

ANALOG ELECTRONIC CIRCUITS LAB REPORT-6

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Course: Analog Electronic Circuits Lab (EC2.103, Spring 2025)

Experiment Title: MOSFET: I-V and Voltage Transfer Characteristics (VTC)

Date: March 21, 2025

1. ID vs VDS Characteristics

Circuit

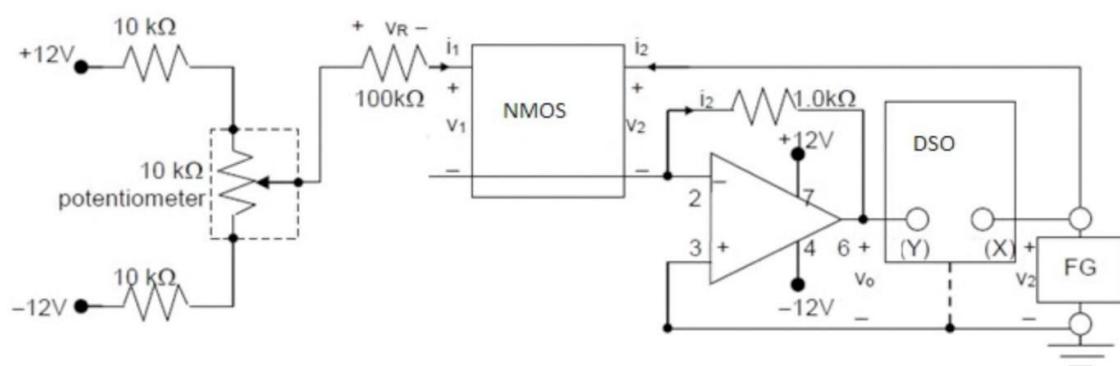


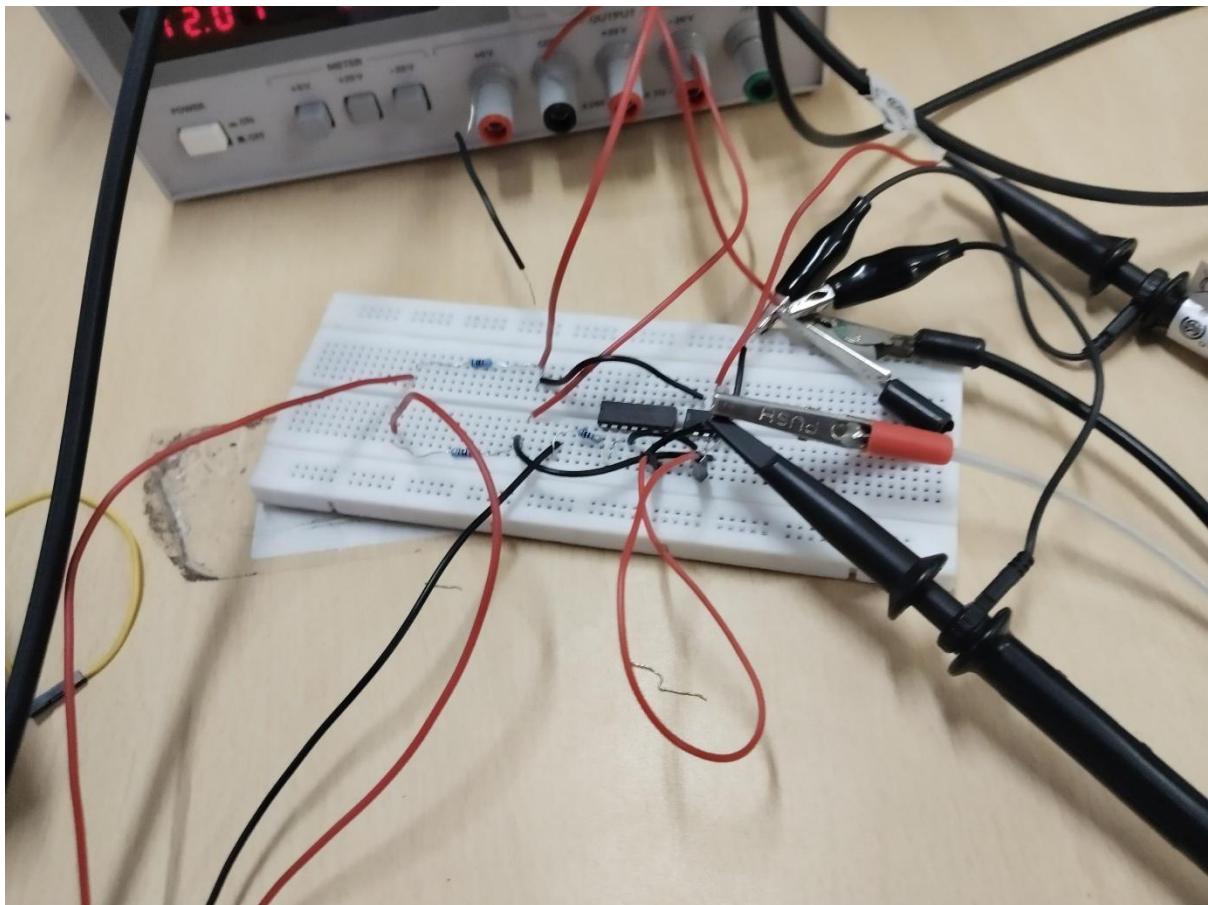
Figure 1: Circuit for displaying the output i-v characteristics of MOSFET

Using an N channel device (NMOS) we will proceed through drain current (ID) versus drain-source voltage (VDS) characteristics of an NMOS transistor using the IC CD4007BE (pins 3, 4, and 5 for Gate, Source, and Drain, respectively, with pin 7 as the common substrate). The circuit configuration ,

uses an operational amplifier with In the below figure, $V_2 = V_{DS}$ and $V_O = -I_2 \times R_0 = -ID \times R_0$, where $R_0 = 1 \text{ k}\Omega$ (between node 2 and 6).

A 100 Hz sine wave with a peak-to-peak voltage of 8 V and an offset of 4 V was applied to the drain terminal using a function generator, while VGS was varied via a potentiometer.

Therefore plot of ID will be proportional to V_O . We will sweep $V_2 = V_{DS}$ using the function generator and plot $V_O(\propto -ID)$.



