TN90003

The Qrr of a MOSFET: its importance in motor-control circuit designs

Rev. 1.0 — 21 July 2020 technical note

Document information

Information	Content
Keywords	MOSFET, reverse recovery charge, Qrr
Abstract	When choosing a MOSFET for a motor-control application, design engineers tend to first study the device's on-resistance characteristic, since this parameter has the greatest effect on the MOSFET's ability to provide sufficient current to the motor without generating excessive heat caused by conduction losses. Some other aspects of the MOSFET's operation also have a marked effect on thermal performance, and attention paid to these factors can offer worthwhile rewards in improved motor-drive design features..

1. Introduction

Motor-drive circuits generally switch at lower frequency (typically 20 kHz - 40 kHz) than switch mode power supplies (SMPS, normally 100+ kHz). This often induces designers to ignore the thermal contribution from MOSFET dynamic switching losses attributable to parameters such as input and output capacitance, since they are assumed to be much smaller than the effect of conduction losses attributable to on-resistance.

In motor-control applications, however, in which the motor and controller are often physically connected by wires, design engineers are increasingly taking account of EMC (Electro-Magnetic Compliance) at the component selection phase. The non-ideal switching behavior of a MOSFET can have a marked effect on electro-magnetic emissions: problems caused by these emissions might only become apparent at the qualification phase of the design project.

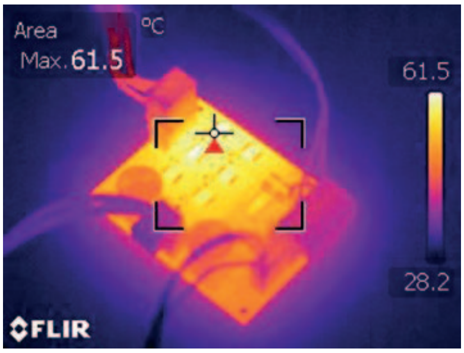
Furthermore, the efficiency of the motor drive does not have an important effect on system efficiency since motors are inherently less efficient than motor drives: 80-85% efficiency is typical for a motor, whereas a drive circuit's efficiency often exceeds 95%.

MOSFET losses in the drive circuit do however greatly affect the operating temperature of the control circuit's PCB (Printed-Circuit Board), and since the MOSFET's on-resistance increases as temperature rises, then excessive heating must be avoided through good design and component selection. As OEMs (Original Equipment Manufacturer) strive to meet consumer demand for smaller, more powerful products such as hand-held power tools and domestic appliances, MOSFETs which generate less waste heat can enable the designer to achieve reductions in size, weight and cost as well as to extend battery run-times.

2. Adding a gate resistor

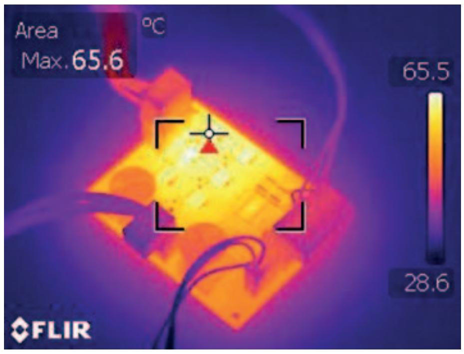
To reduce electro-magnetic emissions in motor-control applications, it is common practice to add a resistor in series with the MOSFET's gate. When combined with the MOSFET's capacitive gate, the resistor makes a low-pass filter which helps to reduce the switching speed of the MOSFET. This can be an effective means of reducing high-frequency harmonics, which contribute to the circuit's electro-magnetic emissions. But designers must be careful not to add too much resistance at the MOSFET's gate, since reducing the switching speed extends the time during which the MOSFET operates in linear mode, causing it to dissipate more waste energy.

The heating effect of adding a 47 Ω gate resistor can easily be observed with a thermal camera, as shown in Fig. 1 and 2.



gate resistor = 0 Ω; load current = 3 A

Fig. 1. MOSFET temperature = 61.5 °C



gate resistor = 47 Ω; load current = 3 A

Fig. 2. MOSFET temperature = 65.6 °C

3. The importance of reverse-recovery charge

A lesser understood parameter, reverse-recovery charge, Q_{rr}, is also known to make a large contribution to electro-magnetic emissions. During the dead-time in a motor-drive circuit, when both MOSFETs are turned off, free-wheel current flows briefly through the body diode of the low-side MOSFET: stored charge, Q_{rr}, accumulates across the body diode's PN junction, as shown in Fig. 3.

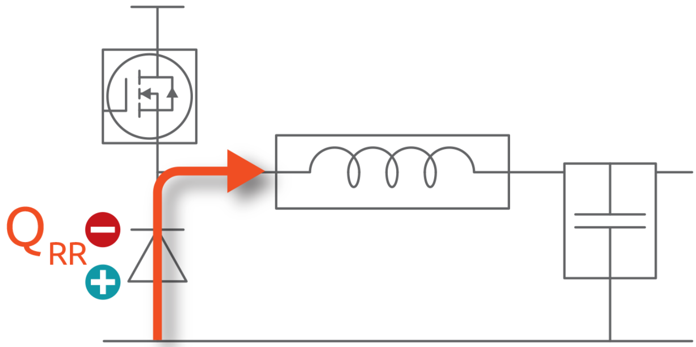


Fig. 3. Reverse-recovery charge accumulates across the body diode's PN junction

When the high-side MOSFET turns on, a current surge occurs, and flows briefly through the high-side and low-side MOSFETs, until the accumulated charge of the low-side is removed, as shown in Fig. 4. I_{RM} (peak recovery current) can be relatively of high values and contributes to switching losses. This high-speed pulse also contributes markedly to electro-magnetic emissions.

