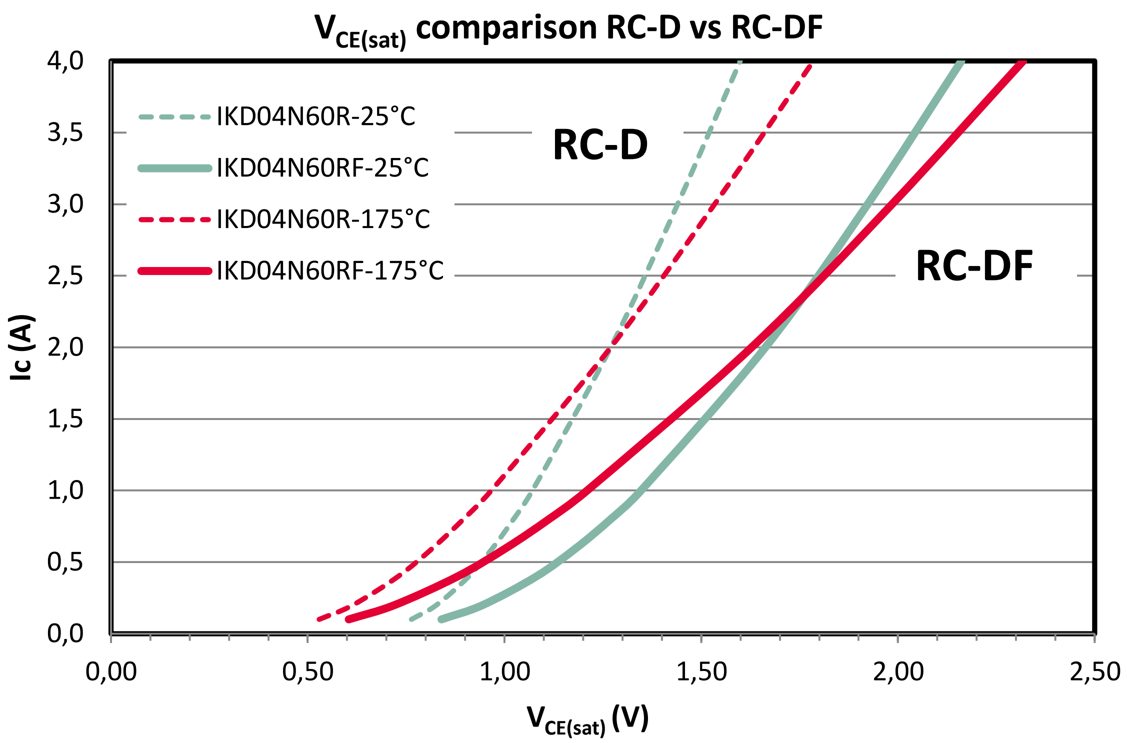


Figure 2 $V_{CE(sat)}$ comparison of the RC-DF vs. the RC-D technology

2.2 Dynamic behavior

The RC-DF maintains the smooth switching behavior and R_G controllability of the basic RC-D technology, by providing drastically reduced turn-off losses of the IGBT. The internal diode is also optimized to reduce the turn-on losses. The devices are characterized in a classical half-bridge test circuit with inductive load: the low side IGBT (DUT) is commutated over the high side diode. Therefore, the diode switching improvement is visible in the IGBT turn-on behavior (see below).

