# Dedicated MOSFET technology for low power consumer applications

## 700 V CoolMOS™ P7 - Infineon's answer for flyback topologies

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## Abstract

Designers are consistently challenged by the increasing demands for every new generation in the consumer sector. Among them are the underlying needs for lower temperature, improved form factors and increased efficiencies, along with significantly reduced system cost.

Infineon's 700 V CoolMOS™ P7 is the first 700 V solution developed and produced on 300 mm for low power applications. It offers a price competitive solution for consumer applications such as flyback chargers and adapters in the power range from 10 W to 75 W. 700 V CoolMOS™ P7 is a tailored technology for flyback and DCM (discontinuous current mode) PFC applications and is not suitable for any half- or full-bridge topology.

This paper focuses on the highly popular flyback-based converters, with special emphasis on the role of MOSFETs within this topology. It also illustrates the benefits of dedicated switching devices by benchmarking some real-world application examples and gives an overview of some of the latest devices on the market.

## Contents

# 1 Introduction

Designers increasingly struggle to overcome technical challenges within today's low power applications aimed at the consumer market. Better thermal performance, reduced size and increased efficiency are among the underlying needs for every new generation. Nevertheless, equally important is a significantly reduced system cost, which is the key to be successful in this price sensitive market segment. Last, but not least, compliance with a stringent set of safety regulations needs to be achieved. As these challenges are getting tougher, leading semiconductor companies are focusing on application tailored devices to fulfil, and ideally exceed, these needs. The flyback topology is commonly used in power supplies to address these consumer applications.

The latest generation of Infineon Technologies' superjunction MOSFETs, the 700 V CoolMOS™ P7, has been developed to serve today's and especially tomorrow's trends in flyback topologies. It equips designers with the best-fit devices that address lower temperature, improved form factor and increased efficiency. As a further benefit, increased efficiency goes hand-in-hand with reduced energy consumption. This helps to reduce CO2 emissions and generates financial benefits for the end-customer due to lower energy consumption.

Developing a highly efficient, extremely dense power system begins with the core concept of the design. The topology chosen, and particularly, the performance of the critical power components have a significant impact and can influence the design's success. The flyback topology has remained popular, especially for cost-sensitive applications such as mobile device chargers or multi-output power supplies in small PCs, due to its simplicity and robustness. This simplicity means that the MOSFET is the main switching component in the powertrain. Therefore, a well-considered selection of the MOSFET defines the overall performance of the final design. As a result, worldwide operating semiconductor companies continue to refine their processes and to develop new technologies. They follow the clear objective of enhancing the key Figures of Merit (FoM) in order to release new and highly efficient generations of MOSFET power switches.

One of the most crucial considerations in designing both high power and low power solutions is how to avoid unwanted heat generation. Especially in low power consumer applications, there is a significant trend towards slim and lightweight end product designs. The available space within these applications is constantly being reduced, hampering heat dissipation. In general, forced air cooling is not possible with chargers and adapters due to form factor and system cost. As a consequence of less ability to dissipate heat, there is a desire to use components that are able to counteract this effect.

With relation to the MOSFET, this implies achieving an increased efficiency and a reduction of energy being converted heat, leading to a size reduction. These efficiency gains also support an extended lifetime of any fixed capacity energy source, such as a battery, based on shortened charging times with a larger number of charging cycles.

700 V CoolMOS™ P7 delivers outstanding efficiency gains, resulting in lower device temperature. This enables designers to achieve improved form factors and contributes to an overall system cost reduction. In addition, designs have to be inherently safe, even under certain fault conditions. They also need to be compliant with legal requirements and standards.

This had also been taken into consideration from the beginning of the design and is implemented in this new generation of superjunction MOSFET technology.
In line with the aforesaid, this white paper will discuss the interdependency of the technically influential factors, conventional flyback topologies and the role of the selected MOSFET. Furthermore, it will illustrate the advantages of 700 V CoolMOS™ P7 in commercially available end-user applications.

## 2 Superjunction MOSFETs: CoolMOS™

Based on a novel drain structure, Infineon Technologies' CoolMOS™ process was introduced in 1999. Since then this game-changing technology has benefitted from substantial development. Following its introduction, over 1.6 billion CoolMOS™ units have shipped, with fewer than 50 failures.