Potentiometer Output Verification:

- Maximum Value: +4 V
- Minimum Value: -4 V

Max Value 4 V



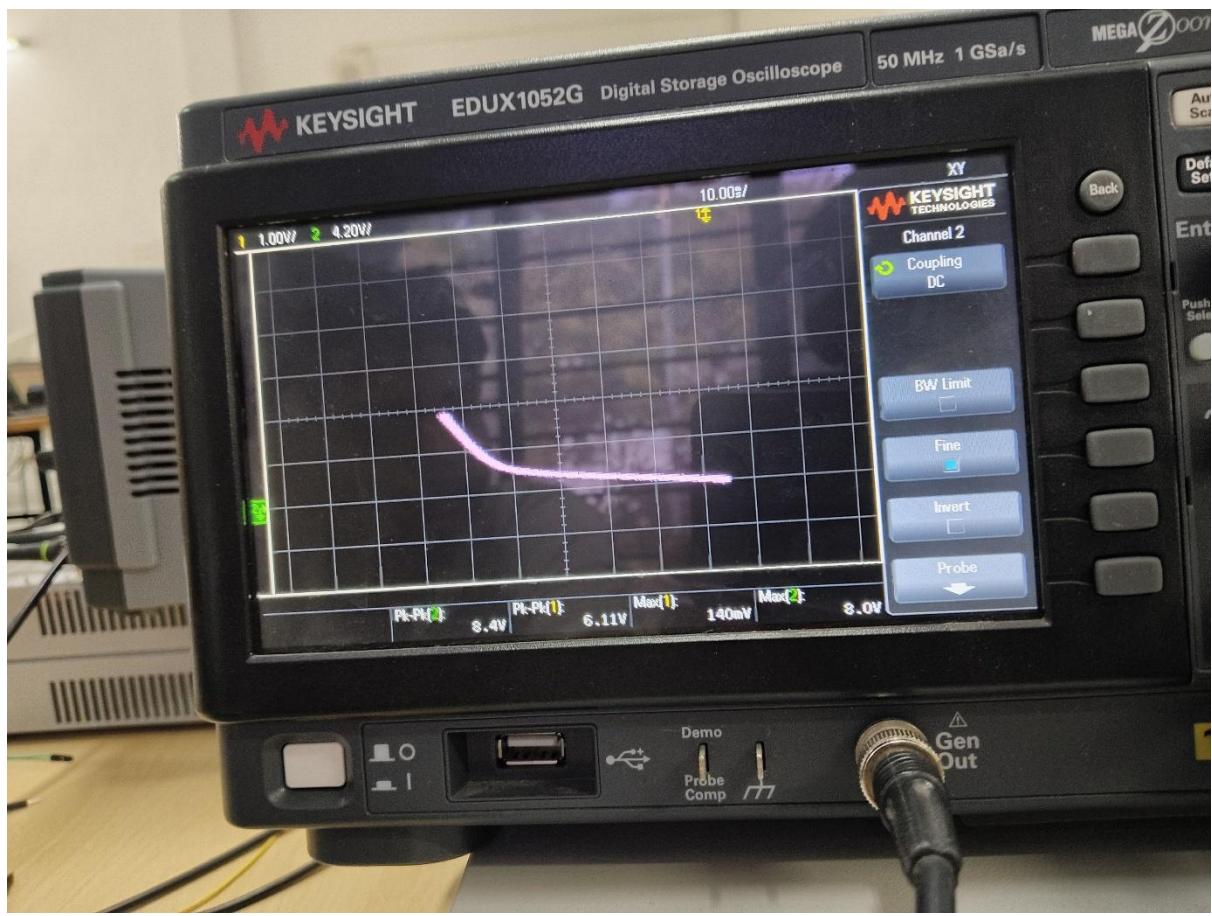
Min Value -4 V

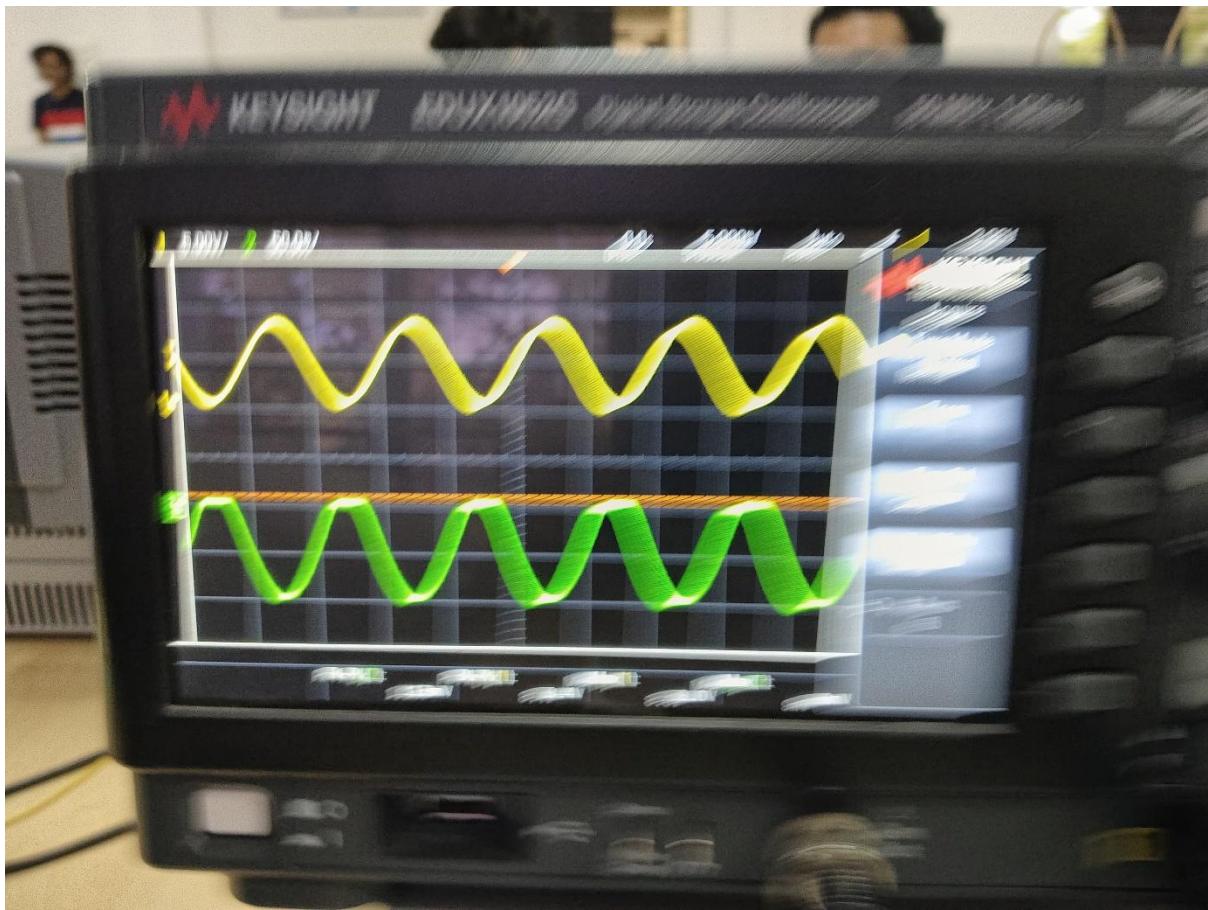


Observations:

The table is measured values of V_O and calculated ID (ID = -V_O / R_O) for various V_{GS} and V_{DS} values.

