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A Spice-2 Subcircuit Representation For Power MOSFETs Using Empirical Methods

Abstract

An accurate power-MOSFET model is not widely available for CAD circuit simulation. This work provides a subcircuit model which is compatible with SPICE-2 software and MOSFET terminal measurements. SPICE-2 is the circuit simulation package of choice for this work because of its universal availability, despite its inherent limitations. These limitations are circumvented through circuit means.

This effort models power-MOSFET terminal behavior consistent with SPICE-2 limitations; hence it will differ from the physical model as suggested by Wheatley, et al[1], Ronan et al[2] and others. We feel we have advanced prior efforts[3] particularly in areas of third-quadrant operations, avalanche-mode simulation, switching waveforms and diode recovery waveforms.

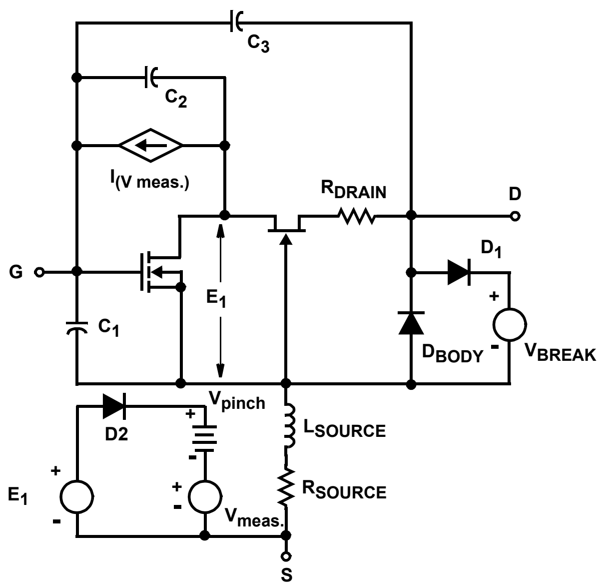

FIGURE 1. SPICE-2 SUBCIRCUIT FOR POWER MOSFET SIMULATION

NOTE: If the JFET source voltage, E_1, is very low relative to its V_{PINCH} voltage, the JFET is in a highly conductive state, tightly coupling C_2 to the JFET drain. However, as the voltage E_1 approaches V_{PINCH}, the JFET operates in a constant-current mode, thereby permitting a much faster drain slew rate, which is determined primarily by C_3.

Discussion

The subcircuit shown in Figure 1 is described in Table 1. All passive circuit elements are constants. The very-high-gain JFET is used to simulate the dual-slope drain voltage vs time switching curve common to the power MOSFET.[1,2]

If E_1 exceeds V_{PINCH}, errors will exist in the turn-on waveforms. The C_2 discharge current-controlled current source remedies this situation in conjunction with the subcircuit containing D_2. The D_2 ideality factor was set at 0.03 to assure that E_1 minus V_{PINCH} does not exceed several millivolts.

The body diode cannot be properly modeled by the JFET gate-drain diode, hence D_{BODY}. Conditions of Table 1 assure that most third-quadrant current flow is via D_{BODY}. Avalanche breakdown is more accurately modeled by the clamp circuit containing D_1.

Table 1 in combination with Figures 2, 3, 4 and 5 provides the required empirical inputs. Table 2 lists the preferred algorithm for parameter extraction.