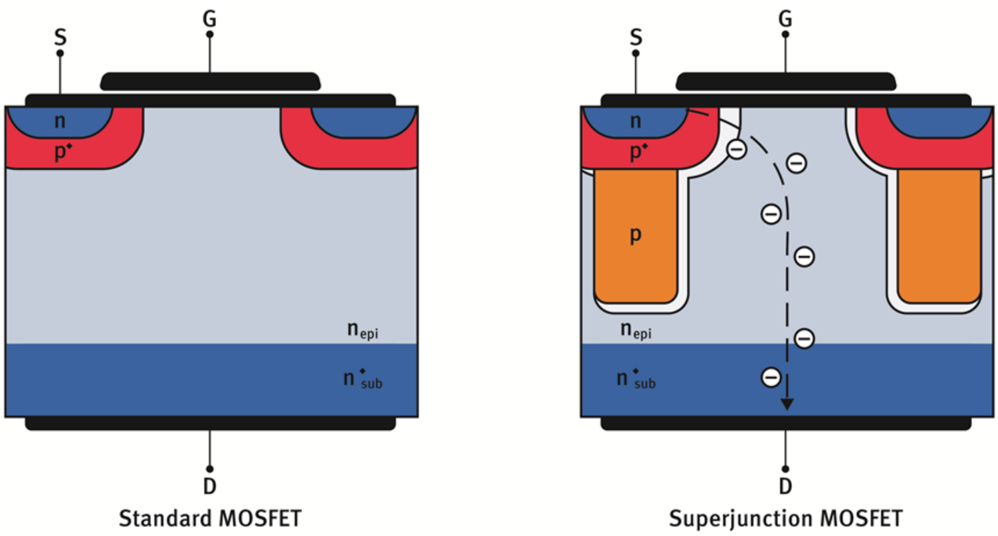



*Figure 1: Comparing the structure of a superjunction MOSFET to a standard MOSFET*

In a CoolMOS™ superjunction MOSFET, the on-state resistance ($R_{DS(on)}$) is lower than for a conventional MOSFET as the main current path has significantly more doping. The precisely sized and doped p-columns constitute a "compensation structure", which balances the heavily doped current path and supports a high blocking voltage.

Such construction improves conduction loss and the significant reduction in chip area reduces capacitance and dynamic losses, allowing CoolMOS™ to beat the silicon limit line and further improve all aspects of power losses, thereby reducing heat generation.

Continual technology development allowed the C7 generation to reduce capacitance and achieve an $R_{DS(on)}$ below 1 $\Omega$*$mm^2$ for the first time. The turn-off losses in C7 were 50% lower than the earlier CP generation. C7 Gold (G7) took this well-established manufacturing technology further, reducing turn-off losses by a further 25 percent. Even with these impressive advances, development continued to match the semiconductor performance with the ever-increasing needs of the market.

The latest development is 700 V CoolMOS™ P7 - the first 700 V solution developed and produced on 300 mm for low power applications. 700 V CoolMOS™ P7 offers a price competitive solution for consumer applications such as Flyback chargers and adapters in the power range from 10 W to 75 W. 700 V CoolMOS™ P7 is a tailored technology for flyback and DCM (discontinuous current mode) PFC applications and is not suitable for any half bridge or full bridge topology.
This paper will describe the performance benefits 700 V CoolMOS™ P7 offers in comparison to older technologies through the evaluation of practical design examples.

## 3 700 V CoolMOS™ P7: Target applications & topologies

700 V CoolMOS™ P7 is optimized for flyback topologies and DCM PFC, especially consumer flyback chargers and adapters between 10 W and 75 W. Chargers differ from adapters in their output voltage, and normally have output voltages between 5 V and 12 V output while adapters are typically close to 19 V. Due to its simplicity and inherently low cost, flyback is the most popular topology in these applications.
While there are many types of flyback converter including ZVS (zero voltage switching) or active clamp, the most popular and common flyback topologies are CCM (continuous current mode), fixed frequency DCM and QR (quasi-resonant).

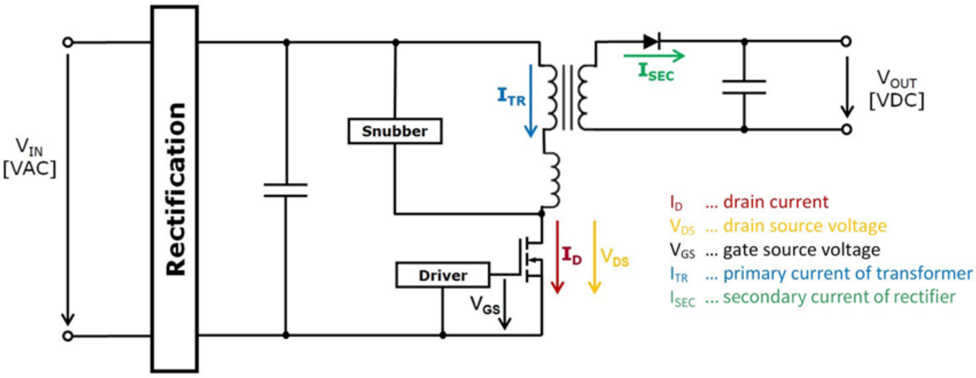



*Figure 2: Simplified schematic for a generic flyback converter*

### 3.1 CCM Flyback

Typically used for adapters in the higher power range above 45 W, a CCM flyback operates with a fixed frequency. Fixed frequency controllers are typically three to four times lower cost than QR controllers.
In this topology, the main transformer current (ITR) never reduces to zero in steady state operation (the blue trace in Figure 3). This creates a fully hard-switching topology where the energy stored in the MOSFET output capacitance ($E_{oss}$) behavior of 700 V CoolMOS™ P7 is at

its best. In order to regulate the output voltage, the duty cycle is varied depending on the output load.
A CCM flyback can also operate in DCM in light load operation, depending on the value of the primary windings and inductance of the main transformer. The principle of operation and simplified waveforms for CCM flyback are shown in Figure 3, based upon a fixed switching frequency ($f_{sw}$).

