OptiMOS™ 7 motor-drive optimized N-channel MOSFET 40 V

Product description and application performance

About this document

Scope and purpose

This application note provides an in-depth look at the advantages and technical details of Infineon's latest 40 V N-channel MOSFET products, featuring the latest OptiMOS™ 7 motor drive-optimized technology. The purpose of this document is to present a detailed description of these products within their standard applications.

Intended audience

This document is primarily designed for design engineers, technicians, and power electronic system developers, who work on electronic systems that necessitate the use of 40 V MOSFETs.

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1 Introduction: the OptiMOS™ 7 motor drive-optimized MOSFET

Infineon's OptiMOS™ 7 motor drive-optimized MOSFET family presents "drive optimized" discrete power MOSFETs, ideally suited for the power and gardening tool applications.

The 40 V motor drive-optimized MOSFETs portfolio offers low on-state resistance ($R_{DS(on)}$) with standard package options, including PG-TDSON (PQFN 5x6), PG-TSDSON (PQFN 3.3 x 3.3), and PG-WSON-8 (PQFN 5x6 dual-side cooled). The full illustration of the portfolio is in Figure 2.

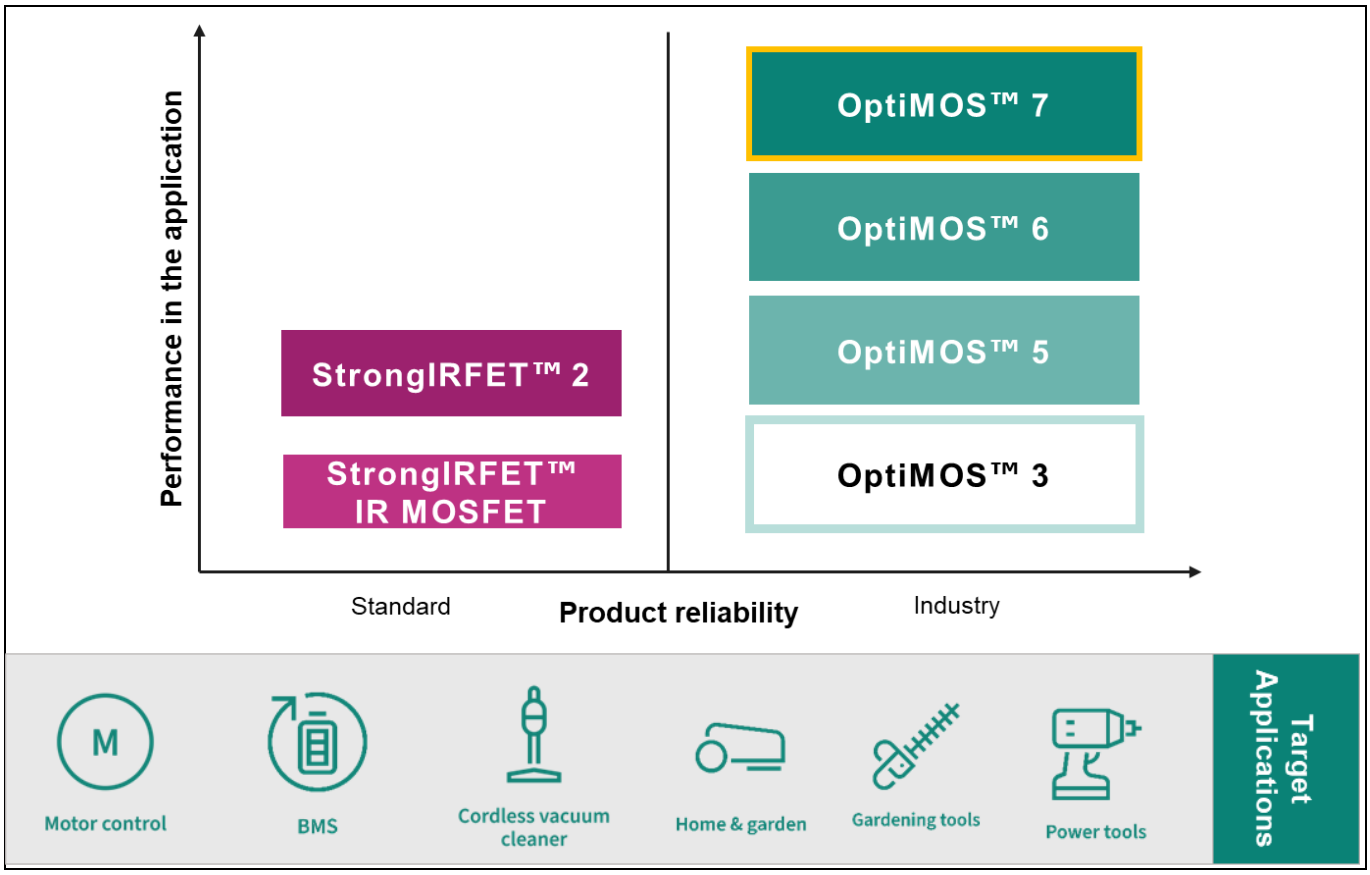


Figure 1 Product positioning of OptiMOS™ 7 motor-drive optimized MOSFET

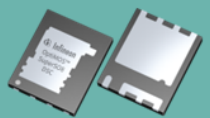
40 V OptiMOS™ 7 MOSFETs Drives Optimized				
	$R_{DS(on)\ max}$ [mΩ]	 PG-TSDSON (PQFN 3X3)	 PG-TDSON (PQFN 5X6)	 PG-WSON-8 (PQFN 5X6 DSC)
	<1		ISCH54N04NM7V	ISCH5xN04NM7VSC
			ISCH69N04NM7V	ISCH7xN04NM7VSC
			ISCH99N04NM7V	ISCH9xN04NM7VSC
	1.1~1.6		ISC011N04NM7V	
			ISC012N04NM7V	
		ISZ015N04NM7V		
			ISC016N04NM7V	

Figure 2 OptiMOS™ 7 motor drive-optimized MOSFET portfolio

1.1 Motor drive in power and gardening tools

A motor drive system is a crucial component in power and gardening tools. The engineers of these products are always working hard to improve:

- Efficiency
- Precise torque control
- Wide speed range
- Lifespan
- Dynamic performance
- Cost-performance balance

The block diagram of a typical drive system in a cordless power tool is shown in Figure 3 [1]. The power source of the system is a pack of rechargeable battery, followed by a 3-phase inverter (power stage) powering an electric motor. As these have been developed for decades, the brushless DC motor (BLDC) becomes the first choice for a drive system.