TABLE 1. EMPIRICAL INPUTS

MOSFET		Enhancement mode; W = L = 1μm; K_P (Figure 2); V_{TO} (Figure 2); C's = 0; I_{DSO} = IE -12
JFET		Depletion mode; areas factor = 1; B = 100K_P (Figure 2); V_{TO} = V_{PINCH} (Figure 5); C's = diode lifetime = R_{SERIES} = 0; diode ideality factor = 1.0, I_{DSO} = IE -20
BODY DIODE		I_S from Figure 4; Ideality Factor = 1.0; R from Figure 4 (must be very much greater than R_D); C (from C_{OSS}); lifetime = best fit to T_{RR}
D_1		I_S = arbitrary; C = lifetime = 0; ideality factor = best low-current fit; R = best high-current fit
D_2		I_S = 1E -8; C = lifetime = R = 0; ideality factor = 0.03
R_S		Figure 2.
R_{DRAIN}		Figure 3
L_S		Approximately (5L) ln (4 L/d) nH; L and d are source wire inches.
V_{PINCH}		V_{TO} of JFET.
V_{BRK}		Avalanche voltage.
C_1		From Figure 5.
C_2		Maximum from Figure 5.
C_3		Minimum from Figure 5.

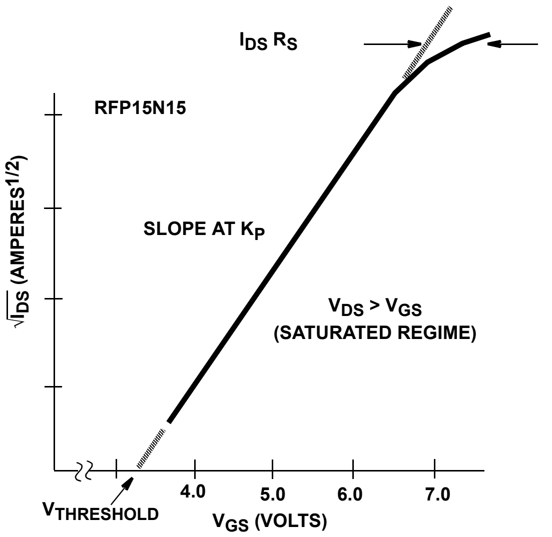

FIGURE 2. SQUARE ROOT OF DRAIN CURRENT VS GATE VOLTAGE DEFINES $V_{THRESHOLD}$, K_P, AND R_S

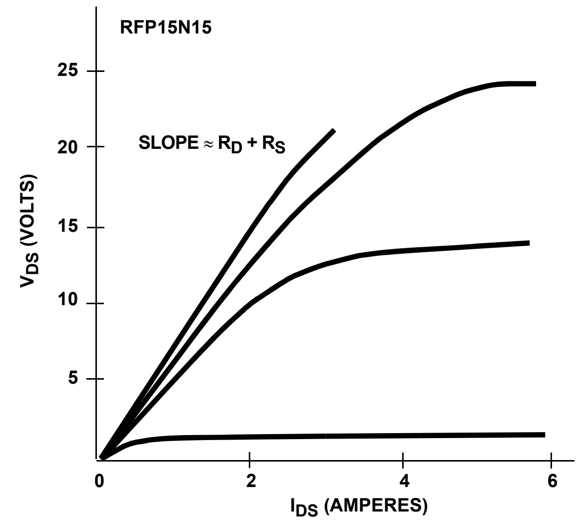

