CoolGaN™ e-mode HEMTs

Mastering power technologies of tomorrow

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Wide bandgap semiconductors
A new era in power electronics

From operating expense and capital expenditure reduction, through higher power density enabling smaller and lighter designs, to overall system cost reduction, the benefits are compelling.
Content

CoolGaN™ e-mode HEMTs 4
Driving CoolGaN™ e-mode HEMTs 7

CoolGaN™ in the applications:
- Server 8
- Telecom 10
- Wireless charging 12
- Adapter and charger 15
- Class D audio 16

CoolGaN™ evaluation environment 18
CoolGaN™ product portfolio 19
CoolGaN™ nomenclature 20
Support 24
Gallium nitride (GaN)
Mastering power technologies of tomorrow

The continuous growth of the world’s population and the acceleration of social development have led to an increasing demand for electricity. The increasingly urgent environmental pressure has forced us to do more with less energy. The key for the next essential step towards an energy-efficient world lies in the use of new materials, like wide bandgap semiconductors which are allowing for greater power efficiency, smaller size, lighter weight, lower cost – or all of these together. Infineon Technologies with its unique position of being the only company currently offering Si, SiC, IGBT and GaN devices is the customer’s first choice in all segments.

Why CoolGaN™
Compared to silicon (Si), the breakdown field of Infineon’s CoolGaN™ enhancement mode (e-mode) HEMTs is ten times higher and the electron mobility is double. Both the output charge and gate charge are ten times lower than with Si and the reverse recovery charge is almost zero which is key for high frequency operations. GaN is the suitable technology of choice in hard switching as well as resonant topologies, and is enabling new approaches in current modulation. Infineon’s GaN solution is based on the most robust and performing concept in the market – the enhancement mode concept offering fast turn-on and turn-off speed. CoolGaN™ products focus on high performance and robustness, and add significant value to a broad variety of systems across many applications such as server, telecom, wireless charging, adapter and charger, and audio.

Comparison of key figures of merit (FOM) for Si, GaN and SiC devices
CoolGaN™ sets the performance benchmark among currently available 600 V devices.

<table>
<thead>
<tr>
<th>Device</th>
<th>Vendor</th>
<th>( R_{\text{DS(on)}} ) [typ mΩ]</th>
<th>( R_{\text{DS(on)}} \cdot Q_{\text{oss}} ) [mΩ•µC]</th>
<th>( R_{\text{DS(on)}} \cdot Q_{\text{gs}} ) [mΩ•µC]</th>
<th>( R_{\text{DS(on)}} \cdot E_{\text{oss}} ) [mΩ•µJ]</th>
<th>( R_{\text{DS(on)}} \cdot Q_{\text{G}} ) [mΩ•nC]</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td>CoolMOS™ C7 600 V</td>
<td>Infineon</td>
<td>57</td>
<td>22.6</td>
<td>32.5</td>
<td>440</td>
<td>3820</td>
<td>Vertical</td>
</tr>
<tr>
<td>CoolGaN™ 600 V</td>
<td>Infineon</td>
<td>55</td>
<td>2.2\textsuperscript{a}</td>
<td>0\textsuperscript{a}</td>
<td>350\textsuperscript{a}</td>
<td>320\textsuperscript{a}</td>
<td>Lateral</td>
</tr>
<tr>
<td>GaN e-mode 650 V</td>
<td>Competitor A</td>
<td>50</td>
<td>2.8</td>
<td>0</td>
<td>350</td>
<td>290</td>
<td>Lateral</td>
</tr>
<tr>
<td>GaN Cascade 600 V</td>
<td>Competitor B</td>
<td>52</td>
<td>3.8</td>
<td>7.0</td>
<td>730</td>
<td>1460</td>
<td>Lateral 2 chips</td>
</tr>
<tr>
<td>GaN D-Drive 600 V</td>
<td>Competitor C</td>
<td>70</td>
<td>4.1</td>
<td>0</td>
<td>530</td>
<td>-</td>
<td>Lateral 2 chips</td>
</tr>
<tr>
<td>SiC DMOS 900 V</td>
<td>Competitor D</td>
<td>65</td>
<td>4.5</td>
<td>4.0</td>
<td>570</td>
<td>1950</td>
<td>Vertical</td>
</tr>
<tr>
<td>SiC TMOS 650 V</td>
<td>Competitor E</td>
<td>60</td>
<td>3.8</td>
<td>3.3</td>
<td>540</td>
<td>3480</td>
<td>Vertical</td>
</tr>
</tbody>
</table>

All values given typical at 25°C incl. package. \( Q_{\text{oss}} \) is exclusive of \( Q_{\text{oss}} \).
\textsuperscript{a} Facilitates dead time setting and enables high frequency designs > 400 kHz
\textsuperscript{b} Switch can be operated as fast switching diode which enables use in totem pole PFC
\textsuperscript{c} Low losses in hard switching topologies
\textsuperscript{d} Low driving losses: benefit especially in light load efficiency

Features
› Low output charge and gate charge
› No reverse recovery charge

Design benefits
› High power density, small and light design
› High efficiency in resonant circuits
› New topologies and current modulation
› Fast and (near-) lossless switching

Advantages
› Operational expenses (OPEX) and capital expenditure (CAPEX) reduction
› BOM and overall cost savings

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GaN devices are by nature normally-on devices, since the 2DEG channel is immediately present in an GaN/AlGaN heterojunction. Power electronics industry, however, strongly wishes normally-off devices. There are two ways to achieve that: the so-called Cascode approach or to realize a real monolithic enhancement mode device. Infineon is focusing on the e-mode GaN concept for its CoolGaN™ 400 V and 600 V devices, suitable for all consumer and industrial applications with the most robust and performing concept in the market.

