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Optimizing Selection Of Low-Voltage Superjunction MOSFETs In Automotive Applications

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The parasitic inductance within the switching loop of automotive application circuits, like dc-dc converters, motor drives, and isolation switches, strongly affects the level of device ringing after a switching event, influencing both oscillation frequency and damping. While these phenomena are well documented, the impact of internal MOSFET parameters like die area and layout have not been investigated as extensively.

In this article, we examine how the active area (AA) and integrated snubber area (SA) of low-voltage silicon superjunction (SJ) MOSFETs (Fig. 1) employed in a half-bridge configuration influence switching losses, ringing, and electromagnetic compatibility (EMC) performance. Although SJ MOSFETs have long been associated with higher voltage classes of transistors, around 650 V and above, thanks to developments from Nexperia, they are emerging as a new option for designs at lower voltages such as the 40-V devices discussed here. These MOSFETs use the company's T9 technology.[1]

We use the results of this analysis to provide a framework for selecting optimal SJ MOSFET device structures—and in turn specific devices—for various automotive applications, based on key performance criteria. This article is based on work previously presented at APEC.[2]

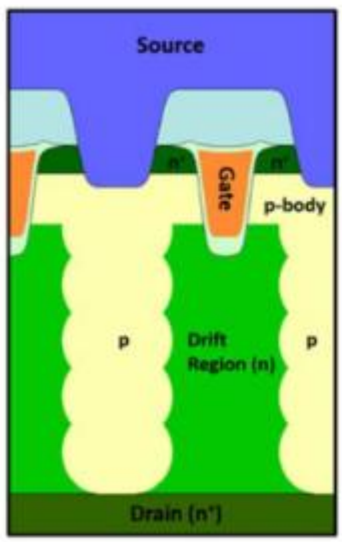

Fig. 1. This article investigates the impact of active area and snubber area on the performance of low-voltage MOSFETs employing this superjunction device structure in automotive power applications.

MOSFETs Are Deployed In Diverse Automotive Applications

In automotive systems, dc-dc converters play a critical role in power management and distribution across diverse vehicle subsystems. They are commonly used to step down battery voltage supplying infotainment and navigation electronics (<100 W) or for converting high-voltage battery pack output in electric vehicles (EVs) to 12 V.

In such designs, low-voltage MOSFETs feature in secondary circuits as synchronous rectifiers or secondary regulators. Boost converters also appear in applications such as lighting (~50 W) and airbag systems (~300 W) that use supply rails above 12 V. MOSFETs are used in motor-drive circuits, where they regulate the speed, torque, and direction of a variety of vehicle motors.

For low-power applications (<200 W), such as body-control systems (windshield wipers, power windows, sunroofs, seat adjusters) and auxiliary pumps (oil, fuel, water), brushed dc motors are often employed, with MOSFETs providing simple on/off control instead of pulse-width modulation. In contrast, brushless dc (BLDC) motors, which demand higher power and improved reliability (>200 W), employ MOSFETs for critical functions like electric power steering (EPS), active suspension, steer- and brake-by-wire systems, and EV cooling pumps.

Isolation switches provide electrical separation between vehicle subsystems to enhance safety and reliability. Typically used as high-side switches, they disconnect loads from power sources, switch multiple loads, or route different supplies to a single load. Apart from protecting sensitive electronics, they also help to minimize energy loss during periods of inactivity. Capable of handling currents from 5 A to 250 A, these switches are also used for reverse-battery protection, rapid shutdown under short-circuit conditions, and to limit inrush currents caused by capacitive loads.

Design Criteria For Various Automotive Applications

Table 1 shows the relative importance of EMC, conduction losses, and switching losses in each of the applications previously discussed. Low-power, high-frequency dc-dc converters and BLDC motor drives place greater emphasis on EMC performance and minimizing switching losses. In contrast, applications with lower switching frequencies like brushed dc motor drives, high-power dc-dc converters, and isolation switches, prioritize reducing conduction losses.

Table 1. Relative importance of different design criteria for various automotive applications.

	Low power dc-dc converter	High power dc-dc converter	Brushed dc drives	BLDC motor drives	Isolation switches
EMC	✓✓	✓	✓	✓✓	✓✓
Conduction losses	✓	✓✓	✓✓✓	✓	✓✓✓
Switching losses	✓✓✓	✓	✓✓	✓✓	✓

EMC Performance Of SJ MOSFETs In An Automotive DC-DC Converter

We used a standardized test setup to evaluate the EMC performance of a typical buck dc-dc converter commonly used in automotive applications. Conducted emissions were measured on the input side of the converter, using a 24-V input to produce an 11.2-V output, providing 62 W of power to a resistivity load of 2 Ω. The switching frequency used was 300 kHz, and the gate resistors of the two MOSFETs were 0.1 Ω.

This setup featured a spectrum analyzer used in combination with Elektra software that complied with the CISPR 25:2008 standard governing EMC testing for automotive systems. An R&S ESH3-Z6 line impedance stabilization network (LISN) was used to ensure a stable source impedance, shield the device under test (DUT) from external power line interference, and enable precise measurement of conducted emissions (according to CISPR 25).

