600 V CoolMOS™ CFD7

Latest fast diode technology tailored to soft switching applications

About this document

Feedback

Scope and purpose

The new **600 V CoolMOS™ CFD7** is Infineon's latest high voltage (HV) SJ MOSFET technology with integrated fast body diode. It completes the CoolMOS™ 7 series, addressing the high-power SMPS market. This new technology offers the lowest reverse recovery charge (Q_{rr}) per on-state resistance ($R_{DS(on)}$) on the market. This technical parameter gives new meaning to the word "reliability" – especially in resonant switching topologies, where hard commutation on a conducting body diode can occur.

This Application Note will illustrate and prove that CFD7 is the best technology for resonant switching applications. It will show all the benefits of the 600 V CoolMOS™ CFD7, based on certain technology parameters. The 600 V CoolMOS™ CFD7 targets new designs that require the highest efficiency, improved power density and an attractive price, while the 650 V CoolMOS™ CFD2 series will further cater to designs where an additional safety margin in break down voltage and greater ease of use (thanks, for example, to increased layout parasitics) are requested. A simple plug-and-play replacement in resonant topologies is not recommended due to the different technology parameters.

Intended audience

Switched mode power supply designers.

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1 Overview and positioning of the 600 V CoolMOS™ CFD7

1.1 Target applications and key facts

As explained above, the 600 V CoolMOS™ CFD7 is a product tailored to resonant switching topologies of the type used in server and telecom applications. Nevertheless CFD7 also has the necessary performance to target the EV charging market for off-board chargers or charging piles. The main topologies used in these markets are the zero voltage switching Phase Shifted Full Bridge (ZVS PSFB) and the LLC. The following figure shows the target applications.

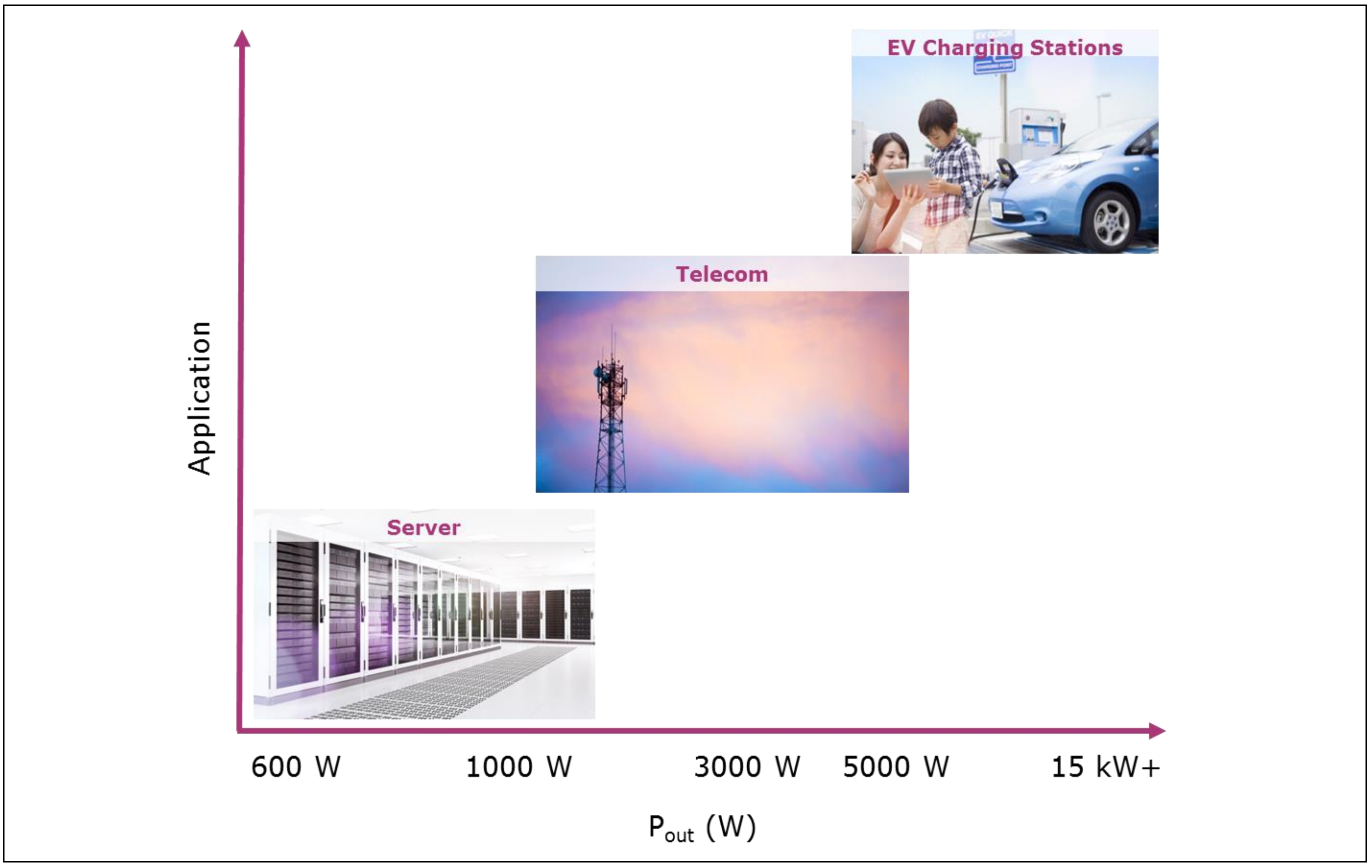

Figure 1 Target applications include the high-power SMPS market for resonant topologies

The key features of the 600 V CoolMOS™ CFD7 are outstanding reliability in resonant switching topologies, and best-fit efficiency for the target markets. As part of the CoolMOS™ 7 series, CFD7 offers an attractive price and competitive long-term price roadmap.

1.2 Price roadmap

Due to the productivity gains, as in the 300 mm process line of Infineon technologies, the 600 V CoolMOS™ CFD7 offers cost benefits right from the start, when compared to the previous CoolMOS™ fast body diode series. The long-term price roadmap indication is shown in the next figure.

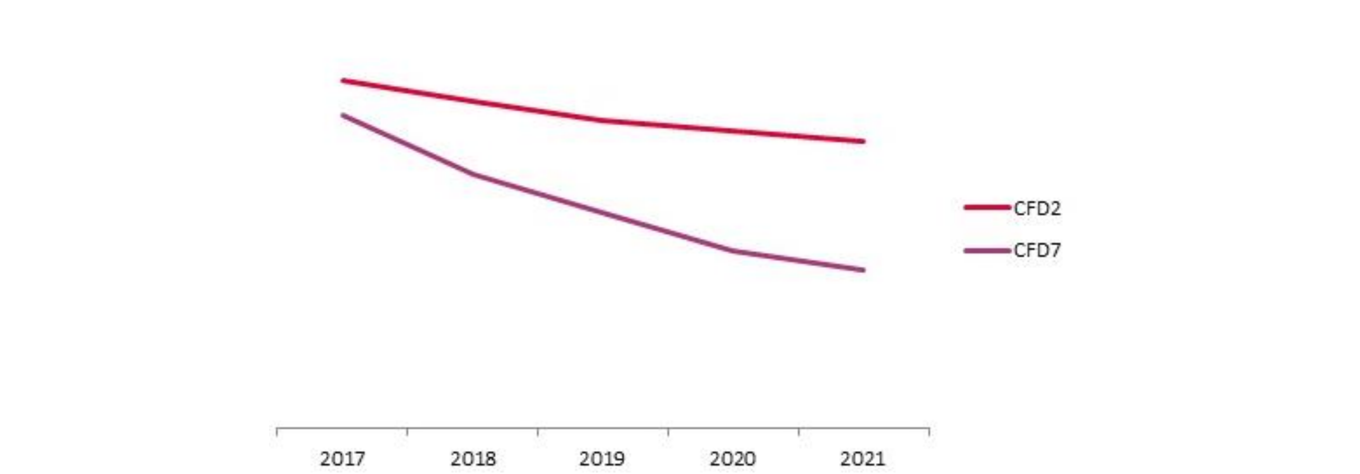

Figure 2 Commercial aspects (indications are based on standard prices at high volumes of more than 500 kpcs/year)

1.3 Positioning in comparison to predecessors

Compared to Infineon's previous HV SJ MOSFETs with integrated fast body diode, the 600 V CoolMOS^{TM} CFD7 offers technical as well as commercial advatages over its predecessors, CFD and CFD2. The following spider chart shows the overall positioning of CFD7 againts the previous fast body diode technologies from Infineon.