Enhancement mode GaN (normally-off)
- Excellent for hard and soft switching topologies
- Turn-on and turn-off optimized
- \(R_{\text{DS(on)}}\) shift immunity
- Excellent \(V_{\text{th}}\) stability
- Best FOMs
- Longer lifetime proven

Hybrid drain-Git, normally-off GaN

GaN enables simpler and more efficient half-bridge topologies such as totem pole
Nowadays, several high efficiency topologies for CCM PFC are available like interleaved stages or dual boost. The BOM costs and part count depend on efficiency targets. CoolGaN™ technology enables to use these simpler and cost effective half-bridge/hard switching topologies and at the same time to achieve higher efficiency. With almost zero reverse recovery charge (\(Q_{\text{rr}}\)) CoolGaN™ allows for simpler, highly efficient, and cost effective system solutions in half-bridge totem pole or full-bridge totem pole topologies.

GaN enables highest efficiency and power density
In the evaluation of Infineon’s 2.5 kW PFC FB totem pole board (EVAL_2500W_PFC_GAN_A), CoolGaN™ demonstrates its unique benefits in hard switching topologies showing a flat efficiency of >99% over a wide load range. The use of simplified topologies and the benefits of GaN switching performance additionally allows potential system cost reduction.

2.5 kW totem pole PFC board: EVAL_2500W_PFC_GAN_A
- 2 x 70 mΩ CoolGaN™ in DSO-20 BSC
- 2 x 33 mΩ CoolMOS™

2.5 kW totem pole PFC, efficiency vs. load (\(f_{\text{sw}} = 65\) kHz)

Measured values
All available boards within +/- 0.1%
CoolGaN™ enables higher power density at the same efficiency

The reduced switching losses - associated with GaN - deliver smaller and lighter designs. On one hand, the SMD packaged device allows compact and modular designs, while on the other hand, smaller heatsinks and less components can be used. Additionally, moving to higher switching frequency in certain applications (when required) reduces the size of the passives. At system level, higher power density achieved by GaN-based power supplies allows more computing power to be installed within the same volume.

Qualification that exceeds industry standards

Infineon’s CoolGaN™ is one of the most reliable globally qualified GaN solution in the market. During the quality management process not only the device is tested, but also its behavior in the application. The performance of CoolGaN™ goes beyond other GaN products in the market. It offers a predicted lifetime of more than 15 years, with a failure rate less than 1 FIT.

Infineon’s CoolGaN™ 400 V and 600 V e-mode HEMTs target consumer and industrial applications such as server, telecom, charger and adapter, wireless charging and audio.
GaN EiceDRIVER™ family
Single-channel isolated gate-driver ICs for enhancement mode GaN HEMTs

Infineon’s CoolGaN™ 400 V and 600 V e-mode HEMTs enable 98% + system efficiency and help customers to make their end products smaller and lighter. Driving enhancement mode devices requires some additional features when choosing the correct gate driver IC; however, CoolGaN™ technology does not require customized ICs. Infineon introduces three new members of its single-channel galvanically isolated gate driver IC family. The new components are a perfect fit for enhancement mode GaN HEMTs with non-isolated gate (diode input characteristic) and low threshold voltage, such as CoolGaN™.

Complete support for all requirements specific to e-mode GaN HEMTs operation:
› Low driving impedance (on-resistance 0.85 Ω source, 0.35 Ω sink)
› Resistor programmable gate current for steady on-state (typical 10 mA)
› Programmable negative gate voltage to completely avoid spurious turn-on in half-bridges

Block diagram: typical application example – totem pole full-bridge PFC

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CoolGaN™ in server

Enabling the efficient data flow and storage

Internet of Things (IoT), big data, machine learning and artificial intelligence are driving the power demand for servers and data centers, posing new challenges to SMPS efficiency and form factors. Data center architects face the challenge to increase the delivered power in a given form factor and/or increase efficiency levels to reduce operating costs of server farms.

Both challenges can be addressed with Infineon’s CoolGaN™ technology. By implementing CoolGaN™ in a totem pole PFC combined with a LLC DC-DC stage, more than 98.5% system efficiency can be achieved (for 48 V output voltage systems) providing a total of 2 billion kWh annual savings for US data centers (~ 300 million USD annual savings at 0.15 USD / kWh). Additionally, GaN based SMPS solutions will enable doubling of computed power per rack by pushing the power density to >80 W/in³ from today’s typical ~30 – 40 W/in³ silicon-based solutions.