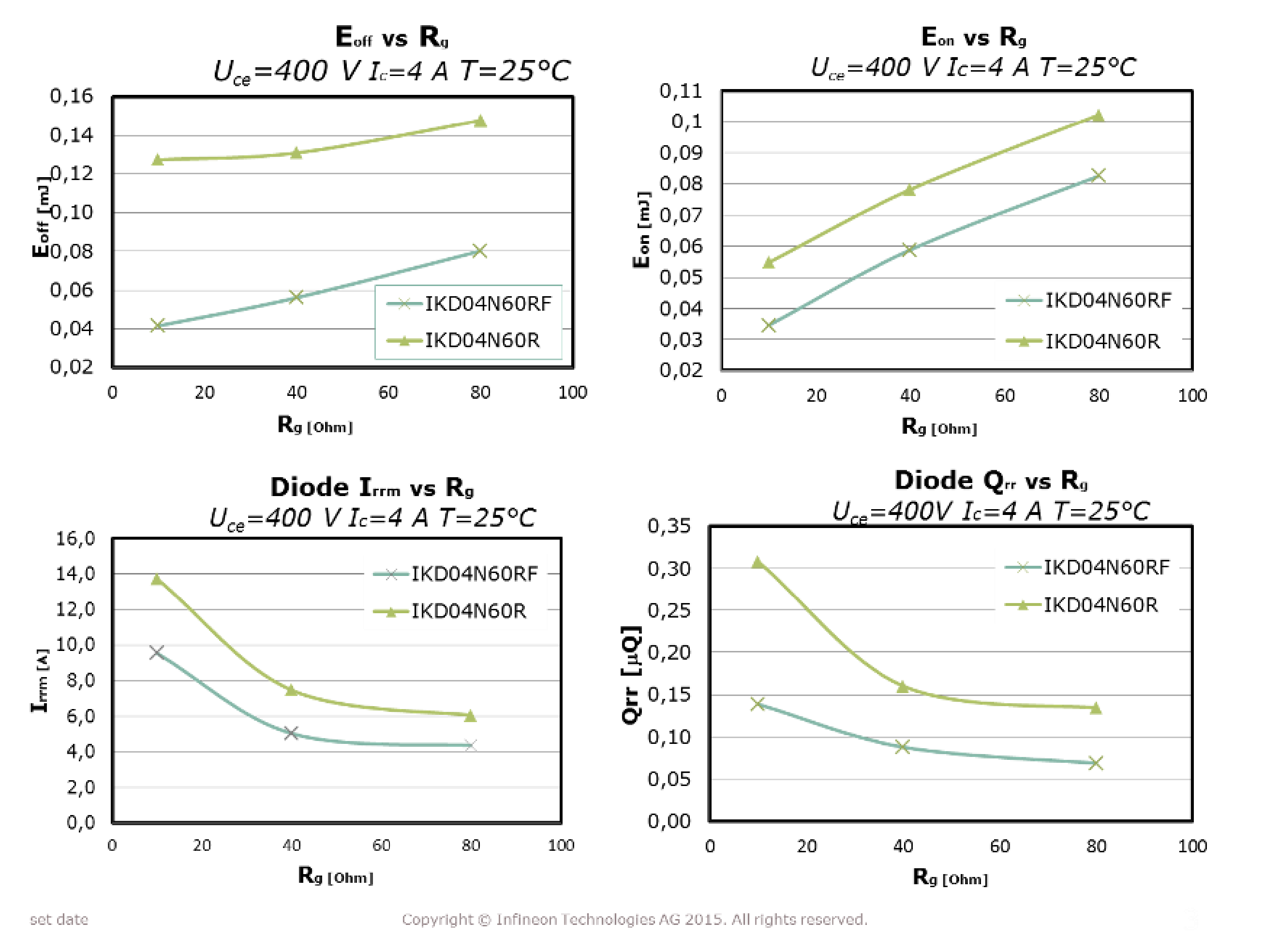


Figure 3 Dynamic switching behavior as a function of external R_G

The turn-on and turn-off waveforms are clearly showing significantly faster switching: both the tail current of the IGBT, the Q_{rr}, I_{rrm} and t_{rr} of the integrated diode are drastically reduced.