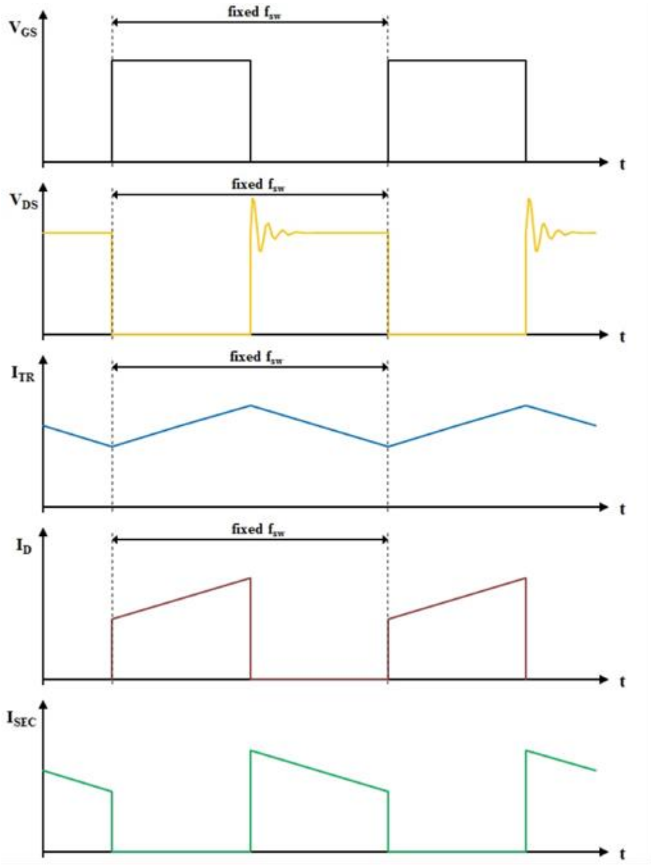



*Figure 3: CCM flyback: principle of operation and key waveforms*

## 3.2 DCM Flyback

The DCM flyback topology is typically used for lower output loads. In a standard DCM flyback the output is also regulated by the duty cycle. The overall efficiency of DCM is very dependent on the MOSFET's $E_{oss}$, meaning that second sourcing can be a challenge as this varies from device to device. Although popular, this approach is used less frequently nowadays due to more stringent efficiency standards. The principle of operation and simplified waveforms are shown in Figure 4 below, showing the similarities to, and differences with, CCM.

