# 《线性电路实验》预习报告

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实验日期： 2025.04.25 实验地点： 教学楼 607 是否调课/补课： 否 成绩：

## 1 实验目的

(1) 加深对 FET 的理解；
(2) 测量 FET 转移特性；
(3) 搭建 MOSFET 放大电路，与双极型晶体管对比；

## 2 实验仪器

(1) 数字万用表：Unit UT61E (C190241394)
(2) 数字示波器：RIGOL 200MSO2202A (DS2F192200361)
(3) 信号发生器：GWINSTEK AFG-22225 (GER910370)
(4) 数字直流电源：GWINSTEK GPD-3303S (GES813705)
(5) 多功能数字测量仪：Analog Discovery 1 (D704387)
(6) 晶体管测试板：Simplified Transistor Tester
(7) 其它：3DJ7H (N-Channel JFET)、2N7000 (N-Channel VDMOS)、IRFP460 (N-Channel Power MOS)、电容、电阻、导线、跳线、测试点等

## 3 实验内容概要

(1) 用万用表测量 FET 的等效二极管压降
(2) 焊接 MOSFET 放大器 PCB 板
(3) 测量 MOSFET 静态特性曲线及转移特性曲线，测试方法详见 Transistor Measurement Methods；测试完成后，对所得数据进行处理，计算出 $r_O$、$g_m$、$\frac{g_m}{I_D}$ (transconductance efficiency) 等小信号参数以及 $R_{ON}$ (导通电阻)；
(4) 测量 common-source amplifier 的波形 (要有图片)、增益曲线 (100 Hz ~ 1 MHz)、输入输出阻抗 (100 Hz ~ 1 MHz)，增益与阻抗曲线的测量需要用到 Analog Discovery 1 (后简称 “AD1”)；增益曲线可在测输出阻抗的 $A_1$ 时测得，无需重复测量；
(5) 测量 common-drain amplifier (source follower) 的波形 (要有图片)、增益曲线 (100 Hz ~ 1 MHz)、输入输出阻抗 (100 Hz ~ 1 MHz)，增益及阻抗曲线的测量需要用到 AD1；增益曲线可在测输出阻抗的 $A_1$ 时测得，无需重复测量；
(6) 更改跳线，测量 CS 组态开关波形；
(7) (选做) 测量 JFET 静态特性曲线及转移特性曲线，测试方法及步骤同第 (3) 条。

# 4 输入输出阻抗的理论与实验测量公式

MOSFET 三种基本放大器的输入输出阻抗理论值如表 1 所示，其中 $R_{drain}$ 和 $R_{source}$ 电阻的含义是：

$$R_{D0} = r_O, \quad R_{S0} = \frac{1}{g_m} \parallel \frac{1}{g_{mb}} \parallel r_O \tag{1}$$

$$R_{drain} = \left(1 + \frac{R_S}{R_{S0}}\right) R_{D0}, \quad R_{source} = \left(1 + \frac{R_D}{r_O}\right) R_{S0} \tag{2}$$