The outstanding performance of Infineon CoolGaN™ is demonstrated in a full-bridge totem pole PFC board (EVAL_2500W_PFC_GAN_A), reaching >99% peak efficiency. The system has been designed using CoolGaN™ 600 V, 70 mΩ devices in a PG-DSO-20 bottom-side cooled package (IGO60R070D1).
## Product portfolio

<table>
<thead>
<tr>
<th>Functional block</th>
<th>Product category</th>
<th>Topology</th>
<th>Product family</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| **PFC**          | High voltage MOSFETs | CCM/interleaved PFC; TTF | 600 V/650 V CoolMOS™ C7 Hitless 600 V/650 V CoolMOS™ C7 | ➔ Best FOM \( \frac{R_{\text{ON}} \cdot Q_c}{V_{\text{gs}}} \) and \( \frac{R_{\text{ON}} \cdot E_{\text{oss}}}{V_{\text{gs}}} \) per package  
|                  |                  |          |                | ➔ Lowest \( R_{\text{ON}} \) per package  
|                  |                  |          |                | ➔ Low dependency of switching losses form \( R_{\text{on}} \)  
|                  | High voltage GaN | Totem pole PFC | CoolGaN™ 600 V | ➔ Enable the highest efficiency and highest power density  
|                  | SiC diodes       | CCM/interleaved PFC | 650 V CoolSiC™ Schottky diode generation 5 | ➔ Low FOM \( V_{\text{f}} \cdot Q_c \)  
| Control ICs      | CCM PFC IC       | ICE3PC50xG |                  | ➔ Ease-of-use  
|                  | GaN driver IC    | Totem pole PFC | EiceDRIVER™ 1EDF673F and 1EDF673K | ➔ Low driving impedance (on-resistance 0.85 Ω source, 0.35 Ω sink)  
|                  |                  |          |                | ➔ Input-output propagation delay accuracy: ±5 ns  
|                  |                  |          |                | ➔ Functional and reinforced isolation available  
| **Main stage**   | High voltage MOSFETs | ITTF | 600 V CoolMOS™ C7/P6 | ➔ Fast switching speed for improved efficiency and thermals, low gate charge for enhanced light load efficiency and low power consumption at no load condition  
|                  |                  |          |                | ➔ Optimized \( V_{\text{gs}} \) threshold for lower turn-off losses  
|                  |                  |          |                | ➔ Rugged body diode which prevents device failure during hard commutation  
|                  | LLC, half-bridge below 1 kW | 600 V CoolMOS™ P7/CFD6 |                  | ➔ Low turn-off losses  
|                  |                  |          |                | ➔ Low \( Q_{\text{gs}} \)  
|                  | LLC, phase shift full-bridge below 1 kW | 600 V CoolMOS™ CFD1 650 V CoolMOS™ CFD2 |                  | ➔ Fast and rugged body diode  
|                  |                  |          |                | ➔ Optimized \( Q_c \) and soft commutation behavior to reach highest efficiency  
|                  |                  |          |                | ➔ Highest reliability for 650 V VDS  
| Control ICs      | HB LLC IC        | ICE1HS01G-1 |                 | ➔ High efficiency and low EMI  
|                  |                  |          |                | ➔ ICE2HS01G  
|                  | GaN driver IC    | LLC, ZVS phase shift full-bridge | EiceDRIVER™ 1EDS663H | ➔ Low driving impedance (on-resistance 0.85 Ω source, 0.35 Ω sink)  
|                  |                  |          |                | ➔ Input-output propagation delay accuracy: ±5 ns  
|                  |                  |          |                | ➔ Functional and reinforced isolation available  
|                  | GaN e-mode HEMTs | LLC, ZVS phase shift full-bridge | CoolGaN™ 600 V | ➔ Enable the highest efficiency and highest power density  
| **Synchronous rectification** | Low voltage MOSFETs | ITTF | 40 V OptiMOS™ | ➔ High efficiency over whole load range, layout tolerance  
|                  |                  |          |                | ➔ High efficiency, low thermals, low \( V_{\text{ds}} \) overshoot  
|                  | ZVS PS FB and center-tap | 60 V OptiMOS™ |                  | ➔ High efficiency over whole load range, low \( V_{\text{ds}} \) overshoot and oscillations  
| **Auxiliary power supply** | Control ICs | QR/FF Flyback CoolSET™ | ICEQ2R0xx000Z(G) 800 V ICE3A5xx000ZG 800 V ICE3Qx70A(Z) 800 V ICEQx70A(Z) 800 V | ➔ Low standby power, high efficiency and robustness  
|                  |                  |          |                | ➔ An integrated 700 V/800 V superjunction power MOSFET with avalanche capability  
|                  |                  |          |                | ➔ Burst mode entry/exit to optimize standby power at different low load conditions  
| **Housekeeping** | Microcontrollers | XMC1xxx |                  | ➔ Flexibility, HR PWM, digital communication  
|                  |                  |          |                | ➔ ARM® based standard MCU family and wide family  
| **Conversion**   | Microcontrollers | XMC4xxx |                  | ➔ Flexibility, HR PWM and digital communication  
| **PFC, PWM/resonant converter, synchronous rectification** | Gate driver ICs | Single-channel isolated | EiceDRIVER™ 1EDI Compact | ➔ 100 ns typical propagation delay time  
|                  |                  |          |                | ➔ Functional isolation  
|                  |                  |          |                | ➔ Separate source  
|                  | Dual-channel non-isolated | EiceDRIVER™ 2EDNx |                  | ➔ 8 V UVLO option  
|                  |                  |          |                | ➔ 10 V input robustness  
|                  |                  |          |                | ➔ Output robust against reverse current  
|                  | Dual-channel isolated | EiceDRIVER™ 2EDFx |                  | ➔ 35 ns typical propagation delay time  
|                  |                  |          |                | ➔ Functional isolation  
|                  |                  |          |                | ➔ 1.5 kV CMTI > 150 V/ns  

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CoolGaN™ in telecom

Full system solution for telecom power supply

Saving operating and capital expenses, overall power supply footprint and highest solution robustness have been and will remain the major concerns in telecommunication infrastructure development. Infineon’s CoolGaN™ solutions address these challenges by providing benchmark efficiency in the entire operation range, maximizing power density and following Infineon’s stringent qualification regimen.