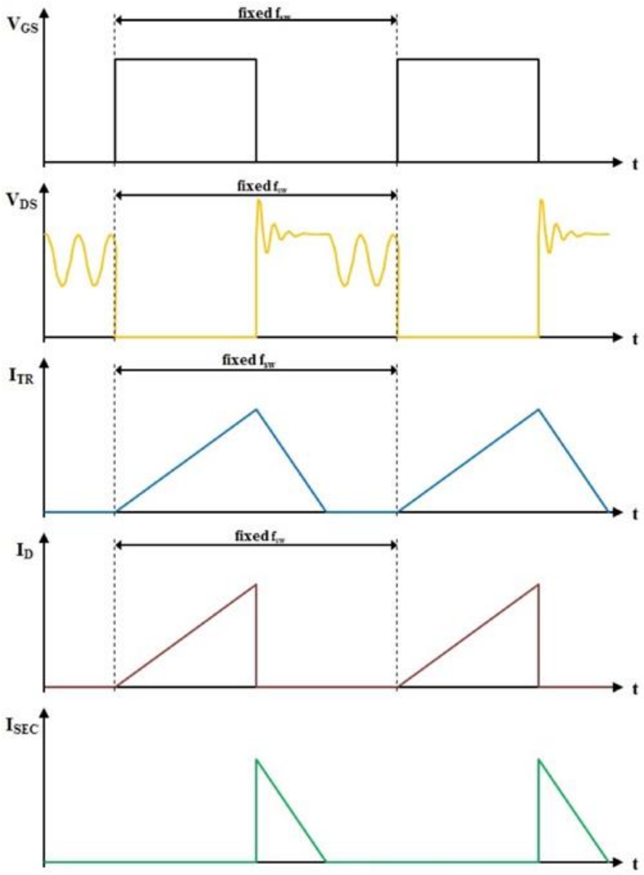



*Figure 4: DCM flyback: principle of operation and key waveforms*

## *3.3* QR Flyback

QR-based flyback topologies are the most commonly used low power charger topologies. They deliver better performance due to reduced switching losses. A QR flyback can only operate in DCM, as the MOSFET switches on during the oscillation phase of the drain node capacitance and transformer main inductance when the current through the main transformer is zero. QR differs from DCM in that QR features valley switching.  In valley switching, the MOSFET is able to turn-on at minimum $V_{DS}$ (drain-source voltage) thereby reducing the $E_{oss}$ losses. Typically, at heavy loads, the MOSFET turns on during the first valley, whereas at very light loads, the MOSFET turns on during a later valley. Any $V_{DS}$ oscillation or ringing is defined by the capacitance value on the drain node and is influenced by the MOSFET output capacitance ($C_{oss}$). Thereby, the switching frequency can be influenced by MOSFET selection.

The principle of operation and simplified waveforms are shown in Figure 5 below.

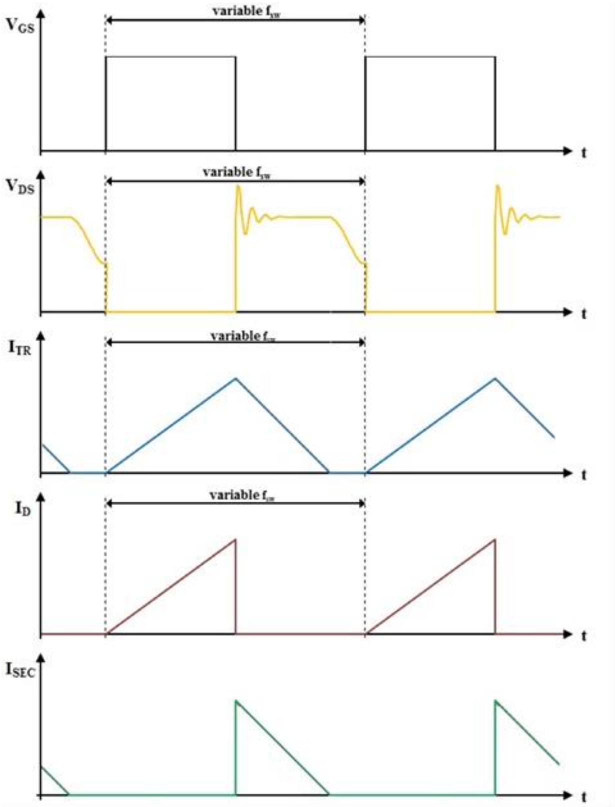



*Figure 5: QR flyback: principle of operation and key waveforms*

## 4 Key technology parameters

When selecting the correct MOSFET for a given flyback topology, there are multiple parameters for designers to review. Each of these parameters has an impact on the performance of the power design. A thorough understanding of these parameters will enable the designer to make the correct trade-offs and select the optimum device for any topology and end application.

### *4.1* $Q_g$ – gate charge

The gate charge ($Q_g$) is discharged and creates heat during each and every switching cycle. Therefore, it can significantly influence the efficiency during light load operation or increased switching frequency.

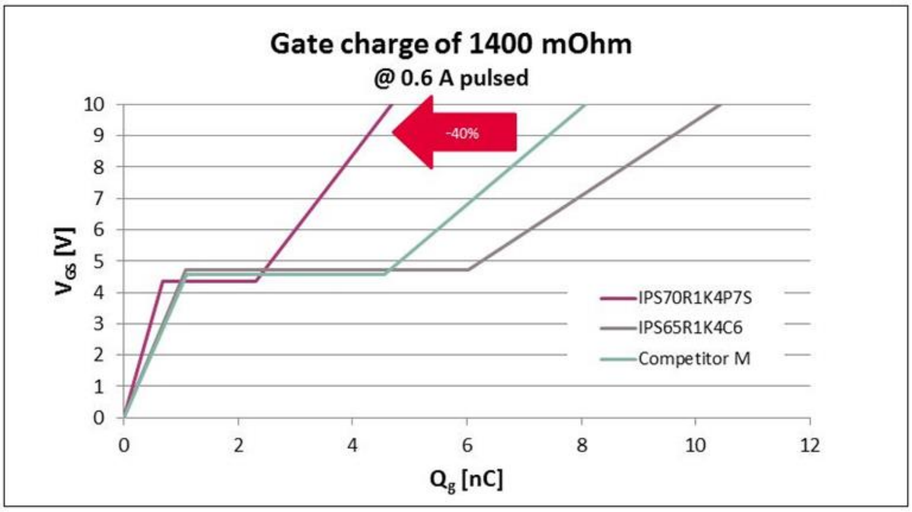



*Figure 6: Gate charge of 1400 mΩ devices at 0.6 A pulsed*

Figure 6 shows that 700 V CoolMOS™ P7 exhibits the lowest $Q_g$ (by at least 40 percent) when compared to earlier technologies. As a result, 700 V CoolMOS™ P7 enables designers to use higher switching frequencies (>100 kHz). This reduces the size and weight of magnetic components used, leading to smaller form factors or higher power densities.

