Lab Report: Experiment 7

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Experiment:
Plot I_D versus V_{DS} graph
of MOSFET for different
V_{GS} values and get
the family of curves.

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1 Theory

1.1 MOSFET Basics

A Metal-Oxide-Semiconductor Field Effect Transistor (MOSFET) is a voltage-controlled device where the current between drain and source (I_D) is controlled by the gate-to-source voltage (V_{GS}). The relationship between I_D, V_{GS}, and V_{DS} depends on the region of operation of the MOSFET.

1.2 Regions of Operation

1. Cutoff Region ($V_{GS} < V_{th}$): In this region, the gate voltage is less than the threshold voltage (V_{th}). No channel is formed and hence,

$$I_D = 0$$

The MOSFET behaves like an open switch.

2. Triode (Linear) Region ($V_{GS} > V_T$ and $V_{DS} < V_{GS} - V_T$): A conductive channel is formed between drain and source. The current increases linearly with V_{DS} and is given by:

$$I_D = \mu_n C_{ox} \frac{W}{L} \left[(V_{GS} - V_T)V_{DS} - \frac{V_{DS}^2}{2} \right] (1 + \lambda V_{DS})$$

where:

- μ_n = electron mobility
- C_{ox} = oxide capacitance per unit area
- W/L = width-to-length ratio of MOSFET channel

3. Saturation Region ($V_{DS} \geq V_{GS} - V_T$): As V_{DS} increases beyond ($V_{GS} - V_T$), the channel is pinched off near the drain end. The current saturates and becomes nearly constant with V_{DS}:

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2$$

The small increase in I_D with V_{DS} is due to channel length modulation, represented by:

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_T)^2 (1 + \lambda V_{DS})$$

where λ is the channel length modulation parameter.

1.3 Shape of the I_D–V_{DS} Curves

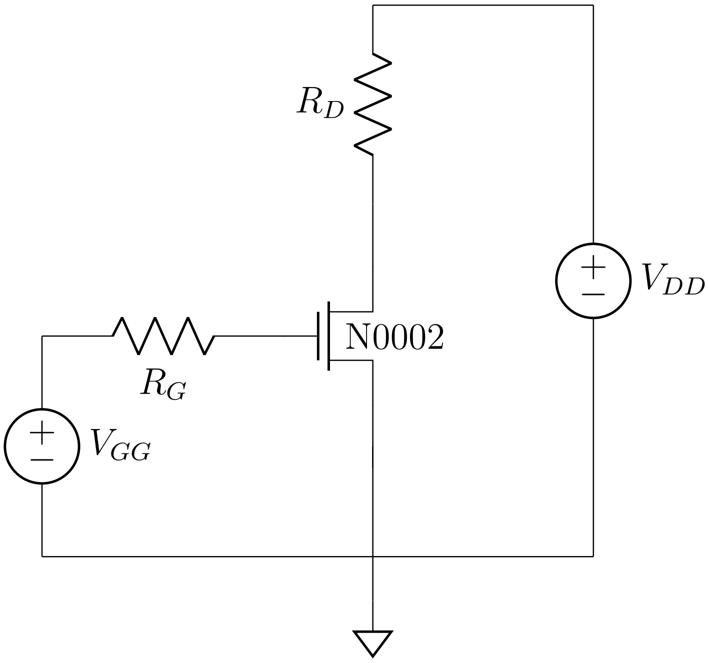
- For $V_{GS} < V_T$: The MOSFET is OFF, $I_D = 0$ (horizontal line on the x-axis).
- For $V_{GS} > V_T$: Initially, I_D increases almost linearly with V_{DS} (ohmic region), and then becomes almost constant (saturation region).
- Increasing V_{GS} shifts the curves upward since I_D increases with $(V_{GS} - V_T)^2$.

