

A More Realistic Characterization Of Power MOSFET Output Capacitance C_{oss}

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 C_{oss} and how it actually affects the power conversion circuit. Other capacitance's such as input capacitance C_{iss} , and reverse transfer capacitance C_{rss} , and the related gate charges have been well explained in previous International Rectifier publications.

In hard switching circuits, C_{oss} is used to calculate the additional power dissipation of power MOSFET due to discharging this output capacitor every switching cycle. In soft switching circuits, C_{oss} 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 C_{oss} varies non-linearly as a function of drain to source voltage V_{ds} . The value of C_{oss} specified in most

manufacturer's data sheets are at 25V V_{ds} 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 C_{oss} (C_{oss} at V_{ds} of 1V and 80% V_{dss}) and also extend the capacitance curves to 80% of V_{dss} , 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 :

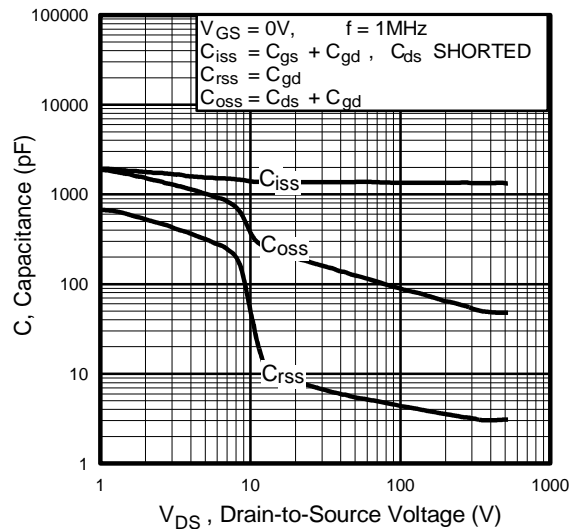


Fig. 1: Typical Capacitance Vs. Drain to Source Voltage

Listed below are the definitions of C_{oss} effective and C_{oss} @ 80% of V_{dss} , how they are measured and how to apply them in circuit design calculations.

C_{oss} effective:

C_{oss} effective is defined as a fixed capacitance that would give the same

charging time as the output capacitance of a MOSFET while V_{ds} is rising from zero to 80% V_{dss} at $V_{gs} = 0V$. Figure 2 shows the test circuit and the associated waveforms used to measure the C_{oss} 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, V_{ds} of the device under test (DUT) starts rising, C_{oss} is being charged by the 100k Ω to V_{dd} of 600V. The time it takes for V_{ds} to rise from zero to 480V, which is 80% of rated V_{dss} , t_c is measured. C_{oss} effective is then calculated per following equations:

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

Where t is the measured t_c , $R = 100k\Omega$, and C is C_{oss} effective. Solving for C_{oss} effective:

$$C_{oss} \text{ effective} = 6.21 * t_c \text{ pF}$$

(t_c is in μS)

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

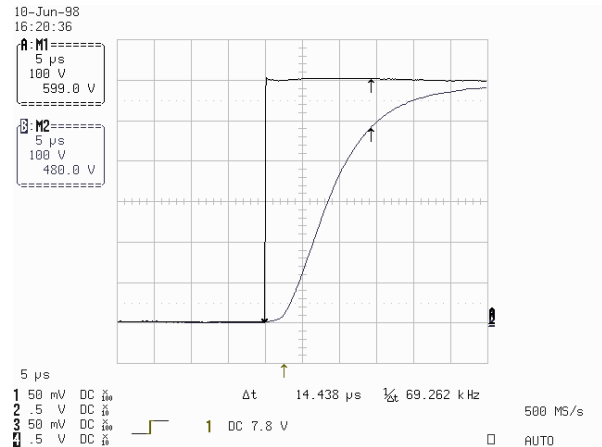
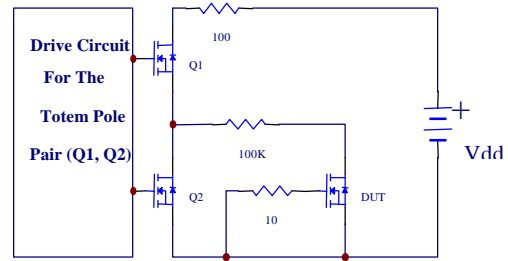
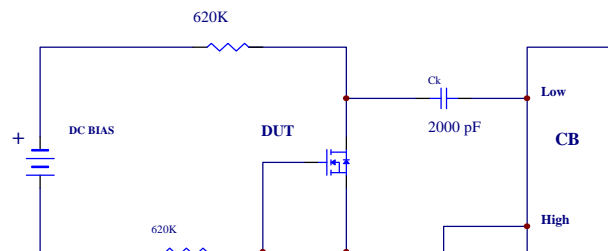


Fig. 2. Circuit For Measuring C_{oss} Effective and The Associated Waveforms

Coss at 80% V_{dss} :

This capacitance value is the C_{oss} measured at $V_{ds} = 80\% V_{dss}$. Figure 3 shows the standard C_{oss} test circuit.

Fig. 3. Test Circuit For C_{oss} (CB is



Capacitance Bridge)
 $C_{oss} (DUT) = C_m * C_k / C_k - C_m$

Each time the MOSFET turns on, the energy stored in the output capacitance will be dissipated in the device, with C_{oss} at the V_{ds} voltage prior to turning on this energy equal to $E = \frac{1}{2} C_{oss} V_{ds}^2$. 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

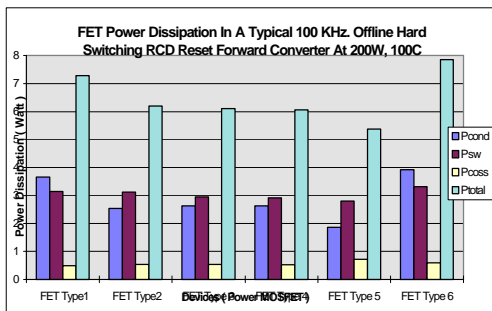


Fig. 4: FET Loss Distribution Comparison @ 100kHz.

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

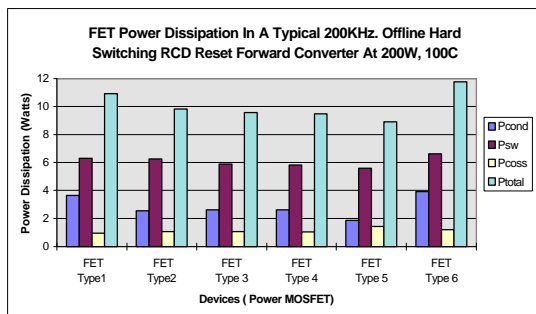


Fig. 5: FET Loss Distribution Comparison @ 200kHz.

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 ($I^2_{rms} \times R_{ds\ on}$) 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.