Quick-reference guide to driving CoolGaN™ GIT HEMTs 600 V

RC interface

Author: Dr. Bainan Sun

About this document

Scope and purpose

This application note introduces the RC interface configuration for Infineon CoolGaN™ gate injection high electron mobility transistor (GIT HEMT) 600 V gate driving. First a brief introduction of Infineon's CoolGaN™ GIT HEMT 600 V ohmic p-GaN structure and typical driving circuit is given. By using a dedicated/standard gate driver, CoolGaN™ GIT HEMTs can be driven easily through the RC interface. A step-by-step RC interface tuning guide is then given. Finally, typical RC interface configuration values are given in the form of look-up tables for different slew-rate requirements and target applications.

This application note is intended to be used as a quick-reference guide for RC interface design in driving Infineon CoolGaN™ GIT HEMTs (**Figure 1**). For a more in-depth explanation of the driving mechanism, please refer to **Driving CoolGaN™ GIT HEMT 600 V high electron mobility transistors** [1]. In addition, to get more insights on the gate drive requirements and driving solutions for CoolGaN™ GIT HEMTs, check out the available Whitepaper [4].

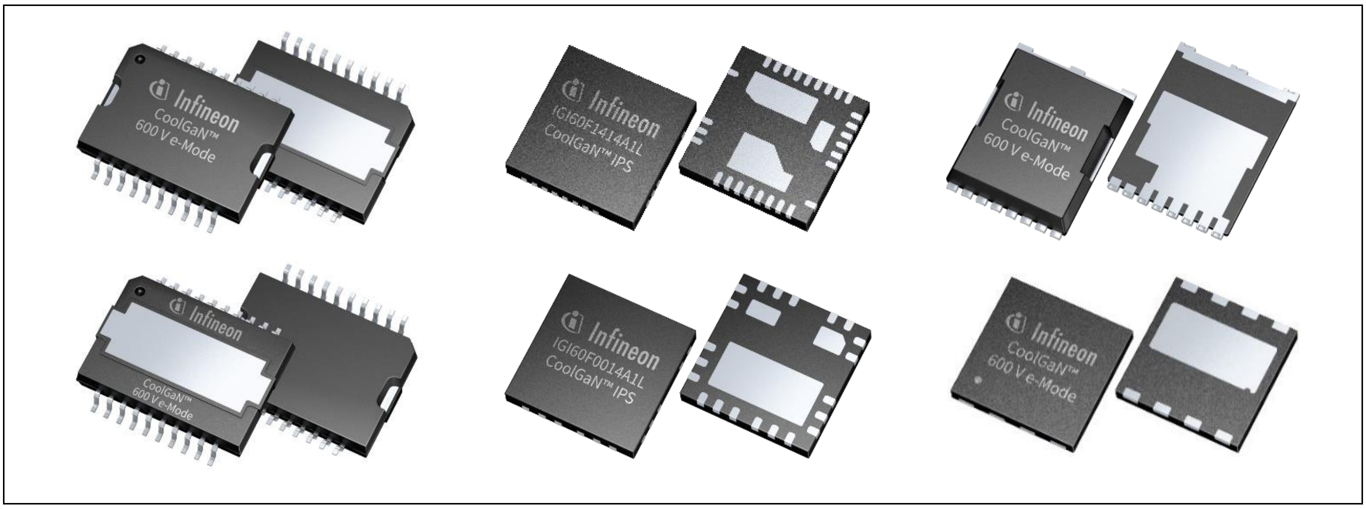

Figure 1 CoolGaN™ GIT HEMTs and CoolGaN™ IPS products

Intended audience

This application note is mainly targeted at application engineers and circuit designers using **CoolGaN™ GIT HEMTs 600 V** [2] and **CoolGaN™ Integrated Power Stage (IPS)** [3].

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1 What are CoolGaN™ GIT HEMT and RC interface?

Infineon's CoolGaN™ GIT HEMT is a highly efficient GaN transistor technology for power conversion in the voltage range up to 600 V. CoolGaN™ GIT HEMT 600 V adopts an ohmic p-GaN gate structure. Relevant advantages of this construction include:

Positive gate threshold voltage

CoolGaN™ GIT HEMT is a normally-off device, and its improved figure of merit (FOM) makes it an ideal replacement for a silicon MOSFET in SMPS applications.

Robust and reliable gate drive

CoolGaN™ GIT HEMTs have diode-like input characteristics. This provides voltage clamp and helps avoid any overvoltage damage to the transistor gate.

