650 V CoolMOS™ CFD7

Latest fast diode technology tailored to soft-switching applications

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About this document

Scope and purpose

The new **650 V CoolMOS™ CFD7** is Infineon's latest high-voltage (HV) superjunction (SJ) MOSFET technology with integrated fast body diode. It extends the CoolMOS™ 7 series with 650 V, addressing the telecom, server and EV charging markets. This new technology offers a low reverse recovery charge (Q_{rr}) per on-state resistance [$R_{DS(on)}$]. This technical parameter gives a brand 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 650 V CoolMOS™ CFD7, based on certain technological parameters. The 650 V CoolMOS™ CFD7 targets new designs that require the highest efficiency, improved power density and an attractive price. The 650 V CoolMOS™ CFD7 also targets designs where an additional safety margin in breakdown voltage is needed. A simple plug and play replacement in resonant topologies is not recommended due to the different technology parameters.

Intended audience

This application note is intended for SMPS and EV charging designers.

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1 Overview and positioning of the 650 V CoolMOS™ CFD7

1.1 Target applications and key facts

As explained above, the 650 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.

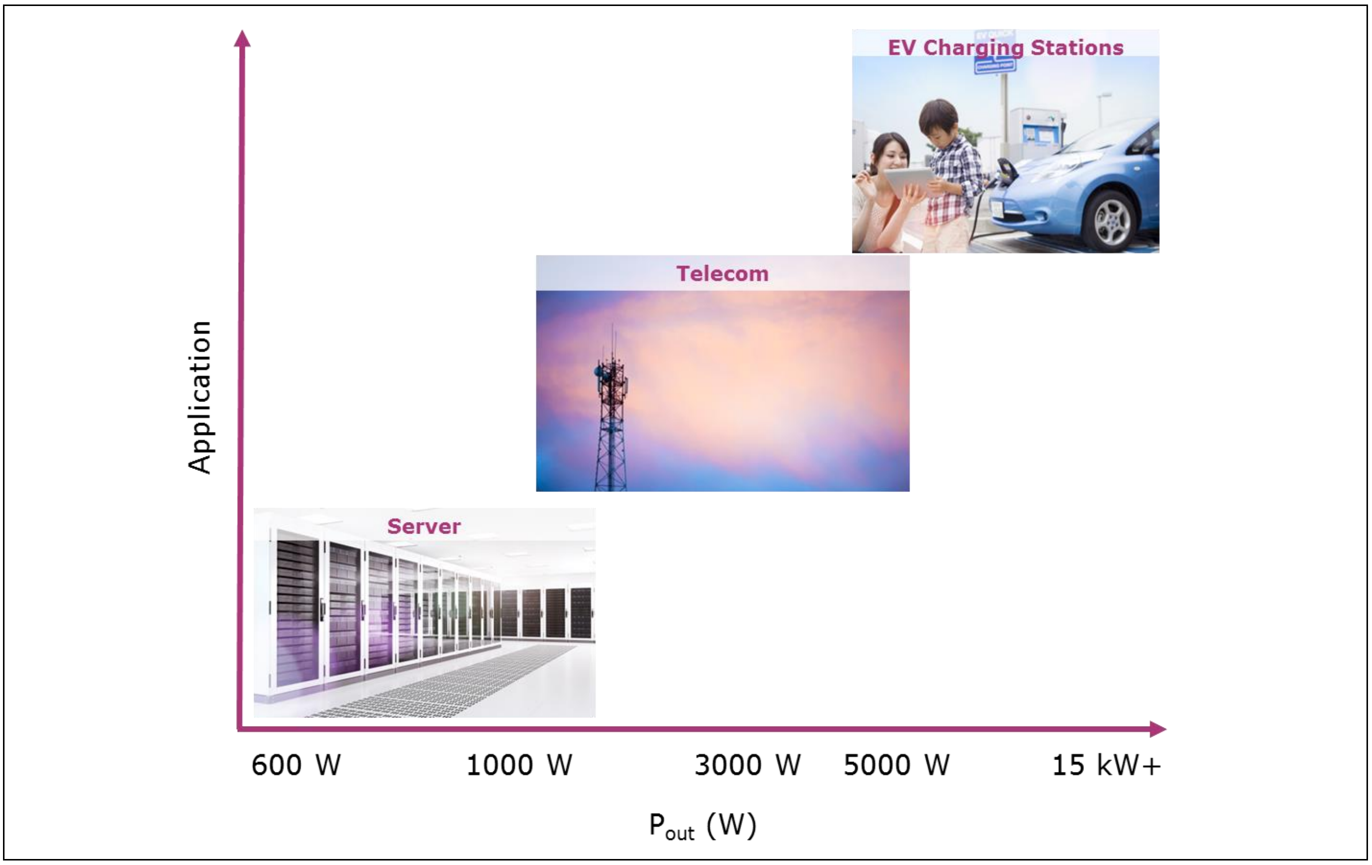

Figure 1 Target applications include the high-power SMPS market for resonant topologies

The key features of the 650 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 now and a competitive long-term price roadmap.

1.2 Positioning of 650 V CoolMOS™ CFD7 in the Infineon product portfolio

Infineon is offering Si-, SiC- and GaN-based power products. This gives customers the chance to cover the whole power transmission line from AC to DC and vice versa. Next, it is necessary to explain the positioning of these three technologies.

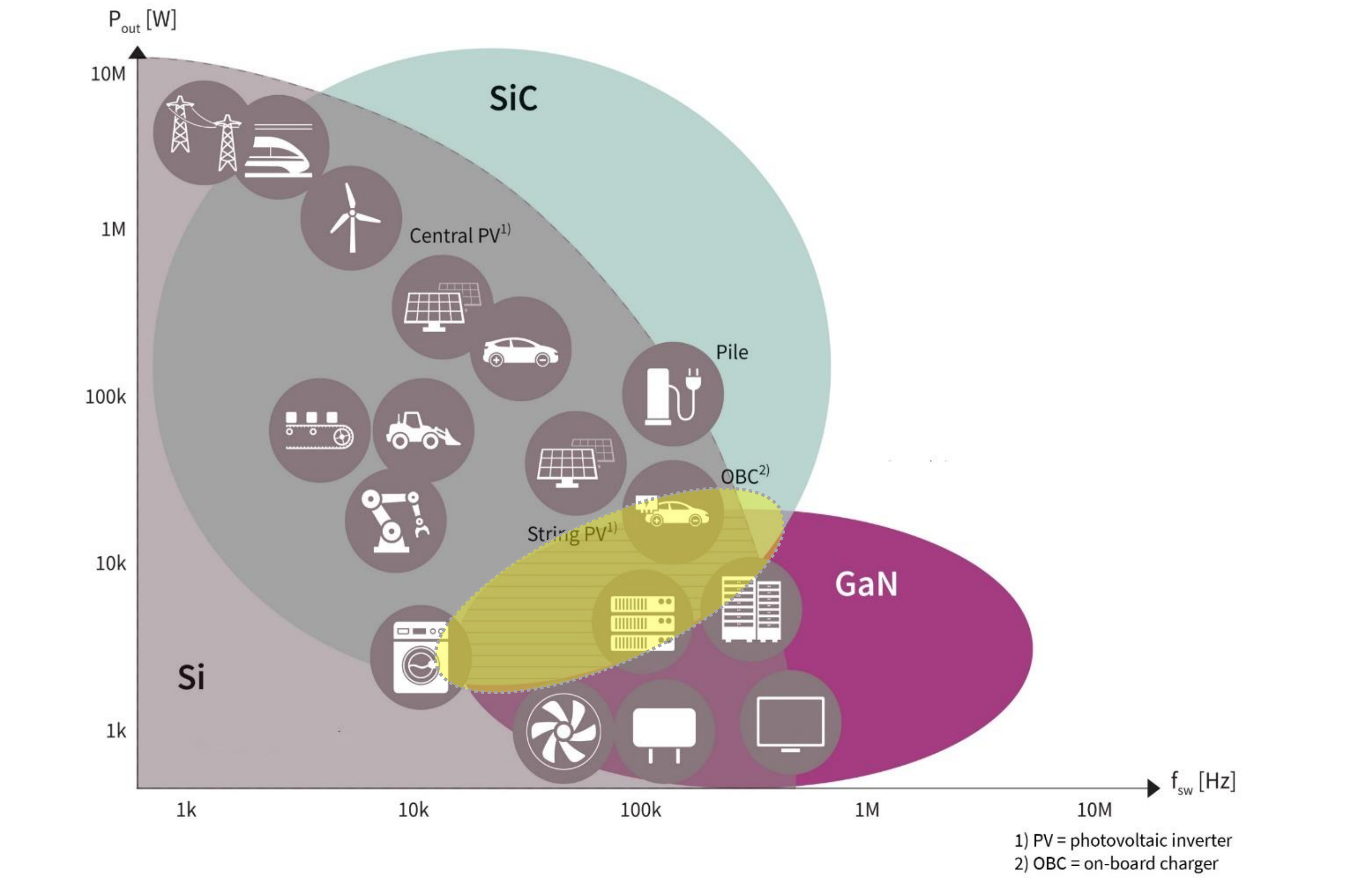

Figure 2 Positioning of Infineon HV power switches (650 V CFD7 – yellow bubble)

As can be seen in the positioning diagram in **Figure 2**, Si- power transistors will remain the mainstream technology in the next few years, covering a wide range of possible applications with adequate power and frequency possibilities. SiC-, on the other hand, complements Si- in many applications but also enables new solutions and topologies for higher-power and robust applications. Moreover, GaN- is able to achieve the highest efficiency, and by nature has the best figure-of-merit (FOM) for achieving the highest switching frequency.