Measurements were conducted using three LFPAK56 SJ MOSFETs, each with a different active area and therefore varying drain-to-source capacitance (C_{DS}). The effect of this capacitance on disturbance peaks was observed within the 70- to 115-MHz range. The voltage rise at the switch node across the low-side MOSFET was also captured and compared, revealing significant variations in damping behavior and oscillation frequency.

As shown in Table 2, the oscillation frequencies and damping factor of the converter voltage correlate closely with the frequencies and amplitudes of the peak disturbances observed in the EMC sweep. In particular, a transistor voltage oscillation with higher damping is associated with a lower amplitude.

Table 2. Parasitic oscillations and EMC sweep results.

	Time domain		Frequency spectrum	
Device	Damping factor	Frequency (MHz)	Amplitude peak (dBμV)	Frequency of peak (MHz)
A	0.123	71.8	61	66
C	0.104	94.7	62	92
E	0.097	115	64	111

Vin = 24 V, R_G = 0.1 Ω, R_{Load} = 2 Ω.

MOSFET Characterization

We then used a double-pulse-testing setup to investigate the performance of several of Nexperia's SJ MOSFETs. The damping factor (DF) was estimated using a logarithm decrement approach on the drain current rise based on the following equations:

$$Log\ Decrement\ = \delta = \ln\left(\frac{I_{Peak2} - I_{Trough2}}{I_{Peak3} - I_{Trough3}}\right)$$

$$DF = \frac{\delta}{\sqrt{4\pi^2 + \delta^2}}$$

Switching energy losses were calculated from the point where I_D or V_{DS} reached 10% of their peak values to the point where the other dropped below 10%, from current rise to voltage fall at turn-on, and vice versa for turn-off. Measurements were made on five LFPAK56 40 V-rated MOSFETs (labeled A to E as shown in Table 3).

These devices were based on the same SJ technology and snubber resistance (1 Ω), but had variations in the size of their SA and AA. For devices A and B, which had almost identical SA but different AA, V_{GS} = 10 V, and V_{DD} = 20 V, I_D was set to 50 A (by varying the duration of the first pulse). Due to their smaller die sizes, I_D = 25 A was used for devices C, D and E.

Table 3. 40-V SJ MOSFETs used for characterization.

Device	A	B	C	D	E
AA (mm^2)	12.07	9.49	6.18	4.16	4.15
SA (mm^2)	1.24	1.23	1.00	0.79	1.00
SA/AA	0.103	0.130	0.162	0.190	0.241

Fig. 2 presents the results of this analysis in a graphical format. From this analysis, the following trends were observed:

- Larger SA increased the DF but had only a small impact on switching losses, a desirable scenario for applications where EMC is a concern.
- Larger AA increased the DF and switching losses but reduced conduction losses. This is desirable for low switching frequency applications or where EMC is a concern.

These findings also correlated with SPICE circuit simulations performed using models for these five MOSFET devices.

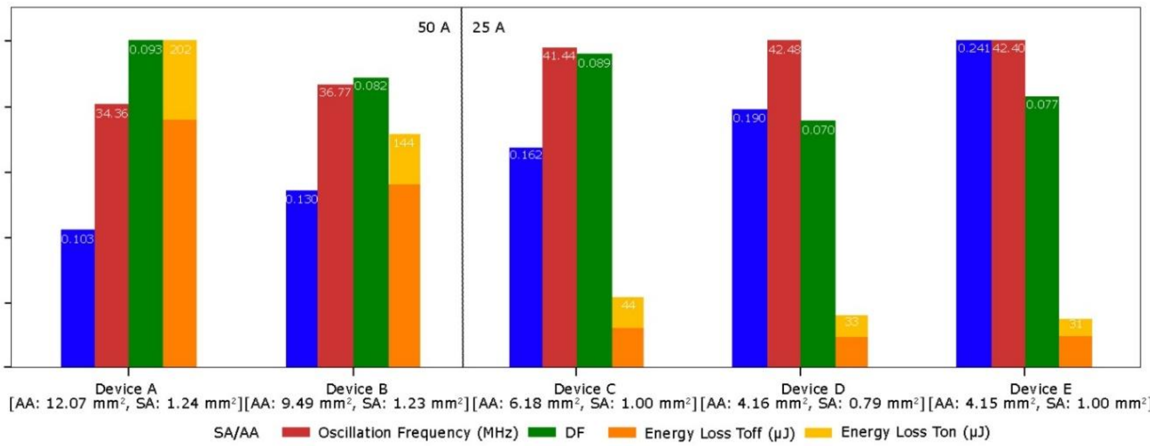

Fig. 2. Effect of device active area (AA) and snubber area (SA) on parameters such as oscillation frequency, damping factor, and switching energy loss at 50 A (A & B) and 25 A (C, D & E).