Highly stable $R_{DS(on)}$ over drain current

During the CoolGaN™ GIT HEMT on-state, constant gate current enables independence of $R_{DS(on)}$ over drain current.

Although CoolGaN™ GIT HEMTs are robust enhancement mode devices, their gate module differs from a MOSFET, which behaves like a diode with a forward voltage V_F of 3 to 4 V. Therefore, a continuous gate current I_{ss} of a few mA is needed during the steady on-state, and high gate charging currents I_{on} and I_{off} up to 1 A are needed for fast-switching transients. Since the switch is normally-off with a low threshold voltage V_{th} around 1.2 V, a negative gate bias during the off-state is needed to prevent false gate triggering in hard-switching applications.

To avoid a dedicated driver with two separate on-paths and bipolar supply voltage, the RC interface is the gate drive circuit recommended by Infineon for CoolGaN™ GIT HEMTS 600 V GIT, which is shown in **Figure 2**.

Three components in the RC interface are included in the gating circuit:

R_{ss}: steady-state gate current tuning resistor

R_{tr}: transient switching speed dv/dt tuning resistor

C_C: coupling capacitor as charge pump to provide fast-switching transient as well as negative gate bias

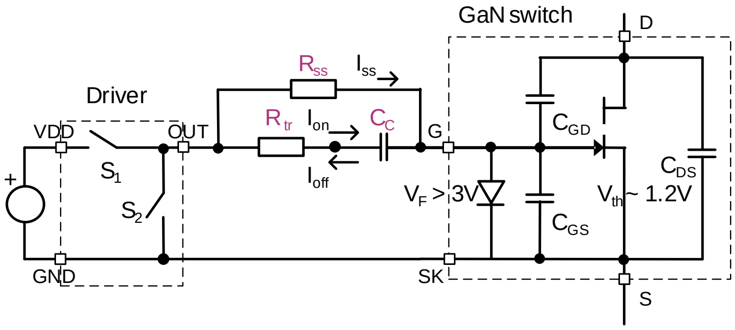

Figure 2 Typical gate drive RC interface for Infineon CoolGaN™ GIT HEMT 600 V

2 RC interface advantages

Key advantages of the RC interface scheme include:

Ease of use

Negative gate voltage can be directly tuned with the RC interface configuration. No level-shift circuit is needed in the gate driver. The RC interface is compatible with dedicated/standard gate drivers.

Controllable dv/dt transient control

Turn-on/-off speed, on-state gate current and off-state reverse gate bias voltage are controllable thanks to the RC interface, which can be fine-tuned for EMI control, common-mode noise reduction and motor-drive applications.

Efficient drive

Negative gate bias is gradually discharged after the turn-off transient, which is beneficial for power loss reduction during operation in the third quadrant.

The typical gating waveform of the Infineon RC interface and piecewise analysis of the gating procedure of CoolGaN™ GIT HEMTs are given in **Figure 3** and **Figure 4** respectively. During the gate-on transient, the fast-charging path is formed by R_{tr} and C_C. After that, constant current is injected into the CoolGaN™ GIT HEMT gate through R_{ss} during the transistor steady on-state. During the gate-off transient, gate charge is discharged through R_{tr} and C_C. During the off-state, charge stored in the coupling capacitor C_C is gradually discharged, which contributes to negative gate voltage $-V_N$ and then gradually decreases to $-V_{Nf}$.