A 3.6 kW system has been designed using CoolGaN™ 600 V, 70 mΩ (IGT60R070D1) devices in parallel configuration. The system is based on LLC DC-DC topology with up to 400 V\text{DC} input and 52.5 V output voltage, delivering up to 3.6 kW of power at 160 W/inch³ power density. Peak efficiency of this system reaches 98.5% (\(V_{\text{IN}} = 390\) V\text{DC}, \(V_{\text{OUT}} = 52.5\) V), and remains greater than 97% for loads higher than 20%.

Combining CoolGaN™ in the DC-DC stage with CoolGaN™ based PFC stages will maximize achievable power density and power conversion efficiency, and therefore reduce operating expenses for telecom suppliers. In addition, Infineon’s CoolGaN™ devices and technology have been fully qualified based on industrial requirements to ensure ultimate robustness when deployed in telecom SMPS.

<table>
<thead>
<tr>
<th>Functional block</th>
<th>Product category</th>
<th>Topology</th>
<th>Product family</th>
<th>Benefits</th>
</tr>
</thead>
</table>
| PFC              | High voltage MOSFETs | CCM/interleaved PFC; TTF | CoolMOS™ C7 | 600 V/650 V | Best FOM \(R_{\text{DS(on)}} \times Q_{g}\) and \(R_{\text{DS(on)}} \times E_{\text{oss}}\)  
Lowest \(R_{\text{DS(on)}}\) per package  
Low dependency of switching losses form \(R_{\text{DS(on)}}\)  |
| PFC              | High voltage GaN | CCM totem pole | CoolGaN™ 600 V | Switching at high frequencies (> 5kHz)  
Enables high power density  |
| PFC              | SiC diodes | CCM/interleaved PFC | 650 V CoolSiC™ Schottky diode generation 6 | Low FOM \(V_{\text{s}} \times Q_{g}\)  |
| Control ICs      | CCM PFC IC | 800 V - ICE3PCS0xG | High PFC and low THD  |
| GaN driver IC    | Totem-pole PFC | EiceDRIVER™ 1EDF5673F and 1EDF5673K | Low driving impedance (on-resistance 0.85 Ω source, 0.35 Ω sink)  
Input-output propagation delay accuracy: ±5 ns  
Functional and reinforced isolation available  |