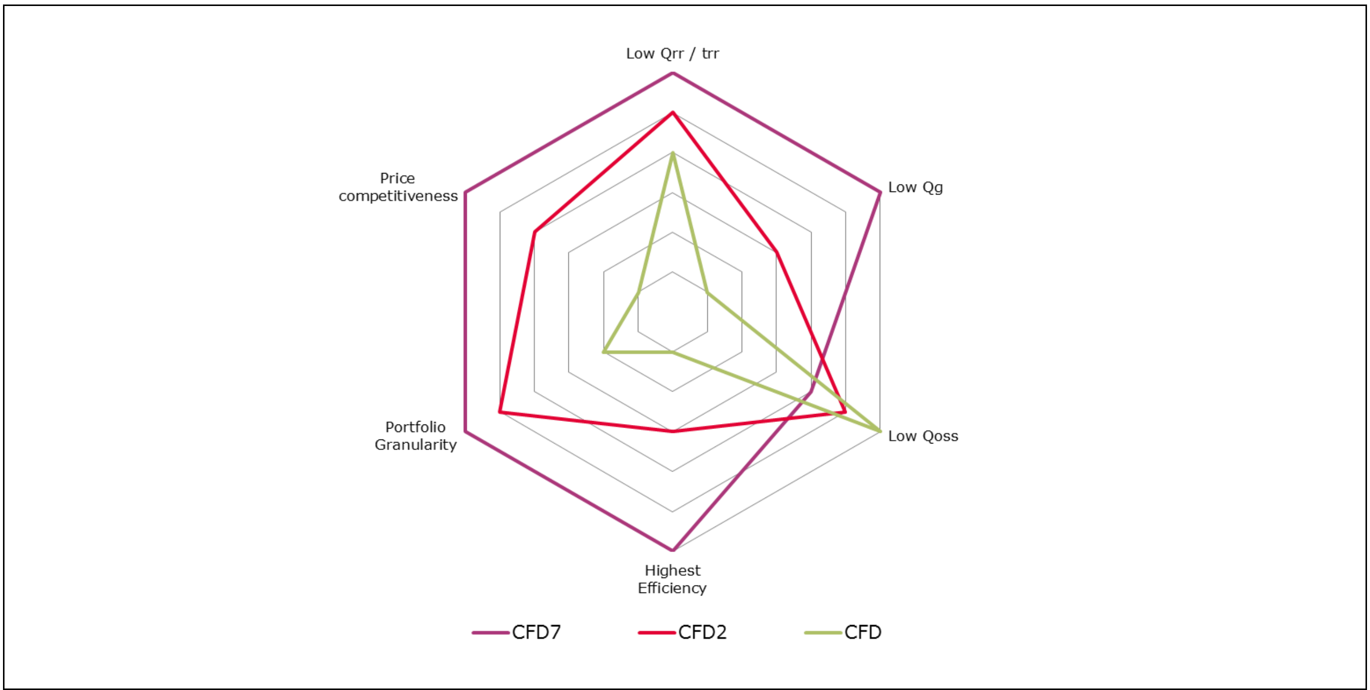

Figure 3 Positioning of the 600 V CoolMOS^{TM} CFD7 against its predecessors

As shown by this spider chart, the 600 V CoolMOS^{TM} CFD7 offers best-in-class Q_{rr} and reverse recovery time (t_{rr}) levels. CFD7 will show a significantly reduced gate charge (Q_g) and competitive charge stored in the output capacitance (Q_{oss}). Furthermore this document will show additional benefits such as the lower temperature dependency of the $R_{DS(on)}$ and the reduced energy losses during turn-off of the MOSFET (E_{off}). All these technology parameters result in the highest efficiency in target applications, as described in more detail later in this AN. In addition, the overall portfolio shows tight granularity, meaning that customers are able to select the best devices for their application.

2 Technology features / parameters

This chapter sets out all the relevant technology parameters of the 600 V CoolMOS™ CFD7 and competitors. Before detailing these features, the next section of this chapter gives a simplified recap of hard commutation on a conducting body diode.

2.1 Reliability

This chapter describes all the relevant technical features and parameters that will increase the reliability of the 600 V CoolMOS™ CFD7 in the target applications.

2.1.1 Hard commutation on the conducting body diode

Hard commutation on a conducting body diode can occur in any half- or full-bridge configuration. The need for CFD7, or a similar fast body diode, is clear under certain operating conditions in an LLC or ZVS PSFB where hard commutation can occur, for example if there is a sudden change of duty cycle or frequency, and there are also other operating conditions in which a repetitive hard commutation can be present for a period of time. In this case it is very important to reduce the generated losses due to the Q_{rr} and resulting reverse recovery energy (E_{rr}) to a minimum, to avoid thermal problems during this operation, which could lead to defects. With the anticipated additional lower Q_{rr}, CFD7 can ensure higher reliability under such operating conditions. Nevertheless, it is not recommended to use any CFD technology in a topology in which hard commutation on a conducting body diode is present each cycle at switching frequency, as it is present for example in the half bridge of a hard switching Totem Pole PFC.

During hard commutation on a conducting body diode the Q_{rr} of the parasitic capacitance of the body diode of the MOSFET needs to be removed, leading to very high dv/dt and di/dt and reverse recovery current (I_{rrm}), which can result in very high power dissipation and return-on effects on the MOSFET. This could result in a defect in the MOSFET. However, the 600 V CoolMOS™ CFD7 offers the lowest Q_{rr} on the market in comparison to other fast body diode SJ MOSFETs, and this reduces the possibility of failure to a minimum and increases the reliability of the whole system.

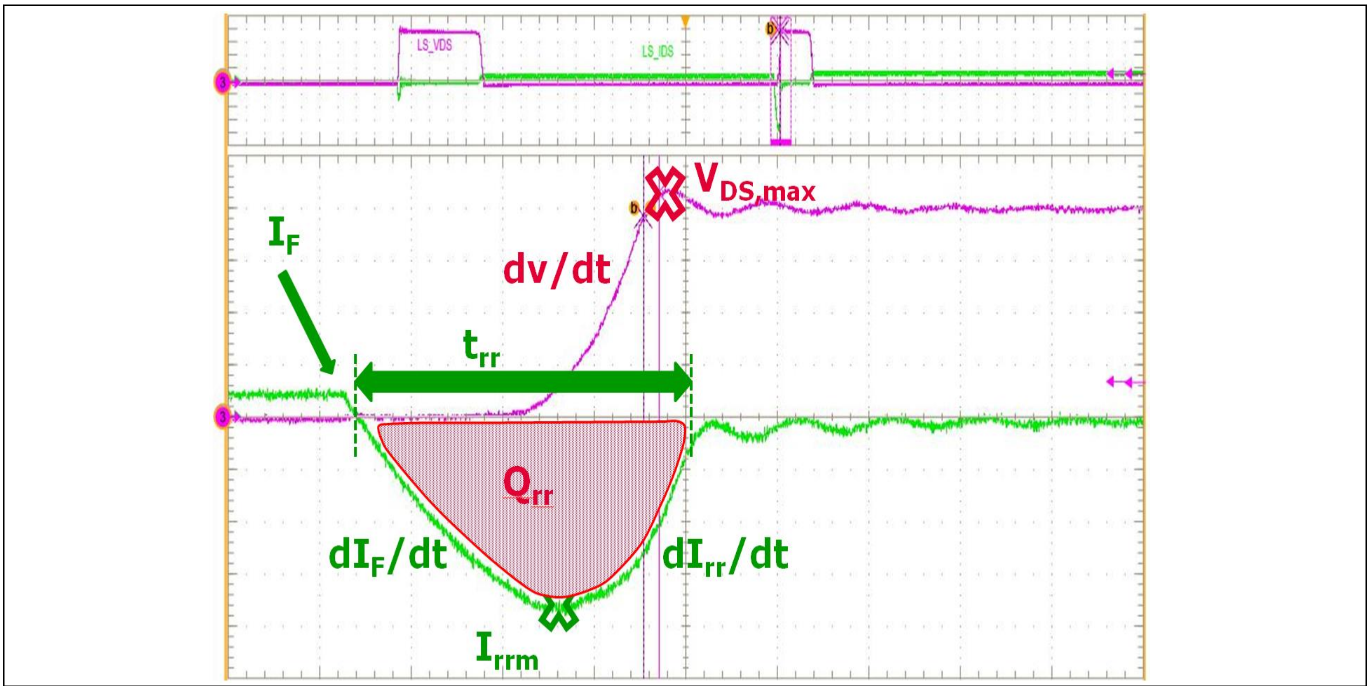

Figure 4 Hard commutation on the conducting body-diode (example)

2.1.2 Q_{rr} (reverse recovery charge)

The Q_{rr} needs to be removed from the body diode during a hard commutation event, which results in a high current flow, high di/dt, high dv/dt and inductive driven drain source voltage (V_{DS}) overshoots.

