Analogue Electronics
Experiment 2 - MOSFET Characteristics
ENG221

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1 Objective

To determine the internal parameters of a MOSFET.

1.1 Background

Output Resistance in Saturation In saturation, the idealised model of the MOSFET tells us that i_D is independent of v_{DS}. This implies that some change Δv_{DS} means that there is no change in i_D, however, this is an idealisation. In reality the device will experience something called channel length modulation. This shrinkage of the length of the channel means that the MOSFET is now modelled by:

$$i_D = \frac{1}{2}k'_n\left(\frac{W}{L}\right)(v_{GS} - V_t)^2(1 + \lambda v_{DS}) \tag{1}$$

where

i_D = current through the device
$\frac{W}{L}$ = ratio of the device width to the device length
k'_n = transconductance parameter
v_{GS} = voltage from the gate to the source
V_t = threshold voltage
λ = channel length modulation parameter
v_{DS} = the voltage from the drain to the source

In equation (1) we see that i_D is linearly dependent on $v_D S$. Extrapolating the model in saturation yields the following formula:

$$V_A = \frac{1}{\lambda} \tag{2}$$

If i_D is now dependent on v_{DS}, then for a given v_{GS}, a change Δv_{DS} yields a change δi_D in the drain current i_D. Hence we define the output resistance as r_o and express it as:

$$r_o = \left[\frac{\partial i_D}{\partial v_{DS}} \right]^{-1}_{v_{GS} \text{ constant}} \tag{3}$$

2 Experimental Data

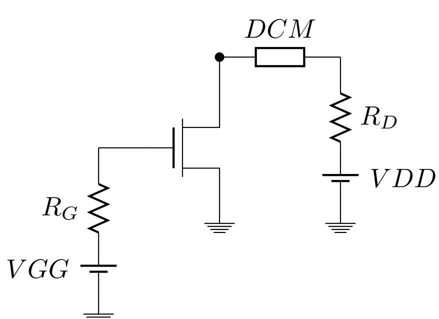

Figure 1: n-type MOSFET circuit

VDD	VGG	V_{R_D}	V_{R_D}/R_D	V_D
10.00 V	1.3 V	0 V	0 mA	10.00 V
10.00 V	2.00 V	0.38 V	0.38 mA	9.62 V
8.00 V	2.00 V	0.38 V	0.38 mA	9.62 V
6.00 V	2.00 V	0.38 V	0.38 mA	9.62 V
4.00 V	2.00 V	0.38 V	0.38 mA	9.62 V
2.00 V	2.00 V	0.38 V	0.38 mA	9.62 V
10.00 V	3.00 V	1.58 V	1.58 mA	8.42 V
8.00 V	3.00 V	1.58 V	1.58 mA	8.42 V
6.00 V	3.00 V	1.58 V	1.58 mA	8.42 V
4.00 V	3.00 V	1.58 V	1.58 mA	8.42 V
2.00 V	3.00 V	1.36 V	1.36 mA	8.64 V
10.00 V	4.00 V	3.48 V	3.48 mA	6.52 V
8.00 V	4.00 V	3.48 V	3.48 mA	6.52 V
6.00 V	4.00 V	3.48 V	3.48 mA	6.52 V
4.00 V	4.00 V	3.48 V	3.48 mA	6.52 V
2.00 V	4.00 V	2.51 V	2.51 mA	7.49 V
10.00 V	5.00 V	5.56 V	5.56 mA	4.40 V
8.00 V	5.00 V	5.56 V	5.56 mA	4.40 V
6.00 V	5.00 V	5.56 V	5.56 mA	4.40 V
4.00 V	5.00 V	5.20 V	5.20 mA	4.80 V
2.00 V	5.00 V	3.33 V	3.33 mA	6.67 V