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<table>
<thead>
<tr>
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<th>Topology</th>
<th>Product family</th>
<th>Benefits</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DC-DC main stage</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
| DC-DC main stage                    | High voltage MOSFETs | CCM/interleaved PFC; TTF HB LLC | 600 V CoolMOS™ C7/P7    | Fast switching speed for improved efficiency and thermals  
Low gate charge for enhanced light load efficiency and low power consumption at no load condition  
Optimized $V_{gs}$ threshold for lower turn-off losses  
Rugged body diode which prevents device failure during hard commutation                                                                                                                                         |
|                                    |                  |                   |                         | Low turn-off losses  
Low $Q_{on}$  
Low $Q_{g}$  
Best-in-class $Q_{r}$ and $t_{r}$ level  
Significant reduced $Q_{g}$  
Improved efficiency over previous CoolMOS™ fast body diode series                                                                                                                                         |
|                                    |                  |                   |                         |                                                                                                                                                                                                           |
| Control ICs                         | HB LLC IC        |                   | ICE1H501G-1, ICE2H501G | High efficiency and low EMI                                                                                                                                                                                 |
| GaN driver IC                       | LLC, ZVS phase shift full-bridge | EiceDRIVER™ 1ED5S663H |                         | Low driving impedance (on-resistance 0.85 Ω source, 0.35 Ω sink)  
Input-output propagation delay accuracy: +/- 5 ns  
Functional and reinforced isolation available                                                                                                                                                       |
| GaN e-mode HEMTs                    | LLC, ZVS phase shift full-bridge | CoolGaN™ 600 V     |                         | Enable the highest efficiency and highest power density                                                                                                                                                   |
| **Synchronous rectification**       |                  | Synchronous rectification MOSFET | OptiMOS™ 80-150 V      | Industry's lowest FOM ($R_{on,ss}Q_{g}$) leading to high efficiency at good price/performance  
Low voltage overshoots enabling easy design-in  
Industry's lowest $R_{on,ss}$  
Highest system efficiency and power density  
Outstanding quality and reliability  
Reduces the need for a snubber circuit                                                                                                                                                                  |
|                                    | Low voltage MOSFETs | Synchronous rectification MOSFET |                         | Quasi-resonant switching operation for high efficiency and low EMI signature  
Fixed frequency switching operation for ease-of-design – 100 KHz and 125 KHz  
Fast and robust start-up with cascade configuration  
Robust protection with adjustable line input over-voltage protection, $V_{	ext{in}}$ and $C_{S}$ pin short-to-ground protection  
Optimized light-load efficiency with selectable burst mode entry/exit profile  
Frequency reduction for mid and light load condition to reduce switching losses and increase efficiency  
Direct feedback and regulation with integrated error amplifier for non-isolated output  
High power delivery of up to 42 W with 800 V heatsink-less SMD package CoolSET™                                                                                                                     |
| **Auxiliary power supply**          | Control ICs      | 5th generation QR/FF flyback CoolSET™ | Q8 800 V - ICEQQRx80Ax  
QF 800 V - ICEQxRxx80AX | Quasi-resonant switching operation for high efficiency and low EMI signature  
Fixed frequency switching operation for ease-of-design – 100 KHz and 125 KHz  
Fast and robust start-up with cascade configuration  
Robust protection with adjustable line input over-voltage protection, $V_{	ext{in}}$ and $C_{S}$ pin short-to-ground protection  
Optimized light-load efficiency with selectable burst mode entry/exit profile  
Frequency reduction for mid and light load condition to reduce switching losses and increase efficiency  
Direct feedback and regulation with integrated error amplifier for non-isolated output  
High power delivery of up to 42 W with 800 V heatsink-less SMD package CoolSET™                                                                                                                     |
| **Housekeeping**                    | Microcontrollers | -                  | XMC1xxx                 | Flexibility, HR PWM, digital communication  
ARM® based standard MCU family and wide family                                                                                                                                                            |
| **Conversion**                      | Microcontrollers | -                  | XMC4xxx                 | Flexibility, HR PWM, digital communication  
ARM® based standard MCU family and wide family                                                                                                                                                            |
| **PFC, PWM/ resonant converter, synchronous rectification** | Gate driver ICs | Single channel non-isolated | EiceDRIVER™ 1EDN751x  | 8 V UVLO option  
(10 V input robustness  
Output robust against reverse current                                                                                                             |
|                                    |                  | Single channel non-isolated | EiceDRIVER™ 1EDN7550 | 8 V UVLO option  
(10 V input robustness  
True differential inputs for >100 $V_{	ext{gs}}$ ground shift robustness                                                                                                                                |
|                                    |                  | Dual channel non-isolated | EiceDRIVER™ 2EDN7x     | 8 V UVLO option  
(10 V input robustness  
Output robust against reverse current                                                                                                             |
|                                    |                  | Dual channel junction isolated | EiceDRIVER™ 2EDL811x  | 20 ns typ. propagation delay time  
20 V bootstrap capability on high side  
(7 V input robustness                                                                                                                                            |
|                                    |                  | Single channel isolated | EiceDRIVER™ 1ED Compact | 100 ns typ. propagation delay time  
Functional isolation 1.2 kV separate source and sync outputs                                                                                                                                            |
|                                    |                  | Dual channel isolated | EiceDRIVER™ 2EDFx      | 35 ns typ. propagation delay time  
Functional isolation 1.5 kV CMTI > 150 V/ns                                                                                                                                                    |
|                                    |                  | Dual channel isolated | EiceDRIVER™ 2EDSx      | 35 ns typ. propagation delay time  
Functional isolation 1.5 kV CMTI > 150 V/ns                                                                                                                                                    |
| **Or-ing**                          | Low voltage MOSFETs | Or-ing MOSFET      | OptiMOS™ 60-200 V       | Industry's lowest FOM ($R_{on,ss}Q_{g}$) leading to high efficiency at good price/performance  
Low voltage overshoots enabling easy design-in                                                                                                                                                       |
| **Battery protection**              | Low voltage MOSFETs | MOSFET             | OptiMOS™ 60-150 V       | Industry's lowest $R_{on,ss}$  
Highest system efficiency and power density  
Outstanding quality and reliability  
Reduces the need for a snubber circuit                                                                                                                                                                  |
| **Isolated DC-DC**                 | Low voltage MOSFETs | Primary side PW MOSFET | OptiMOS™ 60-200 V       | Industry's lowest $R_{on,ss}$  
Highest system efficiency and power density  
Outstanding quality and reliability  
Reduces the need for a snubber circuit                                                                                                                                                                  |
|                                    |                  | Synchronous rectification MOSFET | OptiMOS™ 40-100 V     | Industry's lowest $R_{on,ss}$  
Highest system efficiency and power density  
Outstanding quality and reliability  
Reduces the need for a snubber circuit                                                                                                                                                                  |
|                                    |                  | Or-ing MOSFET      | OptiMOS™ 25-30 V        | Industry's lowest $R_{on,ss}$  
Highest system efficiency and power density  
Outstanding quality and reliability  
Reduces the need for a snubber circuit                                                                                                                                                                  |

* Upcoming Q1 2019
The prospect of wirelessly charging our mobile devices has been around for years and has recently become reality with the proliferation of inductive wireless charging technology. However, to make wireless charging truly ubiquitous and offer improved end-user convenience (e.g., improved freedom of positioning), wireless charging solutions need to further evolve, and likely will apply the magnetic-resonance technology over time. For the latter, high transmission frequencies (multiple MHz) are required, which poses significant challenges to standard silicon power technologies within the transmitter and the receiver devices. Infineon is developing resonant solutions for transmitter, receiver and adapter to serve the upcoming requirements of various wireless charging applications.

Due to its significantly reduced parasitic capacitances, CoolGaN™ technology is the ideal choice when switching at frequencies in the MHz range (e.g., 6.78 MHz as required by the resonant AirFuel wireless charging standard).

Class E and class D topologies are the main topologies of choice when resonant wireless charging is applied. Both topologies reduce switching losses by transitioning between on- and off-switching position of the power devices at zero volt across the respective power switch. In the class D ZVS topology, lower breakdown voltage devices can be used, thereby increasing the overall system efficiency. In the class E topology, however, simpler driver architecture (low-side only) and only a single switch per class E branch offer the prospects of reduced system cost. CoolGaN™ is ideally suited to address both topologies by either maximizing overall system performance (in class D implementations) or reducing overall system solution cost (in class E implementation).