Selecting MOSFETs For Different Design Criteria

In Fig. 3, we suggest a graphical approach for selecting a MOSFET (from those used in this analysis) for automotive applications according to whether switching performance or conduction losses are design priorities. Although the experimental data is based on Nexperia's 40-V LFPAK56 devices, the same selection principles can be applied more broadly to superjunction MOSFETs from different voltage classes (and different vendors), provided equivalent parameters are available.

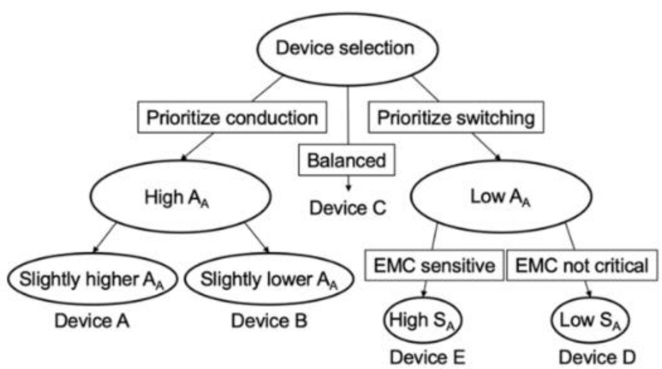

Fig. 3. MOSFET selection guide for different design criteria.

- Low-power dc-dc converters require MOSFETs that can switch at high frequencies (1.5 MHz or more), meaning a device with larger AA is required. While this means having higher conduction losses and lower DF, this is acceptable in this type of application, thus making device D or E preferable. On the other hand, high power dc-dc converters use a lower switching frequency, meaning a MOSFET with a larger AA, like device C, would be a better choice in these applications.
- For BLDC motor drive applications where EMC is a concern, it is better to use a MOSFET with a larger snubber area and a higher DF. Since BLDC drives also typically operate at lower switching frequencies than dc-dc converters, the MOSFET's active area can be made larger, especially for high-load designs. For this type of application, devices C or E would be an appropriate choice.

- Brushed dc motor drives switch at low frequencies, so to reduce conduction losses, a MOSFET with a larger AA is required. Simpler drive circuitry (no PWM) means this application is not as sensitive to EMC, making device B the best choice.
- Finally, isolation switches switch only occasionally, meaning conduction losses and thermal performance are key. Some high-power protection applications can also be sensitive to EMC. Devices A or B would therefore make the best choice to use in isolation switch applications.

While MOSFETs with higher DF generate less noise, making them more suitable for EMC-sensitive environments, additional filtering may still be necessary in some applications. When using MOSFETs with a lower DF in EMC-sensitive applications, more complex and costly filtering is required.

Conclusion

This article describes and presents the findings of our experimental analysis, examining how active area (AA) and integrated snubber area (SA) influence the drain-current oscillatory switching behavior of superjunction MOSFETs, using damping factor and energy loss to link these design parameters with overall EMC performance. The results showed that increasing the die area of a device raises its internal parasitic capacitances, thereby slowing the switching speed, reducing ringing, and lowering the oscillation frequency in the drain current.

Based on these findings, we also presented an approach for selecting a MOSFET according to the performance requirements of typical automotive applications. Devices with smaller AA and hence lower switching losses help improve efficiency in dc-dc converters, and their EMC behavior can be further enhanced by increasing SA.

Conversely, devices with a larger die have lower conduction losses, making them more suitable for use in isolation switches and brushed dc motor drives. For BLDC motor drives, increased SA helps suppress ringing, while high-power applications may require a carefully adjusted AA to provide an appropriate balance between conduction and switching losses.

Reference

1. "Automotive Trench 9 - Power MOSFETs designed for performance and endurance," Nexperia website.
2. "Optimizing MOSFET Selection for EMC-Critical Automotive Applications" by Sacha J. Cazzitti, Christian Radici, Andrew J. Forsyth, Cheng Zhang and Peter Vines, 2025 IEEE Applied Power Electronics Conference and Exposition (APEC), March 2025.

About The Authors

Sacha Cazzitti is a PhD candidate studying at the University of Manchester's department of electrical and electronic engineering and working in collaboration with Nexperia. Their research focuses on optimizing silicon automotive MOSFETs, with a particular emphasis on improving their efficiency and EMC across different MOSFET die layouts and structures. Through experimental and simulated studies, Sacha aims to contribute to the development of next-generation power devices tailored to the specific requirements of automotive applications.

Christian Radici is an application engineer in the automotive team at Nexperia, Manchester. Since joining in 2019, he has focused on aligning simulations and measurements of low-voltage power MOSFETs, supporting the development of Nexperia's customer tools. His work spans thermal simulation, MOSFET modelling, RLC parasitic extraction, and switching characterization, and he has authored several application notes on power MOSFET usage. Christian holds a master's degree in analog and power electronics from Politecnico di Torino, Italy.

For further reading on power MOSFETs, see the How2Power Design Guide, locate the "Component" category and select "Power Transistors".