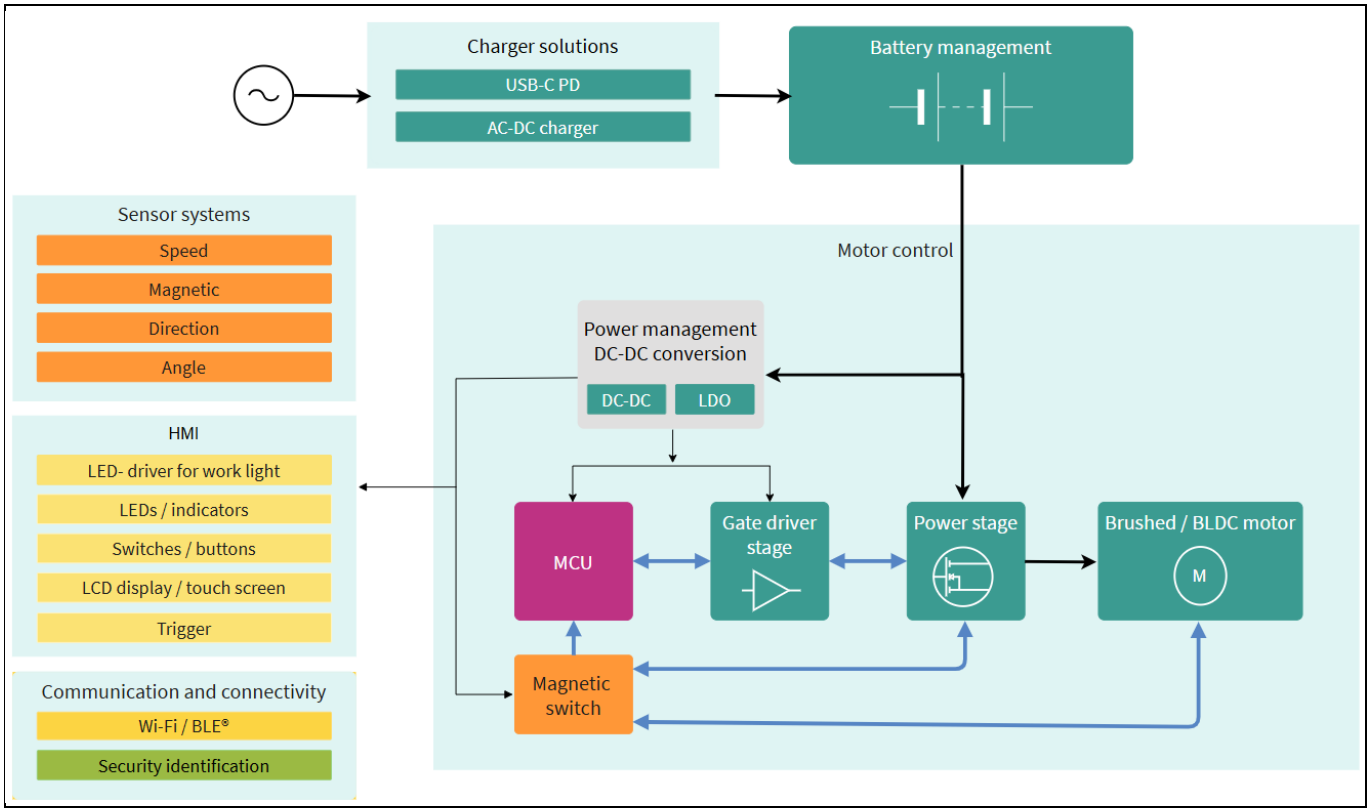


Figure 3 Battery powered tools system diagram

A good algorithm and electronics of the BLDC drive system are critical to a drive system performance. Block commutation control methods are widely used in the drive system. However, compared to block commutation, field-oriented control (FOC) with proper design has the following advantages:

- Higher efficiency
- Smooth and precise torque control
- Wider speed range
- Better performance at low-speed range
- Faster dynamic response

However, these benefits have some requirements. FOC requires the hardware with:

- High accuracy current sense on 2 or 3 phases
- Accurate rotor position sensing instead of hall sensing
- More powerful MCU
- Faster feedback and control
- Optimized MOSFETs

As increasingly power and gardening tools are implementing FOC, the demand for the related electronics products is increasing.

Infineon's OptiMOS™ 7 motor drive-optimized MOSFETs are introduced to fulfill the demand.

1.2 Motor drive optimized specs of OptiMOS™ 7 MOSFET 40 V

Infineon's OptiMOS™ 7 motor drive-optimized devices are designed to fulfill the demand of MOSFETs that fit for higher power-density systems and FOC-algorithm-based motor drive systems. The major improvements are highlighted in Figure 4.