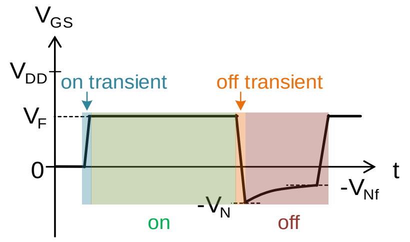

Figure 3 Typical gate voltage of CoolGaN™ GIT HEMT

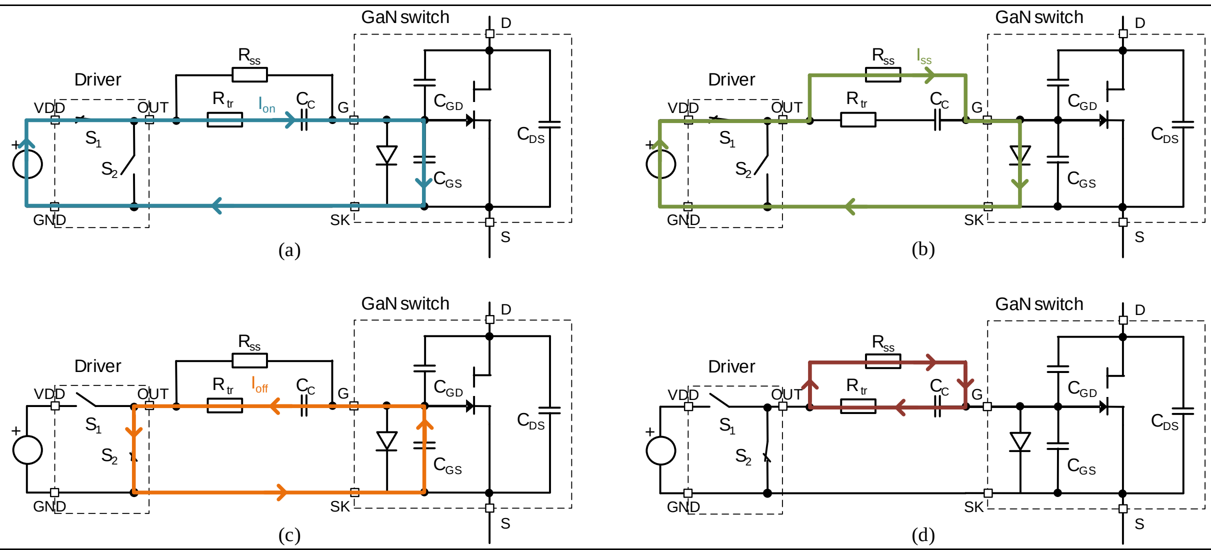

Figure 4 Typical gating procedure of CoolGaN™ GIT HEMTs

3 Tuning the RC interface

3.1 General tuning rules

R_{ss} tuning

R_{ss} is tuned according to gate voltage V_{DD}, gate diode forward voltage drop V_F (3~4 V), and desired on-state gate current I_{ss}. Reference R_{ss} selection in different $R_{DS(on)}$ devices is given in **Table 1**.

It should be noted that reference I_{ss} and R_{ss} values are given to maintain the device at low $R_{DS(on)}$ in typical applications. In low source current applications, dependence of device $R_{DS(on)}$ on I_{ss} is low. In this case, a higher R_{ss} value can be chosen to lower gate driver loss and achieve higher overall efficiency. In high source current applications, a lower R_{ss} value should be used to maintain the device at the lowest $R_{DS(on)}$.

Please always refer to typical drain-source on-resistance curve in the CoolGaN™ GIT HEMT and CoolGaN™ IPS product datasheet for fine-tuning in different source current use cases.

$$I_{ss} = \frac{V_{DD} - V_F}{R_{ss}} \tag{1}$$

Table 1 Reference I_{ss} value for different CoolGaN™ GIT HEMTs

$R_{DS(on,typ)}$	55 mΩ	100 mΩ	140 mΩ	200 mΩ	270 mΩ	500 mΩ
$R_{DS(on,max)}$	70 mΩ	130 mΩ	190 mΩ	260 mΩ	340 mΩ	650 mΩ
Reference I_{ss}	10~12 mA	5~6 mA	3~4 mA	~3 mA	~2 mA	~1 mA
Reference R_{ss}	470 Ω	860 Ω	1.2 kΩ	1.5 kΩ	2.2 kΩ	4 kΩ

Note: Reference R_{ss} values are given with V_{DD} = 8 V.

R_{tr} tuning

R_{tr} is tuned according to the desired switching slew rate in different applications. In hard-switching conditions, low R_{tr} is desired to achieve a high slew rate and thus reduce hard-switching loss. A typical R_{tr} value for $R_{DS(on,typ)}$ = 140 mΩ device is within the range of 20 to 50 Ω with V_{DD} = 8 V. This value can be scaled to other ohmic class devices according to the desired slew rate. In soft-switching conditions, selection of R_{tr} is uncritical.

Maximum source and sink current can be quantified according to:

$$I_{on,max} \sim \frac{V_{DD} - V_{Nf}}{R_{tr}} \qquad I_{off,max} \sim \frac{V_{th} + V_N}{R_{tr}} \tag{2}$$

C_C tuning

C_C is tuned according to the desired negative gate voltage bias $-V_N$ during the transistor off-state. V_N must always be positive and can be quantified according to:

$$V_N = \frac{C_C \cdot (V_{DD} - V_F) - Q_{Geq}}{C_C + C_{GS}} \tag{3}$$

with Q_{Geq} denoting an equivalent switching gate charge ($Q_{Geq} = Q_{GS}$ for a hard-switching system and $Q_{Geq} \sim Q_{GS} + Q_{GD}$ for a soft-switching system).