FIGURE 3. DRAIN CURRENT VS DRAIN VOLTAGE WITH CONSTANT GATE VOLTAGE DEFINES “ON” RESISTANCE

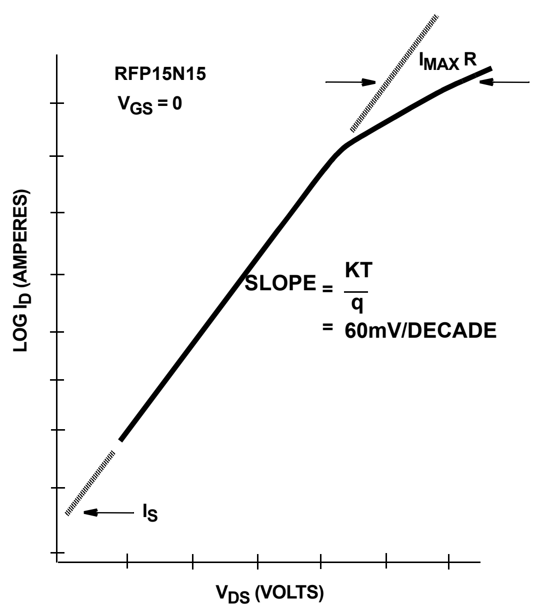

FIGURE 4. THIRD-QUADRANT OPERATION DEFINES I_S AND R OF DIODE D_{BODY}

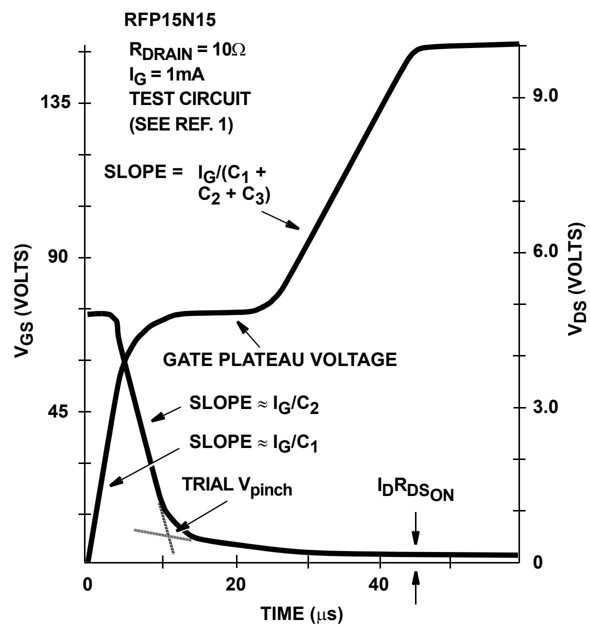

FIGURE 5. DRAIN AND GATE VOLTAGE VS TIME DETERMINE C_1, C_2, C_3 AND V_{PINCH}.

TABLE 2. PREFERRED ALGORITHM FOR PARAMETER EXTRACTION

1. Determine K_P of lateral MOS
2. Determine V_{TH} of lateral MOS
3. Determine C_1
4. Determine $C_1 + C_2 + C_3$
5. Determine R_{DS}
6. Assign B of JFET = 100 x K_P of lateral MOS
7. Use trial V_{PINCH}
8. Use C_2 (Maximum), C_3 (Minimum) are curve-fit C’s
9. Adjust V_{PINCH} to fix gate voltage plateau

Results

Figure 6 and Figure 7 compare measured static data to calculated transfer curves and output curves. Calculated static-output curves are shown in Figure 8 and Figure 9 for third-quadrant range, including avalanche. Calculated switching data is compared to measured switching curves[1,2] in Figure 10 and Figure 11. Calculated body-diode recovery curves are shown in Figure 12.