**表 1: Three basic types of CMOS amplifiers**

| Parameter | CS (Common Source) | CD (SF, Source Follower) | CG (Common Gate) |
|---|---|---|---|
| $R_{out}$ | $R_D \parallel R_{drain}$ | $R_S \parallel R_{source}$ | $R_D \parallel R_{drain}$ |
| $G_m$ | $\frac{g_m}{1+\frac{R_S}{R_{S0}}}$ | $\frac{-g_m}{1+\frac{R_D}{r_O}}$ | $\frac{-1}{R_S+R_{S0}}$ |
| $A_v$ | $-g_m r_O \cdot \frac{R_D}{R_D+R_{drain}}$ | $g_m R_{S0} \cdot \frac{R_S}{R_S+R_{source}}$ | $\frac{R_D \parallel R_{drain}}{R_S+R_{source}}$ |
| $\lim\limits_{r_O\to\infty} R_{out}$ | $R_D$ | $R_S \parallel \frac{1}{g_m} \parallel \frac{1}{g_{mb}}$ | $R_D$ |
| $\lim\limits_{r_O\to\infty} G_m$ | $\frac{1}{(1+\eta)R_S+\frac{1}{g_m}}$ | $-g_m$ | $\frac{-1}{R_S+\frac{1}{g_m+g_{mb}}}$ |
| $\lim\limits_{r_O\to\infty} A_v$ | $\frac{-R_D}{(1+\eta)R_S+\frac{1}{g_m}}$ | $\frac{R_S}{(1+\eta)R_S+\frac{1}{g_m}}$ | $\frac{R_D}{R_S+\frac{1}{(1+\eta)g_m}}$ |
| $\lim\limits_{\substack{g_{mb}\to 0\\ r_O\to\infty}} R_{out}$ | $R_D$ | $R_S \parallel \frac{1}{g_m}$ | $R_D$ |
| $\lim\limits_{\substack{g_{mb}\to 0\\ r_O\to\infty}} G_m$ | $\frac{g_m}{1+g_m R_S}$ | $-g_m$ | $\frac{-1}{R_S+\frac{1}{g_m}} = \frac{-g_m}{1+g_m R_S}$ |
| $\lim\limits_{\substack{g_{mb}\to 0\\ r_O\to\infty}} A_v$ | $\frac{-R_D}{R_S+\frac{1}{g_m}}$ | $\frac{R_S}{R_S+\frac{1}{g_m}}$ | $\frac{R_D}{R_S+\frac{1}{g_m}}$ |

设 $A_1$ 为实验测得的原始增益，$A_2$ 为加入特定电阻后的增益，则有计算公式：

$$Z_{in} = \frac{R_S}{\left(\frac{A_1}{A_2} - 1\right)}, \quad Z_{out} = \left(\frac{A_1}{A_2} - 1\right) R_L \tag{3}$$

注意 $A_1$ 和 $A_2$ 是复数，当两者相位区别不大时，可作近似：

$$|Z_{in}| \approx \frac{R_S}{\left(\left|\frac{A_1}{A_2}\right| - 1\right)}, \quad |Z_{out}| \approx \left(\left|\frac{A_1}{A_2}\right| - 1\right) R_L \tag{4}$$

# 5 Electrical Characteristics of N-Channel VDMOS 2N7000 (onsemi)

**ABSOLUTE MAXIMUM RATINGS** Values are at $T_C$ = 25°C unless otherwise noted.

| Symbol | Parameter | Value | | | Unit |
|---|---|---|---|---|---|
| | | 2N7000 | 2N7002 | NDS7002A | |
| $V_{DSS}$ | Drain−to−Source Voltage | 60 | | | V |
| $V_{DGR}$ | Drain−Gate Voltage ($R_{GS}$ ≤ 1 MW) | 60 | | | V |
| $V_{GSS}$ | Gate−Source Voltage − Continuous | ±20 | | | V |
| | Gate−Source Voltage − Non Repetitive (tp < 50 ms) | ±40 | | | |
| $I_D$ | Maximum Drain Current − Continuous | 200 | 115 | 280 | mA |
| | Maximum Drain Current − Pulsed | 500 | 800 | 1500 | |
| $P_D$ | Maximum Power Dissipation Derated above 25°C | 400 | 200 | 300 | mW |
| | | 3.2 | 1.6 | 2.4 | mW/°C |
| $T_J$, $T_{STG}$ | Operating and Storage Temperature Range | −55 to 150 | | −65 to 150 | °C |
| $T_L$ | Maximum Lead Temperature for Soldering Purposes, 1/16−inch from Case for 10 s | 300 | | | °C |

Stresses exceeding those listed in the Maximum Ratings table may damage the device. If any of these limits are exceeded, device functionality should not be assumed, damage may occur and reliability may be affected.