Infineon recommends the different technologies as follows:

CoolMOS™:

- Maintaining cost/performance benefit across a wide range of applications
- High efficiency (up to 97 percent) for certain power density limitations
- Easy design-in
- PFC topologies and resonant topologies covering switching frequency from 45 kHz to 300 kHz
- Short evaluation times and plenty of experience using silicon in PSUs

CoolGaN™:

- Top efficiency and density: best FOM efficiency and power density
- Best for maintaining high efficiency while increasing frequency
- Totem-pole PFC and any hard- and resonant switching topology operating at higher frequencies
- Daughter card/SMD-optimized design approach

CoolSiC™:

- High efficiency and density: applications where high power is combined with high-temperature operating conditions
- Totem-pole PFC and any hard- and resonant switching topology
- Robustness

There is a clear overlap between the three technologies, and the selection of the right technology is heavily dependent on the application requirements, as all three technologies have a specific value proposition in the 600 V/650 V segment.

1.3 Positioning in comparison to predecessors

Compared to Infineon's previous HV superjunction MOSFETs with integrated fast body diode, the **650 V CoolMOS™ CFD7** offers technical as well as commercial advantages over its predecessor **650 V CoolMOS™ CFD2**. The following chart shows the overall positioning of CFD7 against the previous fast body diode technologies from Infineon.

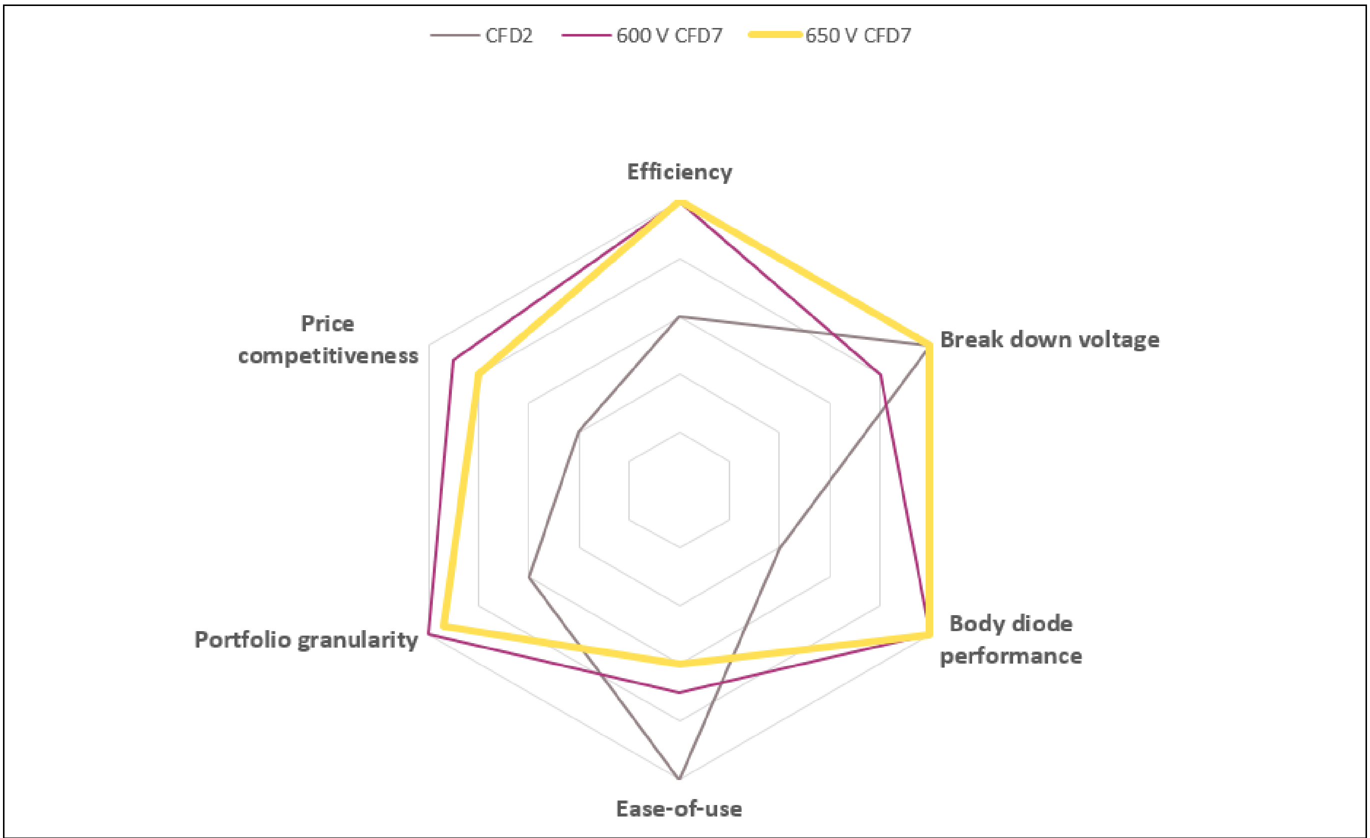

Figure 3 Positioning of the 650 V CoolMOS™ CFD7 against its predecessor and 600 V CoolMOS™ CFD7

As shown by this chart, the 650 V CoolMOS™ CFD7 offers highest efficiency at 650 V, with a competitive price. In addition, the high granularity in lower-ohmic devices, combined with the robust body diode make it to the best CFD2 successor. Furthermore, this document will show additional benefits such as the lower temperature dependency of the $R_{DS(on)}$, the reduced energy losses during turn-off of the MOSFET (E_{off}), and the lower Q_{rr} and Q_{gd}. These technology parameters result in the highest efficiency in target applications, as described in more detail later in this application note.

2 Technology features/parameters

This chapter sets out all the relevant technology parameters of the 650 V CoolMOS™ CFD7 and CFD2. 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 650 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 CFD7 or a similar fast body diode device is needed under certain operating conditions in an LLC or ZVS PSFB. In these topologies, hard commutation can occur, in case of a sudden change of duty-cycle or frequency. 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 keep the resulting reverse recovery energy (E_{rr}) to a minimum, to avoid thermal problems during this operation, which could lead to destruction. 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 re-turn-on effects on the MOSFET. This could result in a defect in the MOSFET. However, the 650 V CoolMOS™ CFD7 offers Q_{rr} among the lowest on the market, and this reduces the possibility of failure to a minimum and increases the reliability of the whole system.

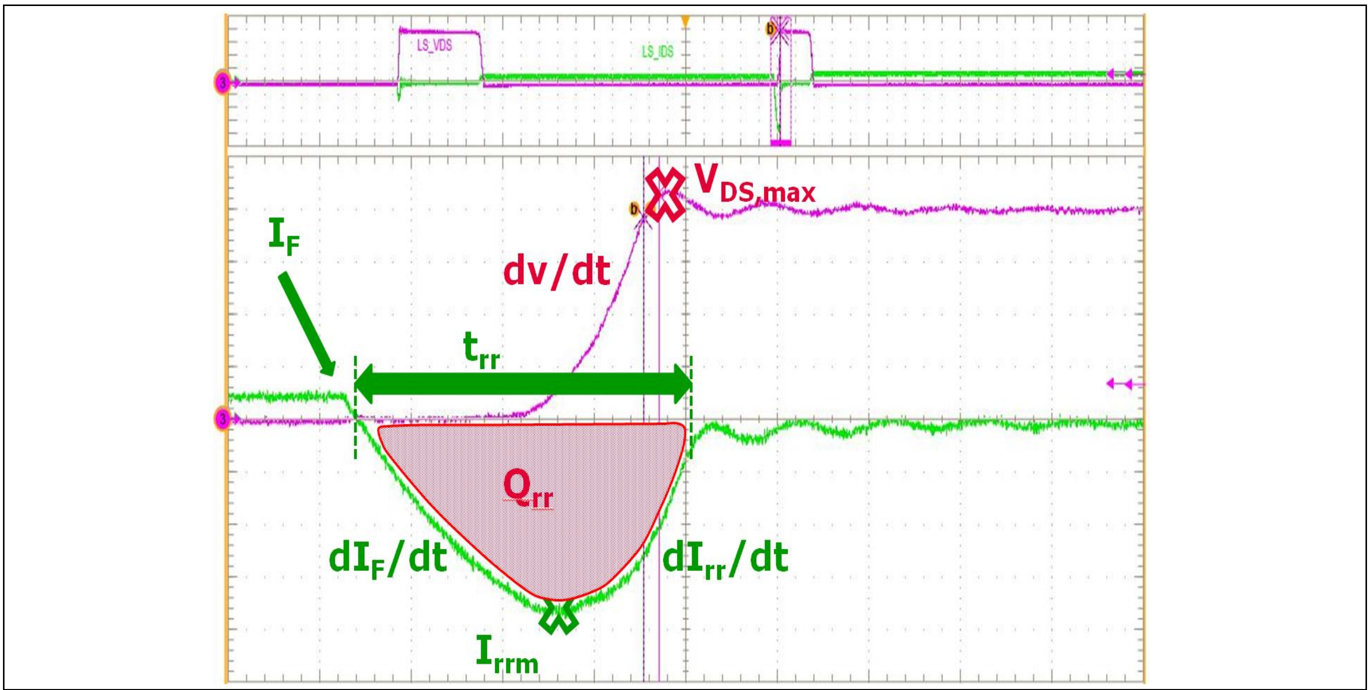

Figure 4 **Hard commutation on the conducting body diode (example)**

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:

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

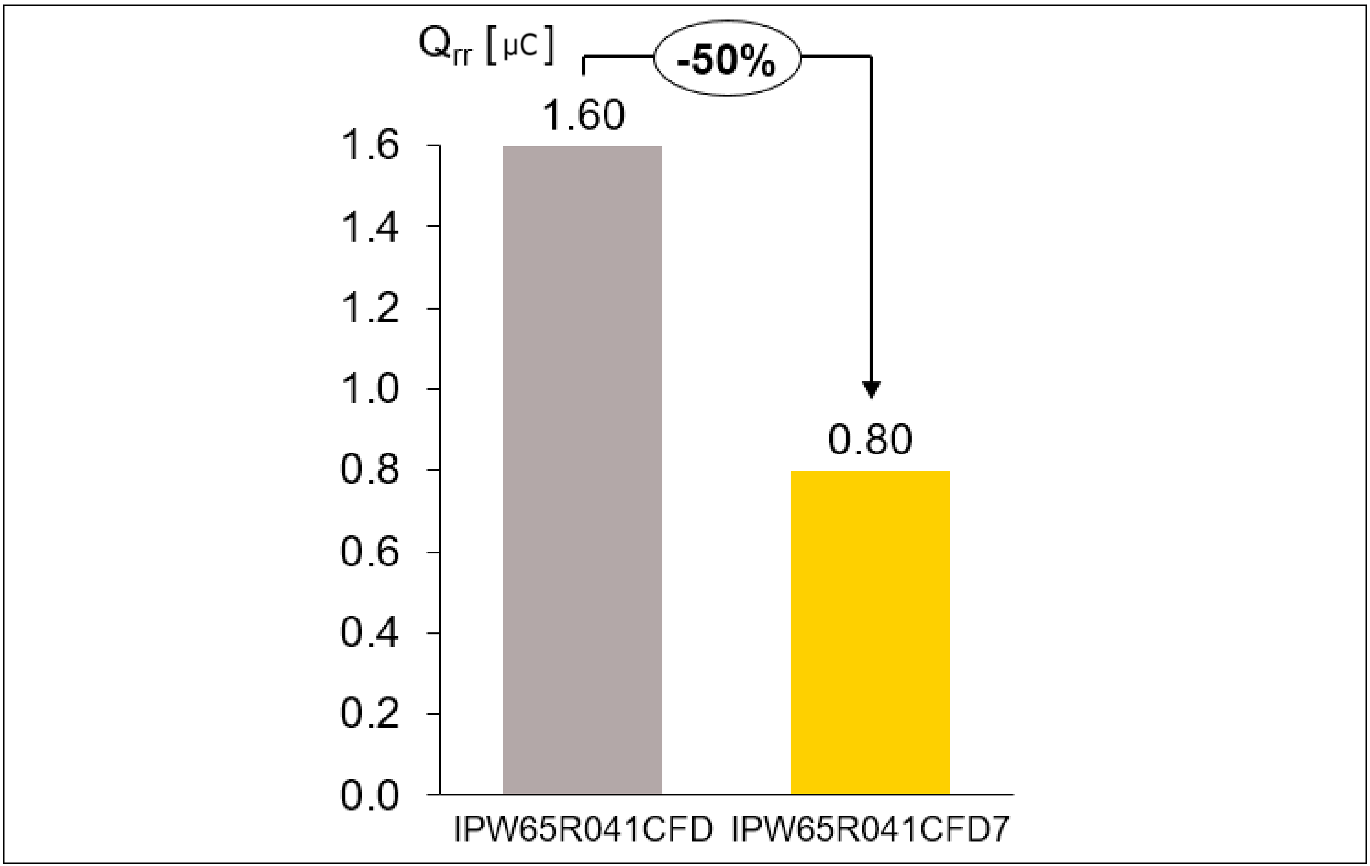

Figure 5 **Q_{rr} comparison of IPW65R041CFD7 vs IPW65R041CFD at dI_F/dt = 100 A/µs**

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. This has even been improved with Infineon's new 650 V CoolMOS™ CFD7, by lowering Q_{rr} by 50 percent. Additionally, the CFD7 has an increased maximum diode commutation speed of 1300 A/µs compared to the 900 A/µs of CFD2. Furthermore, we increased the reverse diode dv/dt from 50 V/ns to 70 V/ns and the MOSFET dv/dt from 50 V/ns to outstanding 120 V/ns, leading to even more robust devices.

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 energy during the hard commutation on a conducting body diode event (E_{rr}) are much lower than CFD2.

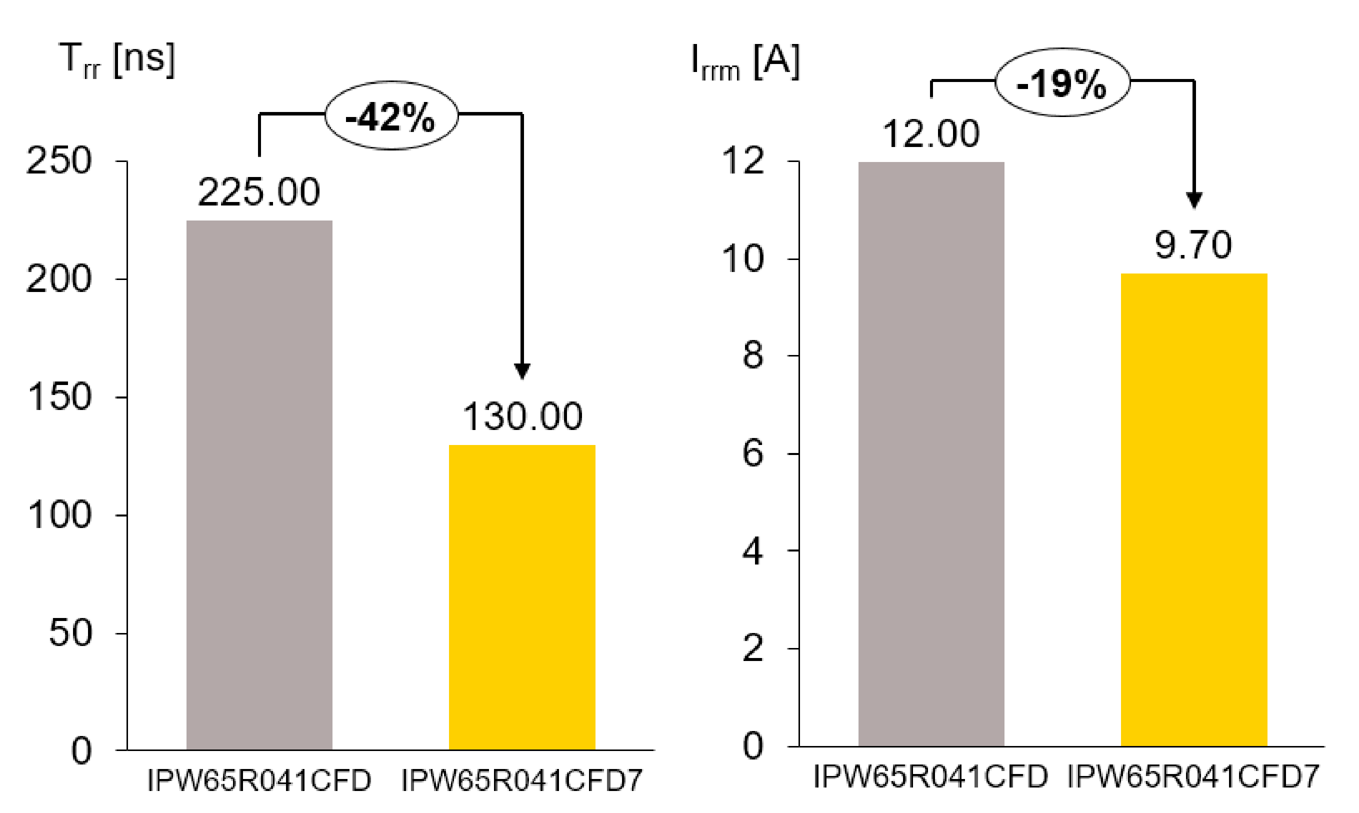

Figure 6 t_{rr} and I_{rrm} comparison of IPW65R041CFD7 vs IPW65R041CFD at 16.4 A; 100 A/µs

Repetitive hard commutation at a high application switching frequency is generally not recommended for any superjunction MOSFET, but in some operating conditions it cannot be avoided, at least for short periods of time. Therefore, the reduced reverse recovery of CFD7's body diode results in much lower power dissipation during these events against CFD2, and especially against non-fast-diode solutions.

2.1.4 Early channel shut-down

All 650 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 reach 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 at a certain drain current. For the 650 V CoolMOS™ CFD7, it is possible to increase the gate resistance and not suffer increased switching losses during turn-off. As can be seen in **Figure 7**, the CFD7 is showing a straight line (E_{off}) over various external resistances, meaning the device is still in early channel shut-down. Compared with the CFD2, one can see that the losses are drastically increasing with raising external resistance – no early channel shut-down.