## 4.2 $R_{DS(on)}$ – temperature dependency of on-state resistance

Conduction losses, as defined by the drain-source resistance ($R_{DS(on)}$) significantly influence the efficiency and thermal behavior of converters, especially at lower input voltages (90 $V_{AC}$ to 110 $V_{AC}$). Due to the superjunction MOSFET structure, 700 V CoolMOS™ P7 $R_{DS(on)}$ changes relatively little due to increasing junction temperature.

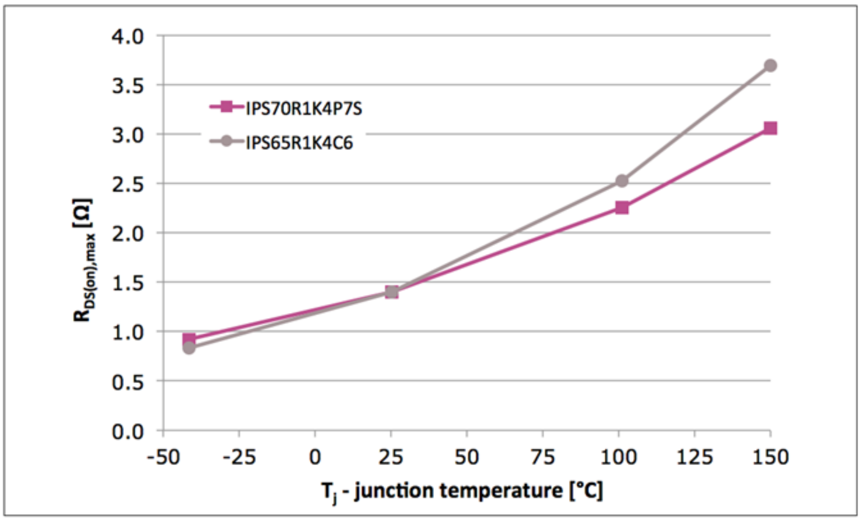



*Figure 7: $R_{DS(on)}$ behavior against junction temperature (Tj)*

At 150°C junction temperature, the 700 V CoolMOS™ P7 shows reductions in $R_{DS(on)}$ by approximately 21 percent compared to Infineon's CoolMOS™ C6 family. This results in reduced MOSFET conduction losses and associated heat generation across the PCB.

## 4.3 $E_{oss}$ – energy stored in output capacitance

High values of $E_{oss}$ can generate significant losses during every MOSFET turn-on. In QR flyback converters, there are no losses ($E_{on}$) as there is no overlap between $I_D$ and $V_{DS}$ as the main transformer current is zero.

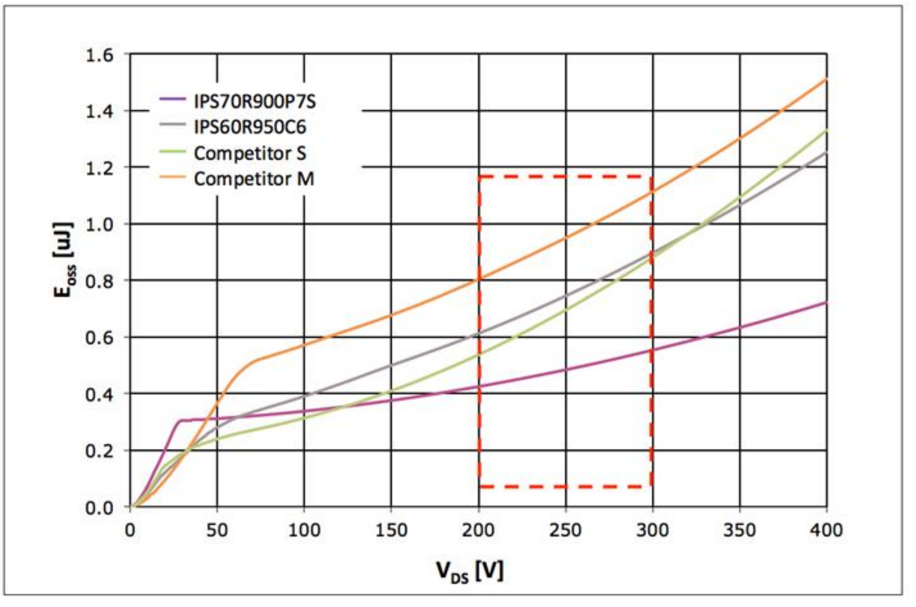



*Figure 8: $E_{OSS}$ comparison of 900 mΩ devices*

700 V CoolMOS™ P7 offers the lowest $E_{oss}$ when $V_{DS}$ is above 50 V. Turn-on $V_{DS}$ at low line is typically between 50 V and 100 V and at high line 200 V to 300 V resulting in turn-on losses that are up to 50% lower than competitive devices. As a result, higher switching frequencies may be used.