V _{GS} (V)	V _{DS} (V)	V _O (mV)	ID (μA)
0.2	8.1	110	110
0.3	8.1	111	111
0.4	8.1	120	120
0.5	8.1	154	154
0.6	8.1	190	190
0.7	8.1	190	190
0.8	8.1	192	192
0.9	8.1	190	190
1.0	8.1	200	200
1.2	8.1	330	330
1.4	8.1	610	610
1.6	8.1	750	750
1.8	8.1	1450	1450
2.0	8.1	1820	1820
3	8.1	4	4
4	8.1	6200	6200



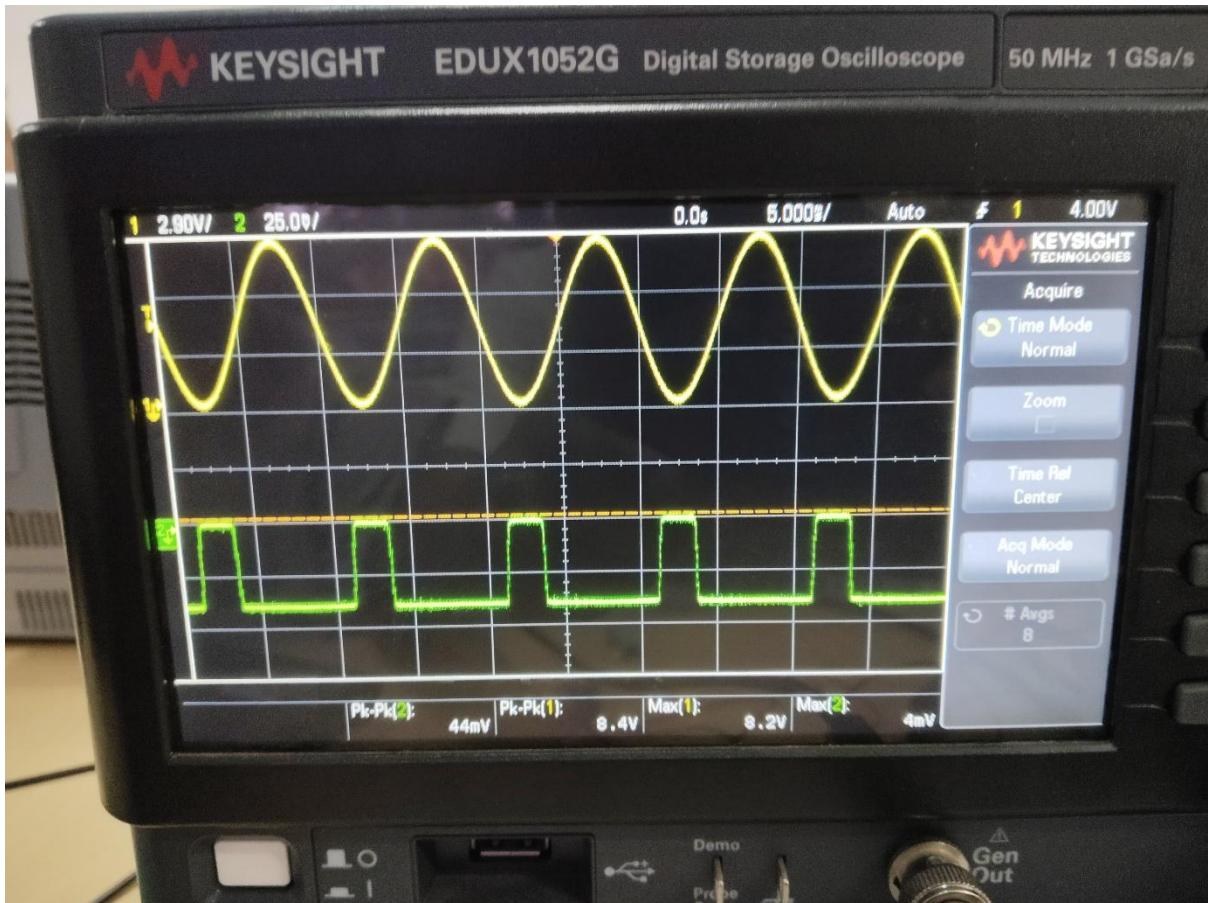
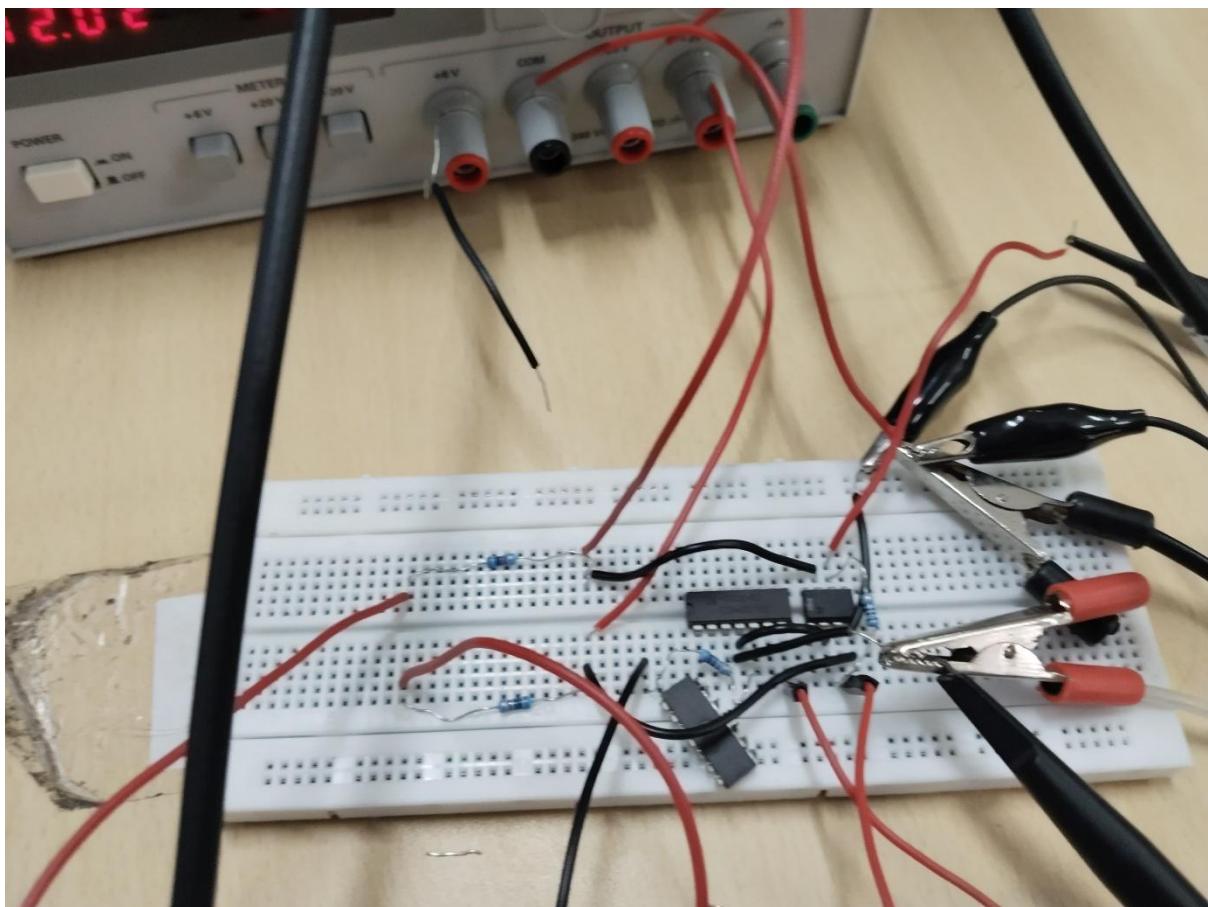


Analysis:

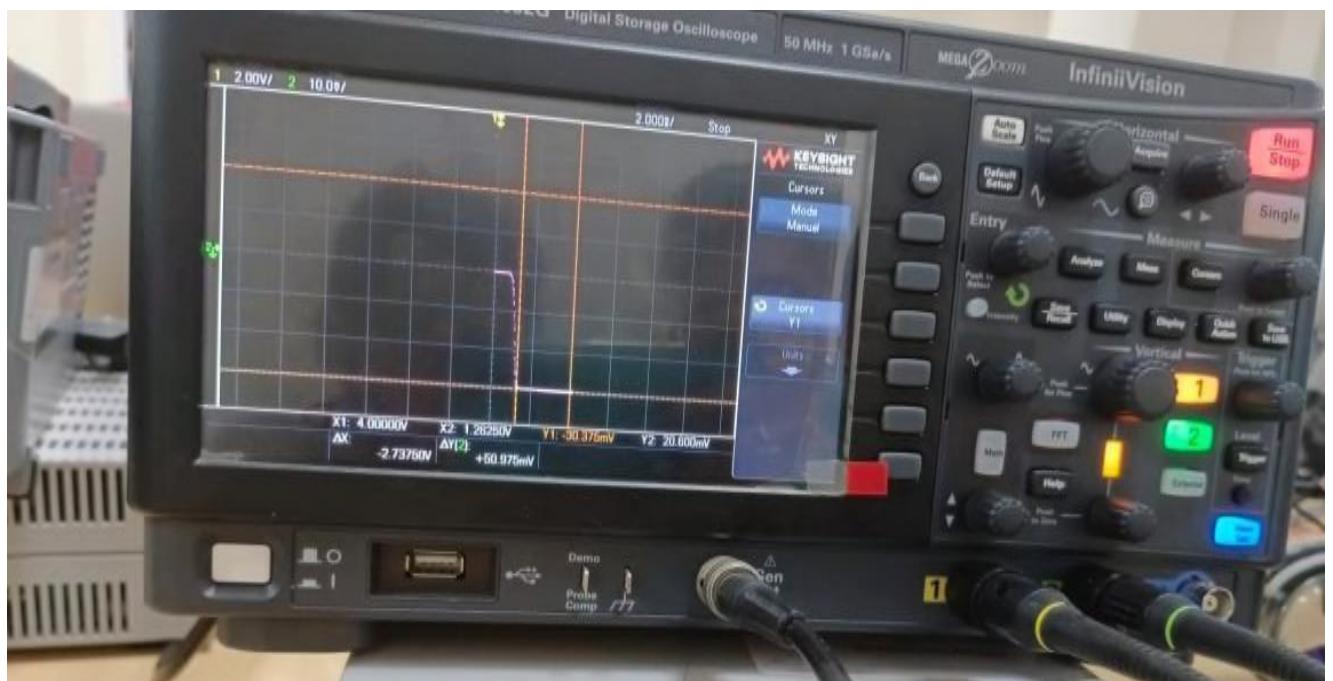
- For $V_{GS} < 1.4$ V, I_D remains relatively constant across V_{DS} , indicating the MOSFET is in the cut-off region or below threshold.
- At $V_{GS} = 1.4$ V and above, I_D increases significantly, showing the saturation and linear regions as V_{DS} varies.

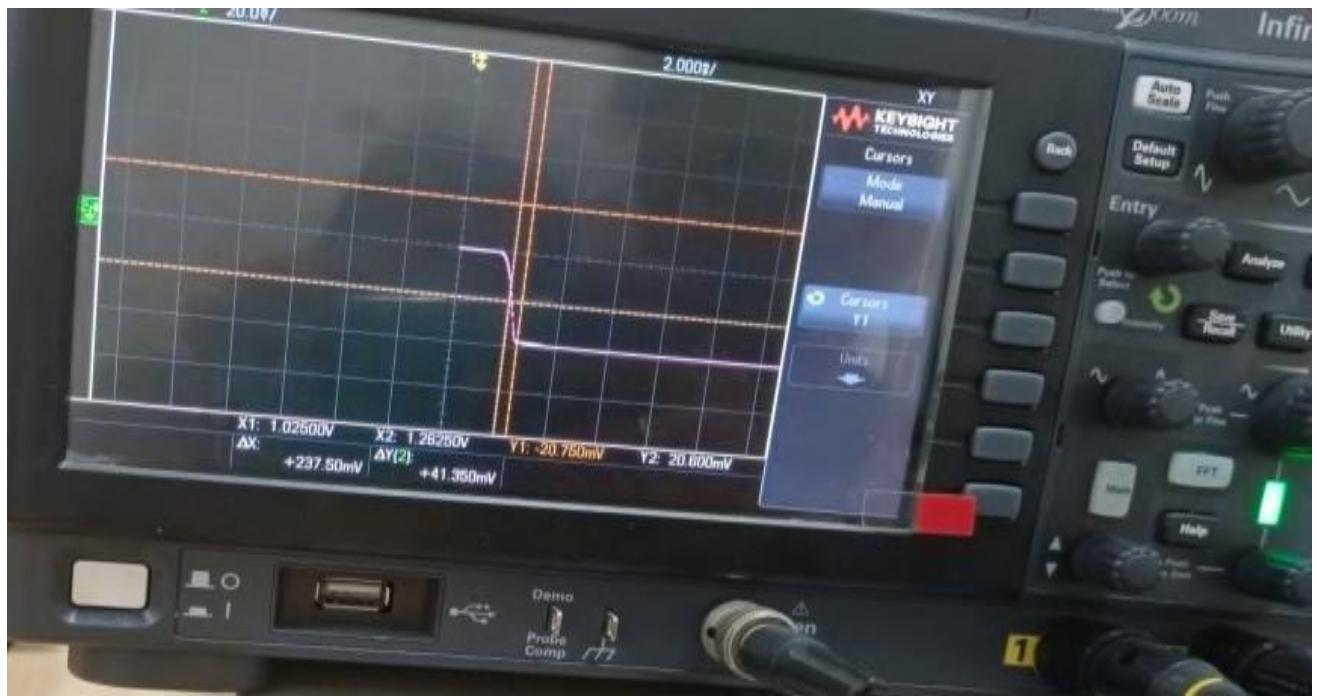
2. ID vs VGS Characteristics and Parameter Extraction

This section involves plotting I_D versus V_{GS} for fixed V_{DS} values and extracting the threshold voltage (V_T) and the parameter $u_n C_{ox} W/L$.









V_{GS}	V_{DS} (Peak to Peak)	V_o	I_D
0.2	8.1V	+10mV 110mV	110mA
0.3	8.1V	111mV	111mA
0.4	8.1V	120mV	120mA
0.5	8.1V	154mV	154mA
0.6	8.1V	190mV	190mA
0.7	8.1V	190mV	190mA
0.8	8.1V	192mV	192mA
0.9	8.1V	190mV	190mA
1	8.1V	200mV	200mA
1.2	8.1V	330mV	330mA
1.4	8.1V	610mV	610mA
1.6	8.1V	0.757V	0.757mA
1.8	8.1V	1.45V	1.45mA
2	8.1V	1.82V	1.82mA
3	8.1V	6.2V	6.2mA
4	8.1V		

Observations:

VDS (V)	VGS (V)	V0 (mV)	ID (uA)
0.1	0.8	-0.5	0
0.1	2.0	-2.0	2.0
0.5	0.5	-0.4	0
0.5	2.0	-5.0	5.0
1.0	1.0	-5.0	5.0
1.0	2.0	-10.0	10.0
2.0	2.0	-20.5	20.5
3.0	4.0	-30.5	30.5
4.0	4.0	-39.0	39.0

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$V_C = V$

LAR-6 MOSFET

(a) After building the circuit, the output voltage obtained at the ends of the OP Amp is $-I_D R_L$, where R_L is the voltage across the OPAMP. \Rightarrow So, for plotting the ~~ID~~ I_D and V_{DS} we can take the plot between the output for OPAMP and output voltage across Drain and source.