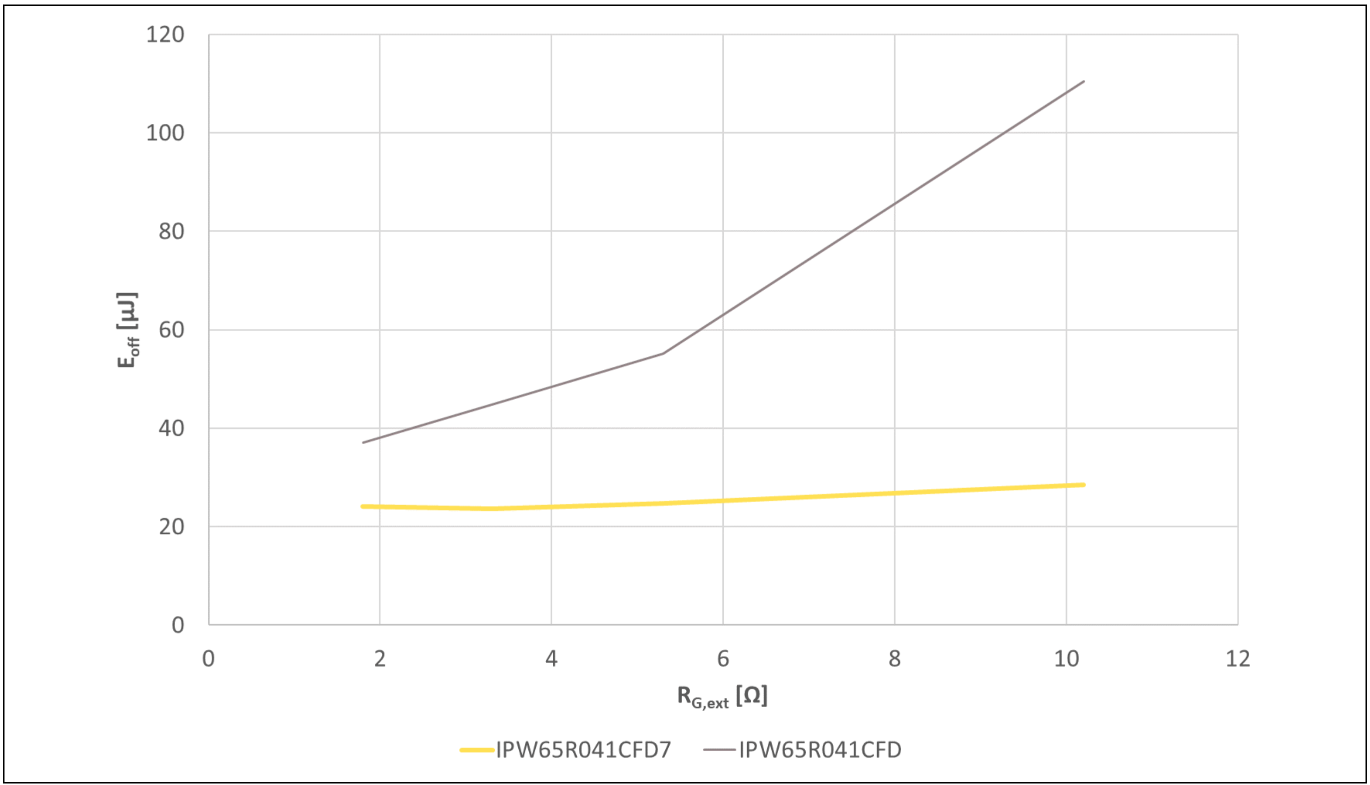

Figure 7 **Early channel shut-down based on 41 mΩ classes at I_D = 12.4 A**

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 performance of the 650 V CoolMOS™ 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.

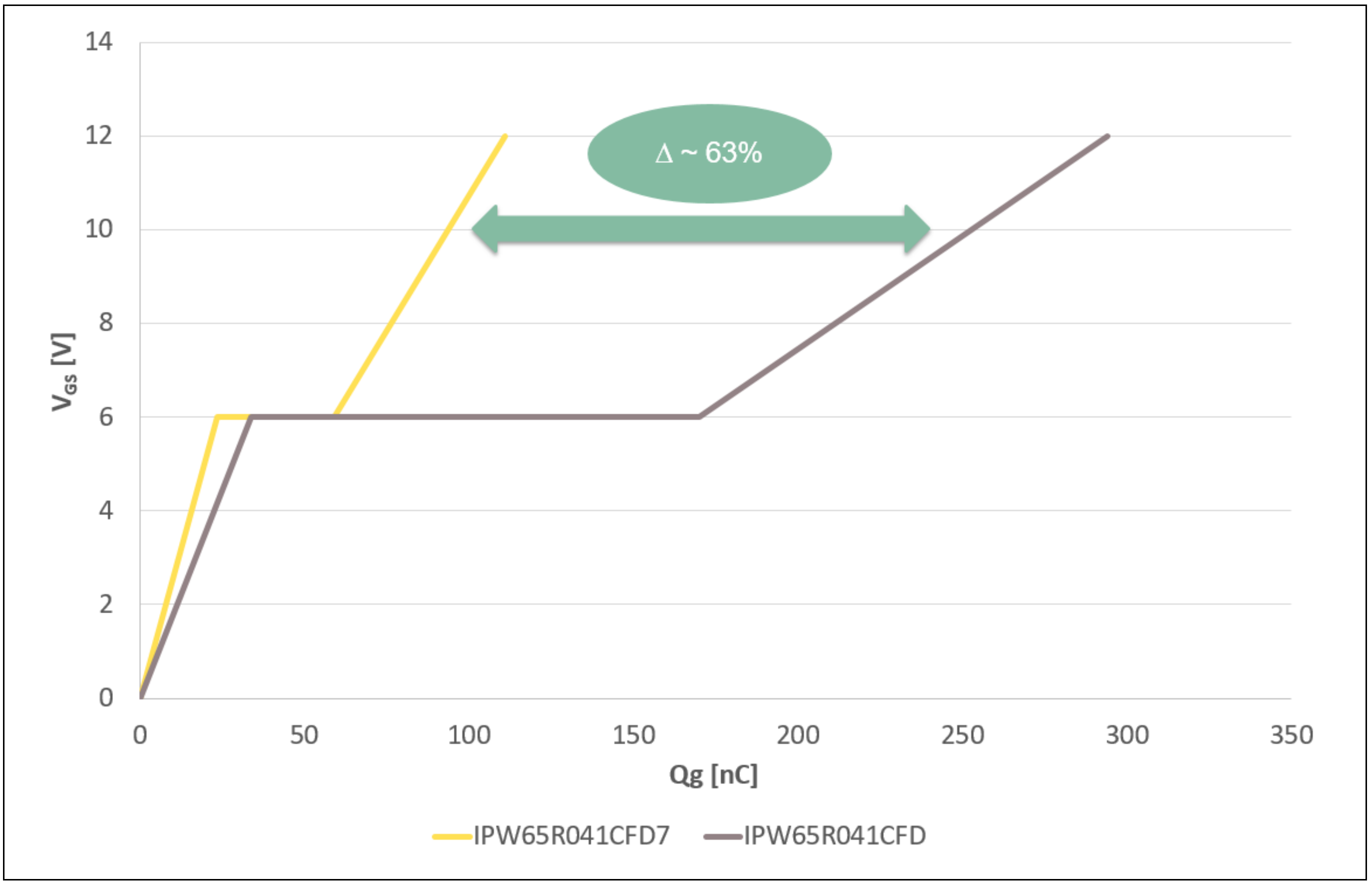

Figure 8 Q_g **comparison at 24.8 A pulsed based on characterization**

As can be seen in the graph above, the 650 V CoolMOS™ CFD7 shows the lowest Q_g in comparison to earlier predecessors. With this behavior, CFD7 can support higher switching frequencies (more than 100 kHz), which can help reduce the magnetic components of the design, leading to smaller form factor or higher power density. It can be clearly seen that the driving losses are reduced by at least ~63 percent in comparison to Infineon's former fast body diode technology.

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

Compared to its predecessor, the 650 V CoolMOS™ CFD7 is nearly on the same level as the CFD2. The Q_{oss} is illustrated in the following figure.

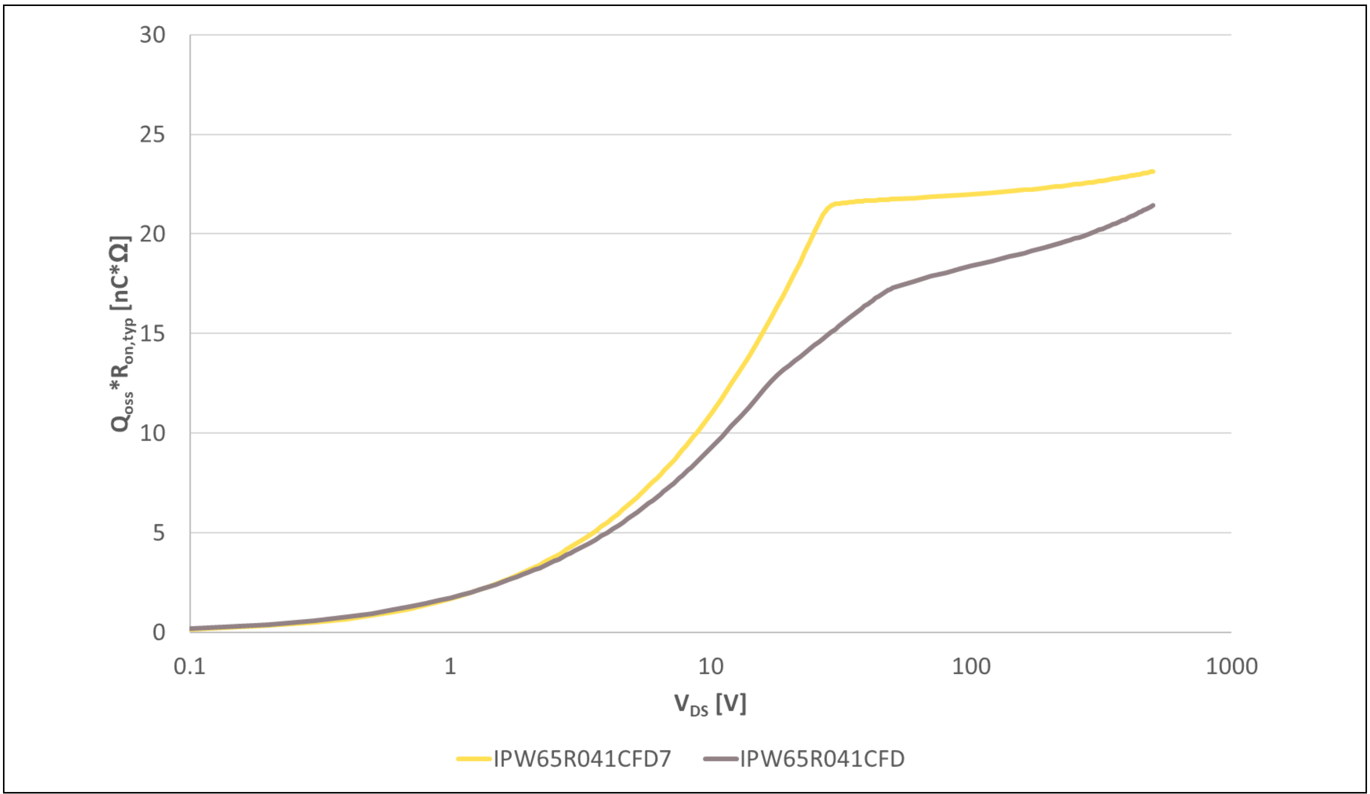

Figure 9 **Q_{oss} comparison based on characterization in 41 mΩ class**

As can be seen, full ZVS operation is not achieved more easily than with CFD2, but this does not represent an overall drawback. Even when 650 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, 650 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 CFD2, as shown in the next chapter. Achieving 25 V V_{DS} during turn-on is even easier, as there are only around 2.8 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 41 mΩ class devices:

CFD7, in order to reach 25 V → $Q_{oss,400V\ to\ 25V} = \frac{2.8\ nC\cdot\Omega}{34\ m\Omega} \approx 68\ nC$

CFD2, in order to reach 0 V → $Q_{oss,400V\ to\ 0V} = \frac{20.8\ nC\cdot\Omega}{37\ m\Omega} \approx 562\ nC$

CFD7, in order to reach 0 V → $Q_{oss,400V\ to\ 0V} = \frac{22.8nC\cdot\Omega}{34\ m\Omega} \approx 670\ nC$

With a ~88 percent lower charge, going with the discharge from 400 V to 25 V with CFD7, there is the possibility of reducing the recirculating current needed to discharge the output capacitance (C_{oss}). Discharging CFD7 to 0 V will lead to 108 nC of higher charge compared to CFD2, requiring higher magnetizing current or higher dead-time to discharge the output capacitance of the MOSFET.

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

650 V CoolMOS™ CFD7 offers improved E_{oss} from 80 V onward compared to CFD2, resulting in 45 percent lower E_{oss} at 400 V.

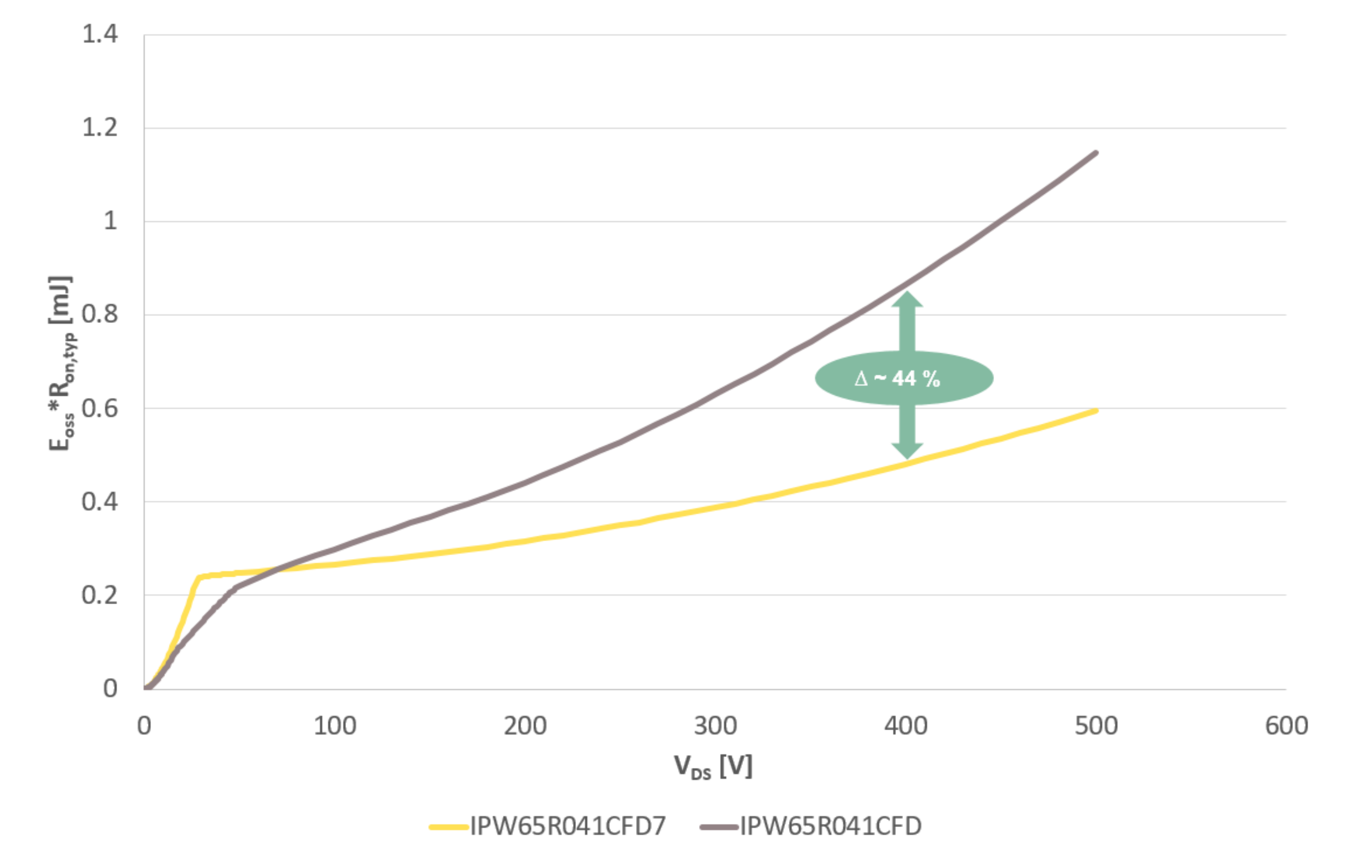

Figure 10 E_{oss} **comparison based on characterization**

At hard-switching turn-on 650 V CoolMOS™ CFD7 has absolutely no competitors; meanwhile 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 CFD2 could achieve full ZVS operation, which increases the turn-on losses of 650 V CoolMOS™ CFD7 to around 5.8 µJ ($E_{oss\ at\ 25V} = \frac{0.2\mu J \cdot \Omega}{34\ m\Omega} \approx 5.8\mu J$) in comparison to CFD2, 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 650 V CoolMOS™ CFD7 offers the lowest E_{off}. Continuing the comparison between CFD7 and CFD2, with lowest Q_{oss} the E_{off} of CFD7 is is 33.6 µJ lower, as shown in the next figure.

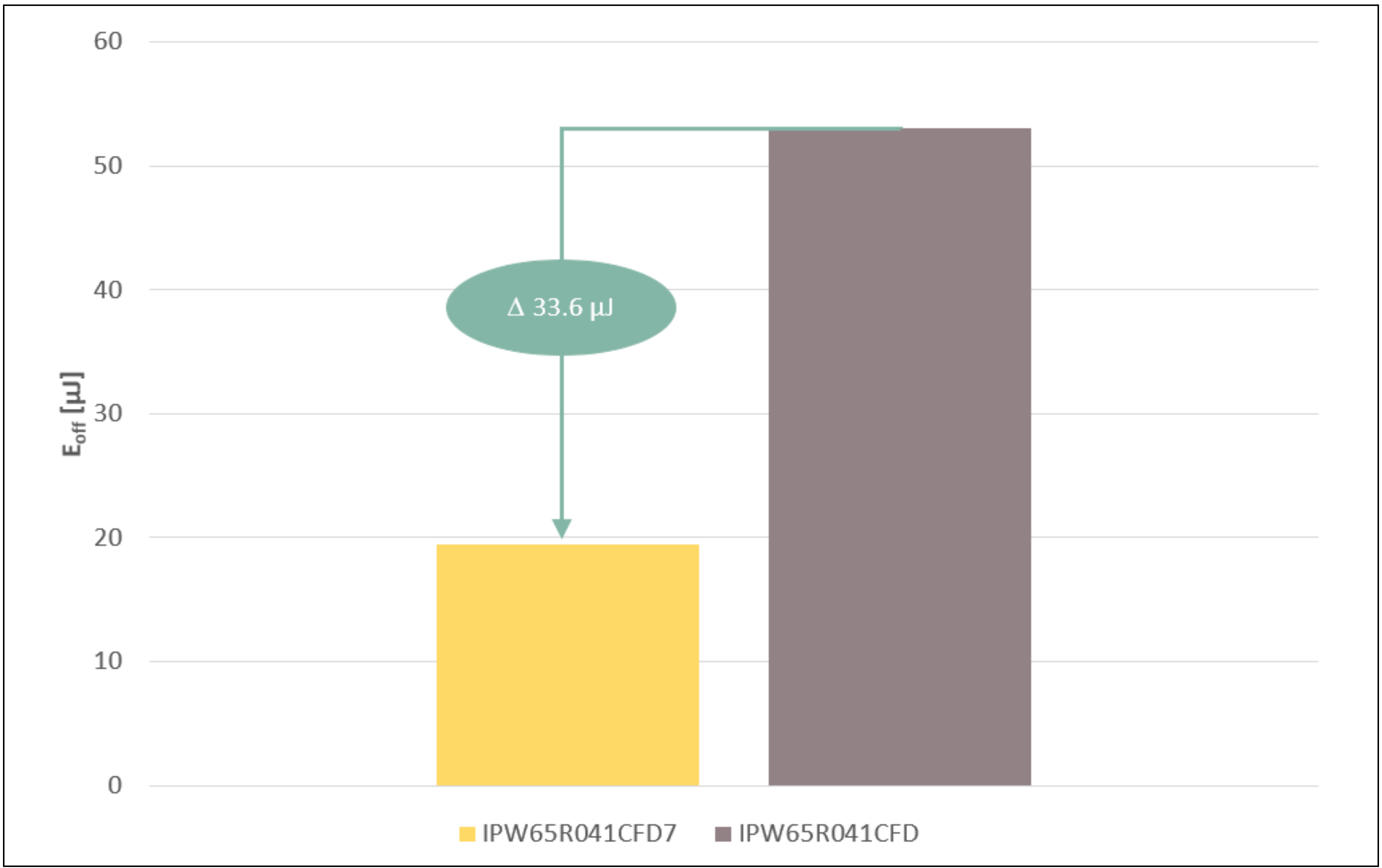

Figure 11 E_{off} **comparison at** $R_{G,ext}$ **= 1.8 Ω;** I_D **= 24.8 A;** V_{DS} **= 400 V**

Considering the E_{oss} at 25 V of 650 V CoolMOS™ CFD7 and E_{oss} = 0 J for CFD2 at 0 V, CFD7 shows lower total switching losses per cycle, as illustrated in the following calculation based on a 41 mΩ device.