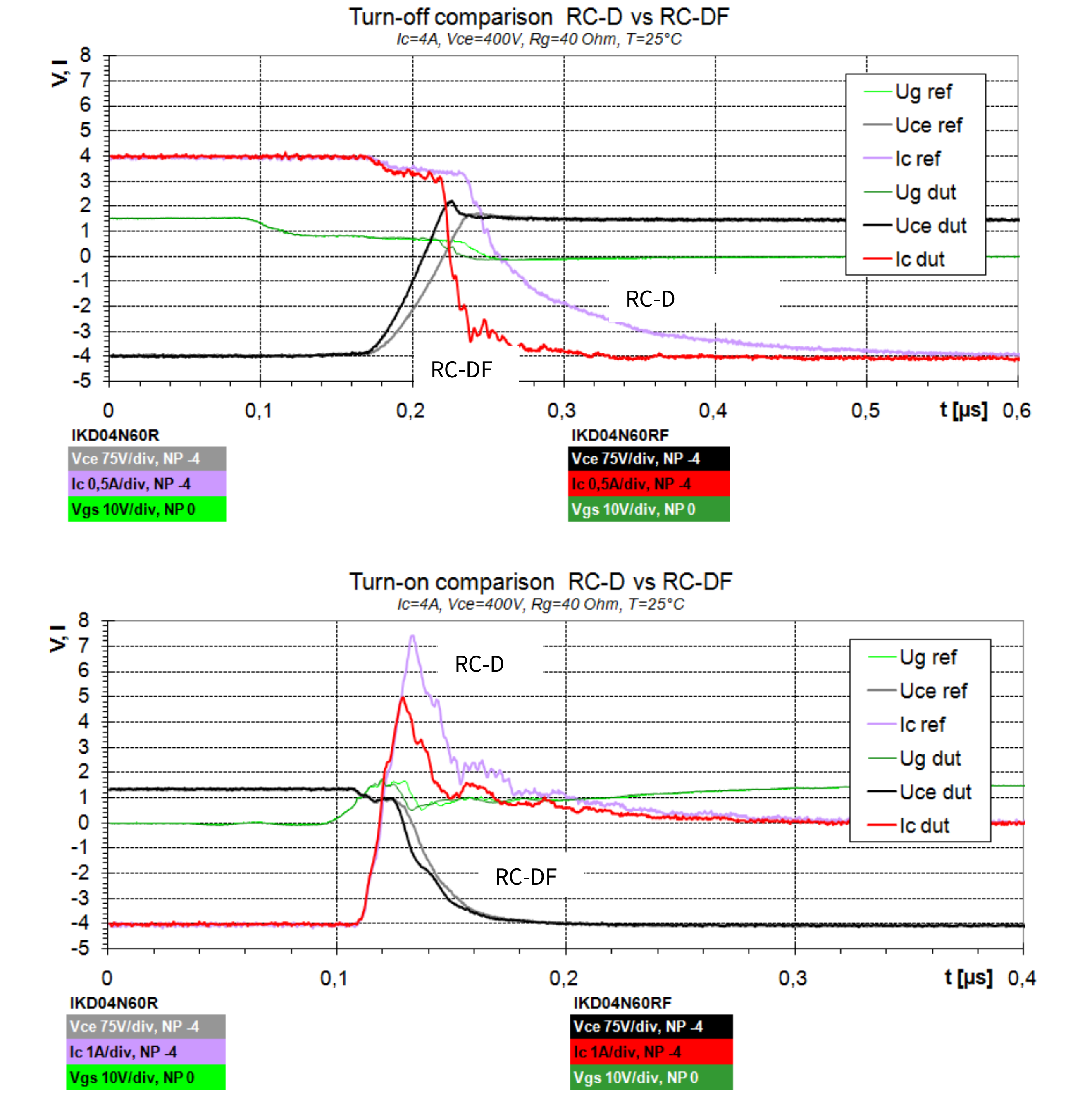


Figure 4 Dynamic switching waveforms: turn-off (top) and turn-on (bottom). Note that the current scales are different

3 Application

RC-D and RC-DF devices are suitable for home appliances as shown in Figure 6, especially as the power component of motor drive inverters. This is usually a two-level three-phase inverter driving a three-phase induction or permanent magnet synchronous motor.

