Refining Switching Charge Interval for Power Loss

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Abstract

Switching charge is a MOSFET parameter that is widely used in the estimation of switching losses for switch-mode power supplies. The definition which most often appears on datasheets relies on the triangular behavior of voltage and current during a switching event. However, reduced surface field devices cannot be approximated in this way, as their capacitance-voltage characteristics differ fundamentally. This application note reviews the traditional assumptions of voltage and current behavior, re-evaluates these assumptions in reduced surface field devices, and proposes a new method for defining the switching charge parameter, supported by measured switching losses.

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I. Background

When discussing power MOSFET losses, and particularly switching losses, the gate charge (Q_G) curve is always a central characteristic. Specifically, the derivative parameter of switching charge (Q_{SW}) is important but requires a closer investigation to practically use due to recent advances in power MOSFETs. The parameter's traditional derivation relied on the region around the Miller plateau, which corresponds to a discharge in the capacitance of the device.

Historically, the Gate Charge curve within a MOSFET datasheet was a reliable method to allow the extraction of Q_{SW} and led to accurate predictions of MOSFET switching loss. However, the shift to Reduced Surface Field (RESURF, also known as Charge Balance) type of MOSFET structures like iDEAL Semiconductor's SuperQ™ as the industry norm for higher voltage rated devices has fundamentally changed the Output Capacitance (C_{OSS}) vs. Voltage Curves (see Figure 1), and by extension, the shape of a device's Drain-Source voltage (V_{DS}) during device switching events.

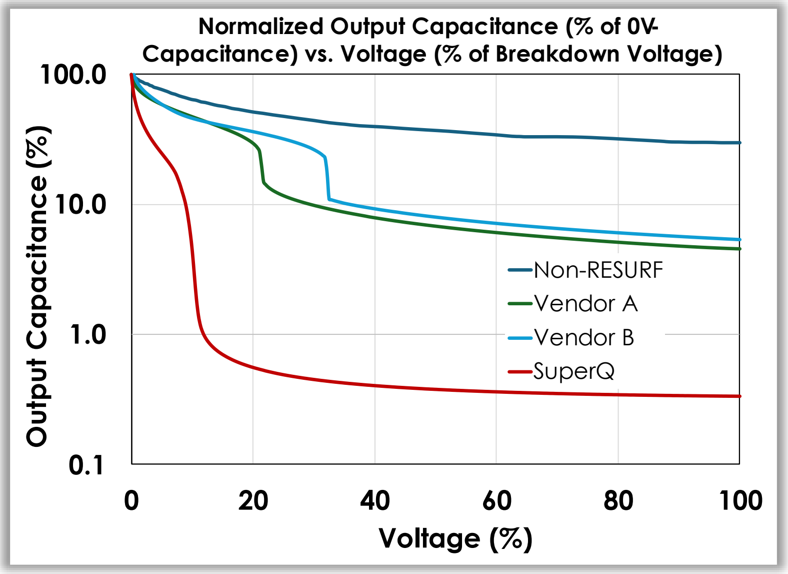

Figure 1: Log-Linear Capacitance vs. Voltage Plot of Four Power MOSFETs

Figure 1 demonstrates the contrasting capacitive behavior of a traditional (non-RESURF) when compared to various RESURF type devices. As a result of this shift, the waveform components representing Q_{SW} must be redefined so that the datasheet parameter can analytically predict switching losses within the device.

This Application Note uses measured voltage and current waveforms during gate charge measurement and application specific hard-switching events to make this comparison, while proposing a new method for realigning the Q_{SW} datasheet parameter with switching losses.

This Application Note will reexamine the traditional Q_G curve used in MOSFET datasheets by reviewing Drain-Source Voltage (V_{DS})and Current (I_{DS}) waveforms within a traditional Qg curve (Section II), analyzing measured V_{DS} and I_{DS} waveforms for a RESURF based MOSFET (Section III) and comparing actual application switching loss (I*V) against the predicted loss given by a traditional datasheet Q_{SW} parameter (Section IV).

II. Review traditional V_{DS} & I_{DS} behavior in a Q_G curve

A gate charge curve is measured by applying a constant current to the MOSFET gate (JEDEC, 2002) (see Figure 2) which is subdivided to represent various timing intervals during the MOSFET switching event (see Figure 3).