Total switching losses calculation for CFD2:

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

$E_{on} = 0\,J$

$E_{off} = 53\,\mu J$

$E_{total} = E_{oss} + E_{on} + E_{off} = 53\,\mu J \rightarrow at\ 200\,kHz \rightarrow\ P_{switching} = 53\,\mu J \cdot 200\,kHz = \mathbf{10.6\,W}$

Total switching losses calculation for 650 V CoolMOS™ CFD7:

$E_{oss} = 5.8\,\mu J \rightarrow turn\ on\ at\ 25\,V$

$E_{on} = 0\,J$

$E_{off} = 19.5\,\mu J$

$E_{total} = E_{oss} + E_{on} + E_{off} = 25.3\,\mu J \rightarrow at\ 200\,kHz \rightarrow\ P_{switching} = 25.3\,\mu J \cdot 200\,kHz = \mathbf{5.06\,W}$

Based on this calculation, the total switching losses of 650 V CoolMOS™ CFD7 are ~52 percent less in comparison to CFD2.

As the switching losses are compared, another important factor in achieving high load efficiency is 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.

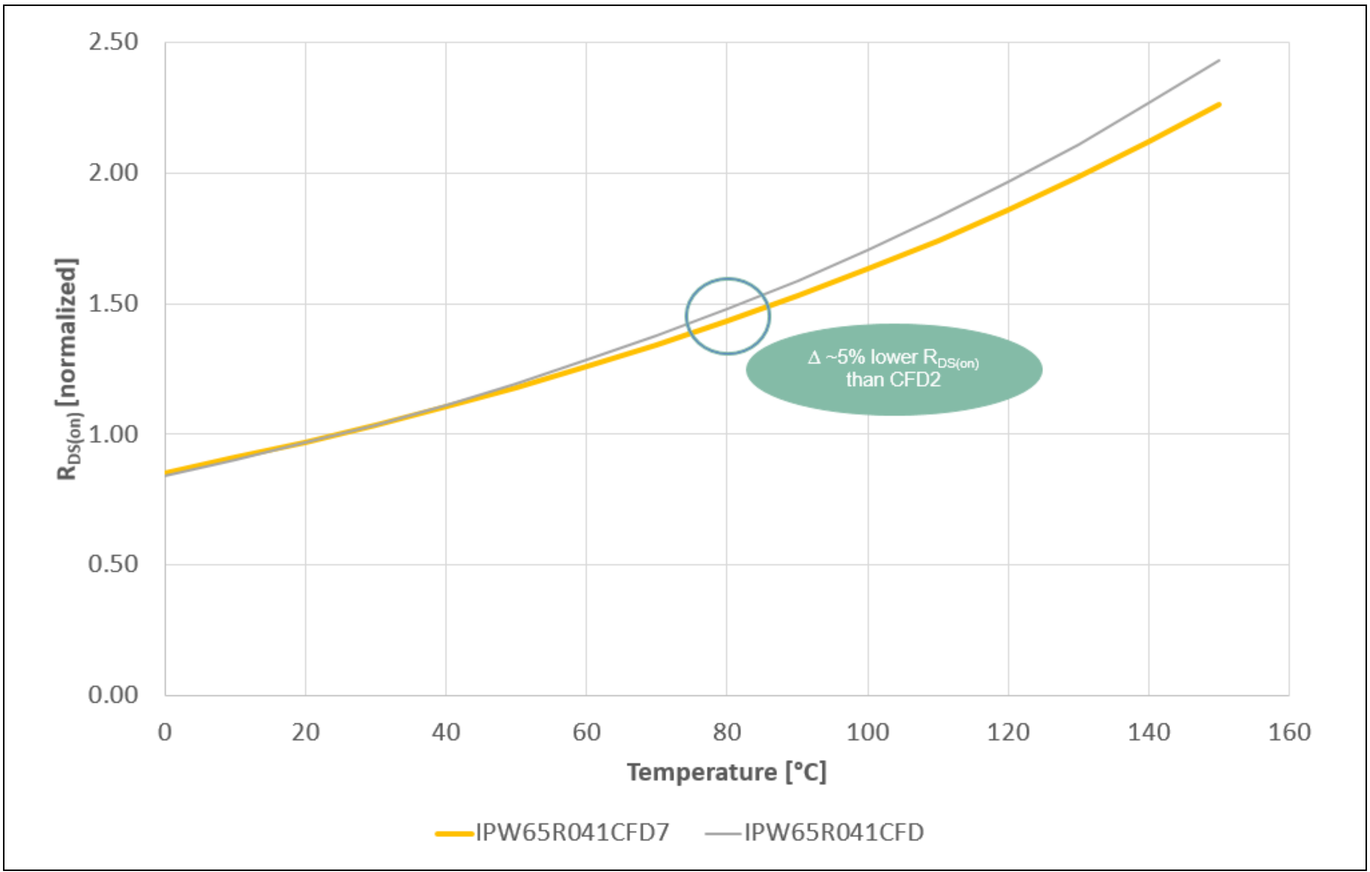

Figure 12 Normalized $R_{DS(on)}$ over junction temperature

As can be clearly seen, 650 V CoolMOS™ CFD7 has around 5 percent lower $R_{DS(on)}$ at 80°C than CFD2, 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, 650 V CoolMOS™ CFD7 offers best-in-class (BiC) $R_{DS(on)}$ in TO-220 and D^2PAK. The following figure compares CFD7 with the next best competitors (NBCs).

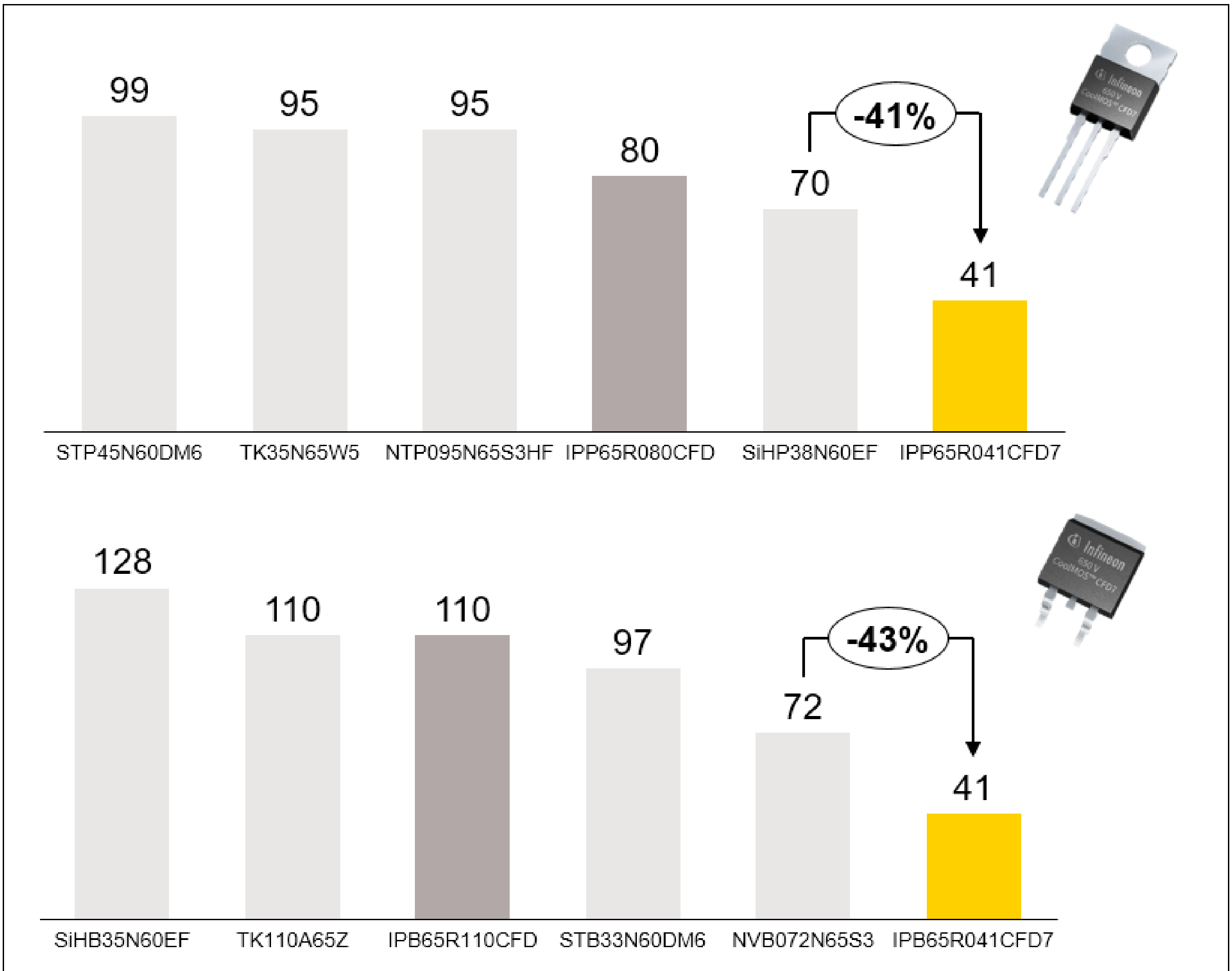

Figure 13 **BiC $R_{DS(on)}$ in different packages**

The sweet spots in the 650 V CoolMOS™ CFD7 portfolio are the BiC devices in TO-220 and D^2PAK. The 650 V CoolMOS™ CFD7 offers a 41 mΩ TO-220 device. In this package, the NBC can offer a 70 mΩ device. So, the 650 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 D^2PAK the 650 V CoolMOS™ CFD7 offers the lowest available $R_{DS(on)}$. Competitors can only offer D^2PAK devices with an $R_{DS(on)}$ of 72 mΩ or higher, while the 650 V CoolMOS™ CFD7 can go down to 41 mΩ.