Hence, the family of curves shows:

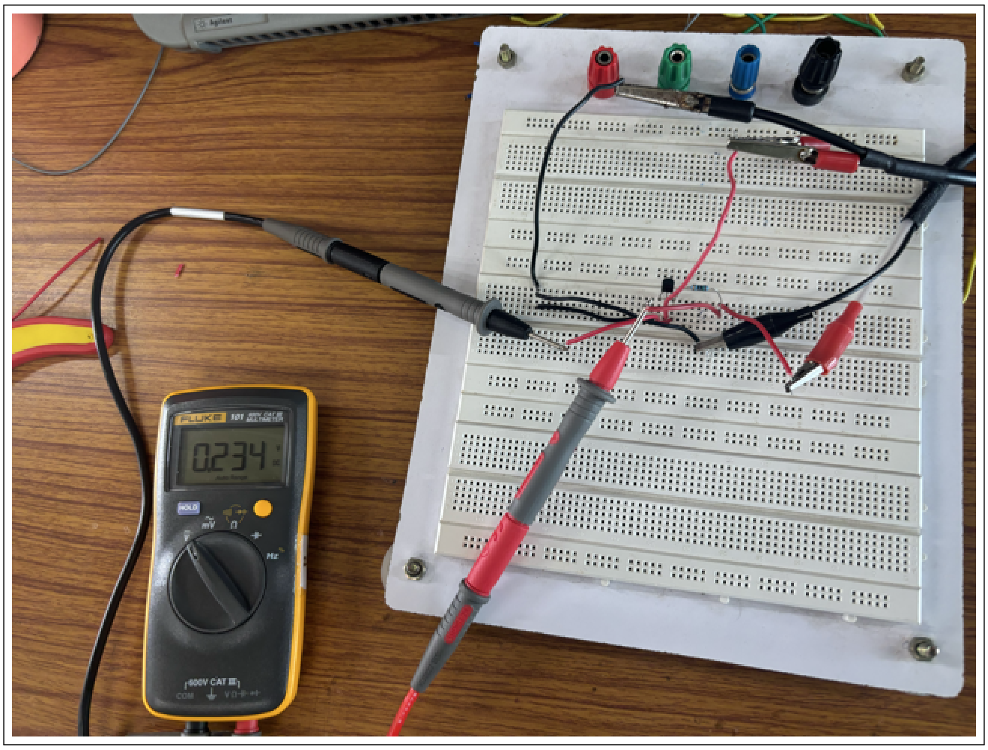
- Steep rise at low V_{DS} (linear region)
- Almost constant I_D at high V_{DS} (saturation region)
- Separate curves for each V_{GS} value