**THERMAL CHARACTERISTICS** Values are at $T_C$ = 25°C unless otherwise noted.

| Symbol | Parameter | Value | | | Unit |
|---|---|---|---|---|---|
| | | 2N7000 | 2N7002 | NDS7002A | |
| $R_{\theta JA}$ | Thermal Resistance, Junction to Ambient | 312.5 | 625 | 417 | °C/W |

**ELECTRICAL CHARACTERISTICS**
Values are at $T_C$ = 25°C unless otherwise noted.

| Symbol | Parameter | Conditions | Type | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **OFF CHARACTERISTICS** | | | | | | | |
| $BV_{DSS}$ | Drain−Source Breakdown Voltage | $V_{GS}$ = 0 V, $I_D$ = 10 μA | All | 60 | − | − | V |
| $I_{DSS}$ | Zero Gate Voltage Drain Current | $V_{DS}$ = 48 V, $V_{GS}$ = 0 V | 2N7000 | − | − | 1 | μA |
| | | $V_{DS}$ = 48 V, $V_{GS}$ = 0 V, $T_C$ = 125°C | | − | − | 1 | mA |
| | | $V_{DS}$ = 60 V, $V_{GS}$ = 0 V | 2N7002 NDS7002A | − | − | 1 | μA |
| | | $V_{DS}$ = 60 V, $V_{GS}$ = 0 V, $T_C$ = 125°C | | − | − | 0.5 | mA |
| $I_{GSSF}$ | Gate − Body Leakage, Forward | $V_{GS}$ = 15 V, $V_{DS}$ = 0 V | 2N7000 | − | − | 10 | nA |
| | | $V_{GS}$ = 20 V, $V_{DS}$ = 0 V | 2N7002 NDS7002A | − | − | 100 | |
| $I_{GSSR}$ | Gate − Body Leakage, Reverse | $V_{GS}$ = −15 V, $V_{DS}$ = 0 V | 2N7000 | − | − | −10 | nA |
| | | $V_{GS}$ = −20 V, $V_{DS}$ = 0 V | 2N7002 NDS7002A | − | − | −100 | |
| **ON CHARACTERISTICS** | | | | | | | |
| $V_{GS(th)}$ | Gate Threshold Voltage | $V_{DS}$ = $V_{GS}$, $I_D$ = 1 mA | 2N7000 | 0.8 | 2.1 | 3 | V |
| | | $V_{DS}$ = $V_{GS}$, $I_D$ = 250 μA | 2N7002 NDS7002A | 1 | 2.1 | 2.5 | |