In hard-switching conditions, V_N is recommended around 4 to 5 V depending on circuit topology and slew rate, which should be designed according to a trade-off between false trigger immunity and third-quadrant operation loss. In soft-switching conditions, V_N can be lowered down to 2 V or even close to zero in specific soft-switching topologies.

3.2 Reference RC interface tuning for typical applications

3.2.1 Hard-switching and soft-switching

In hard-switching applications, the turn-on slew rate should be well-controlled to achieve a trade-off between switching loss and drain-source voltage overshoot. Typical RC interface designs in hard-switching applications are given in **Table 2**.

Table 2 Typical RC interface designs in hard-switching applications

$R_{DS(on,typ)}$	$R_{DS(on,max)}$	R_{tr}	R_{ss}	C_C	Turn-on slew rate	$-V_N$
55 mΩ	70 mΩ	5.6 Ω	470 Ω	3.3 nF	~ 105 V/ns	~ -3 V
		10 Ω	470 Ω	3.3 nF	~ 90 V/ns	~ -3 V
		15 Ω	470 Ω	3.3 nF	~75 V/ns	~ -3 V
		10 Ω	470 Ω	4.7 nF	~ 90 V/ns	-4 V ~ -5 V
140 mΩ	190 mΩ	20 Ω	1.8 kΩ	1.5 nF	~ 100 V/ns	~ -3 V
		27 Ω	1.8 kΩ	1.5 nF	~ 80 V/ns	~ -3 V
		47 Ω	1.8 kΩ	1.5 nF	~ 60 V/ns	~ -3 V
		20 Ω	1.8 kΩ	3.3 nF	~ 100 V/ns	-4 V ~ -5 V

Note: Reference values are given with EiceDRIVER™ 1EDi/2EDi series gate driver and V_{DD} = 8 V. The slew rate in applications is subject to system design and PCB layout.

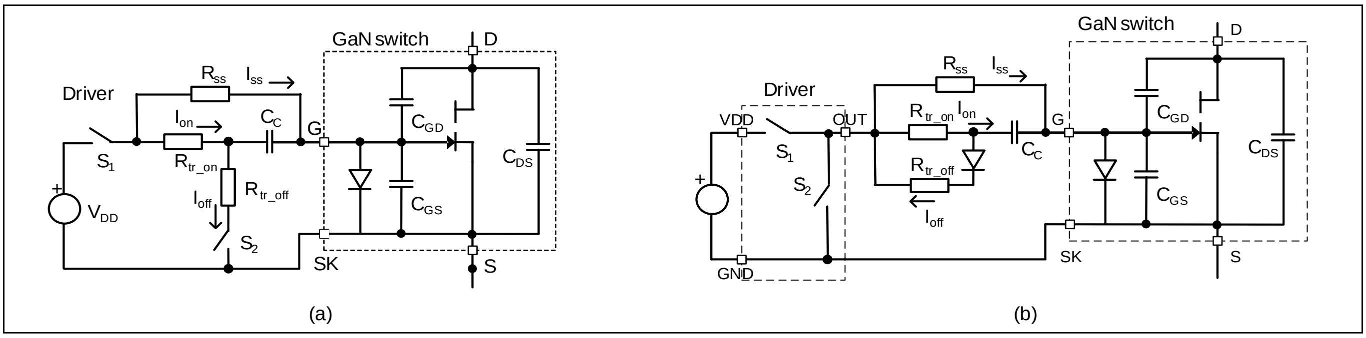

Figure 5 Reference RC interface design for CoolGaN™ GIT HEMT in separate gate path applications

When designing a gate driver with a separate gate path, the RC interface can be configured with an independent transient gate-on resistor R_{tr_on} and gate-off resistor R_{tr_off}, as shown in **Figure 5(a)**. For a gate driver with unified output, a diode in the gate-off loop can be installed to independently control the turn-on and turn-off speed as shown in **Figure 5(b)**. In hard-switching applications, a larger R_{tr_on} is selected to avoid transistor drain-source voltage overshoot and a smaller R_{tr_off} is selected to guarantee sufficient damping of oscillations in the gate loop.