2 Experimental Procedure, Setup

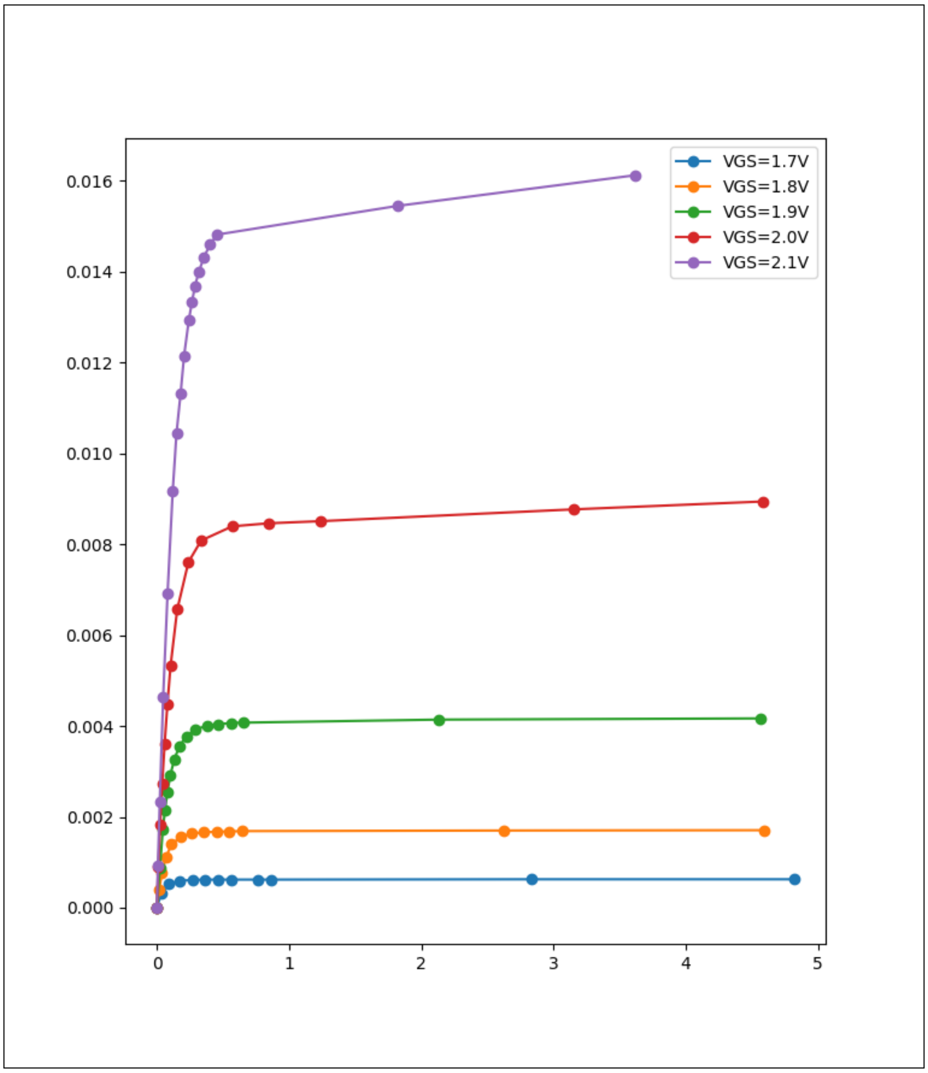
Circuit, NMOS used was $N000$, and $R_D = R_G = 150\Omega$.



1. Connect the circuit as shown
2. Figure out threshold voltage
3. Bias the MOSFET appropriately such that $V_{GS} > V_{TO}$.
4. Vary V_{DS} and measure I_D. Since we can't measure currents using oscilloscope, we measure potential drop across drain resistor.
5. Repeat the experiment for different values of V_{GS}.
6. Plot all the points to obtain the family of curves.