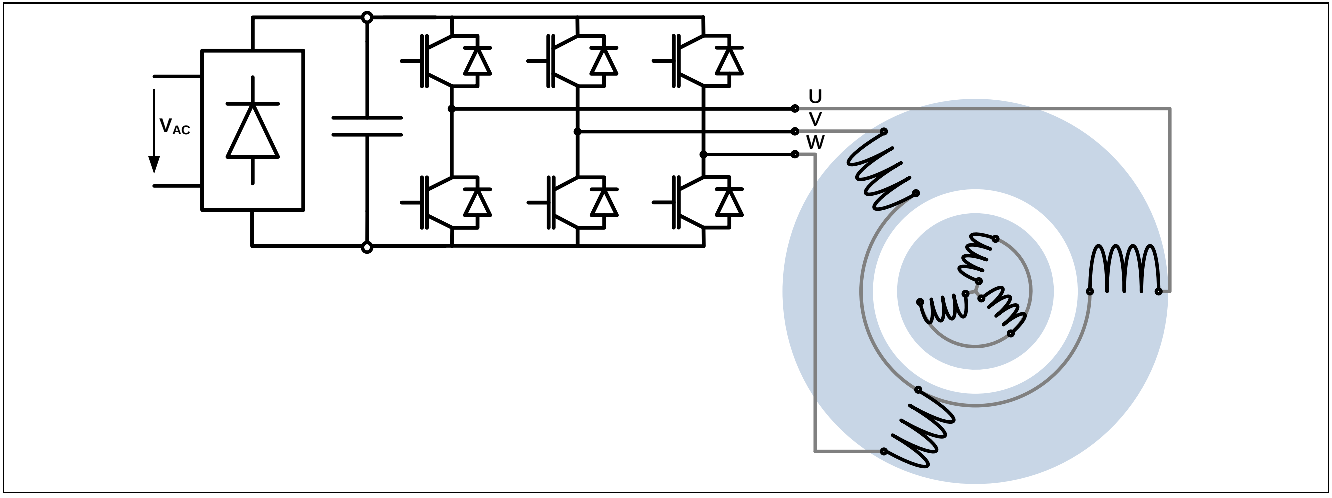


Figure 5 Three-phase two-level inverter

Figure 6 Commercial air-conditioning split system, showing the motor drive card housed on the back of the BLDC fan motor

RC-DA is a device that can be used for automotive applications such as, High Intensity Discharge (HID) lamps and piezo injection. HID lamps have two important issues, a greater starting voltage and the presence of acoustic resonance. The first issue is resolved by using a sort of starting aid, called igniters, which ignites the lamp. In order to avoid acoustic resonance and flickering, the designer must avoid the combination of power fluctuation and operating frequency. The frequency used in the application is higher than 100 Hz and below 1 kHz. Power fluctuation can be avoided by using square wave alternate current techniques. This current control can be achieved by using a full bridge that converts the DC current coming from a DC/DC converter into an AC current for the lamp.

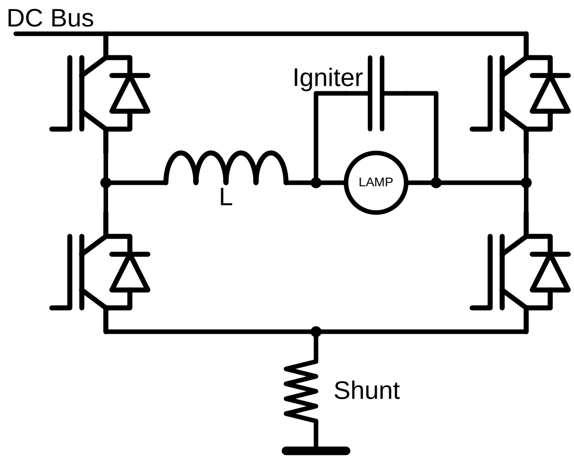


Figure 7 HID lamp output stage

Figure 8 Automotive application: piezo injection and High Intensity Discharge(HID) lights

4 In-circuit application test on 200 W motor drive board

4.1 Efficiency

In order to verify the improvement of the RC-DF in a real application conditions, the new devices were tested on a demo board developed by Infineon and used as test bench to simulate a real air-conditioning outdoor fan. The board is designed for a 200 W output and consists of an input rectifier stage, inverter stage and output filter. The IGBTs are driven by a 600 V three-phase driver IC from Infineon (6ED003L06-F), and the modulation pattern is provided by an 8 bit Infineon microcontroller (XC-878) mounted on an external card. No heat-sink is required, just thermal vias through the PCB. The control method is sensor-less FOC using a single shunt-based feedback loop. The board is driving a 200 W induction motor coupled to an adjustable DC brake, which allows controlling the output power from the inverter. The efficiency is monitored by a Siemens power meter and case temperature is monitored by an IR camera.

