Exclusive Technology Feature

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Redefining Q_{SW} To Obtain Accurate Switching Loss Estimates In RESURF-Based MOSFETs

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Switching loss estimation in power MOSFETs has traditionally relied on parameters derived from the gate-charge curve, particularly switching charge, Q_{SW}, defined as the portion of gate charge delivered after threshold is reached. Q_{SW} consists of the remaining gate-to-source charge (Q_{GS2}) plus the Miller charge (Q_{GD}), and is used as a proxy for the energy dissipated during turn-on and turn-off transitions.

For many years, this method produced results that aligned reasonably well with measured performance, especially for planar MOSFETs whose switching transitions were approximately linear and whose capacitance characteristics varied smoothly with voltage.

However, as superjunction and other RESURF-based MOSFET architectures have become dominant in medium- and high-voltage converters, designers have increasingly observed a divergence between calculated and measured switching losses. In many cases, loss estimates derived from datasheet Q_{SW} exceed measured values by a significant margin, even when operating conditions are well controlled and measurement techniques are sound. This discrepancy reflects a fundamental mismatch between the traditional definition of Q_{SW} and the actual voltage and current waveforms observed in modern devices.

This article reviews how assumptions about MOSFET switching behavior are used to calculate switching loss accurately in planar MOSFETs. It then explains why these assumptions are not valid in superjunction and other RESURF MOSFETs, leading to overestimations when the switching loss equation is applied. Essentially, the period of voltage-current overlap in RESURF devices differs from that of planar transistors due to evolutions in capacitance characteristics.

Application-level measurements performed on a 204-W active-clamp forward quarter-brick converter provide a practical illustration of this effect. When switching loss is calculated using the conventional Q_{SW} definition, predicted loss substantially exceeds measured electrical and thermal results. When the switching interval is redefined based on the actual voltage and current waveforms, calculated and measured results align closely.

The Legacy Assumptions For Q_{SW}-Based Loss Estimation

Switching loss is fundamentally determined by the overlap between the drain-source voltage and the drain current during switching transitions. To simplify this inherently dynamic behavior, early models assumed that voltage and current changed approximately linearly and that the dominant energy dissipation occurred from the threshold through the Miller plateau region of the gate-charge curve.

Under these assumptions, Q_{SW} was defined as the gate charge extending from threshold voltage through the Miller plateau. When combined with gate-drive current, this definition enabled compact analytical expressions that proved sufficiently accurate for planar MOSFET technologies.

The usefulness of this approach depended on a strong correspondence between the gate-charge curve and the time-domain behavior of voltage and current. For earlier device structures, that correspondence was reasonably consistent. However, the underlying physical behavior of modern RESURF devices differs in important ways.

How RESURF Structures Alter The Switching Event

Superjunction and related RESURF MOSFETs achieve reduced on-resistance through charge-balanced structures that significantly reshape capacitance versus voltage characteristics. This class of devices includes multiple architectural implementations, including SuperQ (see the reference), which further optimizes charge balance and capacitance distribution. In these devices, output capacitance varies sharply as drain-source voltage changes, resulting in voltage transitions that are distinctly non-linear. During turn-on, drain-source voltage can collapse rapidly while current rises in a similarly non-linear manner.

As a result, meaningful voltage-current overlap is confined to a much narrower portion of the transition than assumed in traditional models. Large segments of the Miller plateau interval occur either before the current has risen significantly or after the voltage has largely collapsed. Although these portions are included in the conventional definition of Q_{SW}, they contribute little to actual switching energy.

The switching-loss equation itself remains valid. The difficulty arises from the interval over which the switching charge is defined.

Identifying The True Energy-Dissipation Interval

Direct examination of switching waveforms in RESURF MOSFETs shows that most switching energy is dissipated during a confined region in which the drain current has risen appreciably, and the drain-source voltage has not yet fully collapsed. A physically meaningful definition of the switching interval can therefore be established using percentage-point boundaries referenced directly to the waveforms.

Defining the beginning of the interval when drain current reaches approximately 10% of its steady-state value, and the end of the interval when drain-source voltage falls to approximately 10% of its off-state value, captures the region in which instantaneous voltage-current overlap is concentrated, as shown in Fig. 1.

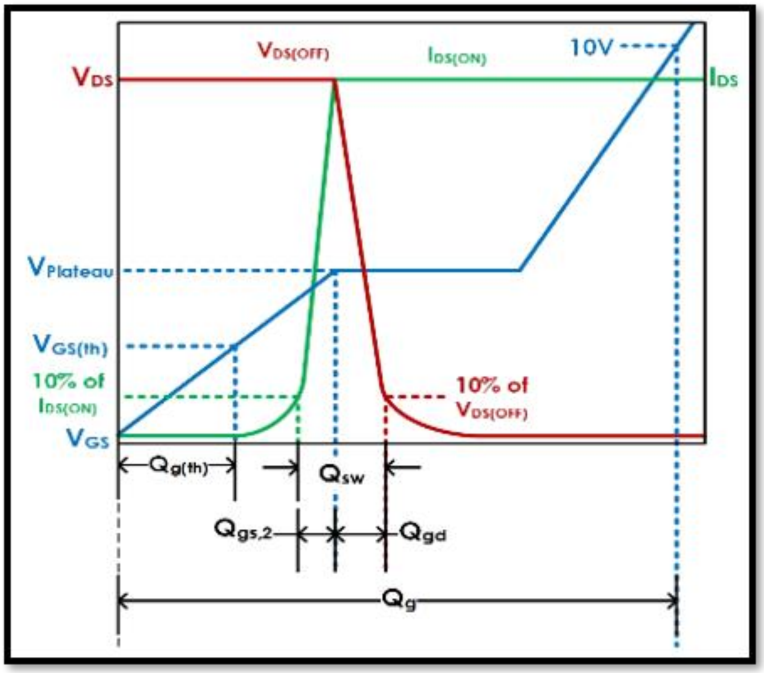


Fig. 1. RESURF MOSFET gate charge curve. Instead of spanning the traditional interval, most switching energy is dissipated during a confined region in which the drain current and drain-source voltage are above 10% of the steady-state value.