By doing this we acquire the plot between the I_D and V_{DS} .

(b) Now let us vary the V_{GS} by changing the potentiometer resistance.

b) Threshold Voltage (VT) Extraction:

- For $V_{DS} = 0.1$ V (linear region), the I_D vs V_{GS} plot was analyzed.
- The point of maximum slope was identified at $(V_{GS}, V_0) = (2.0 \text{ V}, -2.0 \text{ mV})$.
- we calculate the approximate slope by considering obtained points in graphs -1.8V.

The next step involves drawing a tangent at the point of maximum slope and determining its intersection with the x-axis (V_{GS}). This intersection point represents

the threshold voltage (VT). Therefore, in this case, the threshold voltage is approximately 0.8V

c) Calculation of $u_n C_{ox} W/L$:

To further analyze the MOSFET's behavior, we can utilize the characteristic equation:

$$ID = u_n C_{ox} W/L (VGS - VT) VDS$$

$$I_D \approx \mu C_{ox} \frac{W}{L} (V_{GS} - V_T) V_{DS}$$

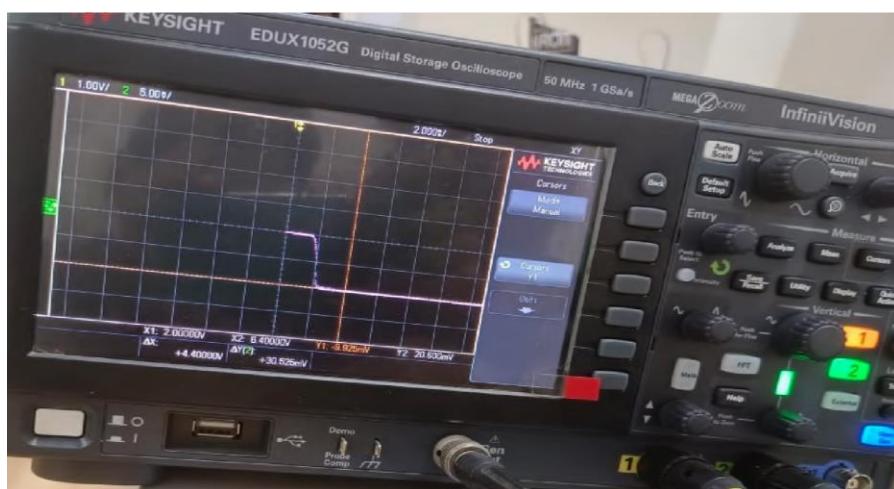
Given:

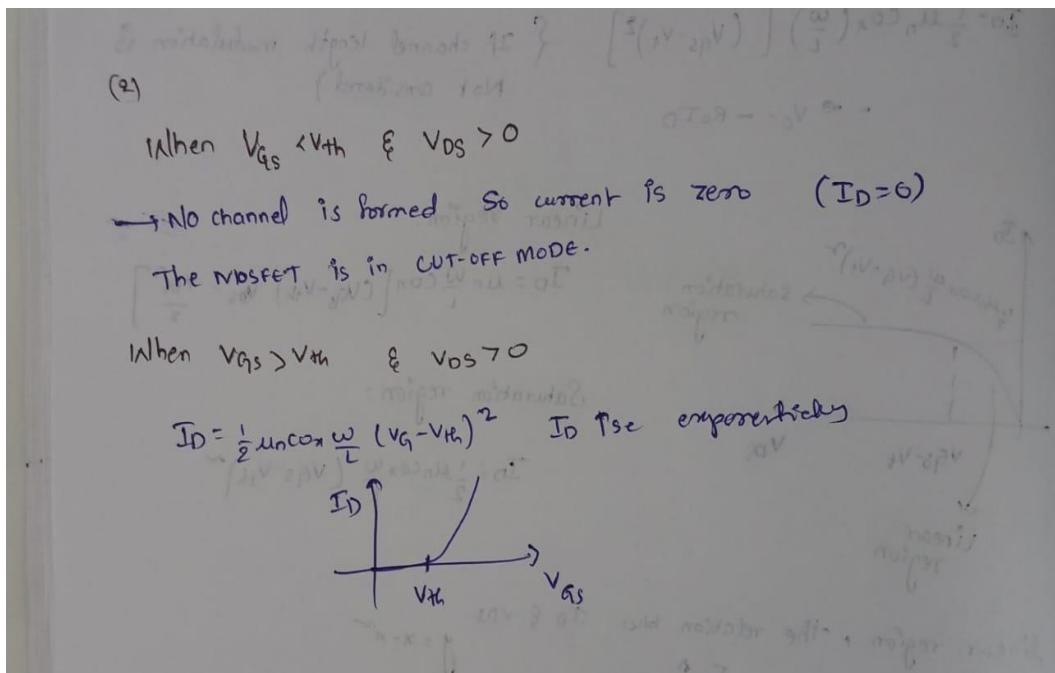
- $V_{DS} = 0.1 \text{ V}$
- $V_{GS} = 2.0 \text{ V}$
- $V_T = 0.8 \text{ V}$
- $I = 2.0 \mu\text{A}$

$$2.0 \times 10^{-6} = u_n C_{ox} W/L (2.0 - 0.8) \times 0.1$$

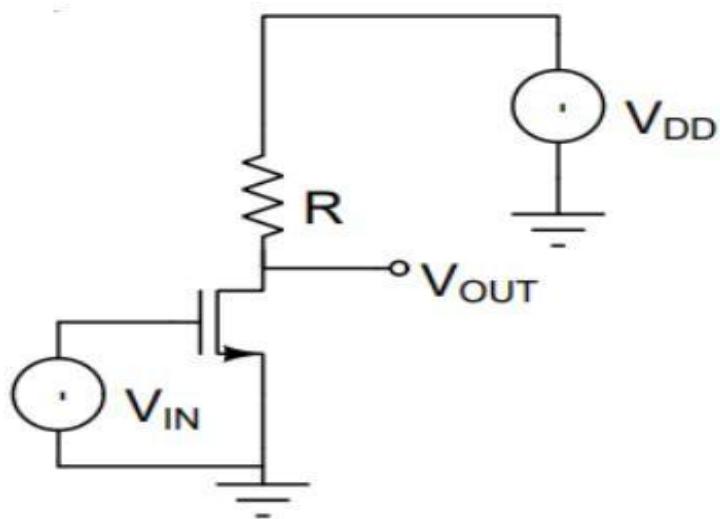
$$2.0 \times 10^{-6} = u_n C_{ox} W/L \times 0.12$$

$$u_n C_{ox} W/L = (2.0 \times 10^{-6}) / 0.12 = 16.67 \mu\text{S/V}$$





3. Large Signal Analysis and Voltage Transfer Characteristics (VTC)



Mode	V_{in}	V_{out}	V_{DS}	ΔV_{out}
Saturation $V_{DS} > (V_{GS} - V_{TH})$	5V	8.61V	16V	7.4
Cutoff $V_{GS} < V_{TH}$	0.680mV	16V	16V	0
Triode $V_{DS} < V_{DSAT} = (V_{GS} - V_{TH})$	3.2V	2.68V	1V	1.68
				Linear difference