**ELECTRICAL CHARACTERISTICS** (continued)
Values are at $T_C$ = 25°C unless otherwise noted.

| Symbol | Parameter | Conditions | Type | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **ON CHARACTERISTICS** | | | | | | | |
| $R_{DS(on)}$ | Static Drain−Source On−Resistance | $V_{GS}$ = 10 V, $I_D$ = 500 mA | 2N7000 | – | 1.2 | 5 | Ω |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA, $T_C$ = 125°C | | – | 1.9 | 9 | |
| | | $V_{GS}$ = 4.5 V, $I_D$ = 75 mA | | – | 1.8 | 5.3 | |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA | 2N7002 | – | 1.2 | 7.5 | |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA, $T_C$ = 100°C | | – | 1.7 | 13.5 | |
| | | $V_{GS}$ = 5 V, $I_D$ = 50 mA | | – | 1.7 | 7.5 | |
| | | $V_{GS}$ = 5 V, $I_D$ = 50 mA, $T_C$ = 100°C | | – | 2.4 | 13.5 | |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA | NDS7002A | – | 1.2 | 2 | |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA, $T_C$ = 125°C | | – | 2 | 3.5 | |
| | | $V_{GS}$ = 5 V, $I_D$ = 50 mA | | – | 1.7 | 3 | |
| | | $V_{GS}$ = 5 V, $I_D$ = 50 mA, $T_C$ = 125°C | | – | 2.8 | 5 | |
| $V_{DS(on)}$ | Drain−Source On−Voltage | $V_{GS}$ = 10 V, $I_D$ = 500 mA | 2N7000 | – | 0.6 | 2.5 | V |
| | | $V_{GS}$ = 4.5 V, $I_D$ = 75 mA | | – | 0.14 | 0.4 | |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA | 2N7002 | – | 0.6 | 3.75 | |
| | | $V_{GS}$ = 5.0 V, $I_D$ = 50 mA | | – | 0.09 | 1.5 | |
| | | $V_{GS}$ = 10 V, $I_D$ = 500 mA | NDS7002A | – | 0.6 | 1 | |
| | | $V_{GS}$ = 5.0 V, $I_D$ = 50 mA | | – | 0.09 | 0.15 | |
| $I_{D(on)}$ | On−State Drain Current | $V_{GS}$ = 4.5 V, $V_{DS}$ = 10 V | 2N7000 | 75 | 600 | – | mA |
| | | $V_{GS}$ = 10 V, $V_{DS} \geq 2\ V_{DS(on)}$ | 2N7002 | 500 | 2700 | – | |
| | | $V_{GS}$ = 10 V, $V_{DS} \geq 2\ V_{DS(on)}$ | NDS7002A | 500 | 2700 | – | |
| $g_{FS}$ | Forward Transconductance | $V_{DS}$ = 10 V, $I_D$ = 200 mA | 2N7000 | 100 | 320 | – | mS |
| | | $V_{DS} \geq 2\ V_{DS(on)}$, $I_D$ = 200 mA | 2N7002 | 80 | 320 | – | |
| | | $V_{DS} \geq 2\ V_{DS(on)}$, $I_D$ = 200 mA | NDS7002A | 80 | 320 | – | |
| **DYNAMIC CHARACTERISTICS** | | | | | | | |
| $C_{iss}$ | Input Capacitance | $V_{DS}$ = 25 V, $V_{GS}$ = 0 V, f = 1.0 MHz | All | – | 20 | 50 | pF |
| $C_{oss}$ | Output Capacitance | | All | – | 11 | 25 | |
| $C_{rss}$ | Reverse Transfer Capacitance | | All | – | 4 | 5 | |
| $t_{on}$ | Turn−On Time | $V_{DD}$ = 15 V, $R_L$ = 25 Ω, $I_D$ = 500 mA, $V_{GS}$ = 10 V, $R_{GEN}$ = 25 Ω | 2N7000 | – | – | 10 | ns |
| | | $V_{DD}$ = 30 V, $R_L$ = 150 Ω, $I_D$ = 200 mA, $V_{GS}$ = 10 V, $R_{GEN}$ = 25 Ω | 2N7002 NDS7002A | – | – | 20 | |
| $t_{off}$ | Turn−Off Time | $V_{DD}$ = 15 V, $R_L$ = 25 Ω, $I_D$ = 500 mA, $V_{GS}$ = 10 V, $R_{GEN}$ = 25 Ω | 2N7000 | – | – | 10 | ns |
| | | $V_{DD}$ = 30 V, $R_L$ = 150 Ω, $I_D$ = 200 mA, $V_{GS}$ = 10 V, $R_{GEN}$ = 25 Ω | 2N7002 NDS7002A | – | – | 20 | |