Infineon’s CoolGaN™ devices have been successfully tested in a 16 W class E wireless charging demonstrator system as well as in customer implementations operating at 6.78 MHz at higher watt class.

Having a reliable partner by your side is key to maximize the performance and consumer appeal of your wireless charging designs. At Infineon, we help you master your design challenges with our broad selection of semiconductors and our powerful CoolGaN™ products.

**System diagram: resonant class E single-ended with CoolGaN™**

**Target applications**
# Components for resonant (AirFuel) and high frequency solutions

<table>
<thead>
<tr>
<th>Sub-application</th>
<th>Voltage class</th>
<th>Package</th>
<th>Part number</th>
<th>( R_{\text{on}} \text{ max} ) @ ( V_{GS} = 4.5 \text{ V} ) [mΩ]</th>
<th>( Q_t ) typical [nC]</th>
<th>( C_{oss} ) typical [pF]</th>
<th>Topology</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inverter MOSFETs</td>
<td>30 V</td>
<td>PQFN 2 x 2</td>
<td>IRLHS6376PbF</td>
<td>48</td>
<td>2.8</td>
<td>32</td>
<td>Class D</td>
</tr>
<tr>
<td></td>
<td>30 V</td>
<td>PQFN 3.3 x 3.3 Dual</td>
<td>BSZ0909ND</td>
<td>25</td>
<td>1.8</td>
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<td>80 V</td>
<td>PQFN 2 x 2</td>
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<td>2.5</td>
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<td>100 V</td>
<td>PQFN 2 x 2</td>
<td>IRL100HS121</td>
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<td>PQFN 3.3 x 3.3</td>
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<td>PQFN 3.3 x 3.3</td>
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<td>7.2**</td>
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<td>BSZ900N20NS3</td>
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** Driver ICs **
- EiceDRIVER™ 2EDL71
- EiceDRIVER™ 1EDN7512, 2EDN7524
- EiceDRIVER™ GaN driver IC 1EDS5663H, 1EDF5673F, 1EDF5673K

** GaN e-mode HEMTs **
- CoolGaN™ 600 V e-mode GaN HEMT IGT60R190D1S (HDSOF-8-3)

** Microcontroller **
- XMC™ MCU and wireless power controller XMC™-SC* (including software IP)

** Voltage regulators **
- IR3841MPbF, IFX20002, IFX901041E,JV50, IFX901221EJV50, IFX81481EJV

** Small signal MOSFETs **
- Please check online

---

* Coming soon
** \( V_{GS} = 8 \text{ V} \)

---

**Find the right solutions for your wireless charging designs in four steps**

For Infineon’s complete offering of devices for inductive, resonant or in-cabin car charging access the Infineon wireless charging selection tool that allows you to find the right solutions for your designs in just four steps: select the application, power range, standard and the topology you want to apply and get an overview of Infineon’s most recommended offerings.
GaN EiceDRIVER™ family

Single-channel isolated gate-driver ICs for enhancement mode GaN HEMTs

Release the full potential of GaN e-mode HEMTs with Infineon’s silicon-based drivers. The combined solution of CoolGaNTM and EiceDRIVER™ reduces the complexity in customer design, bringing ease-of-use into modern topologies.

Interested? Learn more at: www.infineon.com/gan
CoolGaN™ in adapter and charger

Travelling with multiple and often clunky chargers and adapters for phones, tablets and laptops has been a nuisance for many consumers, and often leads to frustrations due to the additional weight and required space. Over the past years, manufacturers of chargers and adapters became increasingly aware of these issues and a trend towards higher power density and consequently smaller devices has emerged. Today, the typical power topology used in such systems is a flyback power conversion topology, and the form factor is limited by the efficiency achievable at 90 VAC input voltage and full load. The highest power density systems available today reach ~12 W/in³ (for 65 W maximum output power).

Infineon’s CoolGaN™ supports a breakthrough with respect to power density for adapter and charger systems, enabling ~20 W/in³ power density systems (for 65 W maximum output power). This advantage can be realized by implementing Infineon’s CoolGaN™ in a half-bridge topology that allows increasing switching frequency and efficiency simultaneously.