FLUKE
101
0.234
HOLD
600V CAT III
COM

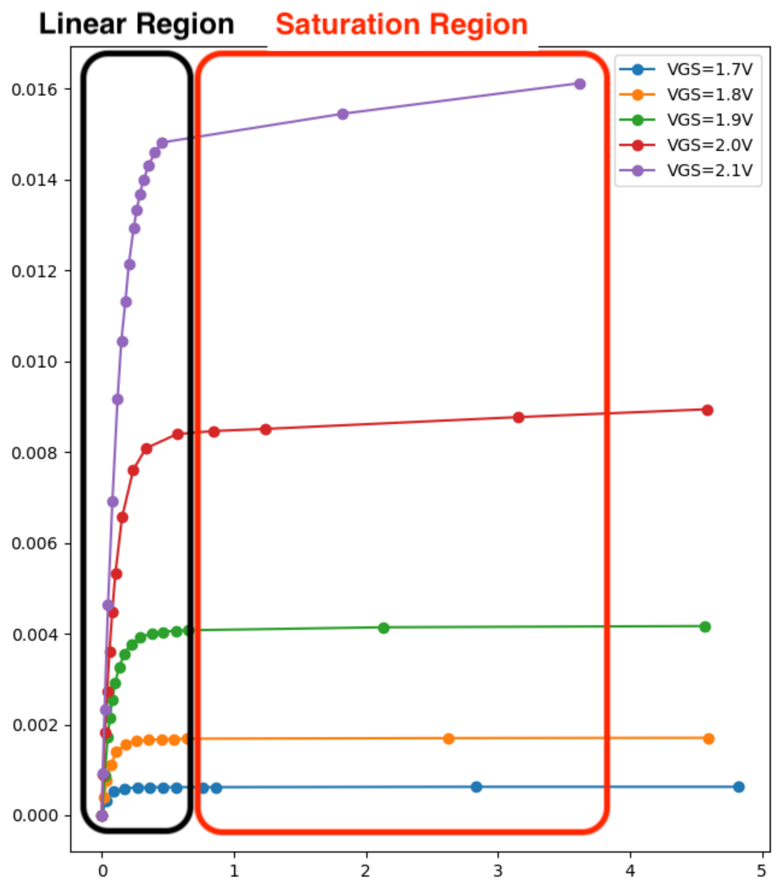
3 Observations and Graphs



V_{DS} (V)	V_R (V)	V_{GS} (V)	V_{DS} (V)	V_R (V)
		$V_{GS} = 1.7\ V$		
0.000	0.000		0.033	0.047
0.088	0.079		0.173	0.089
0.269	0.092		0.367	0.093
0.466	0.093		0.565	0.093
0.764	0.093		0.862	0.093
2.837	0.094		4.818	0.094
		$V_{GS} = 1.8\ V$		
0.000	0.000		0.017	0.060
0.039	0.116		0.069	0.168
0.112	0.209		0.179	0.234
0.262	0.245		0.355	0.249
0.450	0.251		0.549	0.252
0.645	0.253		2.621	0.255
4.598	0.256			
		$V_{GS} = 1.9\ V$		
0.000	0.000		0.023	0.131
0.045	0.258		0.061	0.320
0.079	0.380		0.101	0.436
0.131	0.488		0.170	0.533
0.223	0.566		0.293	0.588
0.377	0.601		0.465	0.606
0.565	0.610		0.656	0.611
2.130	0.621		4.570	0.625
		$V_{GS} = 2.0\ V$		
0.000	0.000		0.011	0.137
0.025	0.273		0.040	0.408
0.059	0.541		0.080	0.673
0.104	0.800		0.154	0.984
0.239	1.141		0.335	1.212
0.570	1.259		0.845	1.269
1.235	1.276		3.152	1.315
4.585	1.341			
		$V_{GS} = 2.1\ V$		
0.000	0.000		0.008	0.139
0.022	0.349		0.048	0.696
0.081	1.037		0.120	1.375
0.149	1.568		0.180	1.698
0.206	1.822		0.242	1.940
0.265	1.998		0.289	2.053
0.318	2.100		0.356	2.147
0.403	2.190		0.456	2.222
1.825	2.317		3.621	2.418

We can find out threshold voltage by varying V_{GS} till we get non zero I_D. For the chosen MOSFET, $V_{TO} = 1.45V$.

4 Observations



The above graph shows output characteristics of Common Source configuration of MOSFET. There are 3 regions in the graph,

- **Cutoff Region:** $V_{GS} < V_{TO}$, this results in the MOSFET being powered off i.e. $I_D = 0$.
- **Linear Region:** Also called Ohmic region, V_{DS} varies linearly with I_D (at a constant V_{GS}) i.e. MOSFET behaves like a resistor.
- **Saturation Region:** $V_{DS} > V_{OV}$ (where V_{OV} is Overdrive voltage). I_D is nearly constant.

5 Conclusion

We observe I_D vs V_{DS} characteristics of a MOSFET in common source configuration. We see all 3 operating regions of the MOSFET - Cutoff, Linear, Saturation.

Code used for plotting, `https://github.com/ArjunPavanje/EE2301/blob/main/Experiment_7/py.py`
Circuit images, `https://github.com/ArjunPavanje/EE2301/tree/main/Experiment_7/figs`