**ELECTRICAL CHARACTERISTICS** (continued)
Values are at $T_C$ = 25°C unless otherwise noted.

| Symbol | Parameter | Conditions | Type | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|---|
| **DRAIN−SOURCE DIODE CHARACTERISTICS AND MAXIMUM RATINGS** | | | | | | | |
| $I_S$ | Maximum Continuous Drain−Source Diode Forward Current | | 2N7002 | – | – | 115 | mA |
| | | | NDS7002A | – | – | 280 | |
| $I_{SM}$ | Maximum Pulsed Drain−Source Diode Forward Current | | 2N7002 | – | – | 0.8 | A |
| | | | NDS7002A | – | – | 1.5 | |
| $V_{SD}$ | Drain−Source Diode Forward Voltage | $V_{GS}$ = 0 V, $I_S$ = 115 mA (Note 1) | 2N7002 | – | 0.88 | 1.5 | V |
| | | $V_{GS}$ = 0 V, $I_S$ = 400 mA (Note 1) | NDS7002A | – | 0.88 | 1.2 | |

Product parametric performance is indicated in the Electrical Characteristics for the listed test conditions, unless otherwise noted. Product performance may not be indicated by the Electrical Characteristics if operated under different conditions.

1. Pulse test: Pulse Width ≤ 300 μs, Duty Cycel ≤ 2 %

## TYPICAL PERFORMANCE CHARACTERISTICS

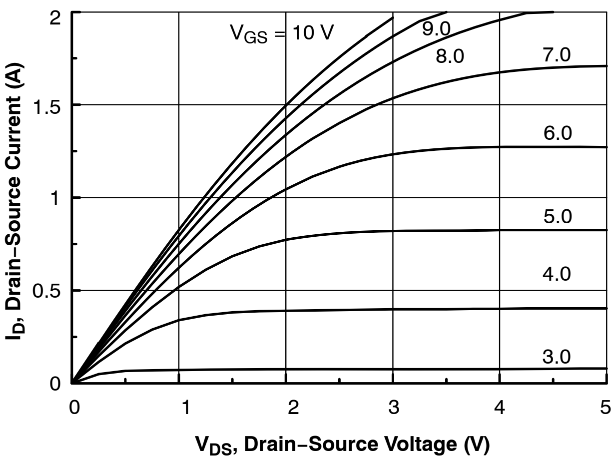


**Figure 1. On−Region Characteristics**

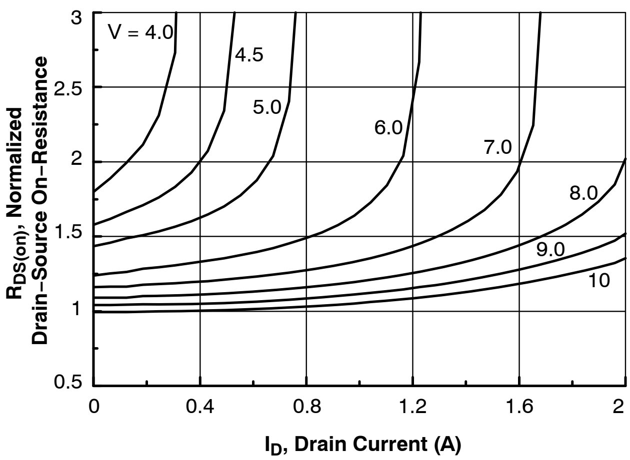


**Figure 2. On−Resistance Variation with Gate Voltage and Drain Current**

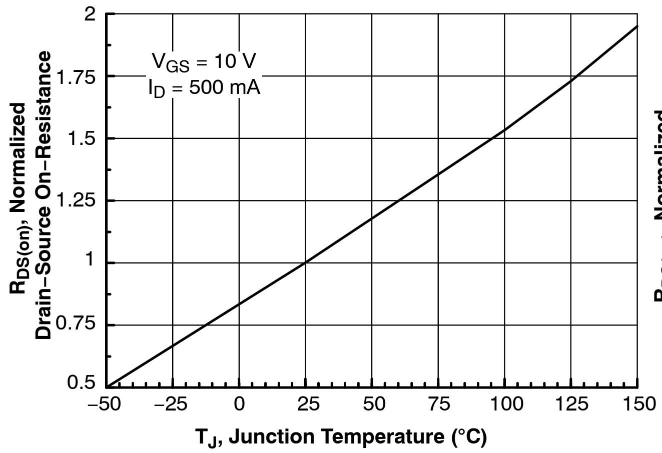


**Figure 3. On−Resistance Variation with Temperature**

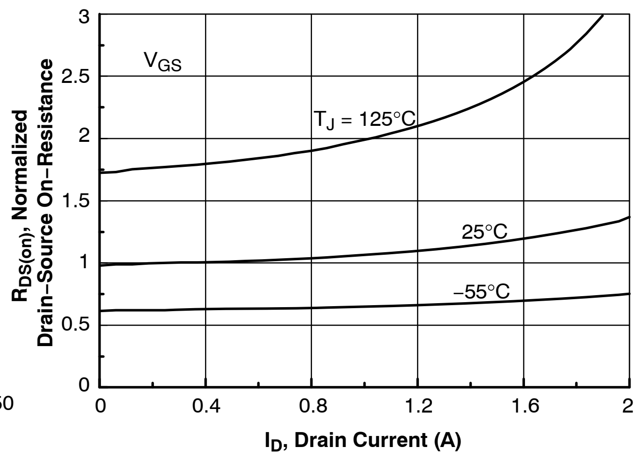