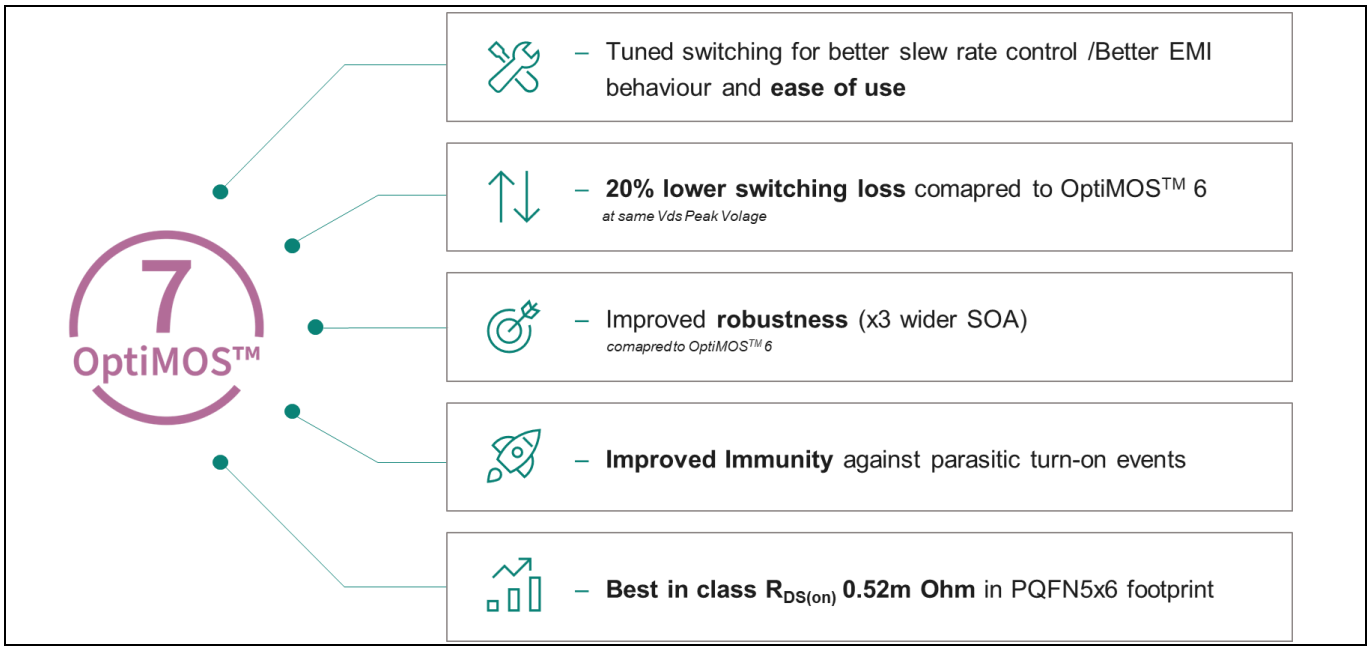


Figure 4 Technology improvement of OptiMOS™ 7 motor drive-optimized MOSFETs

1.2.1 Superior $R_{DS(on)}$

The losses of a MOSFET in 3-phase inverter of a motor drive can be divided into three parts: conduction loss, switching loss, and body-diode conduction loss.

Conduction loss is dependent on many factors, such as phase current, duty cycle, and $R_{DS(on)}$ of the MOSFET. But for the MOSFET itself, $R_{DS(on)}$ is the only factor that affects conduction loss. The lower $R_{DS(on)}$, the lower conduction loss, if other conditions remain the same.

OptiMOS™ 7 power MOSFET 40 V family provides superior $R_{DS(on)}$: $R_{DS(on)\text{-}max}$ of the best-in-class MOSFET in the OptiMOS™ 7 family with PQFN 5x6 package is 0.52 mΩ. Compared to the same-in-class MOSFET of the OptiMOS™ 6 family, the OptiMOS™ 7 MOSFET has up to 20% lower $R_{DS(on)}$.

1.2.2 Improved immunity

The value of induced voltage on the gate (induced V_{GS}) of a MOSFET is a critical factor for false-turn-on in motor drive applications. As shown in Figure 5, during the high-side turn-on transient, the V_{DS} of the low-side MOSFET rises from zero to BUS voltage. The fast-increasing V_{DS} causes current flow through the C_{GD} (I_{CGD}). The current I_{CGD} flowing through R_G and V_{GS} will consequently increase.

A MOSFET with a higher threshold voltage ($V_{GS(th)}$) has higher immunity to induced V_{GS}.

The threshold voltage ($V_{GS(th)}$) of OptiMOS™ 7 motor drive optimized MOSFETs is 2.8 V (typical), which is higher than OptiMOS™ 6 MOSFETs.

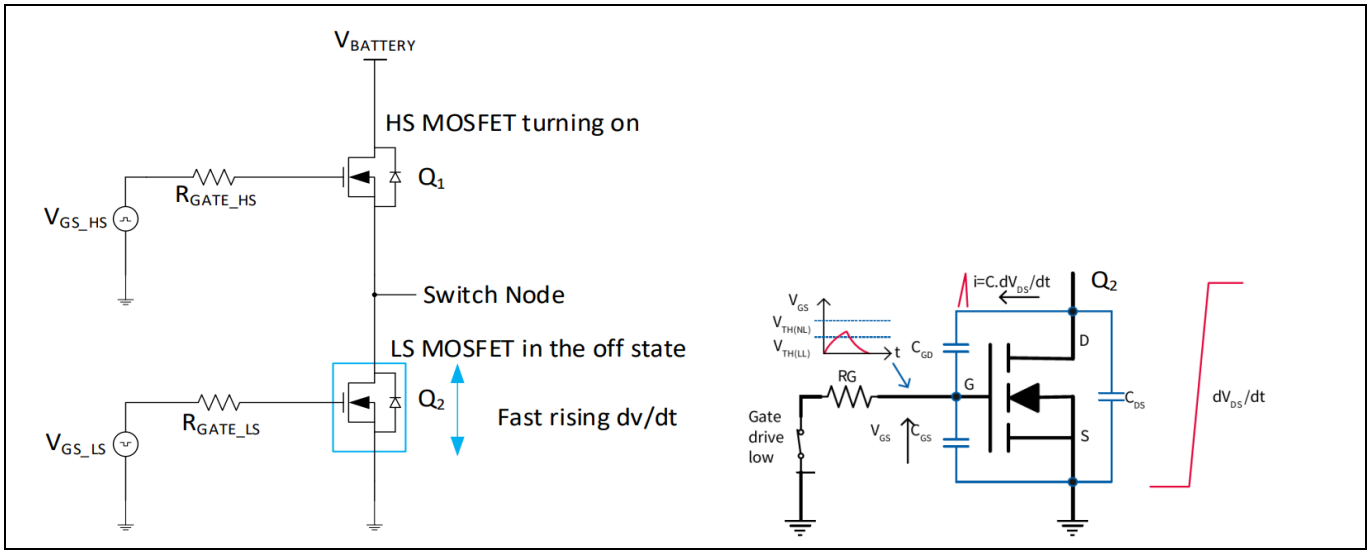


Figure 5 Mechanism of induced gate voltage

1.2.3 3X wider safe operating area

The safe operating area (SOA) is a critical attribute of a MOSFET in a motor drive. The SOA diagram defines the allowed maximum current-voltage range of a MOSFET.

In motor drive applications, wider SOA provides higher current capability and better reliability, especially during low-speed-high-torque scenario and locked-rotor scenario.