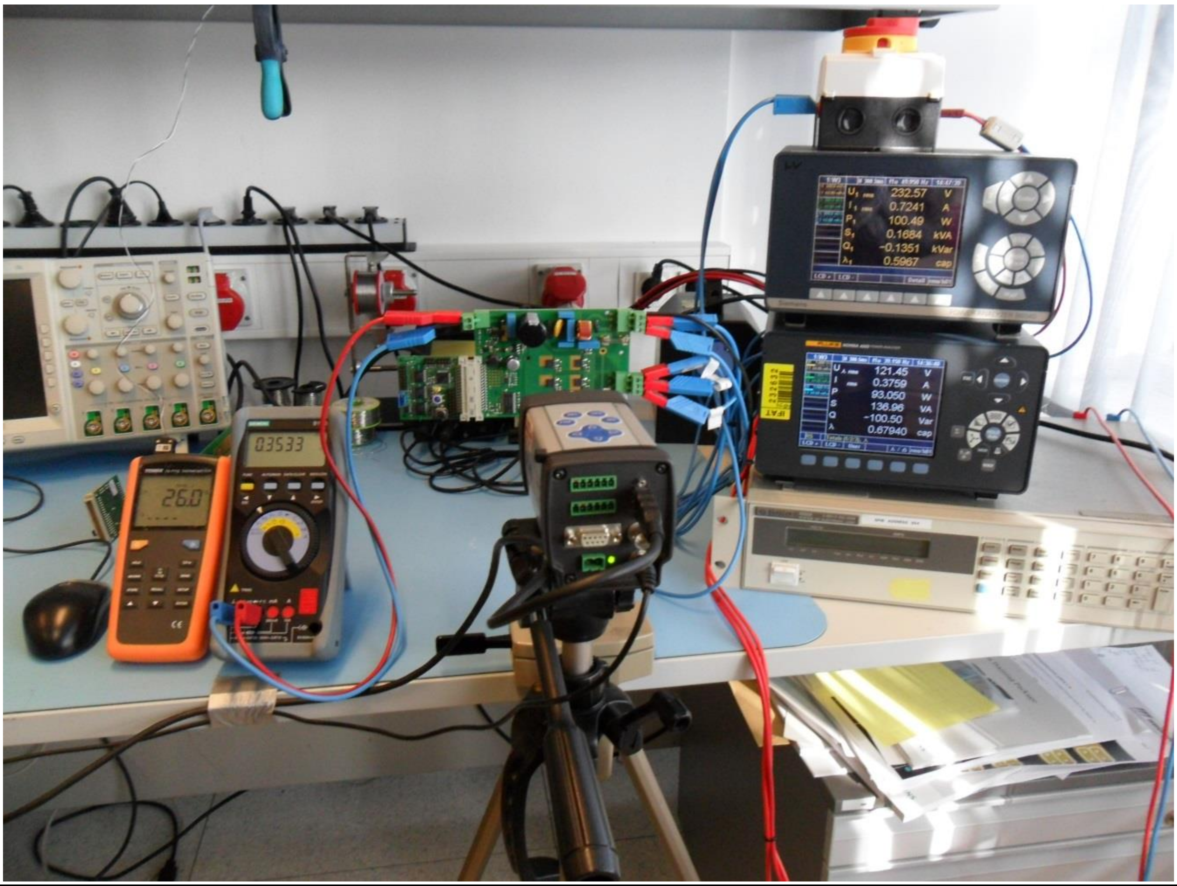


Figure 9 Test set-up for the application measurements

Already at switching frequency of 10 kHz a clear efficiency improvement is observed. At the target f_{sw} of 18 kHz the RC-DF provides 2.8% improvement at 50 W input power and 1.6% at 100 W:

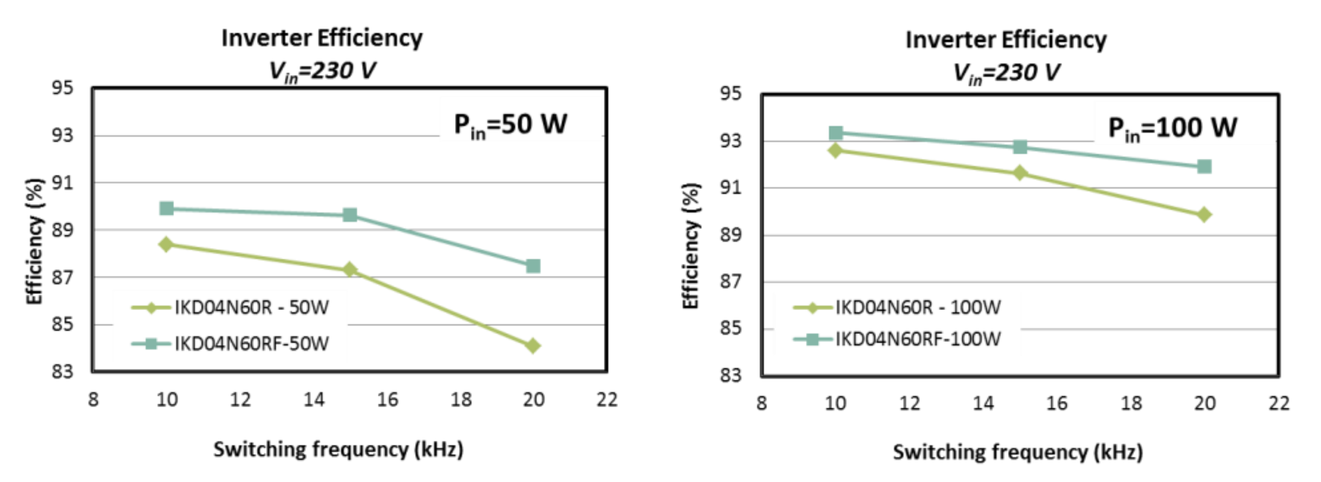


Figure 10 Inverter efficiency as a function of input power and switching frequency

4.2 Thermal behavior

The increased efficiency for the RC-DF translates in lower case temperature, as verified by thermal images with infrared camera:

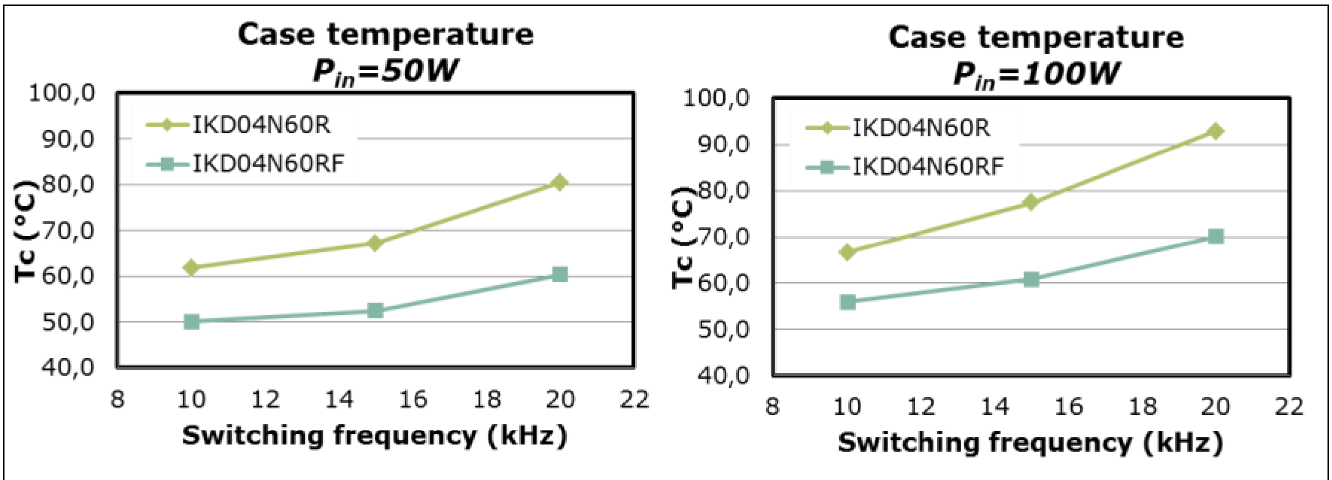


Figure 11 Inverter efficiency as a function of input power and switching frequency

The RC-DF shows outstanding thermal performance providing lower case temperature over the entire frequency range: at the target switching frequency of 18 kHz, the case temperature is lowered by 20°C. The temperature distribution is quite uniform, as demonstrated by detailed analysis of the thermal images:

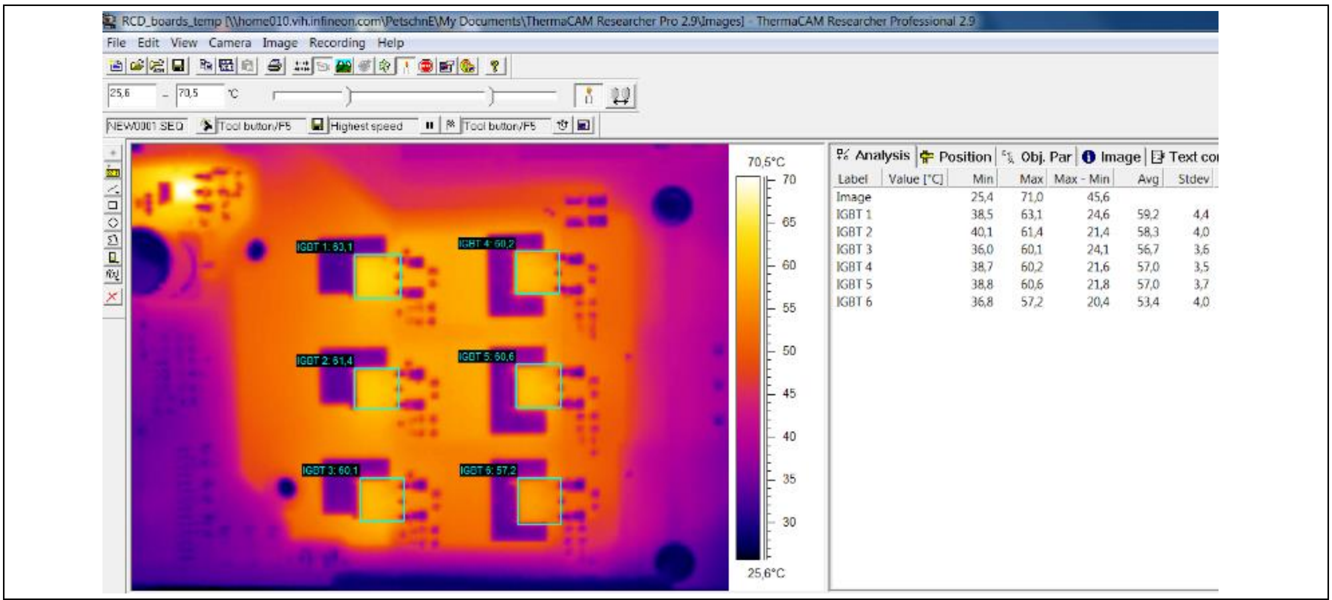


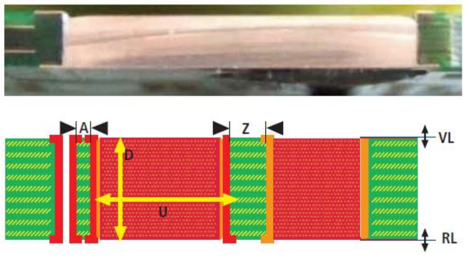
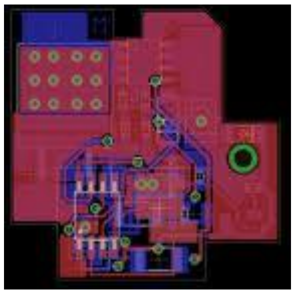
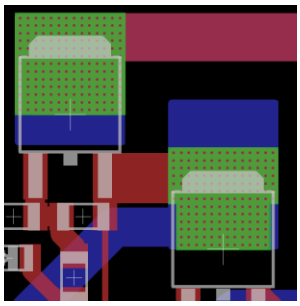
Figure 12 Thermal images at P_{in}= 50 W, f_{sw}= 20 kHz

This translates in increased reliability and longer life expectancy for the device, especially in the harsh thermal environments to be encountered in a real application. In the case of outdoor fan for domestic split aircon systems, for example, the board is mounted directly on the back of the motor in a close environment without airflow. In this case high ambient temperature up to ~60°C can be expected:

4.3 Cooling considerations

When the power range of the inverter exceeds ~200 W, along with careful PCB design (avoid placing devices too close to each other or to the edge of the PCB), some type of cooling is required for the SMD devices. In case of DPAK packages, top side cooling is not effective due to the relatively high thickness of the mold compound on top of the chip and the poor heat exchange. Infineon recommends cooling from the bottom of the chip by thermal vias through the PCB. Several methods for vias formation are adopted in the industry:

Table 3 Commonly adopted vias concepts

Copper inlays	Production limited and quite expensive concept. Adopted in high efficiency converter for SMPS applications	 Copper inlays (Ruwel GmbH)
Thermal vias	Placed around the leadframe or partially under the drain contact. Typical vias diameter is 400 µm. Filled with synthetic resin to avoid solder voids at RC-Drives leadframe due to a solder reflow through the vias. Most common solution in consumer drives.	 Classical thermal vias with resin
Small drill holes	Holes diameter below 0.2 mm for the thermal vias are filled during Cu galvanic deposition to avoid solder reflow.They can be placed under the drain for the most effective heat exchange.	 Thin-via-concept (small drill holes)

Infineon recommends, when allowed by the process capability of PCB supplier, the small drill holes concept for optimum power dissipation. The concept was tested successfully on several reference designs and allowed to reach up to 1.2 kW output power utilizing RC-D devices in DPAK package.