**Figure 4. On−Resistance Variation with Drain Current and Temperature**

## TYPICAL PERFORMANCE CHARACTERISTICS (Continued)

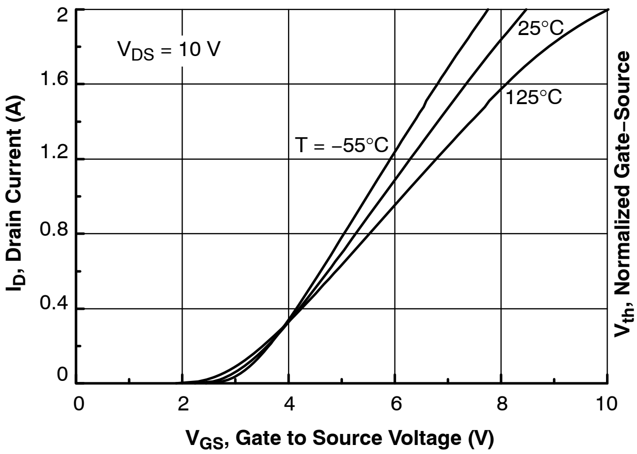


**Figure 5. Transfer Characteristics**

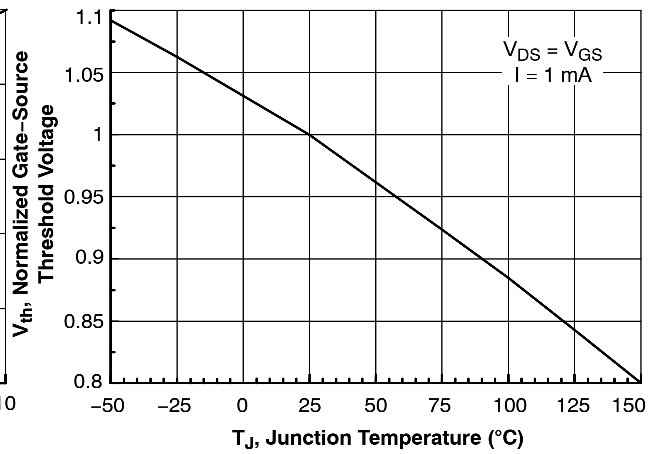


**Figure 6. Gate Threshold Variation with Temperature**

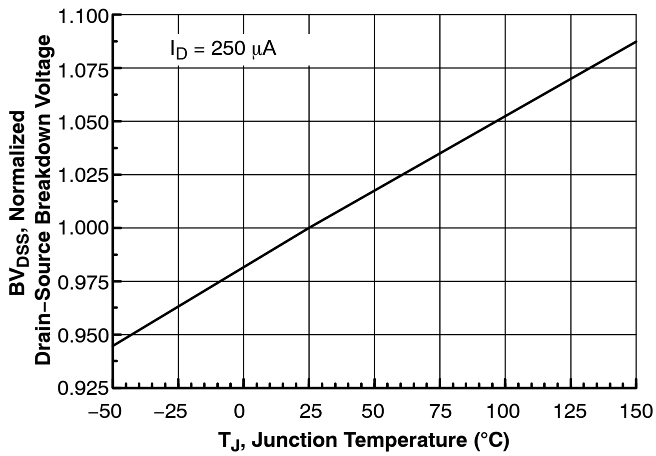


**Figure 7. Breakdown Voltage Variation with Temperature**

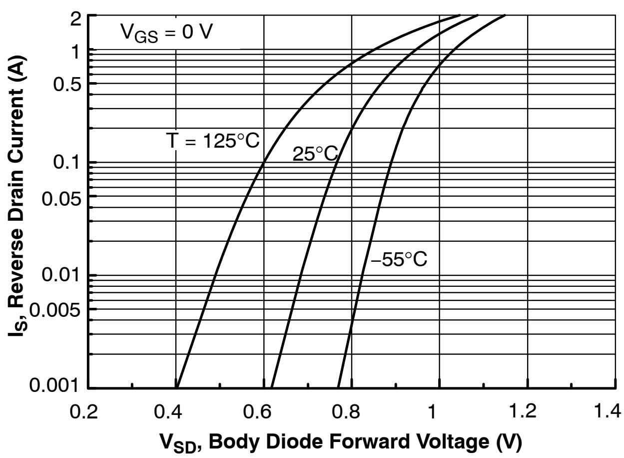


**Figure 8. Body Diode Forward Voltage Variation with**

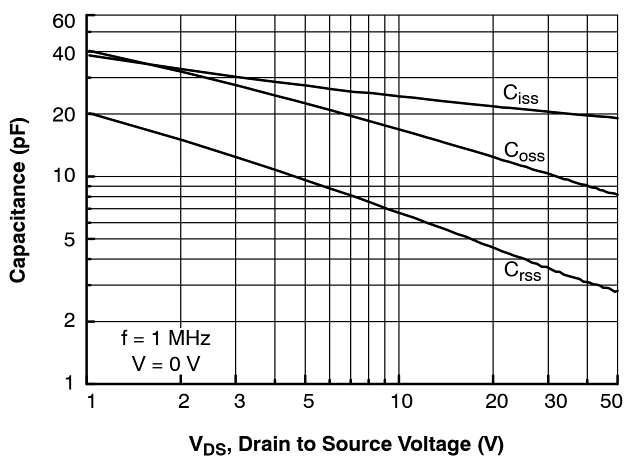


**Figure 9. Capacitance Characteristics**

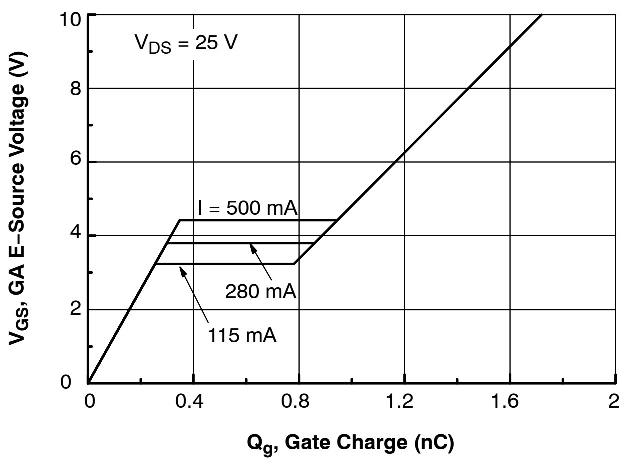


**Figure 10. Gate Charge Characteristics**