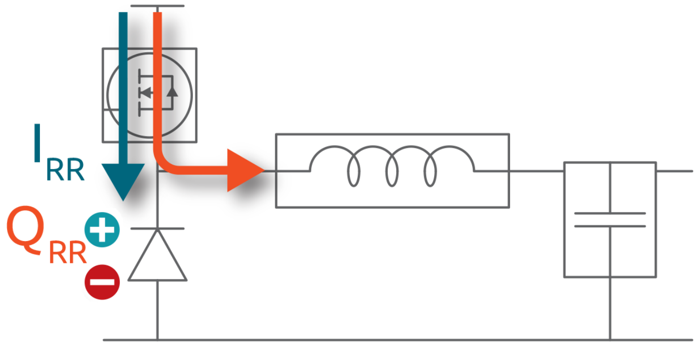


Fig. 4. Surge current in the high-side MOSFET caused by Q_{rr} in the low-side MOSFET

Low Q_{rr} – reduced body diode reverse recovery current I_{rr}

Fig. 5 shows the SPICE simulation results for 2 same devices, one of which was modelled to have twice the amount of Q_{rr}.

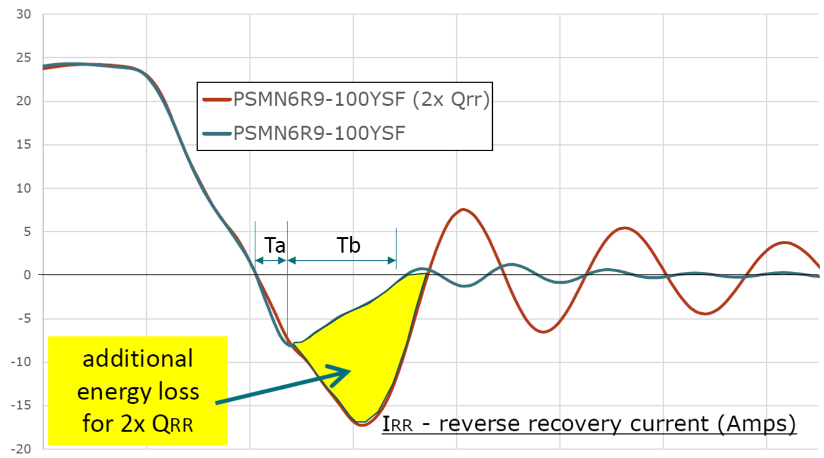


Fig. 5. SPICE simulation result

The SPICE simulations show the benefits of low Q_{rr} in switching applications, I_{rr} reduced by 50% for low Q_{rr} types. In Fig. 5 the shaded area represents the additional energy loss for parts with 2 x Q_{rr}.

Nexperia NextPower 100 V types have a higher softness factor (t_b / t_a > 1) - gives lower ringing / resonance and lower spike voltage. Lower I_{rr}, ringing resonance also contributes to lower EMI emissions

EMC

The I_{rr} pulse interacts with the MOSFET's lead-frame, and with the PCB's parasitic inductance and capacitance, to create a resonant circuit. The I_{rr} effect when combined with parasitic or package inductance will typically resonate at around 60 to 130 MHz.

Resonance can be reduced by carefully reducing the PCB's parasitic inductance through good PCB design, adding a snubber circuit, or by choosing MOSFETs with a low Q_{rr} rating.

The spectrum analyzer trace, shown in Fig. 6, compares the measured RF emissions for a low-Q_{rr} NextPower 100 V MOSFET from Nexperia with those of a competitor's MOSFET the Q_{rr} of which is twice as high. In this example, the NextPower 100 V low-Q_{rr} technology offers a reduction in electro-magnetic emissions of around 6 dB at frequencies between 70 MHz and 110 MHz. Use of the Nexperia low Q_{rr} part thus markedly reduces the risk of encountering EMC problems during qualification of a motor-drive design.

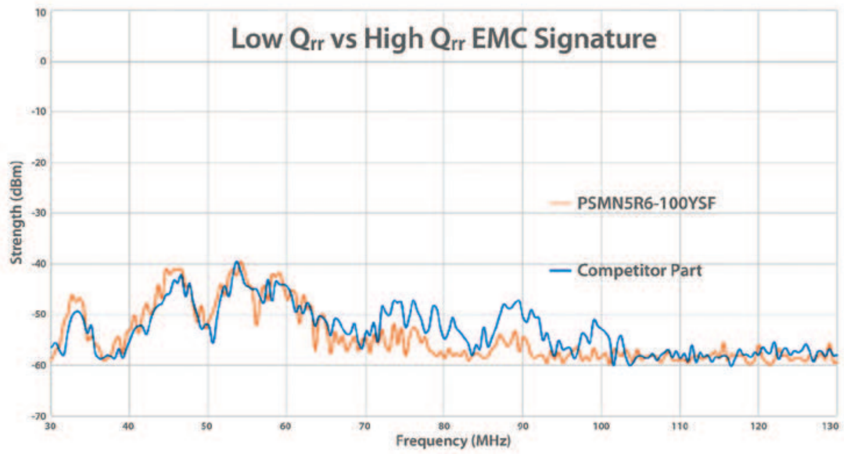


Fig. 6. Reduced electro-magnetic emissions from a Nexperia NextPower MOSFET which has low Q_{rr}

4. Revision history

Table 1. Revision history

Revision number	Date	Description
1.0	2020-07-21	intitial version.

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Date of release: 21 July 2020