Below an example of small drill holes vias design and related heatsink mounting with isolation foil:

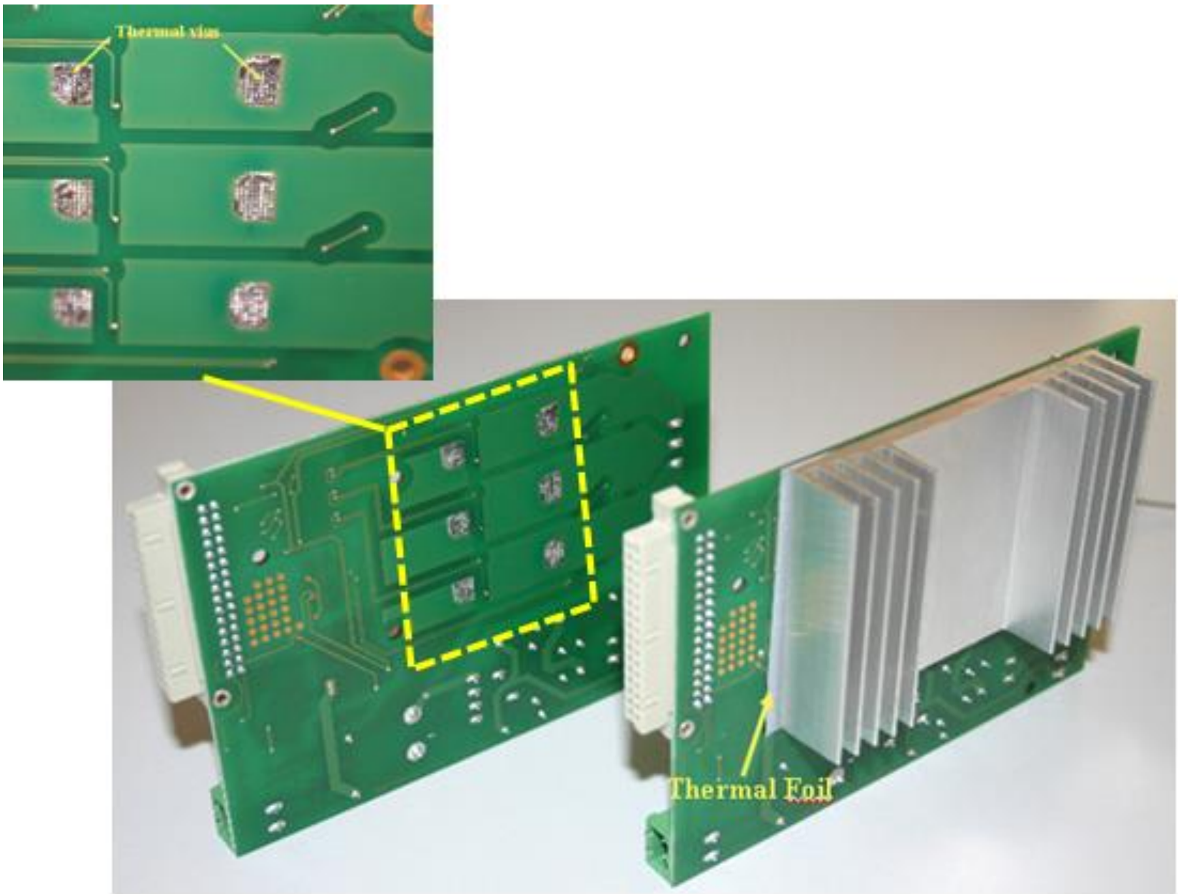


Figure 13 Example of thermal vias and heatsink mounting for RC-D and RC-DF test boards

Revision history

Major changes since the last revision

Page or reference	Description of change

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