<table>
<thead>
<tr>
<th>Functional block</th>
<th>Product category</th>
<th>Topology</th>
<th>Product family</th>
<th>Benefits</th>
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<tbody>
<tr>
<td>Flyback converter</td>
<td>High voltage MOSFETs</td>
<td>Flyback</td>
<td>600 V/700 V/800 V CoolMOS™ P7</td>
<td>Fast switching speed for improved efficiency and thermals. Reduced gate charge for enhanced light load efficiency. Optimized VGS threshold for lower turn-off losses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Active clamp flyback</td>
<td>CoolGaN™ 600 V</td>
<td>Highest efficiency. Highest power density.</td>
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<tr>
<td></td>
<td></td>
<td>Hybrid flyback</td>
<td></td>
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<tr>
<td></td>
<td>Low voltage MOSFETs</td>
<td>Flyback/auxiliary</td>
<td>OptiMOS™ 100 V-150 V</td>
<td>Low conduction losses and reduced overshoot. Logic level can support low voltage gate drive to achieve high efficiency.</td>
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<tr>
<td>Control ICs</td>
<td></td>
<td>synchronous rectification</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Control ICs</td>
<td>QR flyback IC</td>
<td>ICEQ503G, ICEQSAG</td>
<td>High efficiency and low standby power.</td>
</tr>
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<td></td>
<td></td>
<td>FFR flyback IC</td>
<td>IDP2105</td>
<td>High power density and digital control.</td>
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<tr>
<td>PFC</td>
<td>High voltage MOSFETs</td>
<td>DCM PFC</td>
<td>600 V CoolMOS™ P7</td>
<td>Fast switching speed for improved efficiency. Reduced gate charge for enhanced light load efficiency. Optimized VGS threshold for lower turn-off losses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ZVS totem pole</td>
<td>CoolGaN™ 600 V</td>
<td>Highest efficiency contribution via less parasitic parameter. Space saving with SMD smaller package.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>DCM PFC</td>
<td>650 V Rapid 1</td>
<td>Easy control of switching behavior due to higher RDS, lower transition losses versus standard MOSFET.</td>
</tr>
<tr>
<td>Boost diode</td>
<td>DCM/PFC</td>
<td>650 V Rapid 1</td>
<td></td>
<td>Low conduction losses.</td>
</tr>
<tr>
<td>Control ICs</td>
<td>DCM PFC ICs</td>
<td>TDA4863G, IRS2505LTPBF</td>
<td></td>
<td>Simple external circuitry. High power factor and low THD.</td>
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<tr>
<td>Main stage</td>
<td>High voltage MOSFETs</td>
<td>HB LLC</td>
<td>600 V CoolMOS™ P7</td>
<td>Fast switching speed for improved efficiency and thermals. Reduced gate charge for enhanced light load efficiency. Optimized VGS threshold for lower turn-off losses.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>CoolGaN™ 600 V</td>
<td></td>
<td>Highest efficiency. Highest power density.</td>
</tr>
<tr>
<td>Synchronous rectification</td>
<td>Low voltage MOSFETs</td>
<td>Synchronous rectification</td>
<td>OptiMOS™ S 100 V-150 V</td>
<td>Low conduction losses, reduced overshoot. Logic level switching.</td>
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<tr>
<td>Control ICs</td>
<td>Synchronous rectification</td>
<td>IR1161TRPBF</td>
<td></td>
<td>High efficiency. Simple external circuitry.</td>
</tr>
</tbody>
</table>

www.infineon.com/smps
CoolGaN™ for class D audio

Maximize audio performance

Class D audio amplifiers have practically eliminated class A/B amplifiers as they offer greatly improved energy efficiency, and thereby enable small form factor designs for even high power amplification. In addition, class D audio amplifiers theoretically can reach 0% distortion and 100% energy efficiency in case the power switch in the class D stage is an ideal switch that results in excellent sound quality and practically negligible thermal design limitations.

Infineon's CoolGaN™ technology allows approaching the theoretical ideal performance of class D audio amplifiers due to its unique characteristics, perfectly suited for this application: zero reverse recovery charge (Qrr) of the body diode, linear input and output capacitances, and extremely fast switching speeds (lowest Qgd and Rg) result in ideal switching waveforms, close to an ideal switch. These ideal switching waveforms are the prerequisite to maximize audio performance and minimize power losses in class D audio amplifiers.

Infineon's CoolGaN™ 400 V devices in PG-DSO-20-87 and PG-TOLL packages have been tested in class D audio amplifier applications on 300 W + 300 W dual-channel system designs.

Infineon’s audio solutions

www.infineon.com/audiosolutions
### Integrated class D audio modules

<table>
<thead>
<tr>
<th>Specifications</th>
<th>IR4301M</th>
<th>IR4321M</th>
<th>IR4311M</th>
<th>IR4302M</th>
<th>IR4322M</th>
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<td>90 W</td>
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<td>130 W</td>
<td>100 W</td>
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<td>~ ±25 V or 50 V</td>
<td>~ ±15 V or 32 V</td>
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### Class D driver IC selection guide

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<th>IRS20965S</th>
<th>IRS20957S</th>
<th>IRS2092S</th>
<th>IRS2052M</th>
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<td>±200 V</td>
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<td>0.6/0.5 A</td>
<td>0.6/0.5 A</td>
<td>0.6/0.5 A</td>
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<td>IRAUDAMP5</td>
<td>IRAUDAMP7S</td>
<td>IRAUDAMP7D</td>
<td>IRAUDAMP9</td>
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<td>IRAUDAMP10</td>
<td>IRAUDAMP8</td>
<td>EVAL_IRAUDAMP23</td>
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</table>

### CoolGaN™ 400 V e-mode GaN HEMTs for class D audio product portfolio

<table>
<thead>
<tr>
<th>Specifications</th>
<th>PG-DSO-20-87 (Top-side cooling)</th>
<th>PG-TOLL (To-Leadless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{max}}$</td>
<td>Up to 500 W</td>
<td>Up to 200 W</td>
</tr>
<tr>
<td>$R_{\text{on, max.}}$</td>
<td>70 Ω</td>
<td>70 Ω</td>
</tr>
<tr>
<td>Typical part number</td>
<td>IGOT40R70D1*</td>
<td>IGOT40R70D1*</td>
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</tbody>
</table>

* Coming soon
CoolGaN™ boards
Driving the innovation

Infineon’s CoolGaN™ devices benefit from Infineon’s innovative spirit towards challenging applications like telecom rectifiers, SMPS servers, or class D audio where CoolGaN™ technology proved to be highly reliable. It is the most rugged and reliable solution in the market, available in high performing SMD packages to fully exploit the benefits of GaN. With a set of available evaluation boards, comprehensive online training materials and a global support structure Infineon allows for an easier transition to these new technologies and allows for faster prototyping and go-to-market.