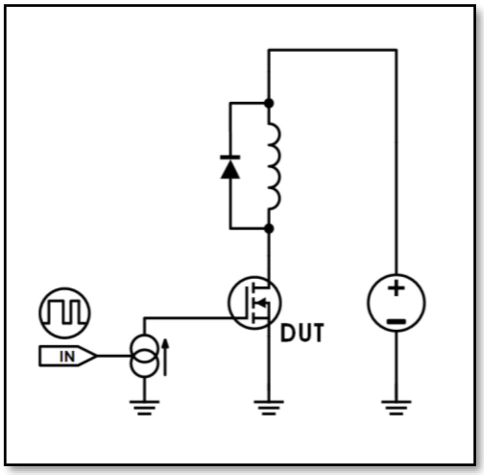

Figure 2: Constant-current gate drive scheme for gate charge measurement of Power MOSFETs

Figure 3 demonstrates the behavior of a non-RESURF device during a gate charge measurement. The device output capacitance is nonlinear with respect to voltage (see Figure 1), but the behavior is still well approximated by the triangular shape of V_{DS} and I_{DS}, which leads to a simple calculation for the switching loss in a power MOSFET. This assumes a symmetrical switching event for device turn-on and turn-off. The generalized equation for switching I*V energy loss (E_{SW}) in a MOSFET during this interval is:

$$E_{SW} = \int_a^b v_{DS}(t) * i_{DS}(t)dt \tag{1}$$

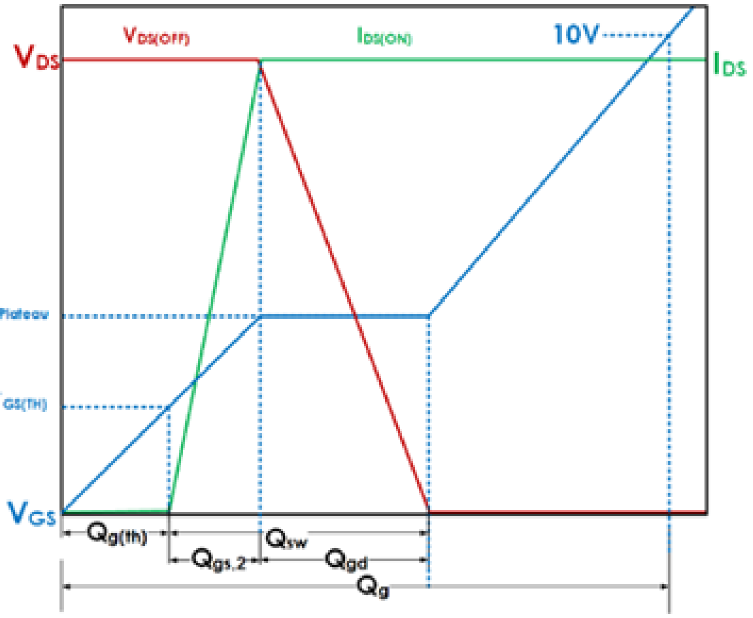

Figure 3: Non-RESURF MOSFET Gate Charge Curve

The Q_{SW} subinterval shown on a MOSFET datasheet traditionally spans from threshold gate charge ($Q_{G(th)}$) until the end of the Miller Plateau, the flat region which ends once the Miller capacitance is fully discharged. This was widely accepted as the relevant switching loss parameter for clamped, inductive-load applications, and is integral to the energy loss estimation below:

$$E_{SW} = \frac{0.5 * V_{DS(OFF)} * I_{DS(ON)} * Q_{SW}}{I_G} \tag{2}$$

This calculation, outlined in (Jauregui, Wang, & Chen, 2011) remains a valid method for estimating power loss in these applications, with the exception being how it defines Q_{SW} for RESURF devices.