In soft-switching applications, simultaneous high current and high voltage in the power switching is avoided, which yields much slower voltage transients with typical slopes of only a few V/ns. Negative gate voltage bias ($-V_N$) should be chosen to be as low as possible, recommended within -2 V. R_{tr_on} and R_{tr_off} are obviously less critical in soft-switching applications and can be chosen to be higher than in hard-switching applications.

3.2.2 CoolGaN™ IPS products

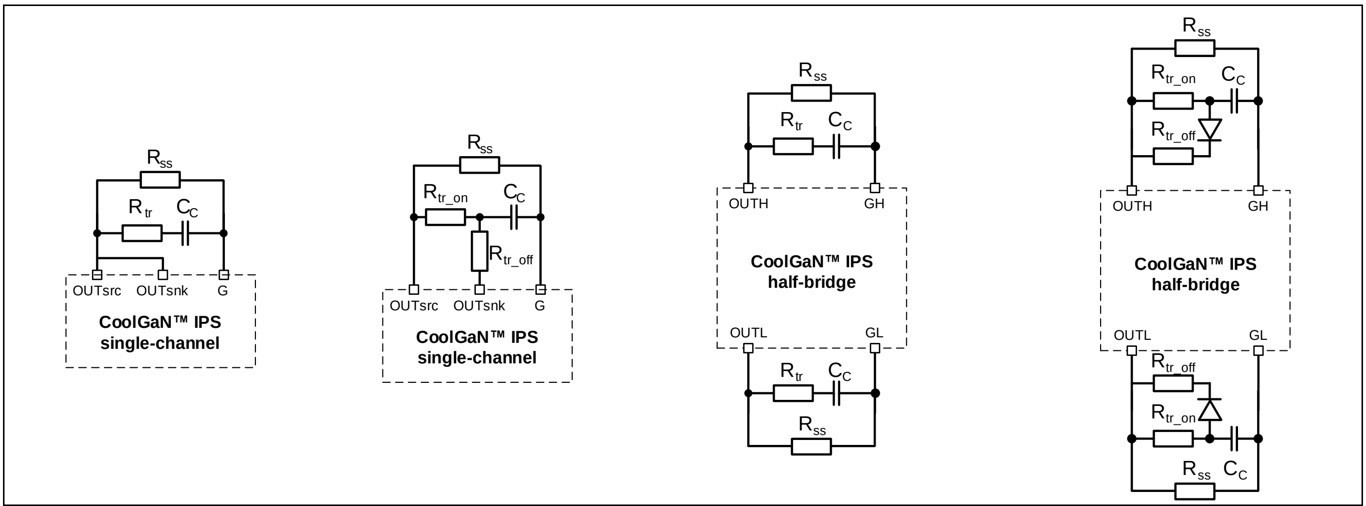

Figure 6 RC interface configuration in CoolGaN™ IPS products

The RC interface circuit is also compatible with **CoolGaN™ IPS products**. The same tuning circuit and methodology can be configured in half-bridge and single-channel products, as shown in **Figure 6**.

3.2.3 Motor-drive applications

CoolGaN™ GIT HEMTs are advantageous in motor-drive applications for their low switching loss, small form factor and high temperature stability characteristics. Considering the physical limitations of motor winding, the slew rate of CoolGaN™ GIT HEMTs should be largely reduced. To achieve this goal, the RC interface shown in **Figure 7** should be configured.

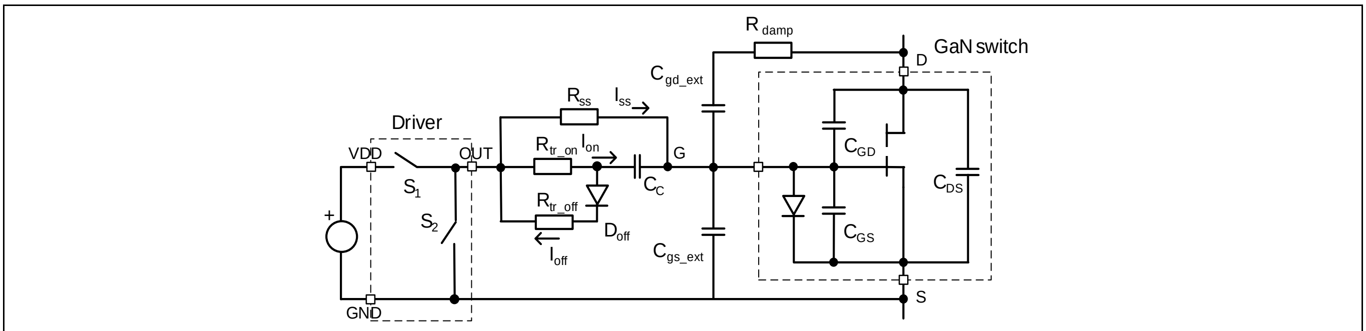

Figure 7 Reference RC interface configuration for CoolGaN™ GIT HEMTs in motor-drive applications