Q_{rr} is defined by:

$$Q_{rr} = \int_{t_{rr,start}}^{t_{rr,end}} i \cdot dt$$

CFD7 offers BiC Q_{rr} in comparison to all competitors on the market, as shown in the following figure.

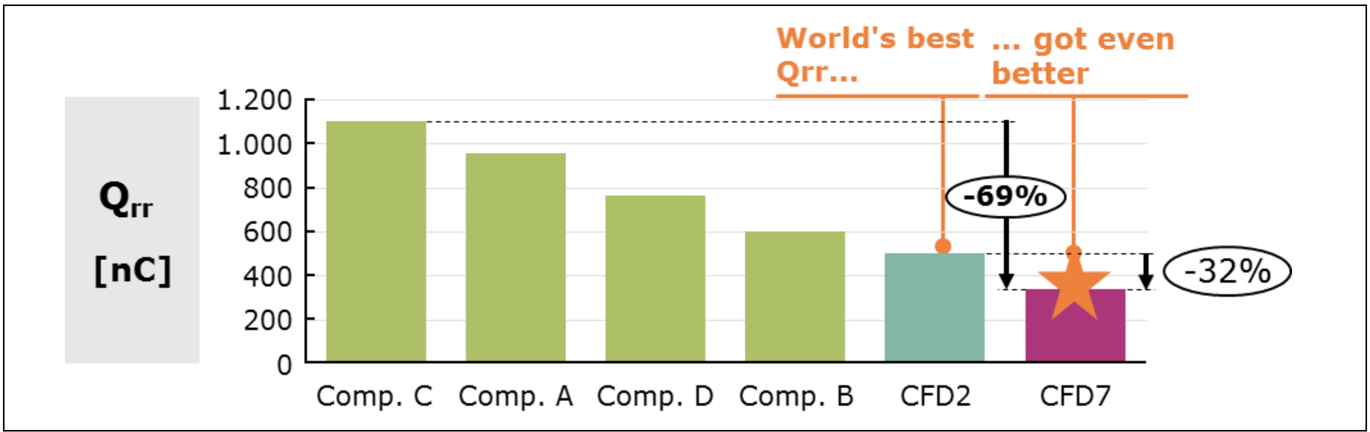

Figure 5 Datasheet Q_{rr} comparison of IPW60R170CFD7 vs competitors in 190 mΩ class

Already CFD2 was offering the world's lowest Q_{rr}, due to the need for higher reliability in operating conditions in which repetitive hard commutation can occur. As can be seen, CFD7 offers an additional 32 percent lower Q_{rr} than Infineon's previous CFD technology, and up to 69 percent lower Q_{rr} than the main competitors.

2.1.3 t_{rr} (reverse recovery time) and I_{rrm} (maximum reverse recovery current)

Due to this reduced Q_{rr}, the t_{rr} and I_{rrm} and the resulting E_{rr} are much lower than any other competitor on the market. In comparison to the BiC competitor the 600 V CoolMOS™ CFD7 offers around 19 percent lower t_{rr} and 11 percent lower I_{rrm}, as shown in the next figure.

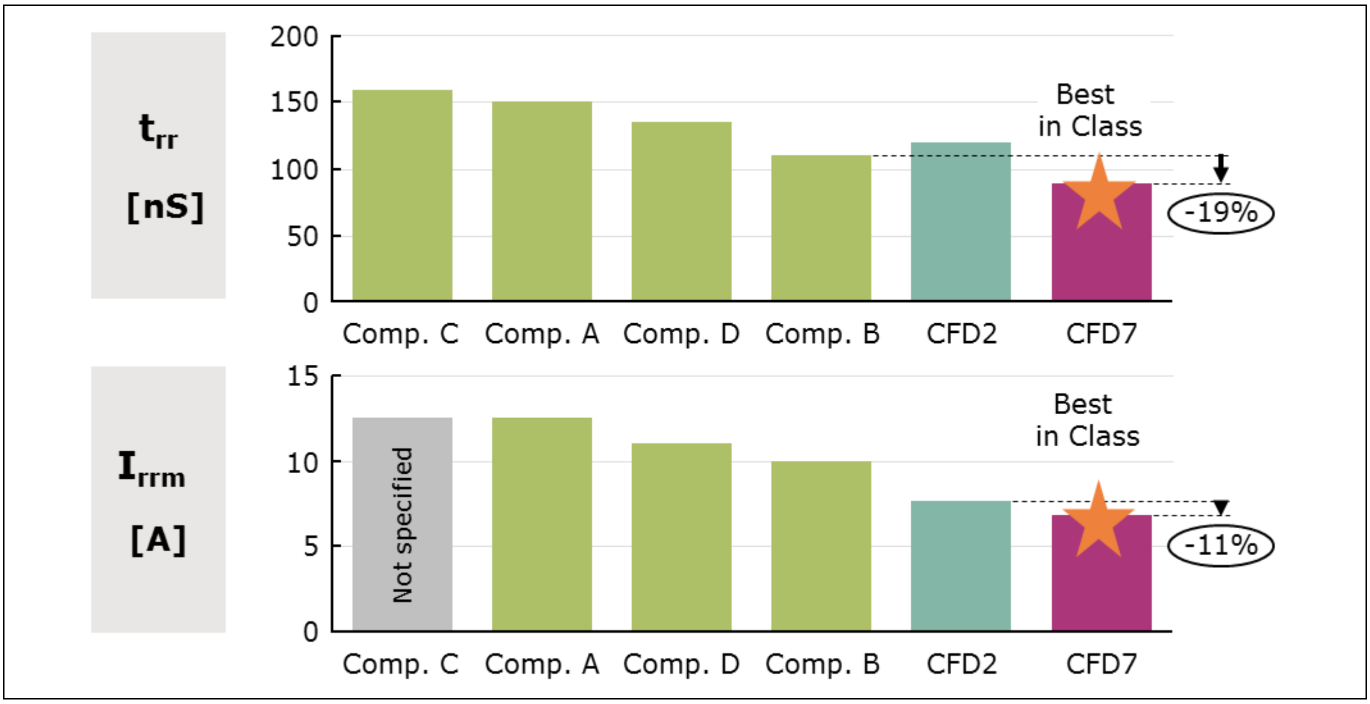

Figure 6 **Datasheet t_{rr} and I_{rrm} comparison of IPW60R170CFD7 vs competitors in 190 mΩ class**

Repetitive hard commutation at a high application switching frequency is generally not recommended for any SJ MOSFET, but in some operating conditions it cannot be avoided, at least for short periods of time. Therefore, the reduced reverse recovery benefits of CFD7's body diode results in much lower power dissipation during these events against all competitors, and especially against non-fast-diode solutions.