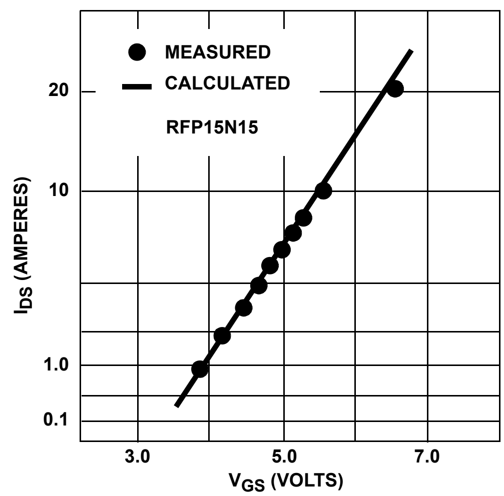

FIGURE 6. DRAIN CURRENT VS GATE VOLTAGE (NOTE SQUARE ROOT SCALE) - MEASURED CURVE VS CALCULATED POINTS

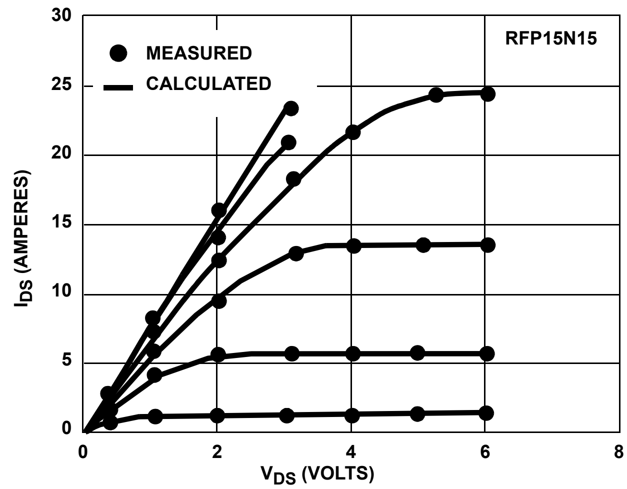

FIGURE 7. DRAIN CURRENT VS DRAIN VOLTAGE FOR CONSTANT VALUES OF GATE VOLTAGE - MEASURED CURVES VS CALCULATED POINTS

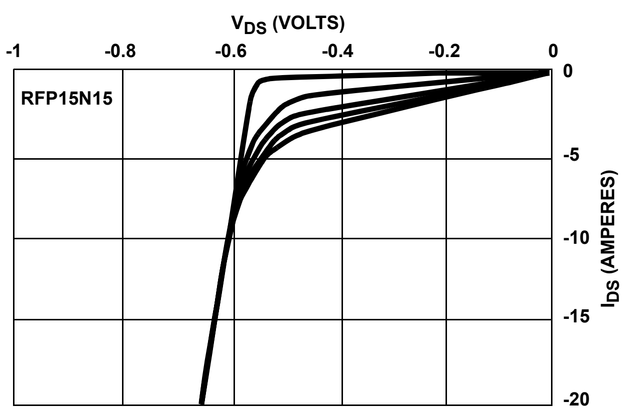

FIGURE 8. THIRD-QUADRANT DRAIN CURRENT VS DRAIN VOLTAGE WITH CONSTANT POSITIVE GATE VOLTAGE (CALCULATED)

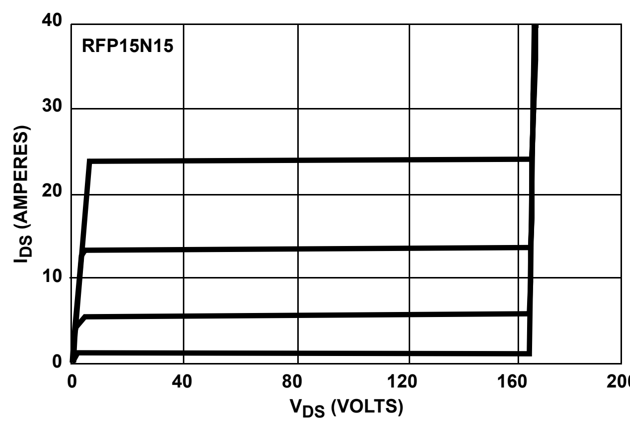

FIGURE 9. FIRST-QUADRANT DRAIN CURRENT VS DRAIN VOLTAGE, V_{GS} = CONSTANT. NOTE AVALANCHE BREAKDOWN (CALCULATED)