Table 3 Reference RC interface design for CoolGaN™ GIT HEMTs in motor-drive applications

$R_{DS(on,typ)}$	$R_{DS(on,max)}$	R_{tr_on}	R_{tr_off}	C_C	R_{ss}	C_{gd_ext}	R_{damp}	C_{gs_ext}	Slew rate
270 mΩ	340 mΩ	200 Ω	20 Ω	3 nF	2 kΩ	5~9 pF	50 Ω	100 pF	~ 5 V/ns
270 mΩ	340 mΩ	200 Ω	20 Ω	3 nF	2 kΩ	w/o	w/o	2 nF	~ 10 V/ns

Note: Reference values are given with EiceDRIVER™ 1EDi/2EDi series gate driver and V_{DD} = 8 V. The slew rate in applications is subject to system design and PCB layout.

The RC interface values shown in **Table 3** are given as reference design for motor-drive applications. A large gate-on resistor R_{tr_on} is selected to slow down the switching speed. A low gate resistance path formed by R_{tr_off}

Tuning the RC interface

and D_{off} provides safe turn-off conditions. Extra capacitance C_{gs_ext} and C_{gd_ext} is paralleled to the transistor input to slow down the switching speed to 5 V/ns and prevent false triggering. R_{damp} is installed to the external C_{gd_ext} path to prevent unwanted gate ringing. For space-constrained applications, a high blocking voltage C_{gd_ext} capacitor is not wanted. In this case, a larger C_{gs_ext} can be selected to reduce slew rate down to 10 V/ns.

4 References

[1] Application note: **Driving CoolGaN™ GIT HEMT 600 V high electron mobility transistors**

[2] Infineon CoolGaN™ HEMT: **https://www.infineon.com/coolgan**

[3] Infineon CoolGaN™ Integrated Power Stage (IPS): **https://www.infineon.com/coolgan-ips**

[4] White paper: Gallium nitride - **Gate drive solutions for CoolGaN™ GIT HEMTs**

List of abbreviations

HEMT .... high electron mobility transistor

CoolGaN™ IPS .... CoolGaN™ Integrated Power Stage

MOSFET .... metal-oxide semiconductor field-effect transistor

SMPS .... switch-mode power supply

$R_{DS(on)}$ .... transistor on-state resistance

$R_{DS(on,typ)}$ .... transistor on-state resistance typical value

$R_{DS(on,max)}$ .... transistor on-state resistance maximum value

V_F .... gate diode forward voltage drop

V_{th} .... gate threshold voltage

I_{on} .... gate-on current

I_{off} .... gate-off current

R_{SS} .... steady-state gate current tuning resistor

R_{tr} .... transient switching speed dv/dt tuning resistor

R_{tr_on} .... transient gate-on resistor

R_{tr_off} .... transient gate-off resistor

C_C .... gate coupling capacitor

$-V_N$ .... negative gate voltage at the start of transistor off-state

$-V_{Nf}$ .... negative gate voltage at the end of transistor off-state

V_{DD} .... gate-supply voltage

V_{GS} .... gate-source voltage

I_{ss} .... on-state gate current

$I_{on,max}$ .... transient maximum gate-on current

$I_{off,max}$ .... transient maximum gate-off current

Q_{geq} .... equivalent switching gate charge

C_{GS} .... gate-source capacitance

Q_{GS} .... gate-source charge

Q_{GD} .... gate-drain charge

C_{gd_ext} .... external gate-drain capacitor

C_{gs_ext} .... external gate-source capacitor

R_{damp} .... damping resistor in external gate-drain capacitor path

Revision history

Document version	Date of release	Description of changes
V 1.0	2021-08-11	First release
V 1.1	2021-12-02	Updated denomination of CoolGaN™ GIT HEMTs

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