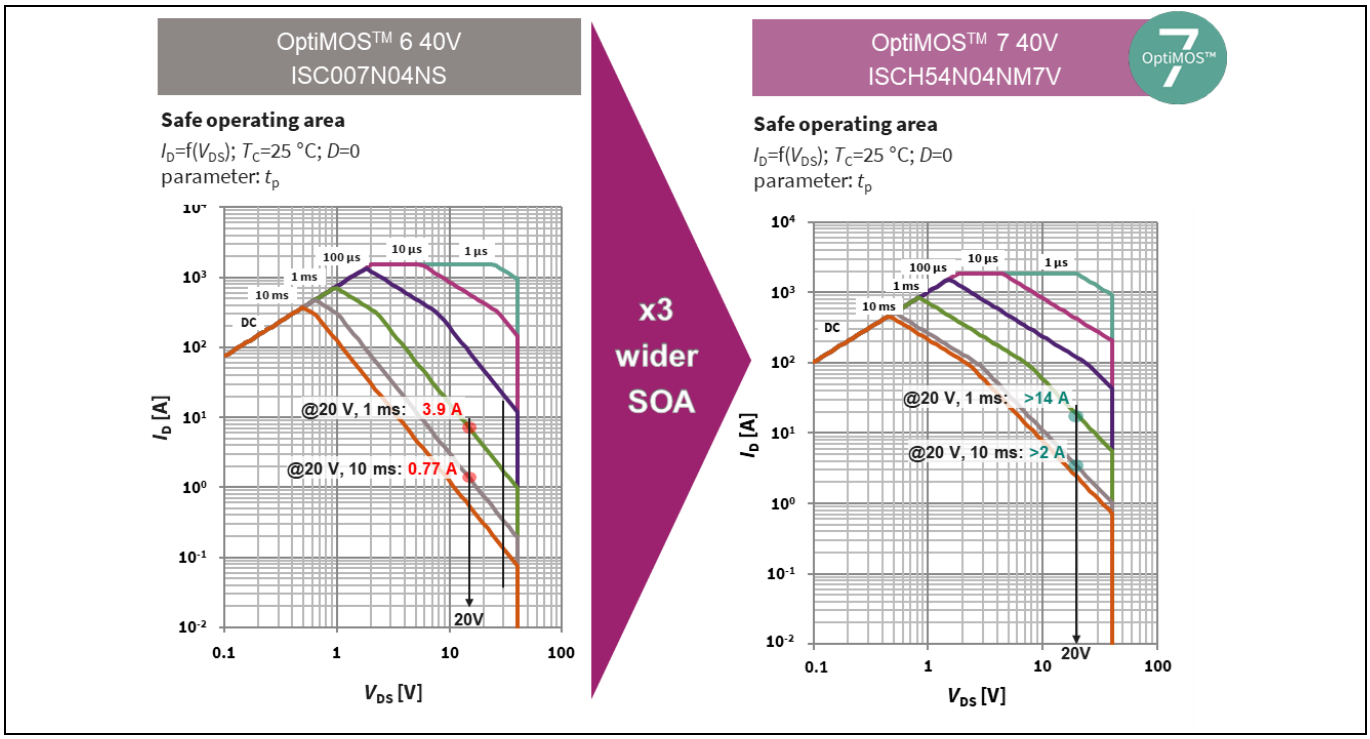


Figure 6 SOA graphs of OptiMOS™ 7 and OptiMOS™ 6

As shown in Figure 6, the SOA of OptiMOS™ 7 MOSFET ISCH91N04LM7 is three times wider than that of OptiMOS™ 6 same-in-class MOSFET BSC009N04LSSC.

1.2.4 Optimized gate characteristics

Gate-source charge (Q_{GS}), gate-drain charge (Q_{GD}), and other gate charge characteristics are important parameters for the switching behavior. The switching performance is also highly dependent on the gate driver circuit design.

Transconductance (g_{fs}) is another fundamental parameter of a MOSFET, representing the relationship between the input gate-source voltage (V_{GS}) and the output current (I_D).

With optimized gate charges and transconductance, the switching losses of OptiMOS™ 7 motor-drive optimized MOSFETs are about 20% lower than OptiMOS™ 6 devices at the same V_{DS} peak voltage.

1.2.5 Dual-side cooled (DSC) package

Infineon's OptiMOS™ 7 motor drive optimized family provides the options of dual-side cooled (DSC) devices. Equation 1 shows that the typical values reported in the datasheets of the three different packaging technologies. The formula to calculate the combined thermal resistance of DSC package is Equation 1. As shown in the formula, the low thermal resistance from junction to top will provide a benefit.

$$R_{th} = \frac{(R_{thJC(top)}+R_{thTA})*(R_{thJC(bot)}+R_{thBA})}{(R_{thJC(top)}+R_{thTA})+(R_{thJC(bot)}+R_{thBA})}$$

Equation 1 Combined thermal resistance of DSC package

Table 1 Comparison of thermal resistances for different packaging technologies

Package	$R_{thJC(top)}$-typ [K/W]	$R_{thJC(bot)}$-typ [K/W]	Definition
SO8	15	15	
SuperSO8 5x6	15	1	bottom-side cooled
SuperSO8 dual-side cooled 5x6	0.7	1	dual-side cooled

2 Switching behavior of the OptiMOS™ 7 motor drive-optimized MOSFET

2.1 Double-pulse test

Double pulse tests are widely used for power device switching behavior evaluations.

The schematic of the tester used in this application note is shown in Figure 7.

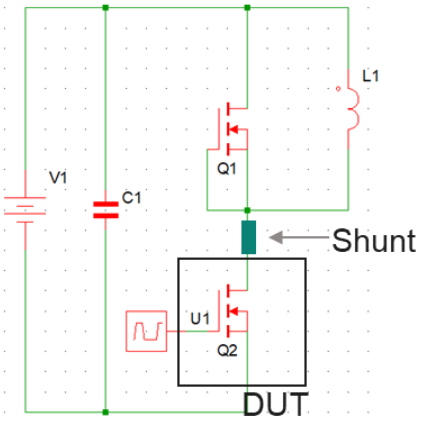


Figure 7 Double pulse tester circuit

All the voltage measurements refer to the low-side DUT (Q2), and the DUT current is measured via the shunt voltage. The high-side switch (Q1) is always off and conducts current through the body diode while the low-side DUT turns off.

Figure 8 shows the double pulse test setup.