III. RESURF reassessment of I_{DS} and V_{DS} behavior in a Q_G curve

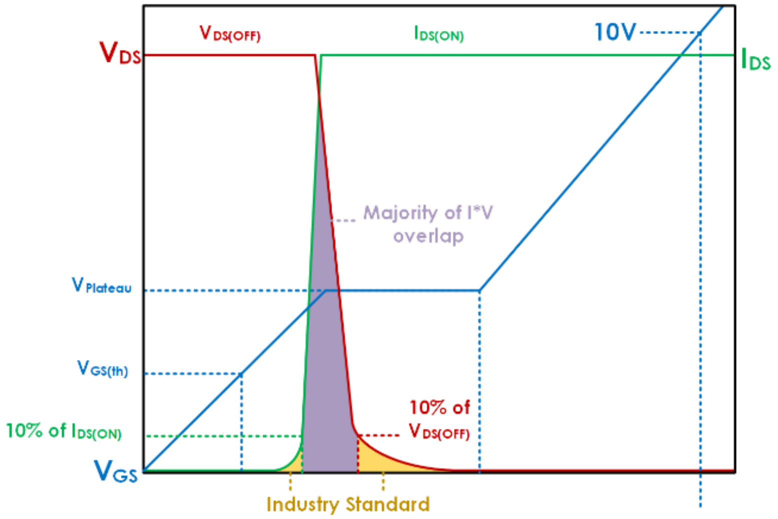

Figure 4: RESURF MOSFET Switching Event

The C_{OSS} behavior of a RESURF device is linked to the device structure itself (Dr. Holger Kapels, 2009), and the C_{OSS} non-linearity leads to drastically different voltage and current behavior during a switching event (see Figure 4). As a result, we cannot make the same assumptions of energy loss during this event. The loss is no longer bound by the $Q_{G(th)}$ interval and the end of the Miller plateau, and therefore Q_{SW} requires redefinition.

By closely examining V_{DS} and I_{DS} (see Fig 4), it is shown that more than 82% of the I*V overlap (purple) falls within a small portion of the traditional Q_{SW} interval. The remaining area within the traditional Q_{SW} interval (yellow) constitutes only 18% of the total I*V overlap. Including this area leads to more than 300% error in the estimated power loss when using this method for obtaining the Q_{SW} value.

Therefore, this note proposes redefining the Q_{SW} interval, placing the left boundary where I_{DS} = 10% of the conducted current ($I_{DS(ON)}$), and the right boundary where V_{DS} = 10% of the blocked voltage ($V_{DS(OFF)}$). It is also proposed to move the right boundary of Gate-Drain charge (Q_{GD}) to where V_{DS} = 10% of $V_{DS(OFF)}$, as the existing definition of Q_{GD} does not accurately represent RESURF behavior. These “percent-point” boundaries are a standard method of measurement for a variety of MOSFET parameters, such as in switching time measurements (JEDEC, 1985). They paint a much more realistic picture of RESURF behavior and can be used to predict application-level MOSFET switching losses more accurately. Measured data from applications supports this conclusion, as will be shown.

IV. Compare application I_{DS} * V_{DS} loss against traditional Q_{SW} loss

An application-level examination of this proposal requires a shift from constant-current gate drive, as in gate charge characterization, to constant-voltage drive (see Figure 5), as is more common for switching applications.

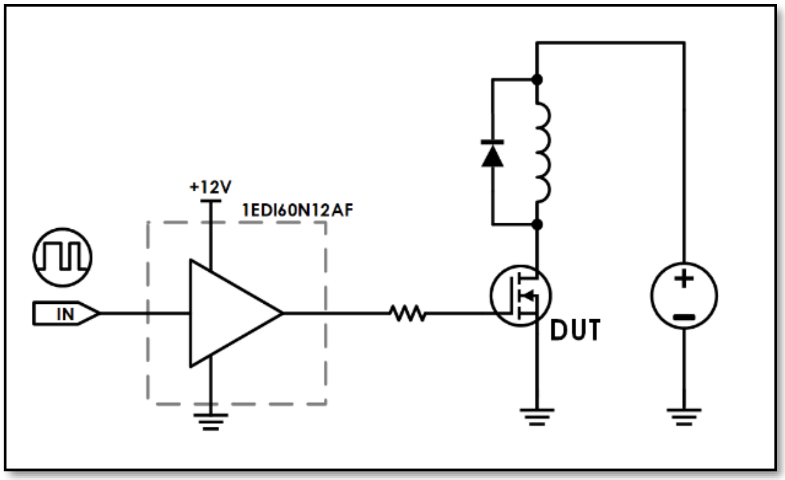

Figure 5: Constant-voltage gate drive for application-level analysis of power MOSFETs

The circuitry for this experiment utilizes a clamped inductive load driven by a double-pulse event. The gate driver used in this circuit is Infineon's high-voltage MOSFET gate driver (P/N 1EDI60N12AF). The device under test (DUT) gate is driven at 12V and on-times are varied to generate the simultaneous current and voltage needed for this analysis. Using this gate drive scheme, we can measure the I*V energy of a single switching event and analyze how it compares to theoretical calculations (see Figure 6).