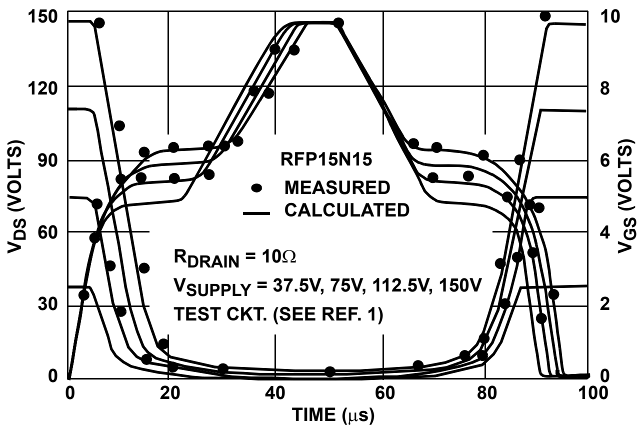

FIGURE 10. DRAIN AND GATE VOLTAGE VS TIME FOR CONSTANT GATE CIRCUIT - MEASURED CURVES VS CALCULATED POINTS

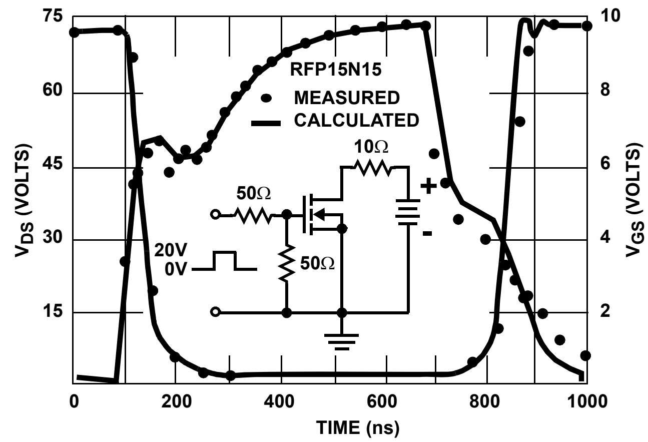

FIGURE 11. DRAIN AND GATE VOLTAGE VS TIME FOR STANDARD SWITCHING CIRCUIT - MEASURED CURVES VS CALCULATED POINTS

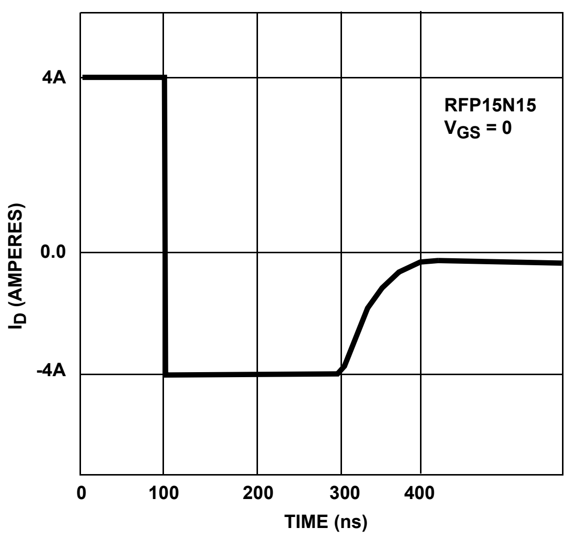

FIGURE 12. THIRD-QUADRANT DIODE - RECOVERY VS TIME CURVE (CALCULATED)

Conclusion

An equivalent-circuit model for power-MOSFETs, that is suitable for use with the SPICE CAD program, has been demonstrated. The model is compatible with all versions of SPICE presently available without modification to the program's internal code. The model addresses static and dynamic behavior of first and third-quadrant operation, including avalanche breakdown, and is empirical in nature. All necessary input parameters may be inferred from data sheets or simple terminal measurements.

Excellent agreement has been obtained between measured and simulated results.

References

[1] Wheatley Jr., C. F. and Ronan Jr., H. R., "Switching Waveforms of the L^{2}FET: A 5-Volt Gate-Drive Power MOSFET," Power Electronic Specialists Conference Record, June 1984, p. 238

[2] Ronan Jr., H. R. and Wheatley Jr., C. F., "Power MOSFET Switching Waveforms: A New Insight," Proceedings of Powercon II, April 1984, p. C-3

[3] Nienhaus, H. A., Bowers, J. C., and Herren Jr., P. C., "A High Power MOSFET Computer Model," Power Conversion International, January 1982, p 65

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