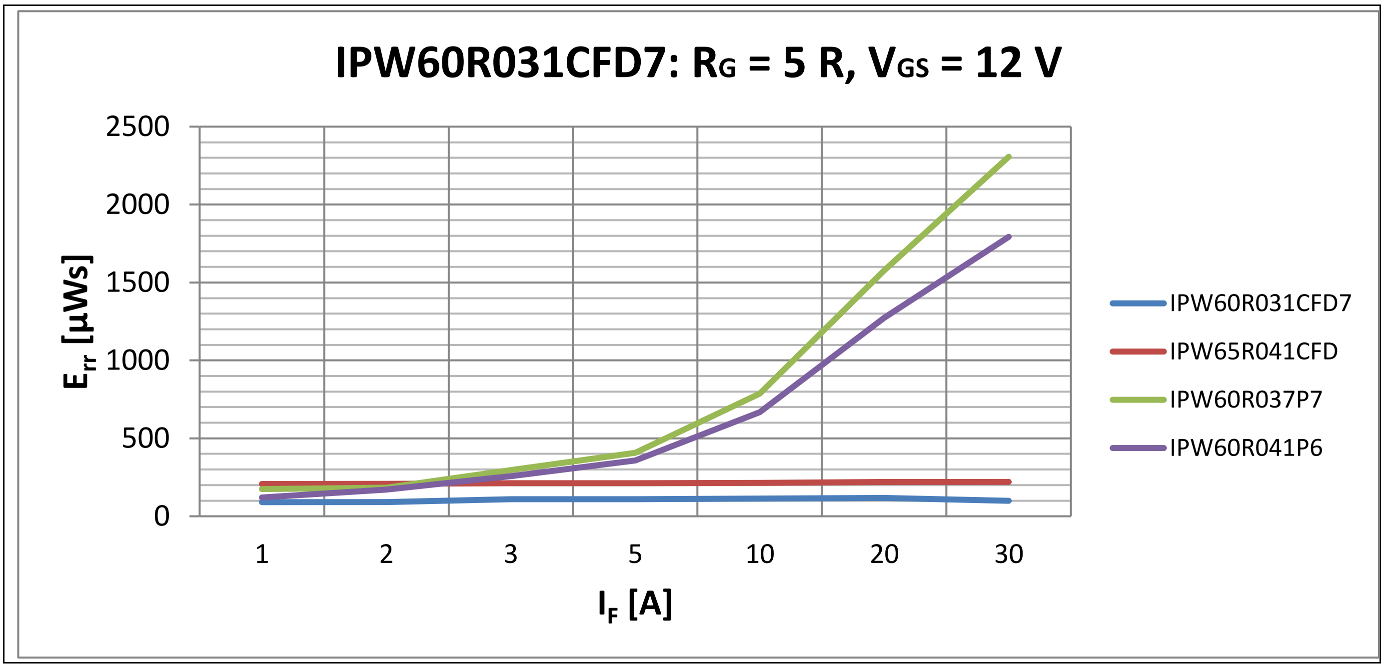

Figure 7 **E_{rr} comparison of CFD7 vs CFD2 and non-fast-diode MOSFETs in a half-bridge configuration with 12 V V_{GS} and an external gate resistor of 5 Ω**

As shown, during a hard commutation event CFD7 suffers only half of the energy dissipation of CFD2, and especially in comparison to a non-fast-diode device, CFD7 has around 10 times smaller E_{rr}, which makes CFD7 to the most reliable SJ MOSFET during repetitive hard commutation.

2.1.4 $V_{DS,max}$ (maximum drain source voltage overshoot)

Another application-related drawback during a hard commutation event is the maximum drain source voltage ($V_{DS,max}$) during turn-off, which is inductive driven and depends on the parasitic inductances in the commutation loop together with high di/dts. Due to its self-limiting behavior, CFD7 also shows a very good performance in this area in comparison to the main competitors. The results shown in the next figure illustrate that CFD7 is on the lowest level, even with the much faster switching behavior.

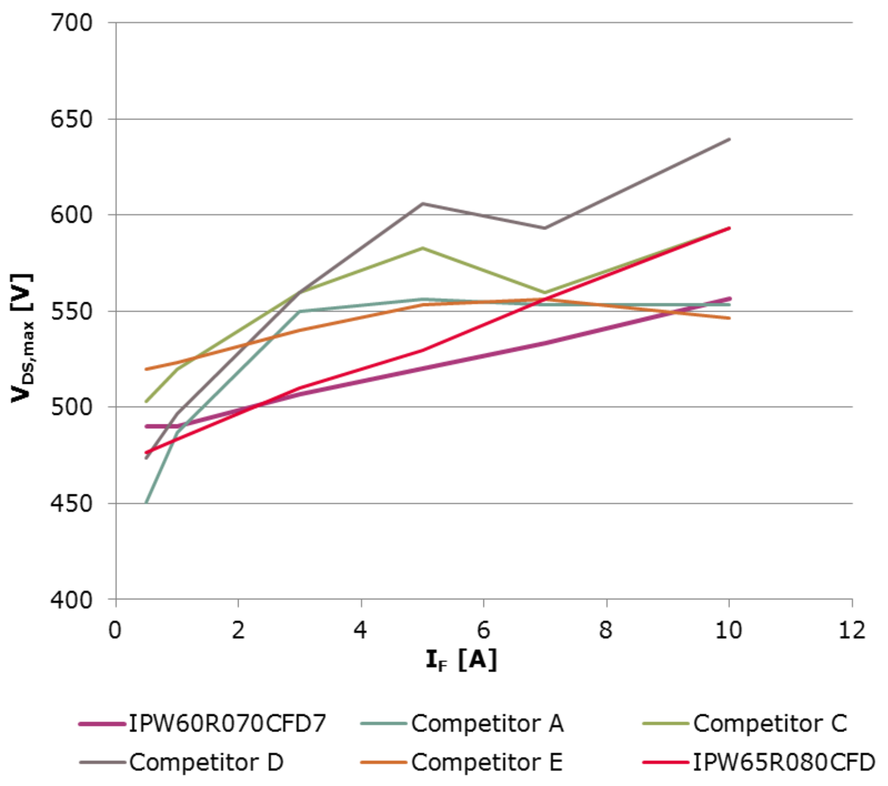

Figure 8 **Maximum V_{DS} voltage overshoot during hard commutation at V_{GS} = 13 V, $R_{G,ext}$ = 10 Ω**

It is clearly visible that the 600 V CoolMOS™ CFD7 increases reliability still further by having the lowest V_{DS} overshoot under the conditions described (during a hard commutation event), while not sacrificing the switching speed and the possibility of achieving the highest efficiency.

2.1.5 Early channel shut-down

All 600 V CoolMOS™ CFD7 $R_{DS(on)}$ classes have an integrated gate resistor ($R_{G,int}$) in order to fulfill the need for highest reliability in hard commutation, and allow for 1300 A/µs di_F/dt. It is also seen that in end applications external gate resistors are used either to slow down the devices for derating reasons, or to limit peak voltages. CFD7 offers the so-called early channel shut-down. This means that every $R_{DS(on)}$ class has a limit, where the switching losses increase with respect to the gate resistance in the gate drive loop. For 600 V CoolMOS™ CFD7 it is possible to increase the gate resistance and not suffer increased switching losses during turn-off. The following figure shows this behavior.