Table 1: Output characteristic

VDD	VGG	V_{R_D}	V_{R_D}/R_D	V_D
10.50 V	5.00 V	5.5 V	5.5 mA	5 V
15.6 V	5 V	5.56 V	5.56 mA	10 V

Table 2: Output resistance

v_{GS}	i_D
1.3 V	10 mA
1.4 V	40 mA
1.5 V	70 mA
1.6 V	110 mA
1.7 V	140 mA
2.0 V	360 mA
3.0 V	1560 mA
4.0 V	3240 mA
5.0 V	3710 mA

Table 3: Control $V_{DD} = 5$V

v_{GS}	i_D
1.3 V	20 mA
1.4 V	30 mA
1.5 V	50 mA
1.6 V	80 mA
1.7 V	130 mA
2.0 V	320 mA
3.0 V	670 mA
4.0 V	740 mA
5.0 V	780 mA

Table 4: Control $V_{DD} = 1$V

v_{GS}	i_D
1.3 V	10 mA
1.4 V	30 mA
1.5 V	70 mA
1.6 V	100 mA
1.7 V	150 mA
2.0 V	390 mA
3.0 V	1610 mA
4.0 V	3350 mA
5.0 V	5460 mA

Table 5: Control $V_{DD} = 10$V

3 Calculations

3.1 Output Resistance

In the second task we are asked to find the resistance to which the characteristic slope corresponds. According to equation (3) we see that the output resistance is the inverse of the slope of the i_D-$v_D S$ line when operating in the saturation region. Hence from equation (3), for a given v_{GS} we can say that:

$$r_o = \frac{\Delta v_{DS}}{\Delta i_D}$$

Using the experimental data in table 2 we see that:

$$\begin{aligned} r_o &= \frac{10 - 5}{5.56\text{E-}3 - 5.5\text{E-}3} \\ &= 83.88\text{k}\Omega \end{aligned}$$

Now the drain to source was shunted with a resistor of magnitude 83.33 kΩ. The previous change in current was:

$$\Delta i_{D_1} = 5.56\text{mA} - 5.5\text{mA} = 0.06\text{mA}$$

The change in current with the shunt added was:

$$\Delta i_{D_2} = 5.62\text{mA} - 5.56\text{mA} = 0.06\text{mA}$$

Now, if $V_G = V_{DS} = 5$V, then the shut resistor should be the same value as above: 83.33 kΩ. This is because V_G is unchanged. The theory outlined in the background tells us that provided the device is operating in saturation, for some given V_G, then i_D and v_{DS} are linearly related. This means that the slope is constant, which in turn implies that the output resistance is constant for a given V_{GS}.

Now to determine V_A and λ we need to determine the equation of the linear relation between i_D and v_{DS}. The slope is simply the inverse of the resistance, hence:

$$i_d = \frac{1}{83.33\text{E}3} v_{DS} + \text{constant}$$

To find the constant, we can use the tuple $(i_D, v_{DS}) = (5.56\text{mA}, 10\text{V})$:

$$\begin{aligned} 5.56\text{mA} &= \frac{1}{83.33\text{E}3} \times 10\text{V} + \text{constant} \\ \text{constant} &= 46.33 \end{aligned}$$

Hence the equation is:

$$i_d = \frac{1}{83.33\text{E}3} v_{DS} + 46.33$$

Setting $i_D = 0$ and solving for v_{DS} will give us the value for V_A. Hence:

$$V_A = 3860678\text{V}$$

Finally, using equation (2) we can solve for the channel length modulation parameter, λ:

$$\lambda = \frac{1}{V_A} = \frac{1}{3860678} = 2.59\text{E-7}$$

3.2 Control Characteristics

To find the device parameters k_n and V_t, we consider two of the experimental data points in table 3. The two points, give us two distinct instances of equation (1), where the modulation parameter, λ, is assumed to be zero. Now, the equations are:

$$i_{D_1} = \frac{1}{2}k_n'(V_{GS_1} - V_t)^2 \tag{4}$$

$$i_{D_2} = \frac{1}{2}k_n'(V_{GS_2} - V_t)^2 \tag{5}$$

If we divide equation (4) by equation (5) we get:

$$\frac{i_{D_1}}{i_{D_2}} = \frac{\frac{1}{2}k_n'(V_{GS_1} - V_t)^2}{\frac{1}{2}k_n'(V_{GS_2} - V_t)^2}$$

