International
IOR Rectifier

Application Note AN-1001

A More Realistic Characterization of Power MOSFET Output Capacitance Coss

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Previously, energy loss through output capacitance in MOSFETs has been deemed insignificant. However, as frequency increases, and application topologies change, this capacitance becomes more important. This paper shows a meaningful way to calculate this parameter and how it contributes to energy loss.

A More Realistic Characterization Of Power MOSFET Output Capacitance Coss

Introduction:

The Power MOSFET has gained popularity and become the dominant switching device in power electronics since 1975. Its fast switching speed has extended power conversion switching frequencies from the 20kHz range of bipolar transistor to beyond 100kHz. in hard switching. With soft switching techniques such as zero voltage switching (ZVS) and zero current switching (ZCS), the switching frequency can exceed Mega Hertz.

As switching frequency moves upward, power MOSFET parasitic parameters such as inductance and capacitance should be well defined and understood in order to optimize the particular power conversion design. This design tip focuses on explaining the power MOSFET output capacitance Coss and how it actually affects the power conversion circuit. Other capacitance's such as input capacitance Ciss, and reverse transfer capacitance Crss, and the related gate charges have been well explained in previous International Rectifier publications.

In hard switching circuits, Coss is used to calculate the additional power dissipation of power MOSFET due to discharging this output capacitor every switching cycle. In soft switching circuits, Coss may be used to calculate the resonant frequency or transition time, which is critical in establishing ZVS and / or ZCS conditions. Unfortunately the value of Coss varies non-linearly as a function of drain to source voltage Vds. The value of Coss specified in most manufacturer's data sheets are at 25V Vds which is not really useful in actual circuit application.

In an effort to better aid circuit designers, International Rectifier has taken the extra steps to specify the effective Coss (Coss at Vds of 1V and 80% Vdss) and also extend the capacitance curves to 80% of Vdss , instead of 50V, for IRs new range of high voltage HEXFETs. An example of these curves for a new 600V HEXFET is shown in Fig. 1 below :

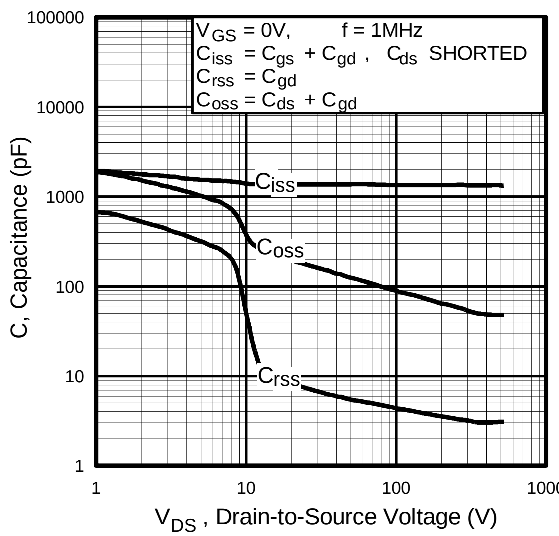


Fig. 1:. Typical Capacitance Vs. Drain to Source Voltage

Listed below are the definitions of Coss effective and Coss @ 80% of Vdss, how they are measured and how to apply them in circuit design calculations.

Coss effective:

Coss effective is defined as a fixed capacitance that would give the same charging time as the output capacitance of a MOSFET while Vds is rising from zero to 80% Vdss at Vgs = 0V. Figure 2 shows the test circuit and the associated waveforms used to measure the Coss effective of this 600V HEXFET. The totem pole driver HEXFET is driven on / off by a short single pulse, at the end of this pulse, Vds of the device under test (DUT) starts rising, Coss is being charged by the 100kΩ to Vdd of 600V. The time it takes for Vds to rise from zero to 480V, which is 80% of rated Vdss, t_c is measured. Coss effective is then calculated per following equations:

$$Vc = 600\ V(1- e^{-t/RC}) = 480V$$

Where t is the measured t_c, R = 100kΩ, and C is Coss effective. Solving for Coss effective:

$$\text{Coss effective} = 6.21 * t_c \ \text{pF}$$
$$(t_c \text{ is in } \mu S)$$

The 80% Vdss value is chosen as a convenient measuring point. It is this Coss effective that should be used in any resonant type of calculation that involves Coss, not the value specified in the standard data sheet, which is a single value at 25V Vds. The Coss at 25V may be two to three times larger than the Coss effective, depending on the silicon cell design and density of the particular MOSFET. The classical LC resonant equation $f_r = ½\ \pi\ (LrCr)^{1/2}$ is used in many modern power converter circuits, where the MOSFET Coss effective may be whole or part of the resonant capacitance. With the defined Coss effective, circuit designers can more accurately determine some other circuit parameters such as transformer, inductor and other stray capacitance's to enable design optimization.