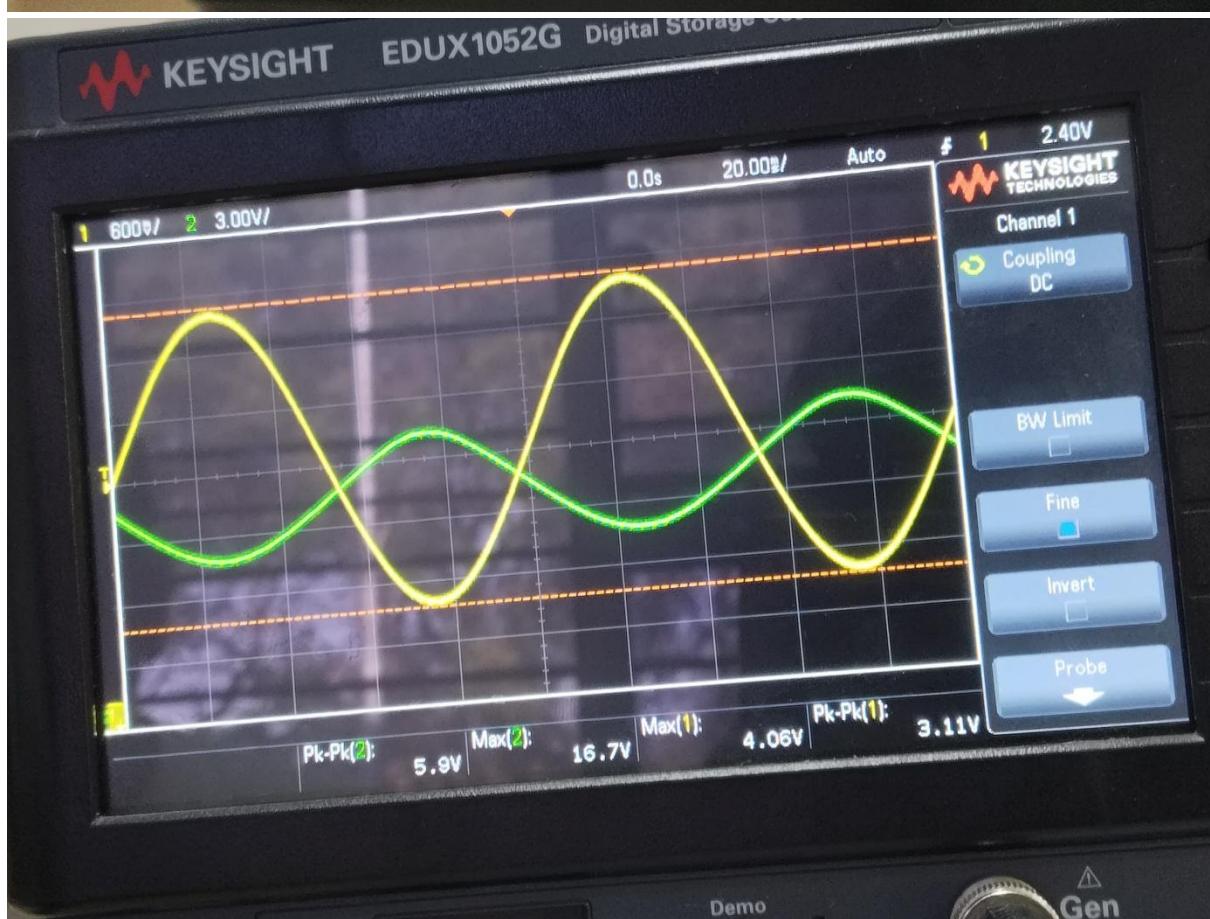
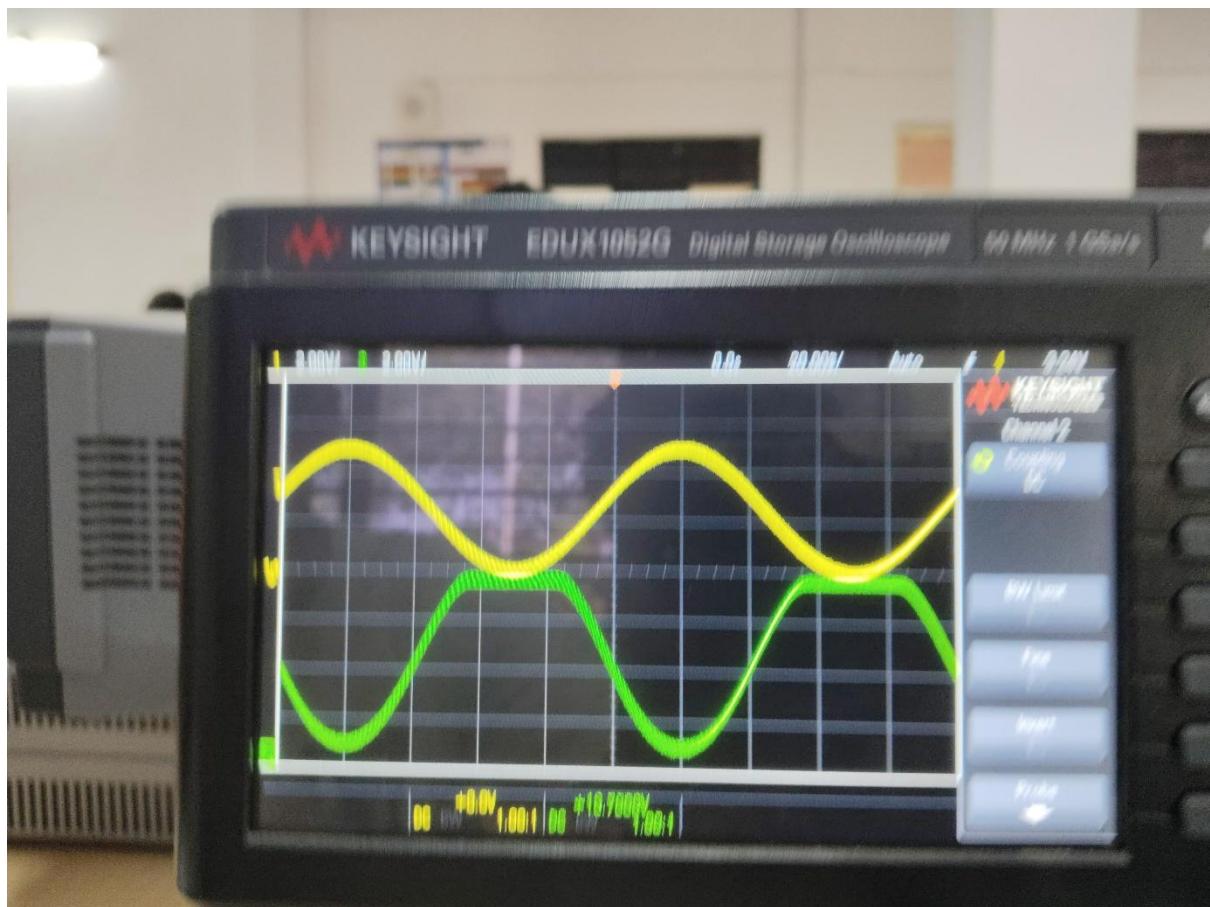
Modes of Operation of MOSFET:

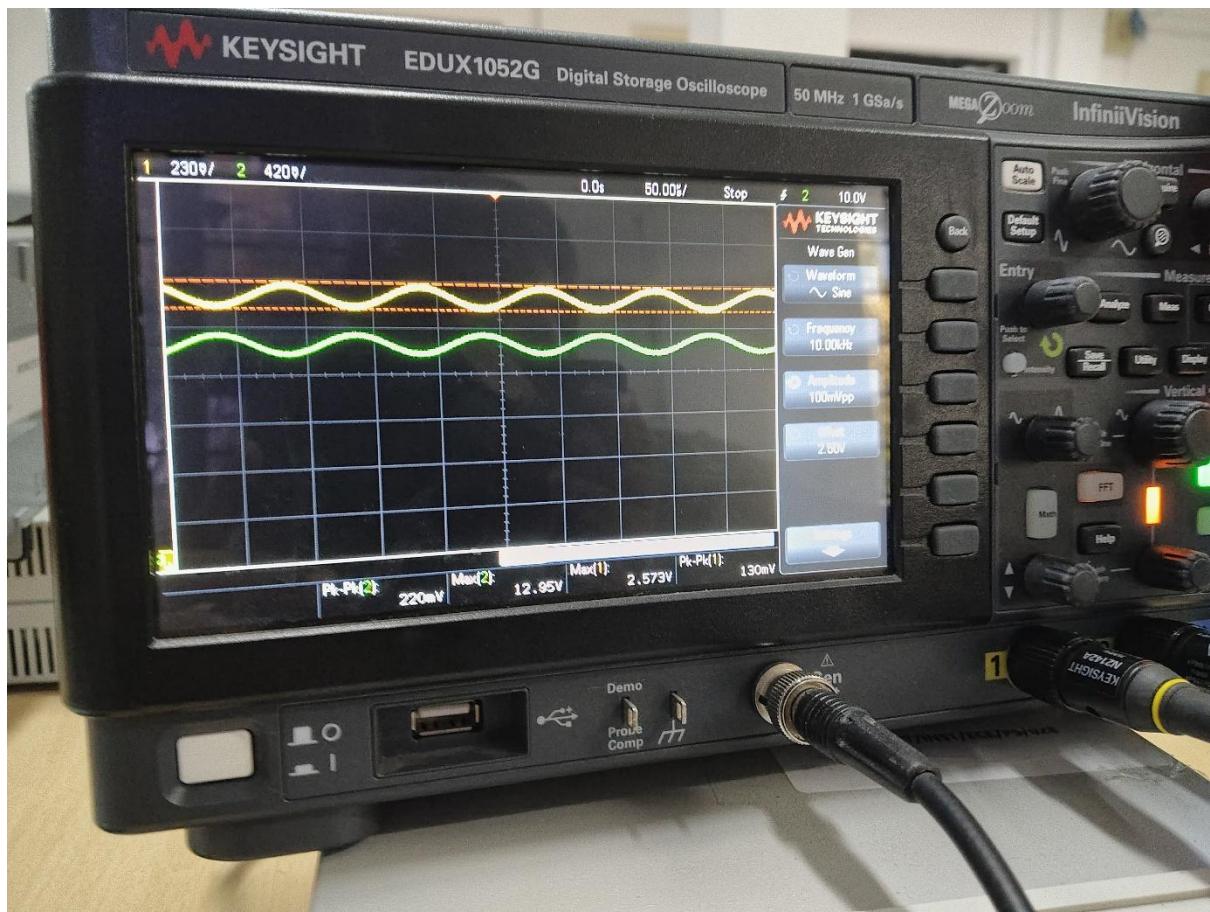
$V_{in}=680\text{mV}$ => cut off mode

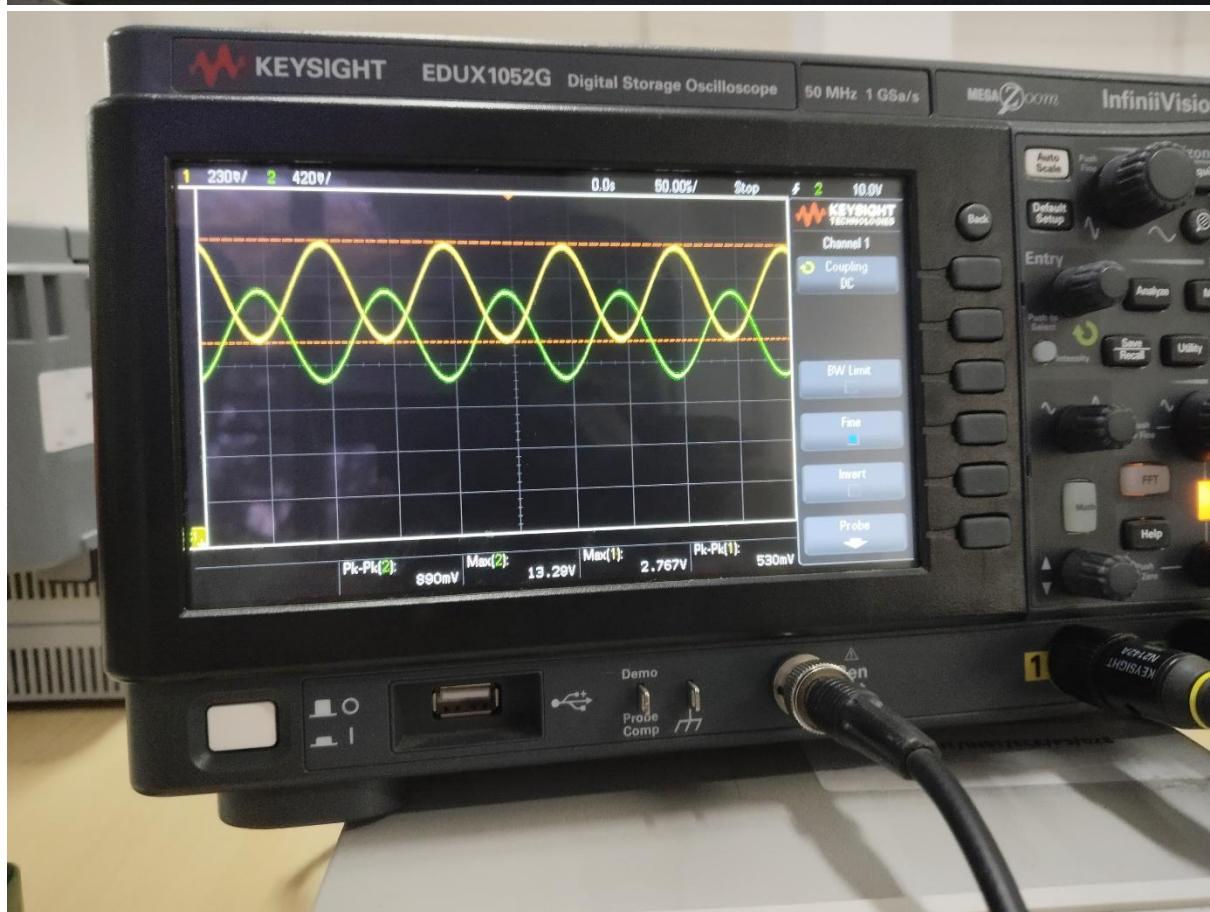