Cancelling the $\frac{1}{2}k_n'$ from the numerator and denominator, we get:

$$\frac{i_{D_1}}{i_{D_2}} = \left(\frac{V_{GS_1} - V_t}{V_{GS_2} - V_t}\right)^2$$

With some algebraic manipulation we arrive at the following relationship:

$$V_T = \frac{\sqrt{\frac{i_{D_1}}{i_{D_2}}}V_{GS_2} - V_{GS_1}}{(\sqrt{\frac{i_{D_1}}{i_{D_2}}} - 1)}$$

Using the two points $(1.3\text{V}, 20\text{mA})$, and $((3\text{V}, 670\text{mA}))$, we get:

$$V_T = 0.944V$$

Hence, we can now solve for k_n:

$$k_n = \frac{2i_D}{(V_{GS} - V_T)^2} = 315.6\frac{\text{mA}}{\text{V}^2}$$

4 Results and Conclusions

4.1 Output Resistance

The value which was calculated from the experimental data for the output resistance was 83.33kΩ. The value for V_A is 3860678V which is very large and consequently the value found for λ, 2.59E-7, is very small. The value for V_A is most likely incorrect as comparable circuits operate with V_A which is many orders of magnitude smaller that the one calculated. The values of both V_A are artefacts of the value chosen for shunt resistor.

The shunt resistor values was matched to the output resistance r_o, but this is very large when compared to the value of the resistance R_D in the circuit, despite providing the same incremental change in device current i_D. The selection of the shunt resistor (and even the value of the output resistance) are most likely erroneous. This is due to misconception and lack of understanding with respect to the fundamental operation of the circuit and how to derive the underlying parameters of the device.

4.2 Control Characteristics

The experimental data from table 3, 4 and 5 was plotted in Matlab and can be seen in figures 2, 3 and 4 respectively. The values of V_t that was estimated was 0.944V and the value of k_n that was estimated using V_t was 315.6 $\frac{\text{mA}}{\text{V}^2}$. The value for V_t is significantly greater than the standard 25 mV and hence the calculated value for V_t and k_n is most likely in error.

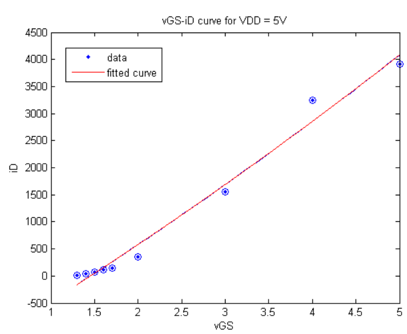

Figure 2: Plot of $v_{GS} vs. i_D$ for $V_{DD} = 5$V

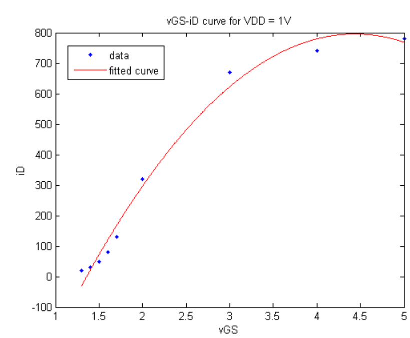

Figure 3: Plot of $v_{GS} vs. i_D$ for $V_{DD} = 1$V

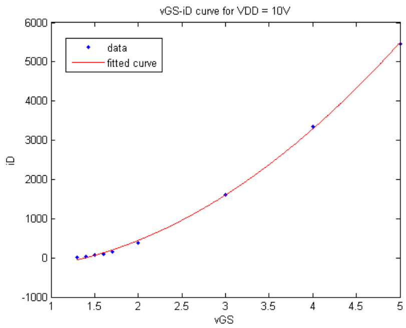

Figure 4: Plot of $v_{GS} vs. i_D$ for $V_{DD} = 10$V