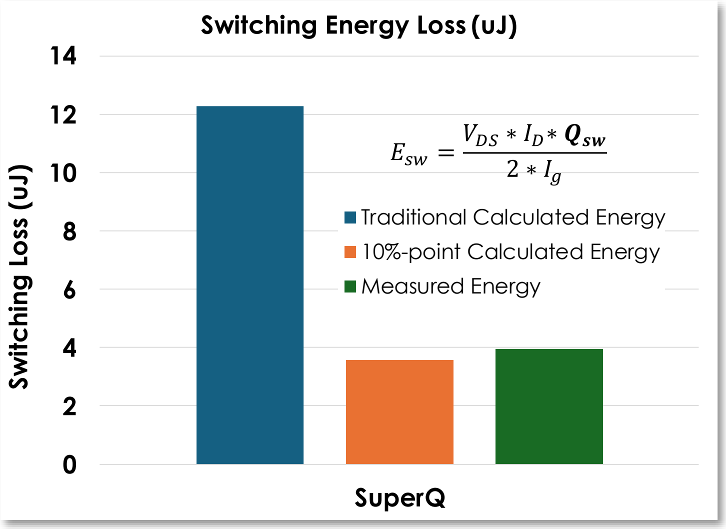

Figure 6: Switching energy loss using the traditional Q_{SW} (blue), using the percent-points Q_{SW} (orange) and measured data (green) on a RESURF type of MOSFET

This plot illustrates the drawbacks of relying on the traditional method for defining Q_{SW} for a RESURF device. As predicted with Figure 4, the traditional Q_{SW} definition yields an estimation which is more than 3 times the measured loss, reinforcing the expectation that the traditional method for defining Q_{SW} is not applicable for RESURF devices. Alternatively, using Q_{SW} from the new proposal shows less than 7% error, and supports this method's use in extrapolating losses for a wider range of devices.

V. Conclusion

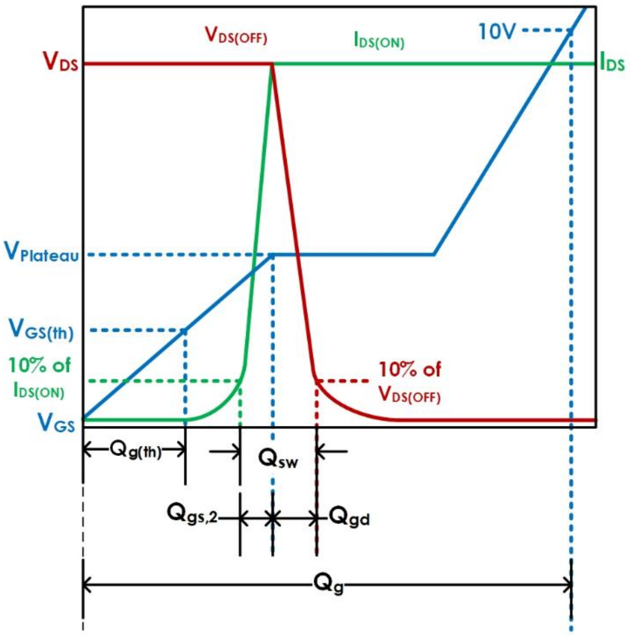

Figure 7: RESURF MOSFET gate charge curve

With the fundamental differences in the CV behavior of modern RESURF MOSFETs like iDEAL's SuperQ and competing SuperJunction, it becomes necessary to redefine Q_{SW}, given its importance in estimating switching losses in applications like switch mode power supplies (SMPS). Note that with this proposed change, Q_{GD} would also be changed to better reflect the nonlinear behavior of SuperJunction devices.

By proposing a new method for Q_{SW} which relies on the shape of V_{DS} and I_{DS} during gate charge measurement, we more accurately represent the behavior of RESURF devices and provide a more reliable estimation of switching losses in an application.

VI. Index Terms

E_{SW} – Switching energy loss from turn-on and turn-off transition in SMPS

I_{DS} – Drain current of Power MOSFET

$I_{DS(ON)}$ – Conducted current of Power MOSFET in the ON state

I_G – Gate current of Power MOSFET

Q_G – Gate charge

Q_{SW} – Switching charge subinterval of gate charge measurement

$Q_{G(th)}$ – Subinterval of gate charge measurement lasting from beginning of curve until $V_{GS} = V_{th}$

Q_{GS2} – Subinterval of gate charge measurement lasting from $V_{GS} = V_{th}$ until the beginning of the Miller plateau

Q_{GD} – Subinterval of gate charge measurement lasting from the beginning to the end of the Miller plateau

RESURF – Reduced Surface Field

SMPS – Switch mode power supply

V_{DS} – Drain to Source Voltage of Power MOSFET

$V_{DS(OFF)}$ – Blocked Voltage of Power MOSFET in the OFF state

V_{GS} – Gate to Source Voltage of Power MOSFET

VII. References

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VIII. Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Initial AN001 Revision A – December 2024

AN001 Revision B – September 2025 – Included Q_{GD} as a modified parameter.

AN001 Revision C – January 2026 – Included Q_{GS2} in Figure 7

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