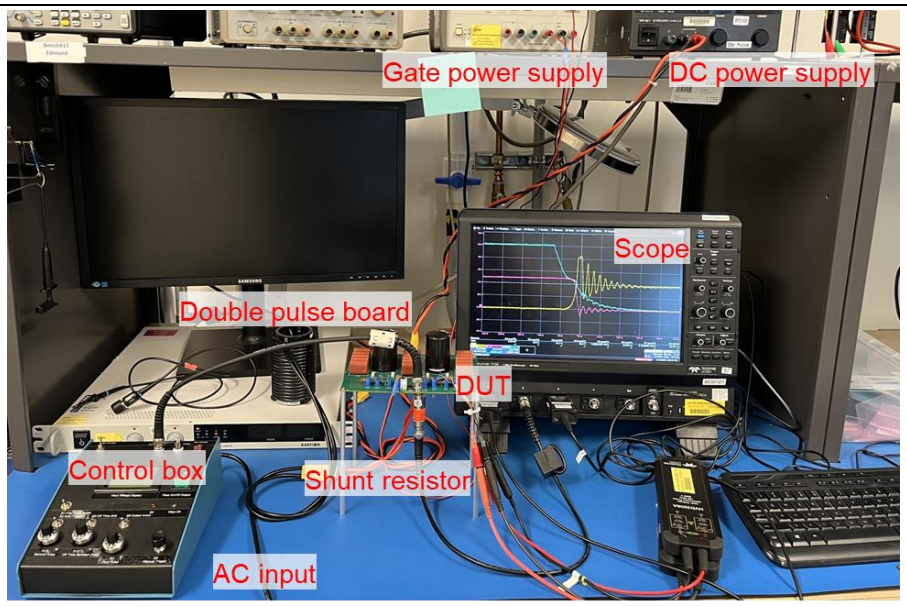


Figure 8 Double pulse test setup

2.2 Switching behavior of different MOSFETs

Double-pulse tests are performed on OptiMOS™ 7 motor-drive optimized MOSFET, OptiMOS™ 6 MOSFET, and vendor's MOSFETs for switching behavior analysis and comparison.

ISC011N04NM7V has been chosen as the representative of Infineon's OptiMOS™ 7 motor drive optimized MOSFET. ISC010N04NM6 is an OptiMOS™ 6 MOSFET with similar $R_{DS(on)}$. The other three parts are from vendors with a similar market position and are selected for comparison.

The key parameters are listed in Table 2.

Table 2 Key parameters (in datasheet) of the devices of double pulse test

Parameter	Drain-source on-state resistance	Output charge	Reverse recovery charge	Total gate charge	Gate threshold voltage
Symbol	**$R_{DS(on)-max}$**	**Q_{OSS}**	**Q_{rr}**	**Q_G @ V_{GS} = 10 V**	**V_{th}**
Unit	**mΩ**	**nC**	**nC**	**nC**	**V**
ISC011N04NM7V	1.1	73	198	58	2.6
ISC010N04NM6	1.0	73	152	67	2.3
Vendor part A	1.1	100	60	72	3.0
Vendor part B	1.2	56	44	62	2.5
Vendor part C	1.05	82	77	50	3.0

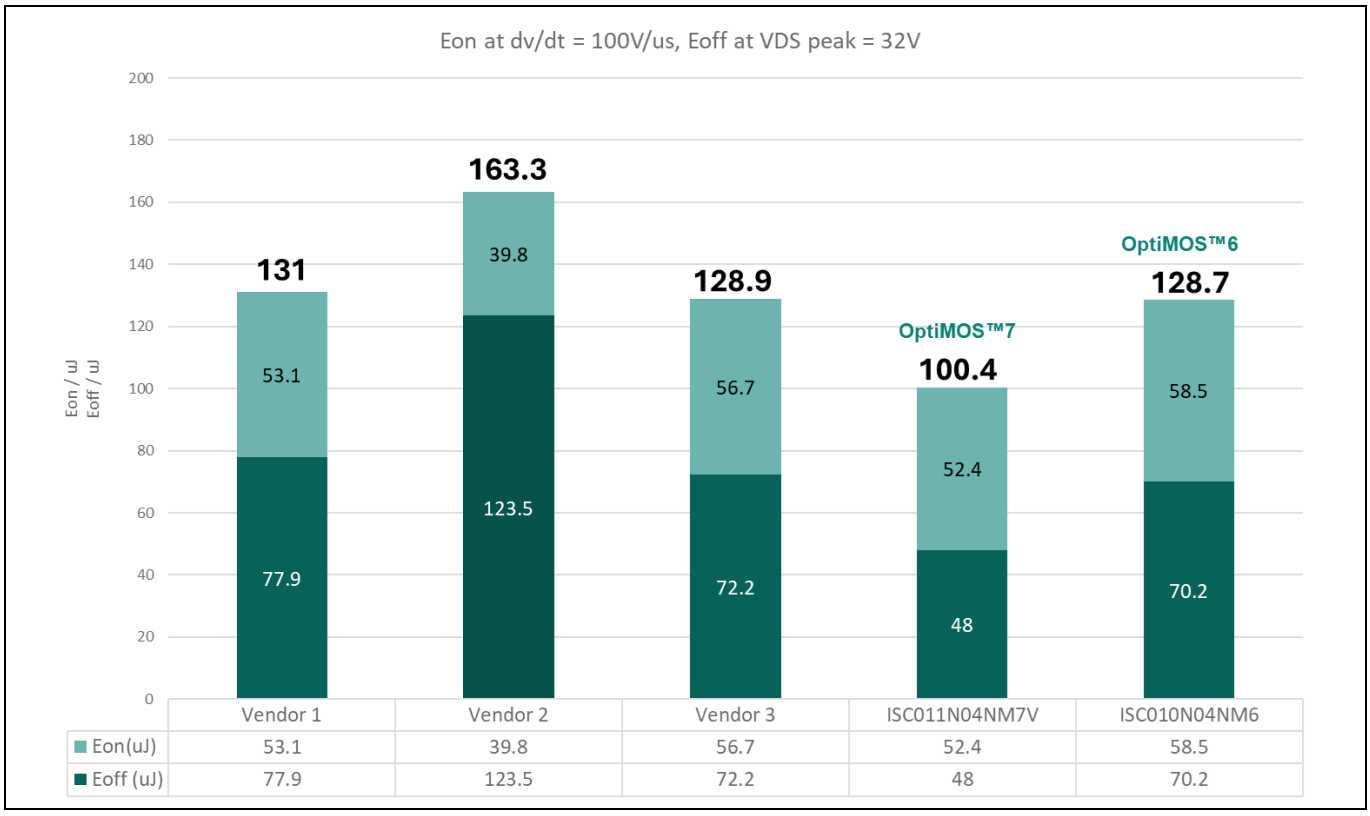


Figure 9 Double-pulse test results, energy losses at V_{DS} peak (turn-off) = 32 V and V_{DS} dv/dt = 100v/µs

Switching behavior of the OptiMOS™ 7 motor drive-optimized MOSFET

For each test, the turn-on gate resistor values are optimized so that the VDS peak = 32 V (80% of the breakdown voltage), and the turn-off gate resistor are tuned at dv/dt = 100V/µs.