When switching charge is aligned with this physically relevant interval rather than the full Miller plateau, the calculated switching energy more accurately reflects the measured behavior. This approach preserves the simplicity of datasheet-based estimation while grounding the parameter in the physical properties of modern MOSFET technologies.

Validation In A 204-W Active-Clamp Forward Converter

The practical impact of redefining Q_{SW} becomes evident when examined in a representative converter. Testing was performed on a 204-W quarter-brick power supply operating from a 48-V input to a 12-V, 17-A output, switching at 270 kHz in an active-clamp forward topology. This topology induces a fully hard-switched transition at both turn-on and turn-off, making it an apt configuration to examine switching losses.

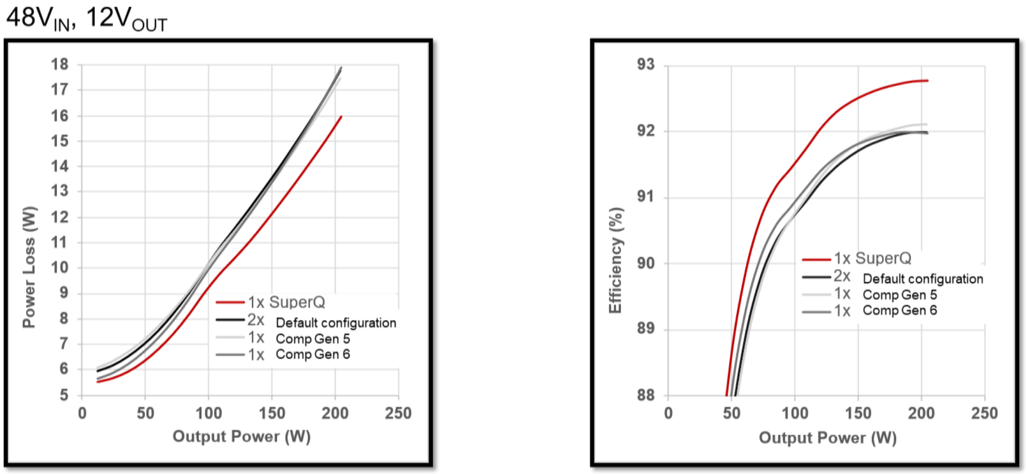
The reference configuration used two parallel 120-V MOSFETs on the primary side. Comparative measurements were performed using a single 150-V SuperQ MOSFET in the same topology as well as a single competitive fifth-generation device and a single competitive sixth-generation device. A comparison of the tested devices is presented in the table.

It should be noted that the Q_{SW} value reported for the SuperQ device was calculated using the revised energy-correlated definition discussed in this article, whereas the competitive devices are reported using the conventional datasheet definition.

Table. Devices tested in a 204-W active-clamp forward converter.

	SuperQ iS15M7R1S1C (x1)	Default configuration (x2)	Comp Gen 5 (x1)	Comp Gen 6 (x1)
BV_{DSS} (V)	150	120	150	150
$R_{DS(ON)}$, typ (mΩ)	5.4	9.6	6	5
$R_{DS(ON)}$, max (mΩ)	6.4	11.5	7.4	5.5
E_{OSS} (75 V) (µJ)	1	1.3	3.4	4.1
Q_{SW} (nC)	4.9	6.8	14	15.9

Under 48-V input, at full load, with no forced airflow, measured efficiency improved by approximately 0.8% relative to the default configuration, corresponding to nearly 2-W lower total power loss, shown in Fig. 2. Thermal measurements after a five-minute soak showed significantly lower primary device temperatures, with reductions exceeding 10°C relative to the default configuration of two parallel devices and more than 30°C relative to a configuration with one competitive sixth-generation device.



Power Loss **Efficiency**

Fig. 2. Comparing power loss and efficiency of a 150-V SuperQ MOSFET with devices of comparable breakdown voltage ratings and $R_{DS(ON)}$ values. Measurements were obtained at 48-V V_{IN} and 12-V, 17-A output with no air flow.

Most importantly, calculated power loss using waveform-based switching definitions closely matched measured efficiency and thermal data.

Implications For Device Comparison And Thermal Design

In high-frequency topologies such as active-clamp forward converters, switching loss accounts for a significant fraction of total power dissipation. If switching energy is overestimated due to an overly broad definition of Q_{SW}, designers may assign excessive thermal margin or incorrectly compare competing devices. Because modern RESURF architectures compress the true voltage-current overlap interval, the discrepancy between traditional Q_{SW}-based estimates and measured performance can be substantial.

Accurate switching-loss prediction, therefore, depends on ensuring that the switching interval reflects the actual physical event. As device architectures evolve, parameter definitions must evolve as well.

Reference

SuperQ Technology Technology page, iDEAL Semiconductor website.

About The Author

Orion Kress-Sanfilippo is a systems and applications engineer at iDEAL Semiconductor, where he works on the development and application of advanced silicon power devices for high-efficiency power conversion systems. In this role, he supports customers in evaluating and implementing next-generation MOSFET technologies across applications such as motor drives, battery management systems, and high-performance power architectures. His work focuses on bridging device-level innovation with real-world system performance, helping engineers optimize efficiency, thermal performance, and overall system cost.

For more on power MOSFET design issues, see How2Power's Design Guide, locate the "Component" category and select "Power Transistors".