## 4.4 $Q_{oss}$ – charge stored in output capacitance

Valley switching typically operates above 50 V $V_{DS}$ where recirculating current creates additional passive losses. Lower levels of $Q_{OSS}$ will reduce these recirculating current losses.

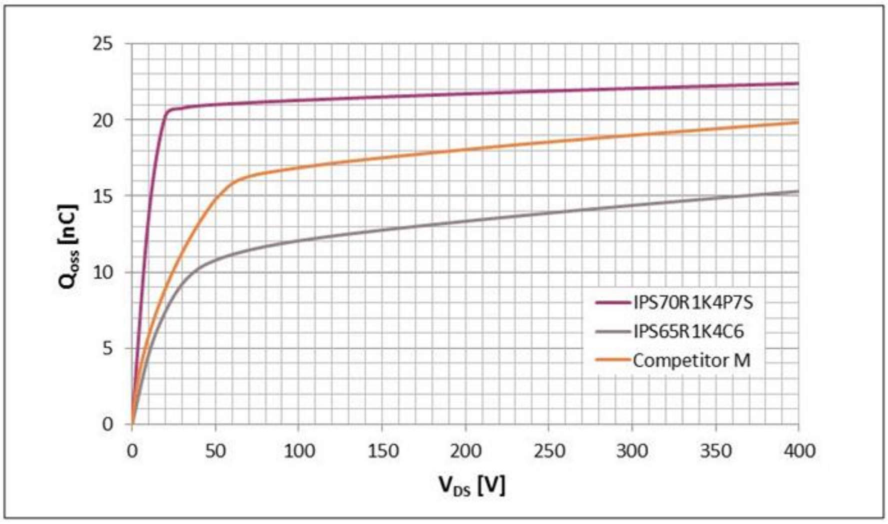



*Figure 9: $Q_{OSS}$ comparison of 1400 mΩ devices*

700 V CoolMOS™ P7 has extremely small $Q_{OSS}$ (1.7 nC) between 50 V and 400 V $V_{DS}$ leading to far lower recirculating current and therefore lower losses when compared to other MOSFETs.

## 5 Benchmarking: 35 W Infineon adapter

Infineon developed a single stage 35 W quasi-resonant flyback adapter, operating between 65 kHz and 80 kHz, that shows the ability to run in DCM for higher power applications while minimizing $E_{on}$ losses. Measurement shows that 700 V CoolMOS™ P7 delivers best performance in higher frequency applications as well as the highest performance in lower frequency applications, thereby also proving the value of 700 V CoolMOS™ P7 in low to mid frequency ranges.