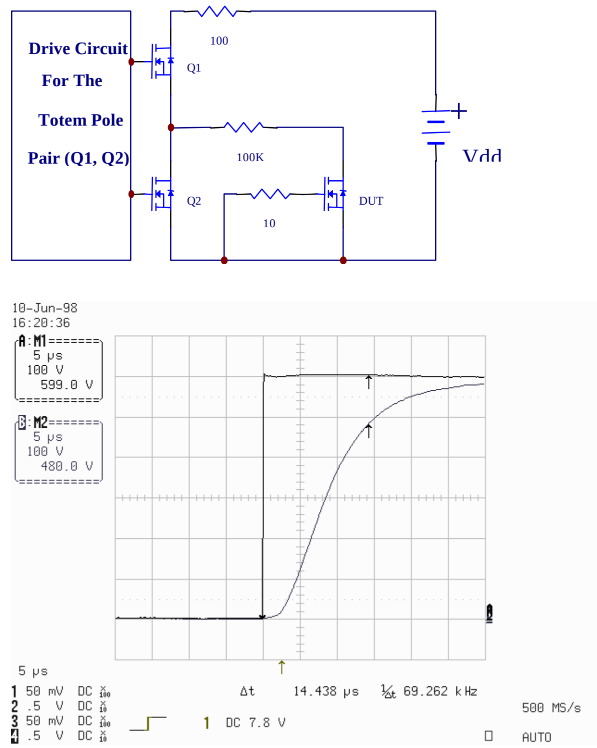
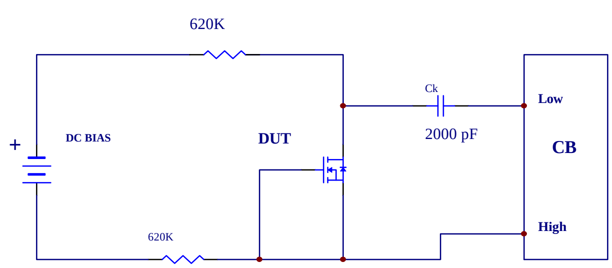


Fig. 2. Circuit For Measuring Coss Effective and The Associated Waveforms

Coss at 80% Vdss:

This capacitance value is the Coss measured at Vds = 80% Vdss. Figure 3 shows the standard Coss test circuit.

Fig. 3. Test Circuit For Coss (CB is



Capacitance Bridge)
Coss (DUT) = Cm * Ck) / Ck - Cm

Each time the MOSFET turns on, the energy stored in the output capacitance will be dissipated in the device, with Coss at the Vds voltage prior to turning on this energy equal to $E = ½\ Coss\ Vds^2$. As the switching frequency goes up the power dissipation ($P_d = E \times f_s$) in the MOSFET due to discharging this energy increases proportionately, which may become a limiting factor in hard switching topologies. Figure 4 shows the loss distribution for various types of power MOSFETs in a typical 200W off line single transistor forward converter operating at 100kHz.

	FET Type1	FET Type2	FET Type 3	FET Type 4	FET Type 5	FET Type 6
Pcond	3.65	2.54	2.63	2.63	1.86	3.93
Psw	3.15	3.12	2.95	2.91	2.80	3.32
Pcoss	0.48	0.53	0.53	0.52	0.72	0.6
Ptotal	7.28	6.19	6.11	6.06	5.38	7.85

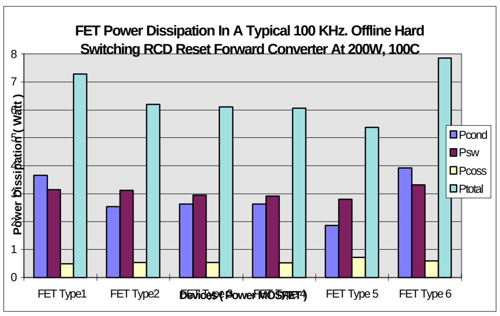


Fig. 4: FET Loss Distribution Comparison @ 100kHz.

Figure 5 shows the same loss distribution as in Figure 4 but at 200kHz. operating frequency.

	FET Type1	FET Type2	FET Type 3	FET Type 4	FET Type 5	FET Type 6
Pcond	3.65	2.54	2.63	2.63	1.86	3.93
Psw	6.3	6.24	5.9	5.82	5.60	6.64
Pcoss	0.96	1.06	1.06	1.04	1.44	1.2
Ptotal	10.91	9.84	9.59	9.49	8.90	11.77

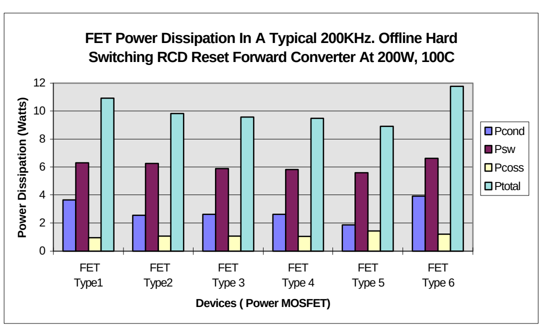


Fig. 5: FET Loss Distribution Comparison @ 200kHz.

From Figure 4 and 5, one can observe that as the switching frequency doubles the conduction loss remains the same, but the switching loss and loss due to Coss doubles. The loss due to Coss is 77.4% that of conduction loss (I^2 rms x Rds on) and 16% of the total losses for the type 5 FET at 200kHz.

Summary:

Coss at 80% of Vdss and Coss effective to 80% of Vdss specified are of different values, and have different implications. Coss is used only for the purpose of calculating its loss' contribution as this loss can't be instrumentally measured. Coss effective is used solely for calculating any resonant circuit that involves the output capacitance of the MOSFET. For all practical purpose, these specified values are sufficed to use for operating Vds voltages in the range of 70% to 90% of Vdss with about 10% or less error. If more accuracy is required, the associated test circuits above can be used to measure to the exact operating voltage .

Conclusion:

Historically the energy loss due output capacitance in a MOSFET has been deemed to be insignificant. With the general increase in application operating frequency and proliferation of differing topologies this design tip demonstrates how important this capacitance can be and shown a meaningful way of calculating its contribution to the switching energy loss.