2.2.7 4-pin packages – advantage of lower power losses

As already introduced with other product families of CoolMOS™, portfolio packages are implemented with Kelvin source connection.

With new generations of power switches becoming faster and faster, the effect of the parasitic elements of package and board are increasingly limiting the overall system performance. In many applications, the switching losses are significantly increased by the negative feedback caused by the parasitic inductance in the source lead of the power switch. An effective measure to overcome this problem is to provide an additional connection to the source (Kelvin connection) that is used as a reference potential for the gate driving voltage, thereby eliminating the effect of voltage drops over the source inductance. The achievable efficiency improvement, resulting mainly from faster switching transients, can in fact be significant.[1]

This is demonstrated by measurements for the 650 V CoolMOS™ CFD7, Infineon's latest generation of superjunction power transistors.

To demonstrate the differences in performance, the Infineon internal EV charging test setup was used. In this test platform, we are able to switch up to 39 A at 360 V with a switching frequency of 150, 250 and 350 kHz, to simulate the behavior in the most common EV charging stations.

The graph below shows the delta between the overall power losses of the complete setup, which includes losses of the passive components on the board as well as the losses of the MOSFET itself. While the losses of the passive components will stay the same, the variation in power loss will be caused by the device under test (DUT). This results in a delta comparision between the tested devices (always two devices – half-bridge configuration), not in a total power loss comparison.

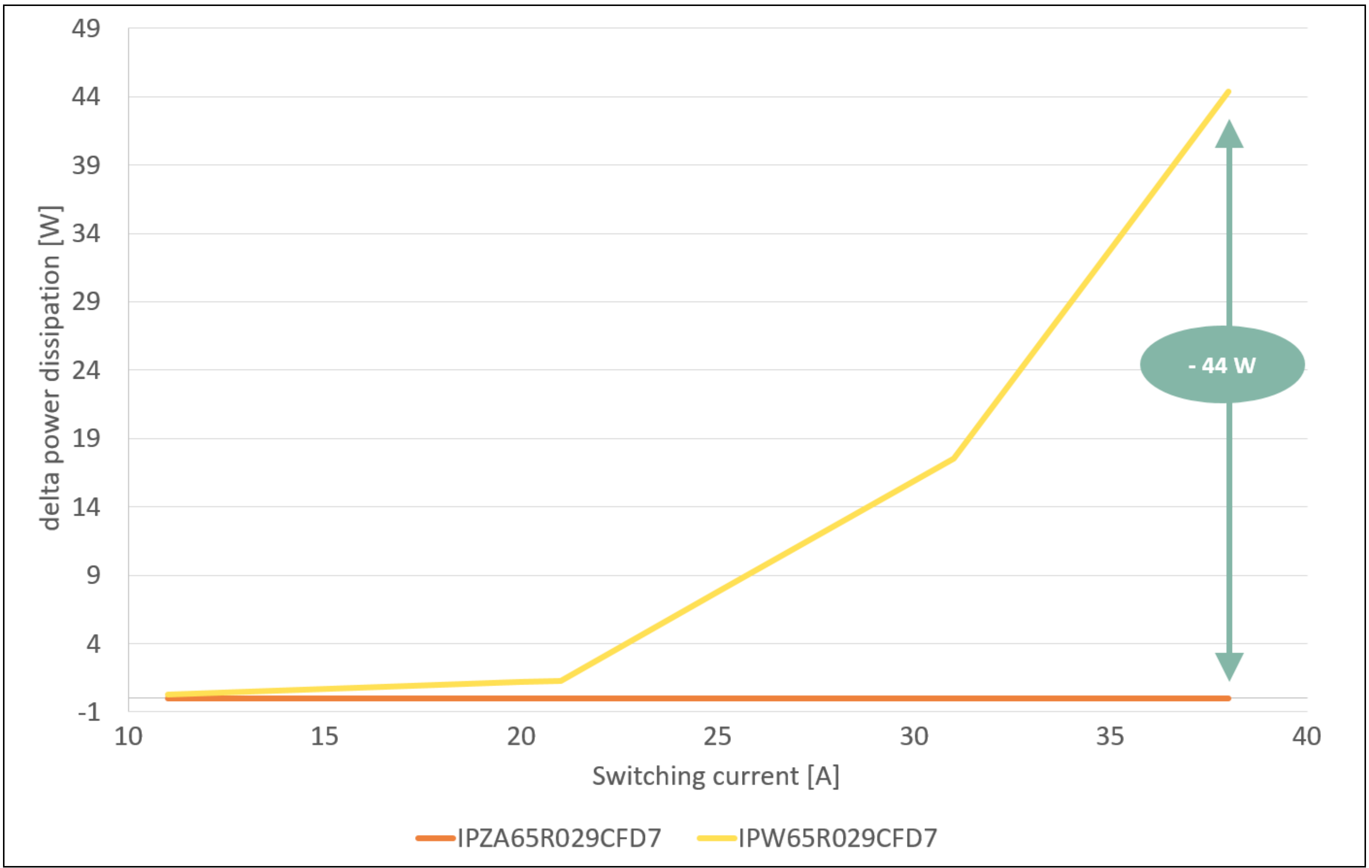

Figure 14 Delta in power loss between three- and 4-pin device at 150 kHz – two MOSFETs

For further information on Kelvin source devices and usage, please refer to the application note **650 V CoolMOS™ C7 switch in a Kelvin source configuration**.

2.2.8 Considerations for design-in

With the newest technologies and faster switching devices correspondingly, a plug and play scenario is not possible any longer, as the optimization of technologies is clearly suited to certain applications and the need for higher power density. Nevertheless, only small adaptations are necessary to perfectly fit the device into your design.

To show which adaptations should be considered, a 3 kW LLC test platform has been used as an example. For further information on the test board used, please refer to the application note **3 kW dual-phase LLC demo board**.

The following example shows the difference in external resistance and dead-time needed when comparing the CFD2 and the new 650 V CFD7 under the worst-case condition – no-load start-up. In this condition hard-switching occures as the board tries to start-up using burst mode.

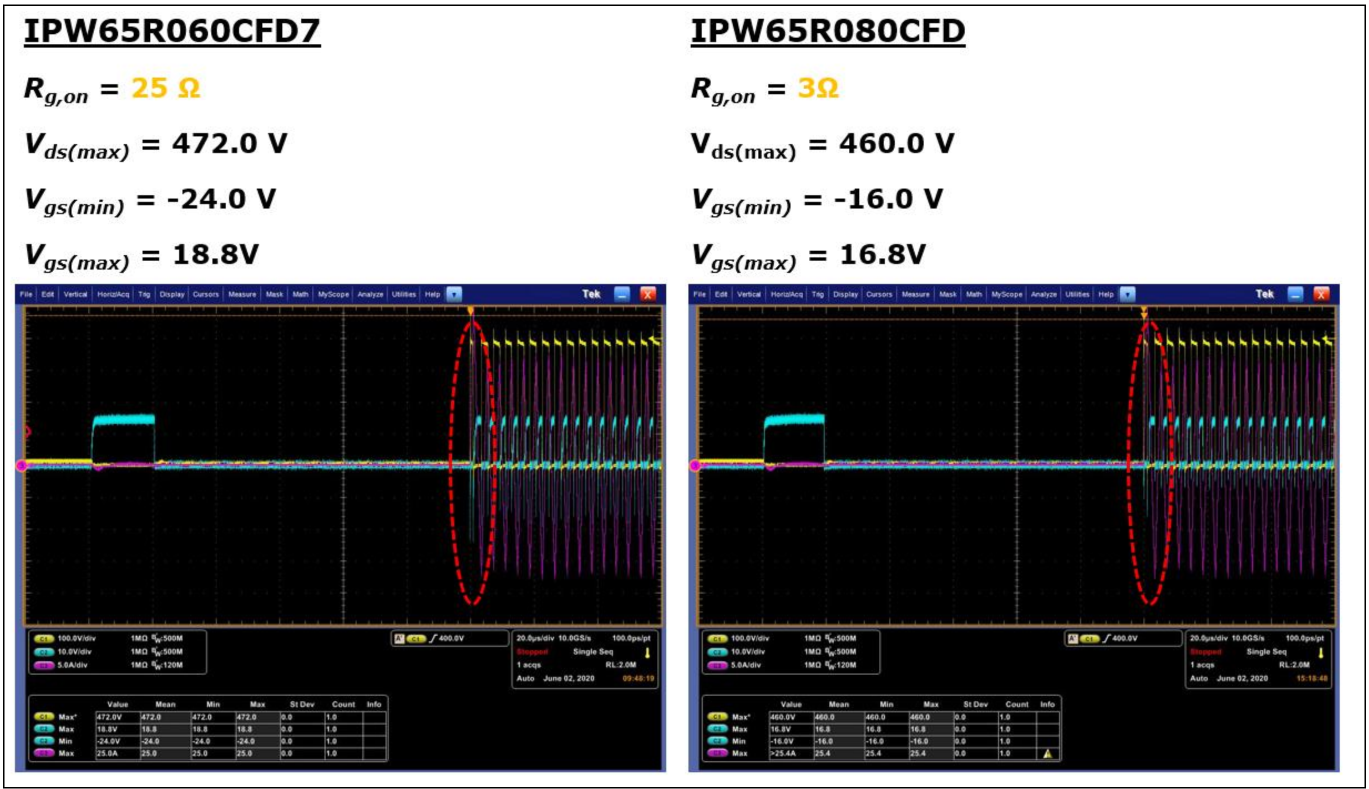

Figure 15 No-load start-up in the 3 kW dual-phase LLC

It is clearly visible that 650 V CFD7 needs a higher turn-on resistor than the CFD2 to be within the datasheet specifications of +/- 30 V V_{GS}. These results are mainly due to its faster switching behavior to achieve the highest efficiency.