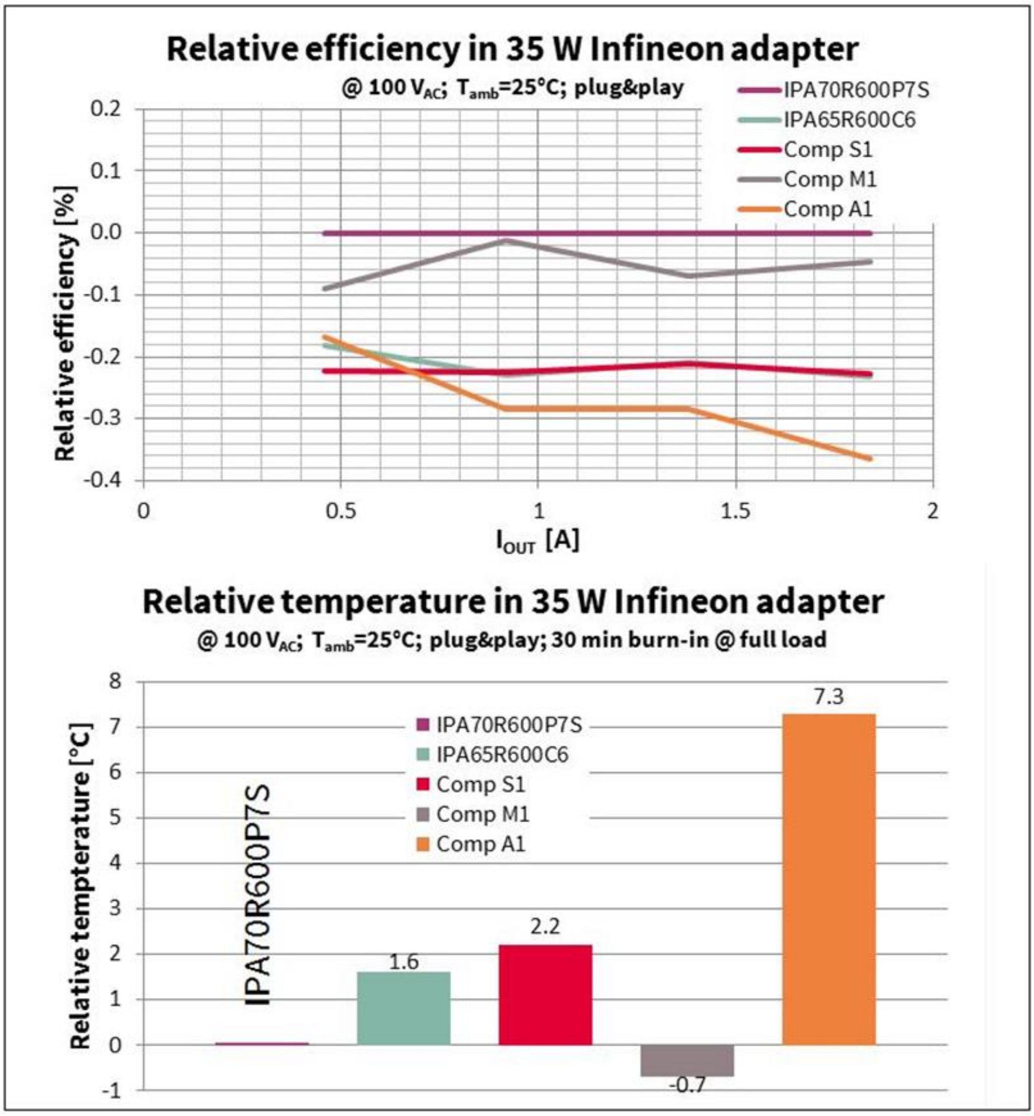



*Figure 10: Efficiency and thermal comparison – 35 W Infineon adapter*

Low to mid frequency performance is not as pronounced as with higher frequency applications. Nevertheless, this analysis also shows that 700 V CoolMOS™ P7 offers higher efficiency and better or equal thermal performance than competitor devices.
Due to the outstanding efficiency in light load conditions, 700 V CoolMOS™ P7 has much higher average efficiency than competitor devices. 700 V CoolMOS™ P7 is an excellent solution for meeting more stringent future efficiency regulations in any new design.

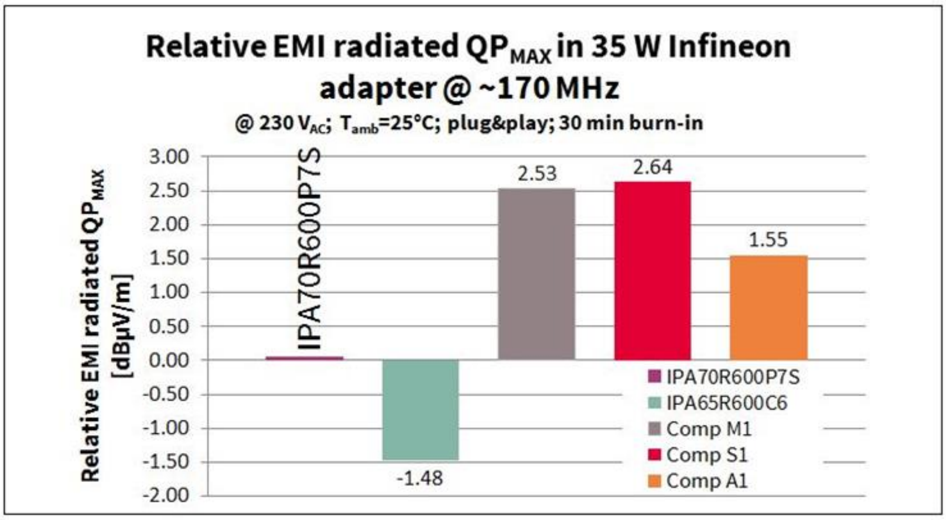
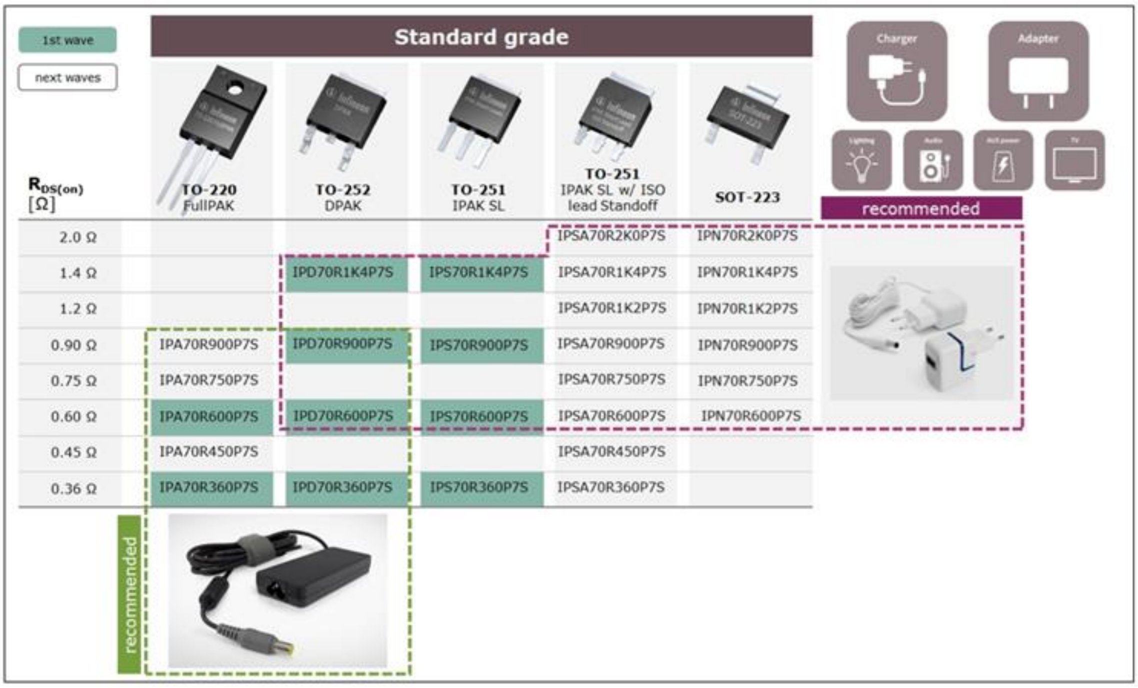