PFC for server SMPS and telecom rectifiers – 99.3% peak efficiency
› 2.5 kW totem pole PFC using IGO60R070D1 (70 mΩ/600 V in DSO-20-85 bottom-side cooling)
› Order code: EVAL_2500W_PFC_GAN_A

LLC for telecom rectifiers – ~160 W/in³ @ >98% peak efficiency
› 3.6 kW LLC, 52 V Vout, 350 kHz using IGT60R070D1 in primary side (70 mΩ/600 V in TO-leadless)
› Order code: EVAL_3K6W_LLC_GAN*

High frequency (>1 MHz) half-bridge platform
› Functional board with 2 x 1EDF5673K in LGA package, 2 x IGOT60R070D1 (DSO-20-87 top-side cooling packages)
› Order code: EVAL_1EDF_G1_HB_GAN**

300 W + 300 W class D audio amplifier
› 300 W + 300 W class D audio amplifier boards, ±75 Vrms using IGOT40R070D1 or IGOT40R070D1 (70 mΩ in TO-leadless or DSO-20-87 top-side cooling packages)
› Order code: EVAL_AUDAMP24*

*Order on request
**Coming soon

Discover 3D models of the boards and get access to GaN training materials:
www.infineon.com/gan
CoolGaN™ product portfolio
Infineon's solutions to master power technologies of tomorrow

CoolGaN™ 400 V e-mode HEMTs

<table>
<thead>
<tr>
<th>Package</th>
<th>PG-DSO-20-87 (Top side cooling)</th>
<th>HSOF-8-3 (TO-leadless)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P_max</td>
<td>Up to 500 W</td>
<td>Up to 200 W</td>
</tr>
<tr>
<td>R_{D(on)\text{max.}}</td>
<td>70 Ω</td>
<td>70 Ω</td>
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<td>Typical part number</td>
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<td>IGT40R070D1*</td>
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</table>

* Coming soon

CoolGaN™ 600 V e-mode HEMTs

<table>
<thead>
<tr>
<th>R_{D(on)\text{max.}}</th>
<th>DSO-20-85 (Bottom-side cooling)</th>
<th>DSO-20-87 (Top-side cooling)</th>
<th>HSOF-8-3 (TO-leadless)</th>
<th>DFN 8x8</th>
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</thead>
<tbody>
<tr>
<td>35 mΩ</td>
<td>IGO60R035D1**</td>
<td>IGO60R035D1**</td>
<td>IGT60R035D1**</td>
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<tr>
<td>70 mΩ</td>
<td>IGO60R070D1</td>
<td>IGT60R070D1</td>
<td>IGLD60R070D1</td>
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<td>190 mΩ</td>
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<td>340 mΩ</td>
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<td>IGT60R190D1**</td>
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</table>

*Standard grade  **Coming soon

GaN EiceDRIVER™ product portfolio
Release the full potential of the e-mode HEMTs

Infineon’s CoolGaN™ devices, driven by single-channel isolated gate driver ICs from the GaN EiceDRIVER™ family, aim to unlock the full potential of GaN.

GaN EiceDRIVER™ family product portfolio

<table>
<thead>
<tr>
<th>Produkt</th>
<th>Package</th>
<th>Input to output isolation</th>
<th>Propagation delay accuracy</th>
<th>Typ. high level (sourcing) output resistance</th>
<th>Typ. low level (sinking) output resistance</th>
<th>SP number</th>
</tr>
</thead>
<tbody>
<tr>
<td>1EDF5673K</td>
<td>LGA, 13-pin 5x5 mm functional</td>
<td>V_{D} = 1.5 kV_{dc}</td>
<td>n.a.</td>
<td>n.a.</td>
<td>-6 ns/+7 ns</td>
<td>0.85 Ω</td>
</tr>
<tr>
<td>1EDF5673F</td>
<td>DSO, 16-pin 150 mil functional</td>
<td>V_{D} = 1.5 kV_{dc}</td>
<td>n.a.</td>
<td>n.a.</td>
<td>-6 ns/+7 ns</td>
<td>0.85 Ω</td>
</tr>
<tr>
<td>1EDS5663H</td>
<td>DSO, 16-pin 300 mil reinforced</td>
<td>V_{D} = 8 kV_{pk} V_{DS} = 5.7 kV_{rms}</td>
<td>V_{D(on)} &gt; 10 kV_{pk}</td>
<td>VDE0884-10 UL1577</td>
<td>-6 ns/+7 ns</td>
<td>0.85 Ω</td>
</tr>
</tbody>
</table>

www.infineon.com/gan
www.infineon.com/gan-eicedriver
CoolGaN™ nomenclature

Company
I = Infineon

Technology
G = GaN

Package type
LD = DFN 8 x 8-LSON
T = TOLL
O = DSO20-BSC
OT = DSO20-TSC

Voltage
Divided by 10 (60x10 = 600 V)

Reliability grade
blank = Industrial
A = Automotive
S = Standard

Generation
1 = 1st generation

Product type
D = Discrete
S = System

$R_{DSS}[\text{m}\Omega]$

$R = R_{DSS}$
A world leader in semiconductor solutions

Our vision
We are the link between the real and the digital world.

Our values
We commit
We partner
We innovate
We perform

Our mission
We make life easier, safer and greener.

Part of your life. Part of tomorrow.
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