This technology tailoring leads to another necessary adaptation compared to older technologies and competitors. With lowering the output capacitance of the MOSFET, the Q_{oss} stored in the output capacitance was raised, as shown in **Figure 9**. Having a fixed magnetizing current in the system, this results in a higher dead-time being needed to discharge output capacitance of the CFD7 compared to CFD2, in order to reach ZVS. In **Figure 16,** the ZVS adjustment of the DUT can be seen. For the 3 kW dual-phase LLC we use a load current of 2 A to adjust the ZVS, leading to ZVS from 10 percent to 100 percent of the load applied.

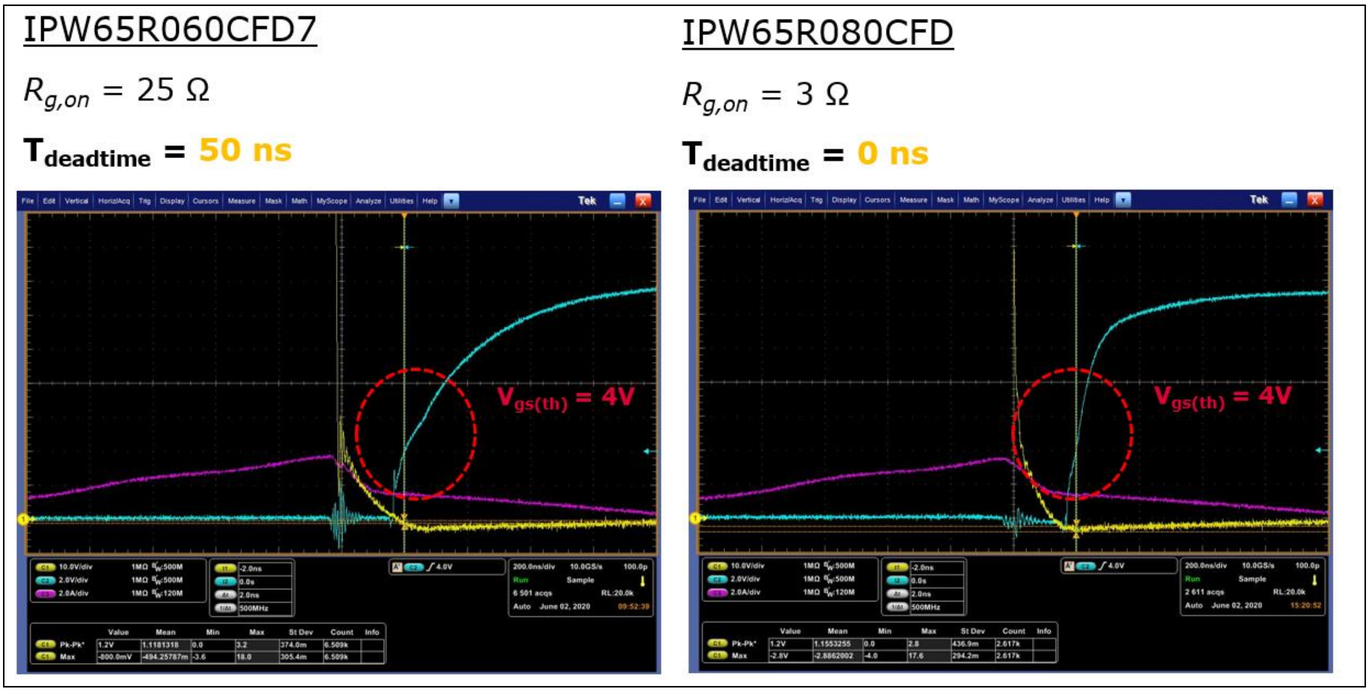

Figure 16 ZVS adjustment and dead-time settings needed to compare CFD7 and CFD2

3 Summary

Considering all these technical features and parameters, the 650 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 the 650 V CoolMOS™ CFD7.

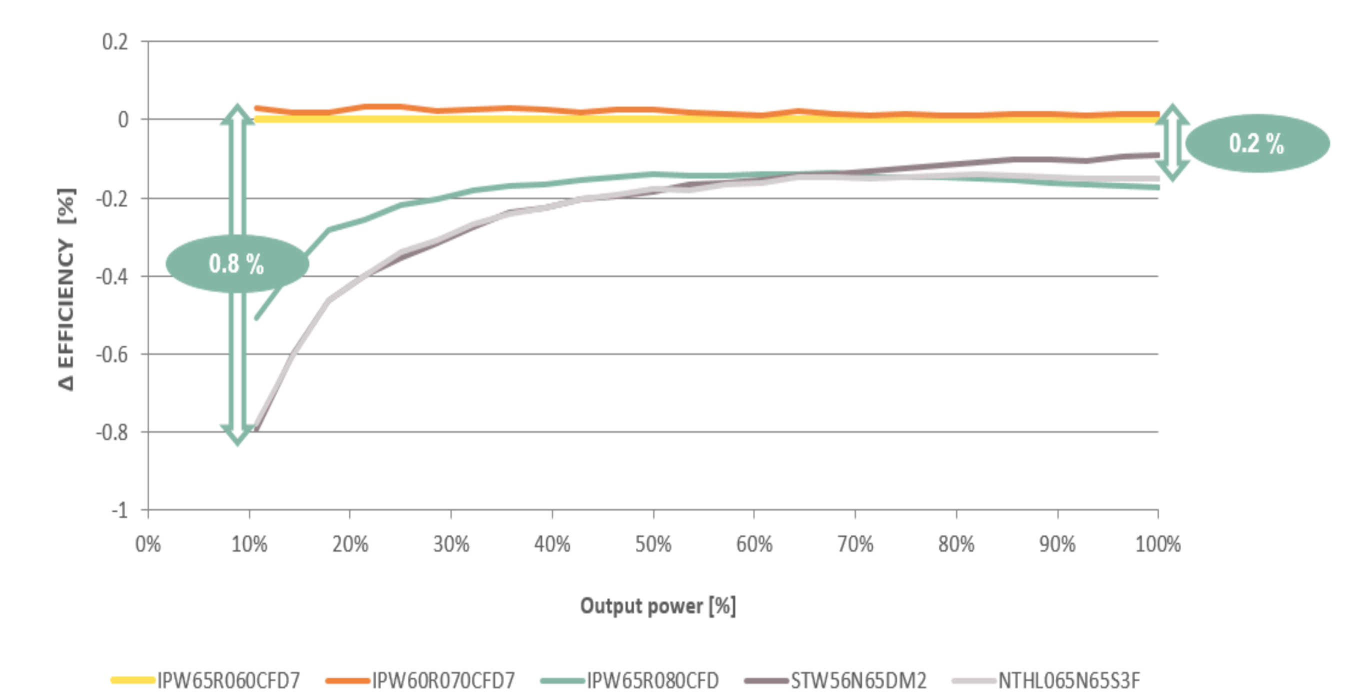

Figure 17 Delta efficiency in 3 kW LLC DC-DC stage (single rail at 1500 W); each device optimized

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 the 650 V CoolMOS™ CFD7. In the figure above, it is clearly visible that with optimized conditions (80 percent V_{DS} derating, within specs of V_{GS}, adapted dead-time) for each device, the CFD7 shows the best efficiency among all competitors.

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 ~0.8 percent higher light-load efficiency when compared to STW56N65DM2, and even ~0.5 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

The 650 V CoolMOS™ CFD7 planned portfolio recommended for LLC and ZVS PSFB topologies as follows:

650 V CoolMOS™ CFD7 SJ MOSFETs

$R_{DS(on)}$ [Ω]	TO-220	TO-247	TO247-4	TO-263 D²PAK	ThinPAK 8x8	TOLL	QDPAK
190/200	IPP65R190CFD7				IPL65R200CFD7	IPT65R190CFD7	
155/160	IPP65R155CFD7	IPW65R155CFD7		IPB65R155CFD7	IPL65R160CFD7	IPT65R155CFD7	
125/130		IPW65R125CFD7		IPB65R125CFD7	IPL65R130CFD7	IPT65R125CFD7	IPDQ65R125CFD7
110/115	IPP65R110CFD7	IPW65R110CFD7		IPB65R110CFD7	IPL65R115CFD7		
90/95/99	IPP65R090CFD7	IPW65R090CFD7		IPB65R090CFD7	IPL65R095CFD7	IPT65R099CFD7	IPDQ65R099CFD7
80						IPT65R080CFD7	IPDQ65R080CFD7
60/65	IPP65R060CFD7	IPW65R060CFD7			IPL65R065CFD7	IPT65R060CFD7	IPDQ65R060CFD7
40 / 41	IPP65R041CFD7	IPW65R041CFD7		IPB65R041CFD7		IPT65R040CFD7	IPDQ65R040CFD7
29		IPW65R029CFD7	IPZA65R029CFD7				IPDQ65R029CFD7
17 / 18		IPW65R018CFD7	IPZA65R018CFD7				IPDQ65R017CFD7

Telecom, Server, EV-Charging, Solar

Solution to address soft-switching applications in high power SMPS

Figure 18 Planned portfolio

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

Revision history

Document version	Date of release	Description of changes
V 1.0	23-09-2020	First release
V 1.1	13-01-2021	Update on Figure 18
V 1.2	11-11-2021	Update on Figure 18
V 1.3	27-04-2023	Update on Figure 18

Trademarks

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