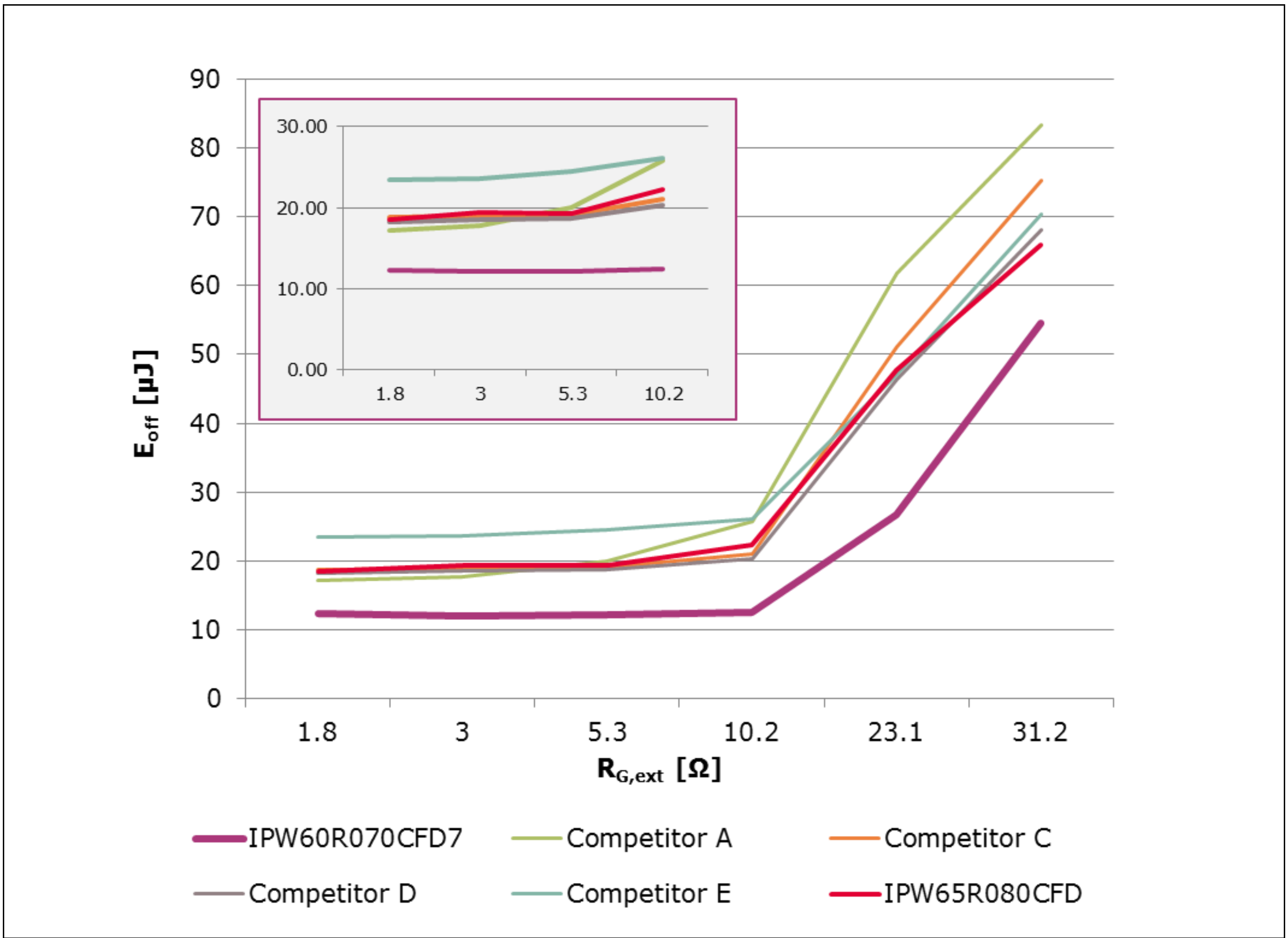

Figure 9 Early channel shut-down based on 70 mΩ classes at I_D = 8 A

Designers can benefit from this behavior as it is possible to define the end applications for safety, EMI and efficiency requirements at the same time.

2.2 Efficiency and performance

This chapter will describe all the relevant technical features and parameters that increase the efficiency and perfomance of the 600 V CoolMOS™ CFD7 in comparison to its main competitors in the target applications.

2.2.1 Q_g (gate charge)

The Q_g influences the driving losses and the ZVS behavior, which could dramatically influence efficiency during light-load operation or increased switching frequency.

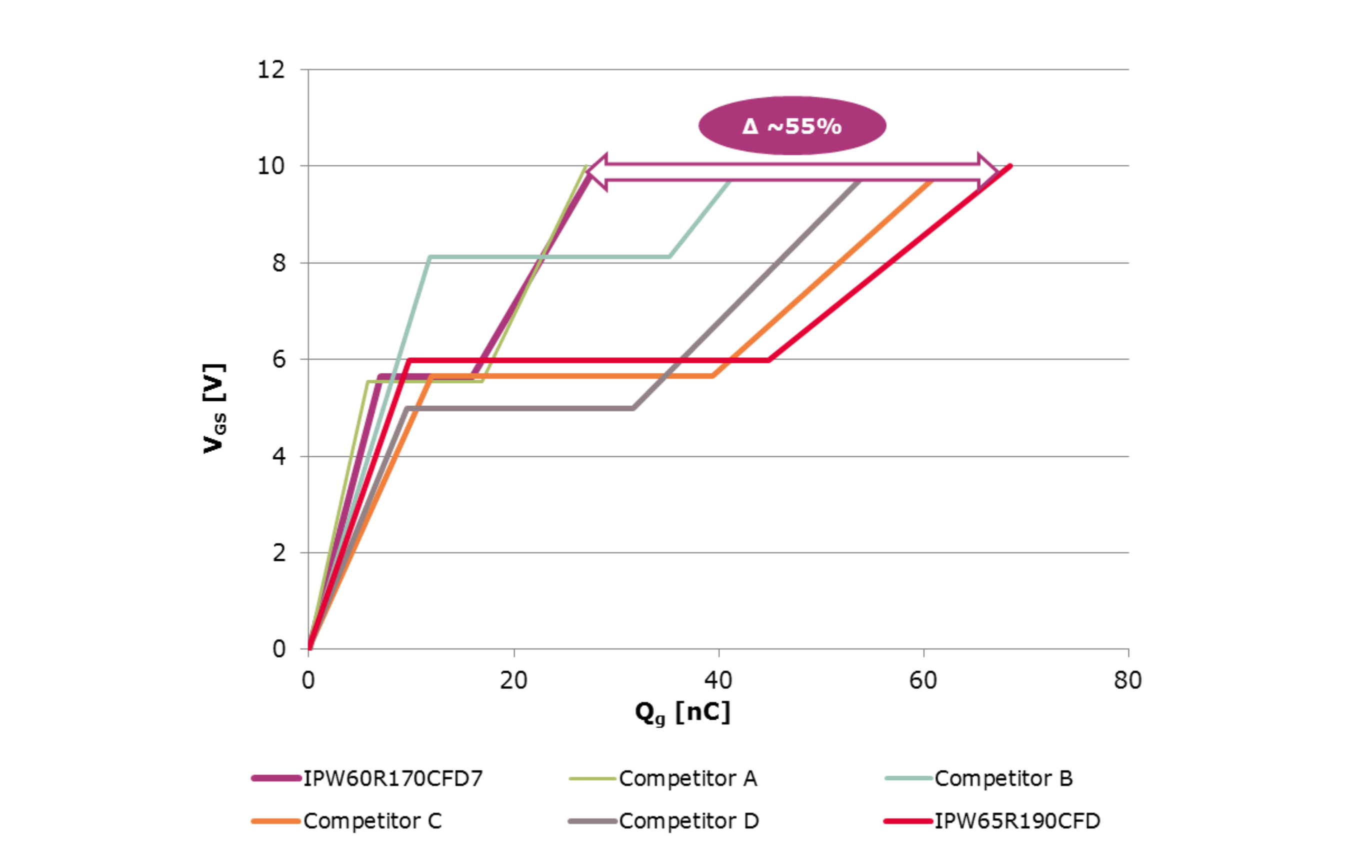

Figure 10 Q_g comparison at 7 A pulsed based on characterization

As can be seen in the graph above, 600 V CoolMOS™ CFD7 shows the lowest Q_g in comparison to all former Infineon technologies and is at least on par with the best competitor. With this behavior CFD7 can support higher switching frequencies (> 100 kHz), which can help reduce the magnetic components of the design, leading to smaller form factors or higher power density. It can be clearly seen that the driving losses are reduced by at least ~55 percent in comparison to Infineon's former fast body diode technology.

2.2.2 Q_{oss} (charge stored in the output capacitance)

Compared to competitors, the 600 V CoolMOS™ CFD7 offers a mid-field Q_{oss} and is nearly on the same level as CFD2. The Q_{oss} is illustrated in the following figure.