The double-pulse test results are shown in Figure 9. The switching losses of the vendor's devices are 190.1 µJ, 251.3 µJ, and 159.3 µJ, respectively. The OptiMOS™ 6 device, ISC010N04NM6, achieves 128.7 µJ switching losses.

The OptiMOS™ 7 motor drive-optimized MOSFET, ISC010N04NM7, can switch faster with V_{DS} peak equal to 32 V due to its motor drive optimized design. Therefore, it achieves the lowest switching losses, 116.3 µJ.

In motor drive applications, the turn-off loss (Eoff) dominates the switching losses because zero-voltage-switching (ZVS) happens during turn-on transient. Eoff of OptiMOS™ 7 motor drive optimized MOSFET is ~30% lower than the OptiMOS™ 6 and is lower than the vendor's devices.

Therefore, it is reasonable to predict that in motor drive tests, OptiMOS™ 7 motor drive-optimized MOSFETs will achieve lower temperature than OptiMOS™ 6 device and vendor's devices.

Therefore, with tuned gate resistors, OptiMOS™ 7 motor drive-optimized MOSFET achieves the lowest switching losses compared to OptiMOS™ 6 device and vendor's devices.

3 Performance of OptiMOS™ 7 motor drive optimized MOSFET in motor drive applications

Motor drive is one of the main target applications of Infineon's OptiMOS™ 7 motor drive optimized MOSFET family.

The performance of the MOSFET family is evaluated in this section.

The comparison between ISCH54N04NM7V (OptiMOS™ 7 motor drive-optimized MOSFET) and ISC007N04NM6 (OptiMOS™ 6) will be discussed in Section 3.2.

Section 3.3 compares ISC011N04NM7V (OptiMOS™ 7 motor drive optimized) and other vendor's devices.

3.1 Test setup and conditions

To perform fair tests for comparison, the test setup (in Figure 10) and conditions (in Table 3) remain the same for the tests in Section 3.2 and Section 3.3.

Table 3 Test conditions

Parameter	Symbol	Unit	Value
Input voltage	V_{in}	V	20
Motor speed	-	rpm	2500
Gate voltage	V_{GE}	V	10
Switching frequency	f_{sw}	Hz	20k
Operating time	-	minutes	12

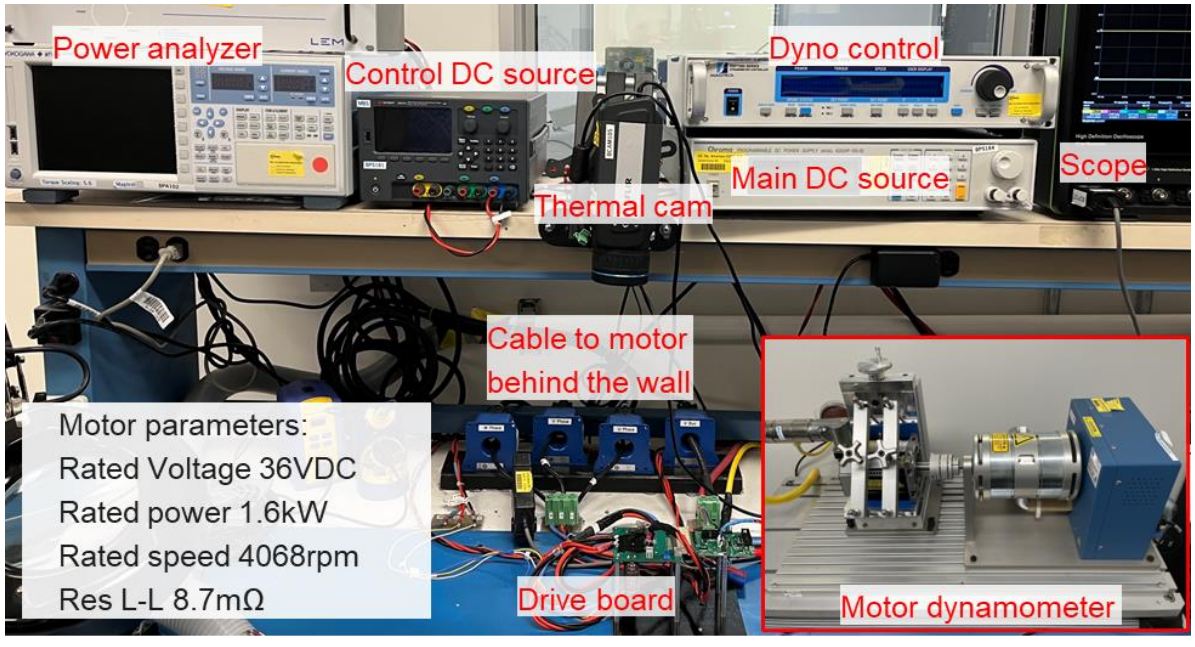


Figure 10 Motor drive test setup

3.2 Motor drive tests: OptiMOS™ 7 motor drive-optimized MOSFET vs. OptiMOS™ 6

To evaluate the performance improvement of OptiMOS™ 7 motor drive-optimized MOSFET over OptiMOS™ 6 MOSFET, the best-in-class MOSFETs from each family are selected as the representatives (ISCH54N04NM7V and ISC007N04NM6), respectively.

The test conditions and setup are described in Section 3.1. The specifications of the selected devices are outlined in the following table.

Table 4 Key parameters of the devices under test

Parameter	Symbol	Unit	ISC007N04NM6	ISCH54N04NM7V
Drain-source on-state resistance	$R_{DS(on)-max}$	mΩ	0.7	0.54
Drain-source voltage	$V_{(BR)DSS}$	V	40	40
Gate threshold voltage	$V_{GS\ (th)}$	V	2.3	2.8
Output charge	Q_{OSS}	nC	103	147
Reverse recovery charge	Q_{rr}	nC	182	82
Total gate charge	$Q_{G\ (10V)}$	nC	94	119
Transconductance	g_{fs}	S	310	110