*Figure 11: Radiated 35 W adapter EMI according to EN55022B*

Figure 11 shows that 700 V CoolMOS™ P7 (IPA70R600P7S) has a smaller maximum quasi-peak EMI value over the entire EN55022B frequency range than competitor devices. Only Infineon's IPA65R600C6 shows a better radiated EMI performance. However the efficiency of this device is lower due to higher $Q_g$ and $E_{off}$.

## 6 700 V CoolMOS™ P7 standard product portfolio

700 V CoolMOS™ P7 offers extensive $R_{DS(on)}$ options and multiple relevant packages for low power applications such as lighting, TV, audio and auxiliary power supply applications.




| $R_{DS(on)}$ [Ω] | TO-220 FullPAK | TO-252 DPAK | TO-251 IPAK SL | TO-251 IPAK SL w/ ISO lead Standoff | SOT-223 |
|---|---|---|---|---|---|
| 2.0 Ω | | | | IPSA70R2K0P7S | IPN70R2K0P7S |
| 1.4 Ω | | IPD70R1K4P7S | IPS70R1K4P7S | IPSA70R1K4P7S | IPN70R1K4P7S |
| 1.2 Ω | | | | IPSA70R1K2P7S | IPN70R1K2P7S |
| 0.90 Ω | IPA70R900P7S | IPD70R900P7S | IPS70R900P7S | IPSA70R900P7S | IPN70R900P7S |
| 0.75 Ω | IPA70R750P7S | | | IPSA70R750P7S | IPN70R750P7S |
| 0.60 Ω | IPA70R600P7S | IPD70R600P7S | IPS70R600P7S | IPSA70R600P7S | IPN70R600P7S |
| 0.45 Ω | IPA70R450P7S | | | IPSA70R450P7S | |
| 0.36 Ω | IPA70R360P7S | IPD70R360P7S | IPS70R360P7S | IPSA70R360P7S | |

*Figure 12: Infineon's 700 V CoolMOS™ P7 offers a broad range of choices for designers*

As this is the most recent technology, not all planned 700 V CoolMOS™ P7 devices are in full production yet, although the second wave of devices is imminent. The complete range will feature Infineon's new IPAK package concept that offers short leads with an isolated lead standoff. IPAK can reduce arcing problems between the leads due to solder residues during soldering process and imperfect cleaning processes.
700 V CoolMOS™ P7 will be fully available in SOT-223 packaging that allows for a completely automated production process, thereby further reducing overall production costs.
In the near future (Q1 2017) demoboards for 700 V P7 will be available - please visit the Infineon homepage for more information: www.infineon.com/p7

## 7 Summary

The latest generation of Infineon Technologies' superjunction MOSFETs, the 700 V CoolMOS™ P7, has been developed to serve today's and especially tomorrow's trends in flyback topologies. Significant advantages across all operational parameters ensure market-leading performance in terms of lower thermals, increased efficiency and state of the art EMI behavior. It equips designers with the best-fit devices for target applications and enables them to go towards improved form factors.
In conclusion, those charger and adapter designs using 700 V CoolMOS™ P7 will be smaller, more efficient and finally, contribute to overall system cost reductions.

## List of Figures

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