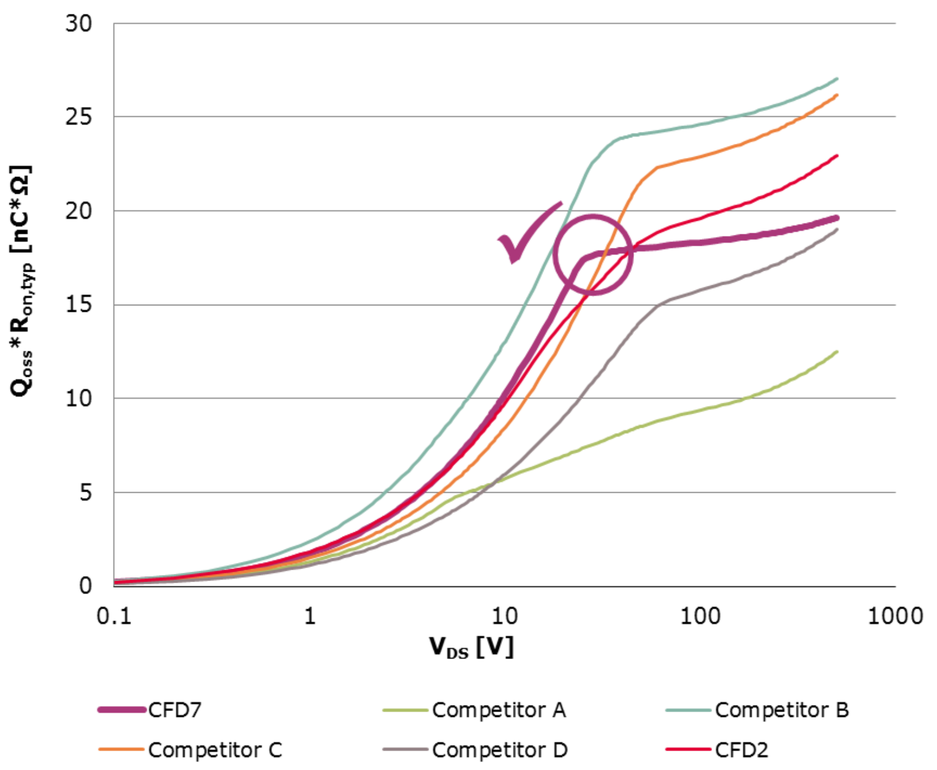

Figure 11 Q_{oss} **comparison based on characterization**

As can be seen, a full ZVS operation is not achieved more easily than with CFD2, but this does not represent an overall drawback. Even when 600 V CoolMOS™ CFD7 is not completely turned on at 0 V V_{DS}, it can achieve higher efficiency at light load. This is enabled when designing the application in such a way that CFD7 turns on at around 25 V V_{DS}. As a result, 600 V CoolMOS™ CFD7 experiences some additional E_{oss} losses, but these additional E_{oss} losses are a small portion of the overall switching losses and are therefore negligible. The main contributors to the total switching losses are the hard-switching E_{off} losses, which are dramatically lower than those of any other competitor, as shown in the next chapter. Achieving 25 V V_{DS} during turn-on is even easier, as there are only around 1.2 nC*Ω of charge stored when going from 400 V to 25 V.

Absolute Q_{oss} values are derived by the following calculation based on 170 mΩ class devices:

CFD7, in order to reach 25 V $\rightarrow Q_{oss,400V\ to\ 25V} = \frac{1.2\ nC\cdot\Omega}{144\ m\Omega} \approx 8nC$

CFD2, in order to reach 0 V $\rightarrow Q_{oss,400V\ to\ 0V} = \frac{19\ nC\cdot\Omega}{171\ m\Omega} \approx 111nC$

This result is that there is the possibility of reducing the recirculating current needed to discharge the output capacitance (C_{oss}).

2.2.3 E_{oss} (energy stored in the output capacitance)

600 V CoolMOS™ CFD7 offers improved E_{oss} over all competitors from 200 V onward. Only competitor A shows lower voltage benefits below 200 V.

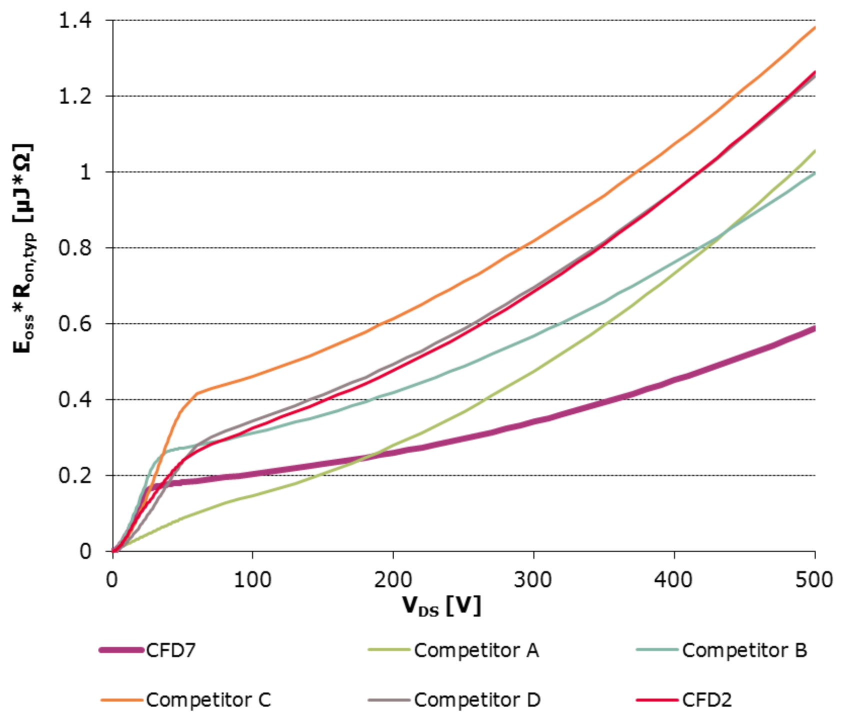

Figure 12 E_{oss} **comparison based on characterization**

At hard-switching turn-on 600 V CoolMOS™ CFD7 has absolutely no competitors; nevertheless at lower voltages the difference for turn-on is marginal. In the previously shown Q_{oss} and the recommended turn-on at 25 V it can be seen that competitor A could achieve full ZVS operation, which increases the turn-on losses of 600 V CoolMOS™ CFD7 to around 1 µJ ($E_{oss\ at\ 25V} = \frac{0.15\ \mu J \cdot \Omega}{144\ m\Omega} \approx 1\mu J$) in comparison to competitor A, as a possible voltage / current overlap is negligible at 25 V V_{DS}. It is therefore also necessary to compare the turn-off losses to the recommended 25 V turn-on.

2.2.4 E_{off} (switching loss during hard turn-off)

The 600 V CoolMOS™ CFD7 offers the lowest E_{off} losses among all competitor offerings. Continuing the comparison between CFD7 and Competitor A, with lowest Q_{oss} the E_{off} of CFD7 is is 5.8 µJ lower, as shown in the next figure.

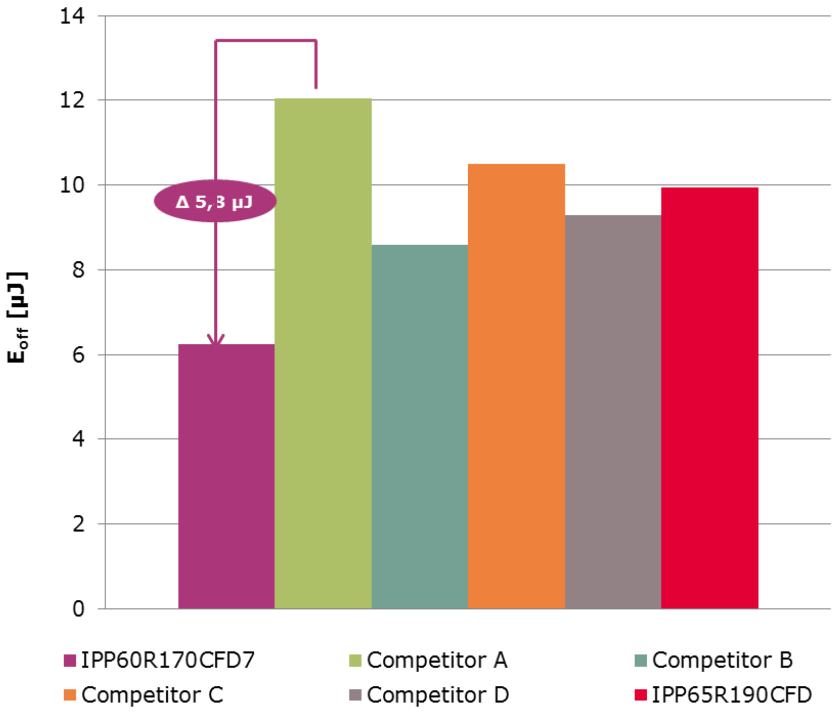

Figure 13 E_{off} **comparison at** $R_{G,ext}$ **= 1.8 Ω;** I_D **= 7 A**

Considering the E_{oss} at 25 V of 600 V CoolMOS™ CFD7 and E_{oss} = 0 J for competitor A at 0 V, CFD7 shows lower total switching losses per cycle, as illustrated in the following calculation based on a 170 mΩ device.