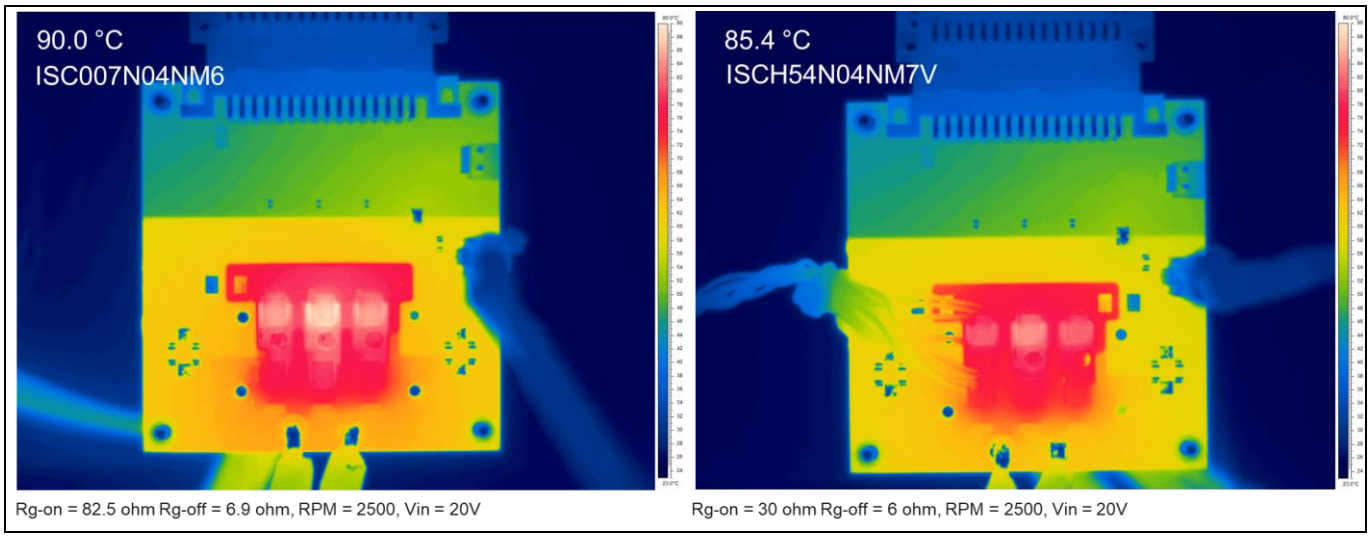


Figure 11 Thermal images of ISC007N04NM6 and ISCH54N04NM7V

The gate resistors are optimized to achieve the fastest switching speed with the V_{DS} overshoot lower than 32 V (80% of the breakdown voltage).

The $R_{g\text{-}on}$ (turn-on gate resistor) for ISCH54N04NM7V is 30 ohm and $R_{g\text{-}off}$ (turn-off gate resistor) is 6 ohm. And $R_{g\text{-}on}$ of ISC007N04NM6 is 82.5 ohm and its $R_{g\text{-}off}$ is 6.9 ohm.

The input power is 600 W. The control method is block commutation.

After 12 minutes of operation, the thermal images are captured and shown in Figure 11. The highest case temperature of ISCH54N04NM7V devices is 85.4 °C and is 4.6 °C lower compared to ISC007N04NM6.

As a conclusion, OptiMOS™ 7 motor drive-optimized MOSFETs can achieve lower case temperature compared to OptiMOS™ 6 MOSFETs with similar parameters.

3.3 Motor drive tests: Infineon vs other vendors

In this section, ISC011N04NM7V is selected as the representative of OptiMOS™ 7 motor drive-optimized MOSFET to compare with three vendor's devices. The vendor's devices have the same market position and similar $R_{DS(on)}$.

The key parameters (in datasheets) of the DUTs are listed in Table 2. The test conditions and setup are described in Section 3.1.

For each device, the gate resistors are optimized to achieve the fastest switching speed with the V_{DS} overshoot lower than 32V (80% of the breakdown voltage).

The case temperatures are recorded after 12-minutes operating.

Figure 12 shows the case temperature vs. input power of DUTs. The results of Infineon's ISC011N04NM7V are shown as green bars. It has the lowest case temperature within all the input power range.