Total switching losses calculation for competitor A:

$$E_{oss} = 0\,J \rightarrow full\ ZVS\ operation$$

$$E_{on} = 0\,J$$

$$E_{off} = 12\,\mu J$$

$$E_{total} = E_{oss} + E_{on} + E_{off} = 12\,\mu J \rightarrow at\ 100\,kHz \rightarrow\ P_{switching} = 12\,\mu J \cdot 100\,kHz = \mathbf{1.2\,W}$$

Total switching losses calculation for 600 V CoolMOS™ CFD7:

$$E_{oss} = 1\,\mu J \rightarrow turn\ on\ at\ 25\,V$$

$$E_{on} = 0\,J$$

$$E_{off} = 6.2\,\mu J$$

$$E_{total} = E_{oss} + E_{on} + E_{off} = 7.2\,\mu J \rightarrow at\ 100\,kHz \rightarrow\ P_{switching} = 7.2\,\mu J \cdot 100\,kHz = \mathbf{0.72\,W}$$

Based on this calculation the total switching losses of 600 V CoolMOS™ CFD7 are ~40 percent less in comparison to competitor A.

As the switching losses are compared, another important factor in achieving high load efficiency are conduction losses, which are purely based on the $R_{DS(on)}$ behavior at operating temperature.

2.2.5 $R_{DS(on)}$ temperature dependency

Good $R_{DS(on)}$ values and $R_{DS(on)}$ margins in all datasheets at 25°C are positive, but it is also very important to know the conduction losses at operating temperature. Therefore, the following figure shows the $R_{DS(on)}$ behavior over the junction temperature.

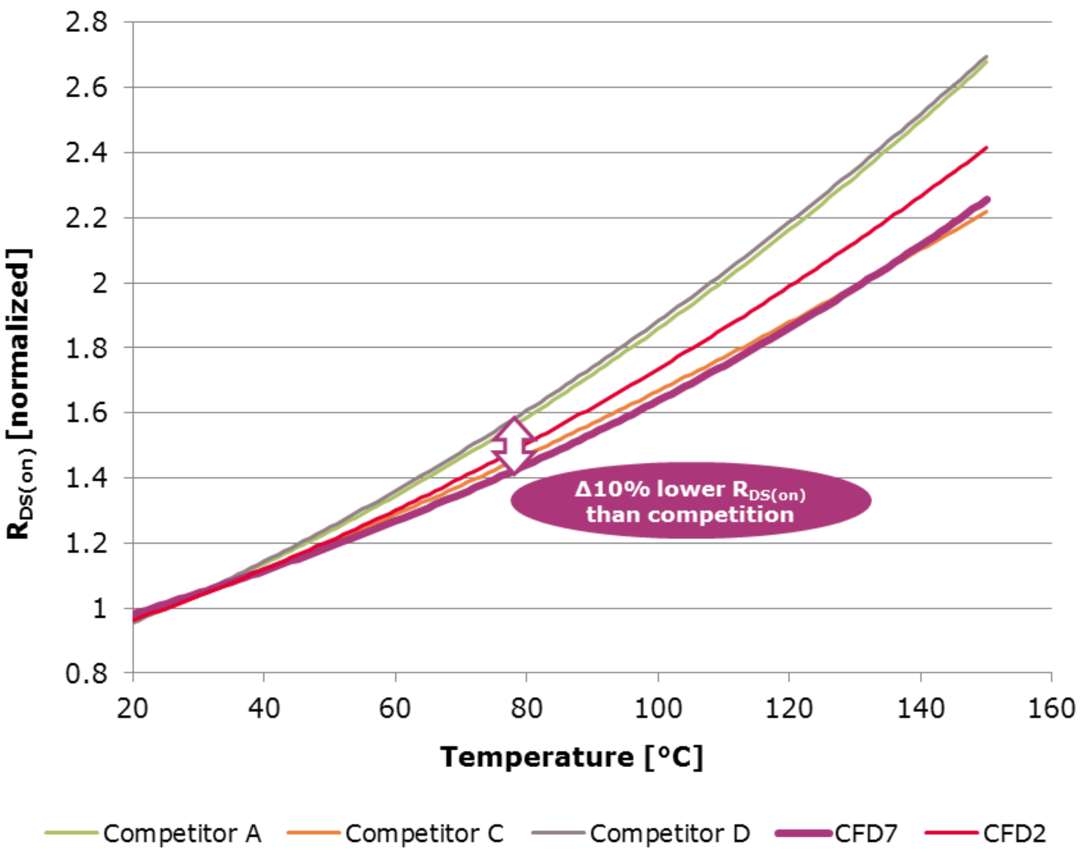

Figure 14 **Normalized $R_{DS(on)}$ over junction temperature**

As can be clearly seen, 600 V CoolMOS™ CFD7 has around 10 percent lower $R_{DS(on)}$ at 80°C than its competitors, which makes it much more efficient in high-power applications under mid- to full-load operation.

2.2.6 Best-in-class $R_{DS(on)}$ in different packages

In order to achieve even higher efficiency and higher power density, 600 V CoolMOS™ CFD7 offers BiC $R_{DS(on)}$ classes in TO-220, ThinPAK 8x8 and TO-247. The following figure compares CFD7 with the next best competitor .

Technology features / parameters

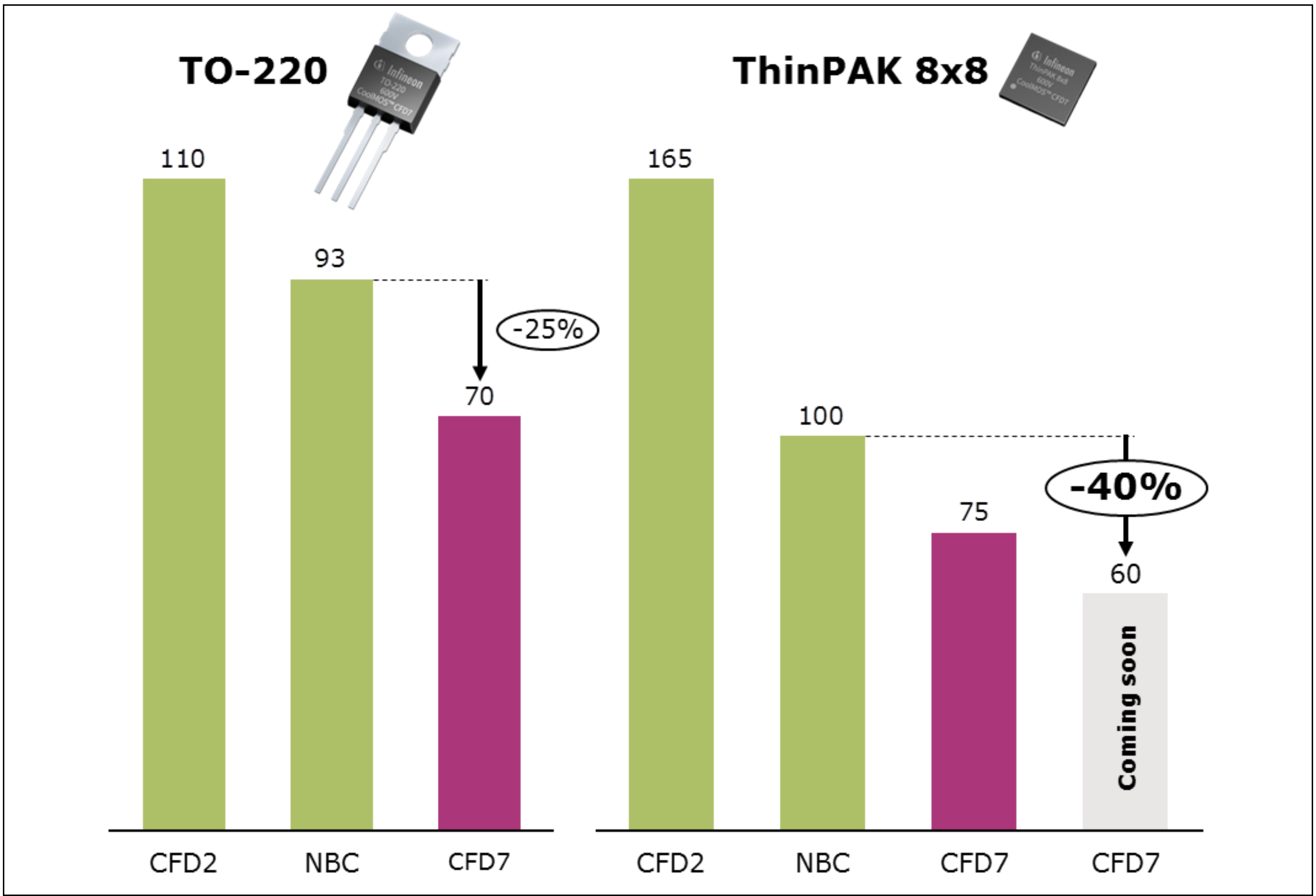

Figure 15 BiC $R_{DS(on)}$ in different packages

The sweet spots in the 600 V CoolMOS™ CFD7 portfolio are the BiC devices in TO-220 and ThinPAK 8x8. The 600 V CoolMOS™ CFD7 offers a 70 mΩ TO-220 device. In this package, the NBC can offer a 93 mΩ device. So the 600 V CoolMOS™ CFD7 gives our customers the benefit of going from a TO-247 to a TO-220 with a 50 percent reduction in package size considering thermal differences. Also in ThinPAK 8x8 the 600 V CoolMOS™ CFD7 offers the lowest available $R_{DS(on)}$. Competitors can only offer ThinPAK 8x8 devices with an $R_{DS(on)}$ of 100 mΩ or higher, while the 600 V CoolMOS™ CFD7 can go down to 60 mΩ.

3 Summary

Considering all these technical features and parameters, 600 V CoolMOS™ CFD7 offers outstanding reliability in soft-switching and hard-switching topologies. CFD7 also enables high power density solutions and achieves the highest efficiency in all target markets. Furthermore, it offers an attractive price and competitive long-term price roadmap.

The following efficiency comparison verifies the performance gain of 600 V CoolMOS™ CFD7.

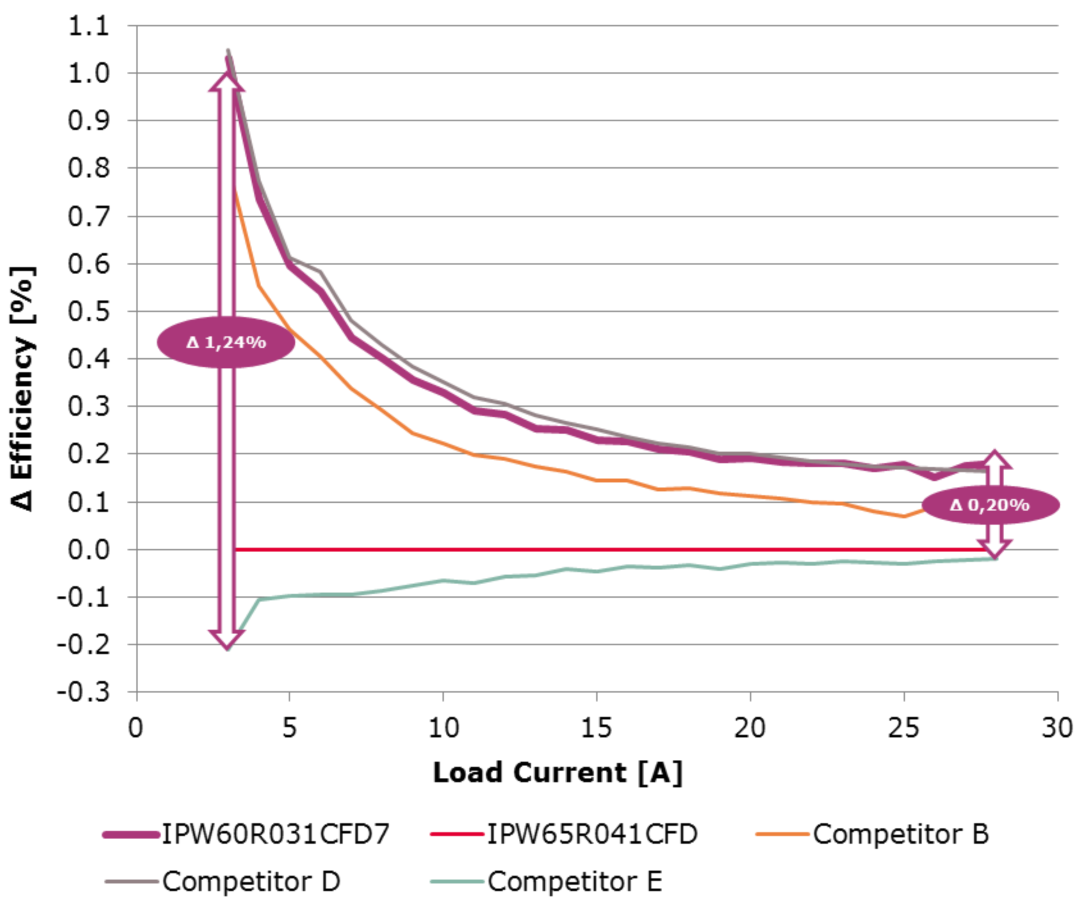

Figure 16 Delta efficiency in 3 kW LLC DC-DC stage

All the previously described points are implemented in the design, including the adaptation of the relevant dead-time settings in order to get the most benefit from 600 V CoolMOS™ CFD7.

It is very important to state once again that for resonant topologies, a plug-and-play scenario will not work at its best, as the overall system performance depends on magnetics and the interaction between the primary side and the secondary synchronous rectification.

It is clear that CFD7 offers ~1.2 percent higher light-load efficiency when compared to competitor E, and even ~1.0 percent higher efficiency than CFD2.

From mid- to full-load, the benefits of the lower $R_{DS(on)}$ and the temperature dependency are also clear. CFD7 offers a granular portfolio that enables customers to choose the product that is the best fit for their designs.

4 Portfolio

Here is the portfolio.

$R_{DS(ON)}$ [mΩ] Max.	TO-263 D²PAK	TO-252 D-PAK	ThinPAK 8x8*	TO-220	TO-220 FullPAK	TO-247	TOLL	DDPAK	QDPAK
360	IPB60R360CFD7	IPD60R360CFD7		IPP60R360CFD7	IPA60R360CFD7				
280	IPB60R280CFD7	IPD60R280CFD7		IPP60R280CFD7	IPA60R280CFD7				
210/215	IPB60R210CFD7	IPD60R210CFD7	IPL60R225CFD7	IPP60R210CFD7	IPA60R210CFD7				
170/185	IPB60R170CFD7	IPD60R170CFD7	IPL60R185CFD7	IPP60R170CFD7	IPA60R170CFD7	IPW60R170CFD7		IPDD60R170CFD7	
145/160	IPB60R145CFD7	IPD60R145CFD7	IPL60R160CFD7	IPP60R145CFD7	IPA60R145CFD7	IPW60R145CFD7	IPT60R145CFD7	IPDD60R145CFD7	
125/140	IPB60R125CFD7		IPL60R140CFD7	IPP60R125CFD7	IPA60R125CFD7	IPW60R125CFD7	IPT60R125CFD7	IPDD60R125CFD7	
105/115	IPB60R105CFD7		IPL60R115CFD7	IPP60R105CFD7		IPW60R105CFD7	IPT60R105CFD7	IPDD60R105CFD7	
90/95	IPB60R090CFD7		IPL60R095CFD7	IPP60R090CFD7		IPW60R090CFD7	IPT60R090CFD7	IPDD60R090CFD7	
70/75	IPB60R070CFD7		IPL60R075CFD7	IPP60R070CFD7		IPW60R070CFD7	IPT60R075CFD7	IPDD60R075CFD7	IPDQ60R075CFD7*
55/60	IPB60R055CFD7		IPL60R060CFD7			IPW60R055CFD7	IPT60R055CFD7	IPDD60R055CFD7	IPDQ60R055CFD7*
40/45	IPB60R040CFD7					IPW60R040CFD7	IPT60R045CFD7	IPDD60R045CFD7	IPDQ60R045CFD7*
31/35						IPW60R031CFD7	IPT60R035CFD7		IPDQ60R035CFD7*
24/26						IPW60R024CFD7			IPDQ60R025CFD7*
18/20						IPW60R018CFD7			IPDQ60R020CFD7*
15									IPDQ60R015CFD7*

*coming soon

Figure 17 Planned portfolio

For information and collaterals, please visit: **www.infineon.com/cfd7**

Additional benchmarking is available inside all evaluation boards application notes launched with 600 V CoolMOS™ CFD7: please visit the Infineon homepage.

Revision history

Document version	Date of release	Description of changes
2.0	2017-11-03	Release of final version
2.1	2019-06-03	Portfolio picture update

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