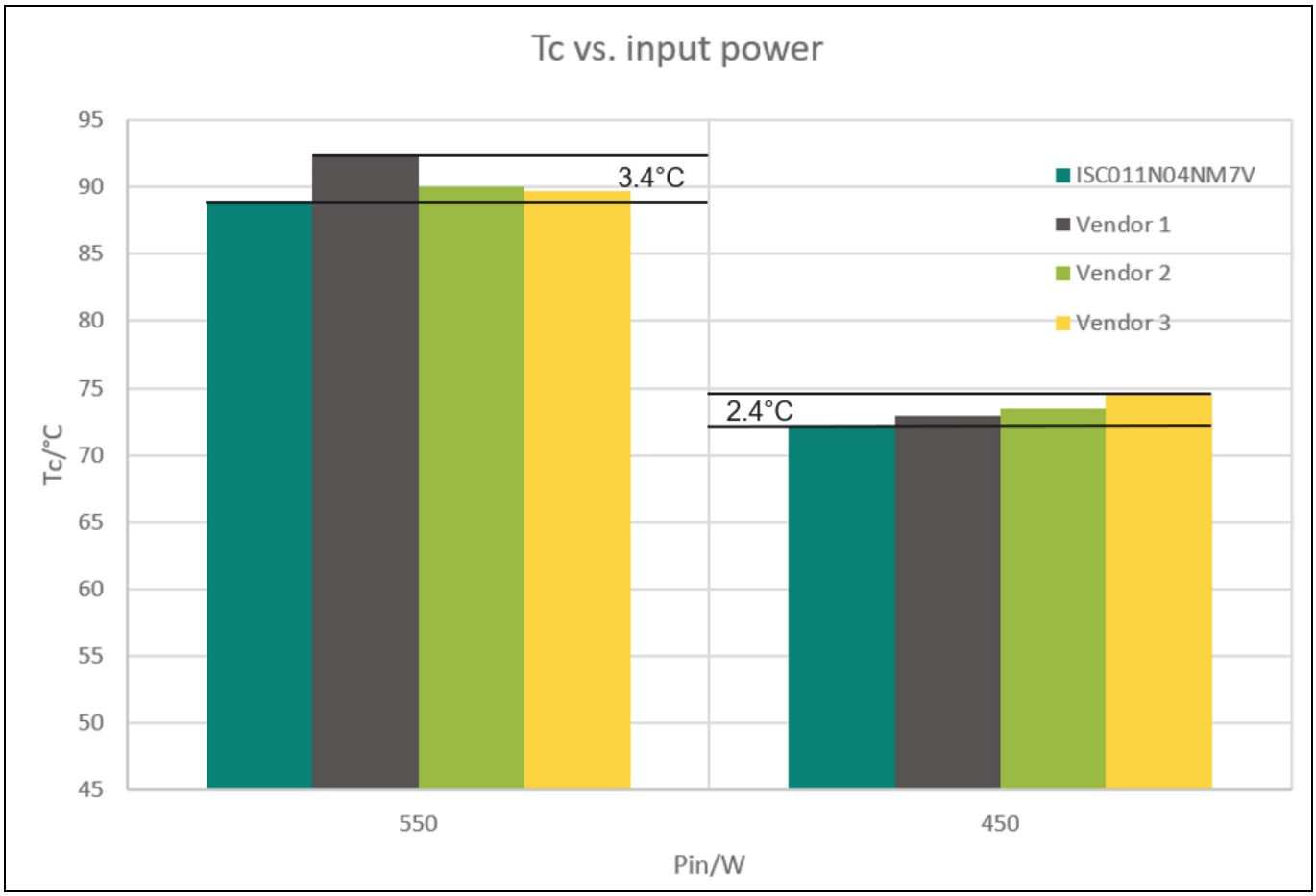


Figure 12 Test results: case temperature (Tc) vs. input power

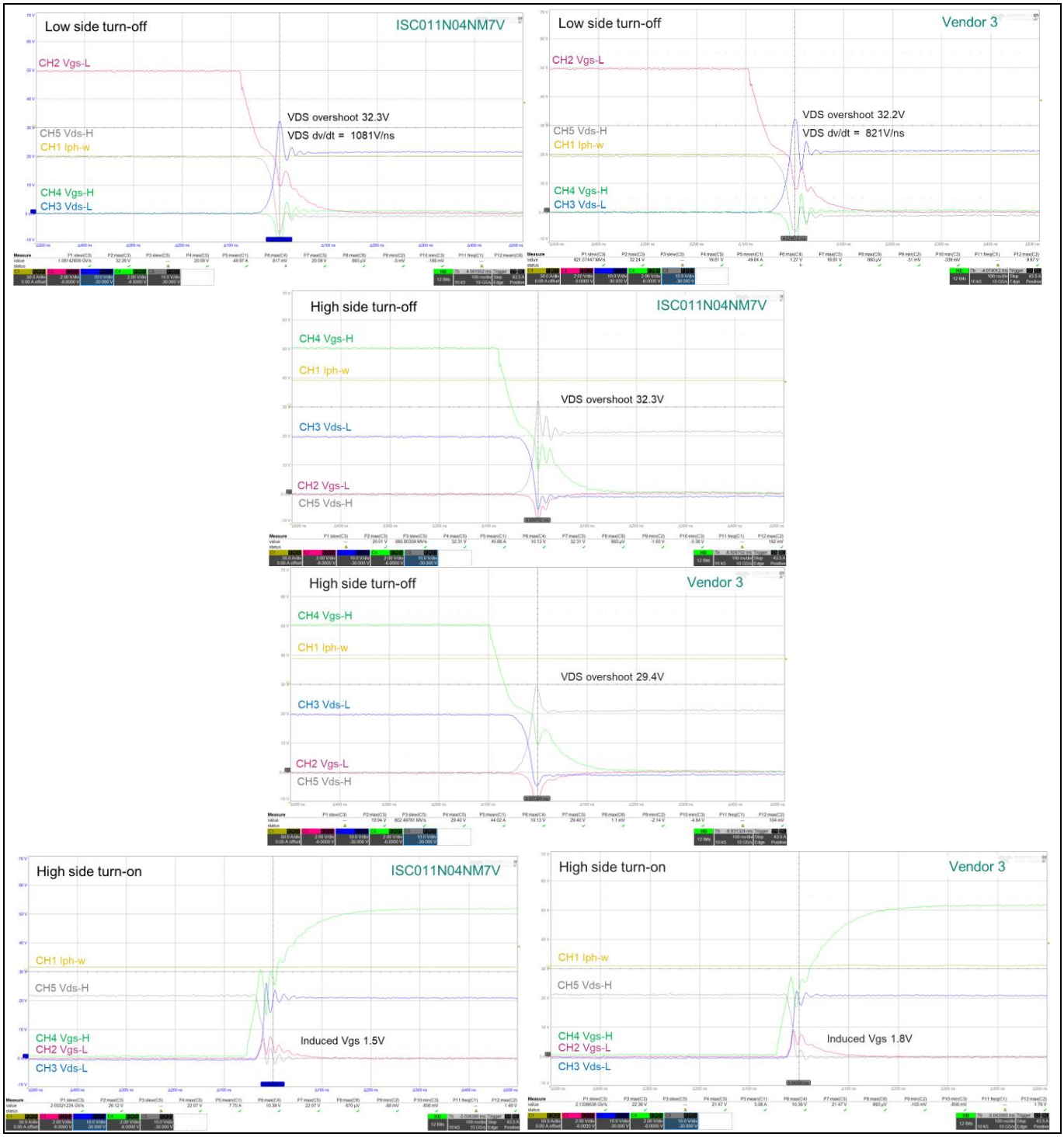


Figure 13 Waveforms – ISC011N04NM7V vs. vendor 3

The switching transient waveforms of ISC011N04NM7V and vendor 3's device are in Figure 13.

Durning the low side turn-off transient, the V_{DS} slew rate of ISC011N04NM7V is 1081 V/ns and 260 V/ns faster compared to vendor 3 device. The V_{DS} overshoots of ISC011N04NM7V and vendor 3 device are 32.3 V and 32.2 V, respectively.

In conclusion: compared to vendor's MOSFETs, ISC011N04NM7V has the fastest switching speed with tuned gate resistors, and consequently, its case temperature is the lowest.

4 Conclusion

Infineon's OptiMOS™ 7 motor drive-optimized MOSFETs are ideally suited for the power and gardening tool applications. The major enhancements of the family are:

- Superior $R_{DS(on)}$
- Improved immunity
- 3X wider safe-operating-area
- Lower switching losses
- Choice of dual-side cooled (DSC) package for lower R_{th}

In double-pulse tests, with optimized gate resistance, the OptiMOS™ 7 motor drive-optimized MOSFET achieves the lowest switching losses compared to the OptiMOS™ 6 MOSFET and three other vendor MOSFETs.

The performances of OptiMOS™ 7 motor drive-optimized MOSFETs are the best to that of the OptiMOS™ 6 MOSFET and the three other vendor MOSFETs in 3-phase motor drive systems.

References

[1] Infineon Technologies AG: OptiMOS™ 7 motor-drives optimized N-channel MOSFET 40 V; Available online

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