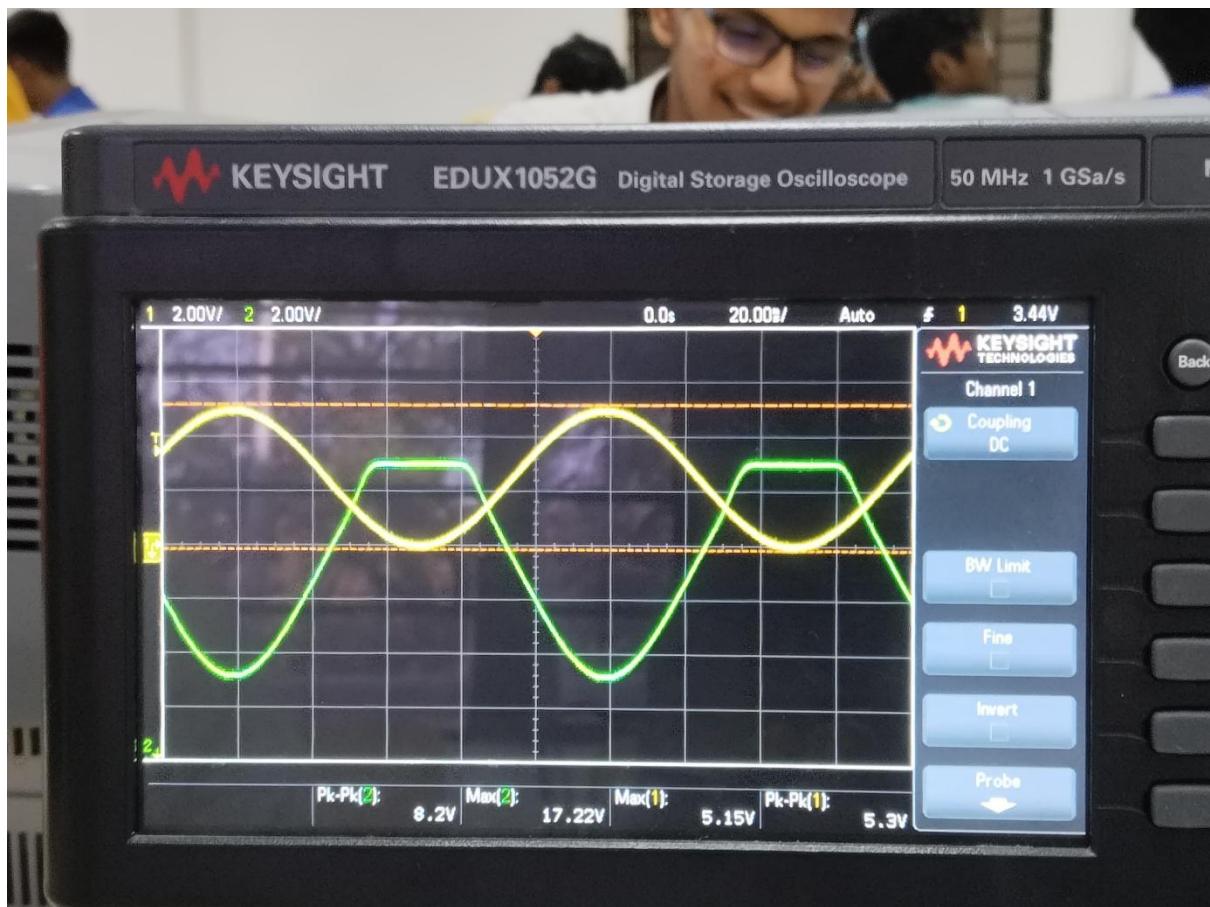
$V_{in}=3.2\text{V}$ => saturation mode

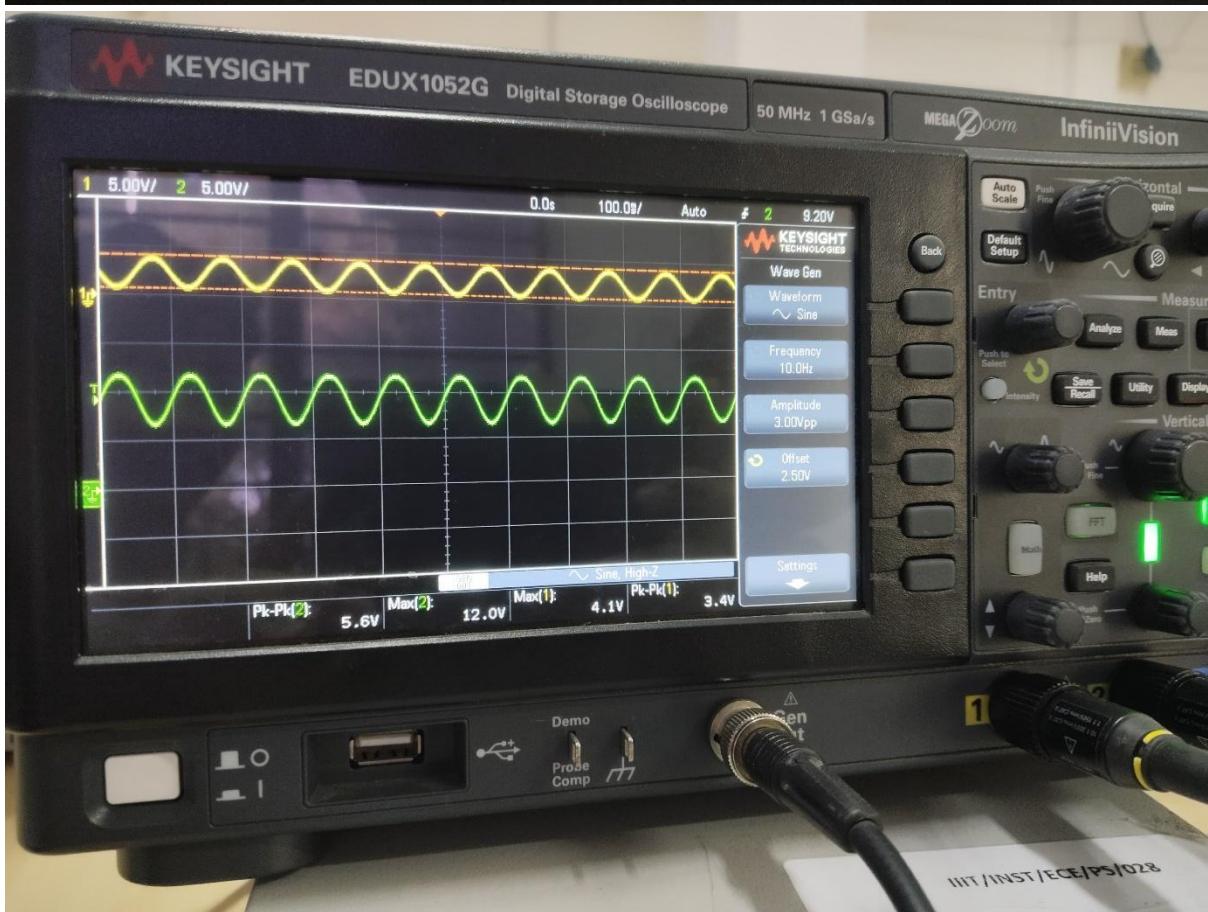
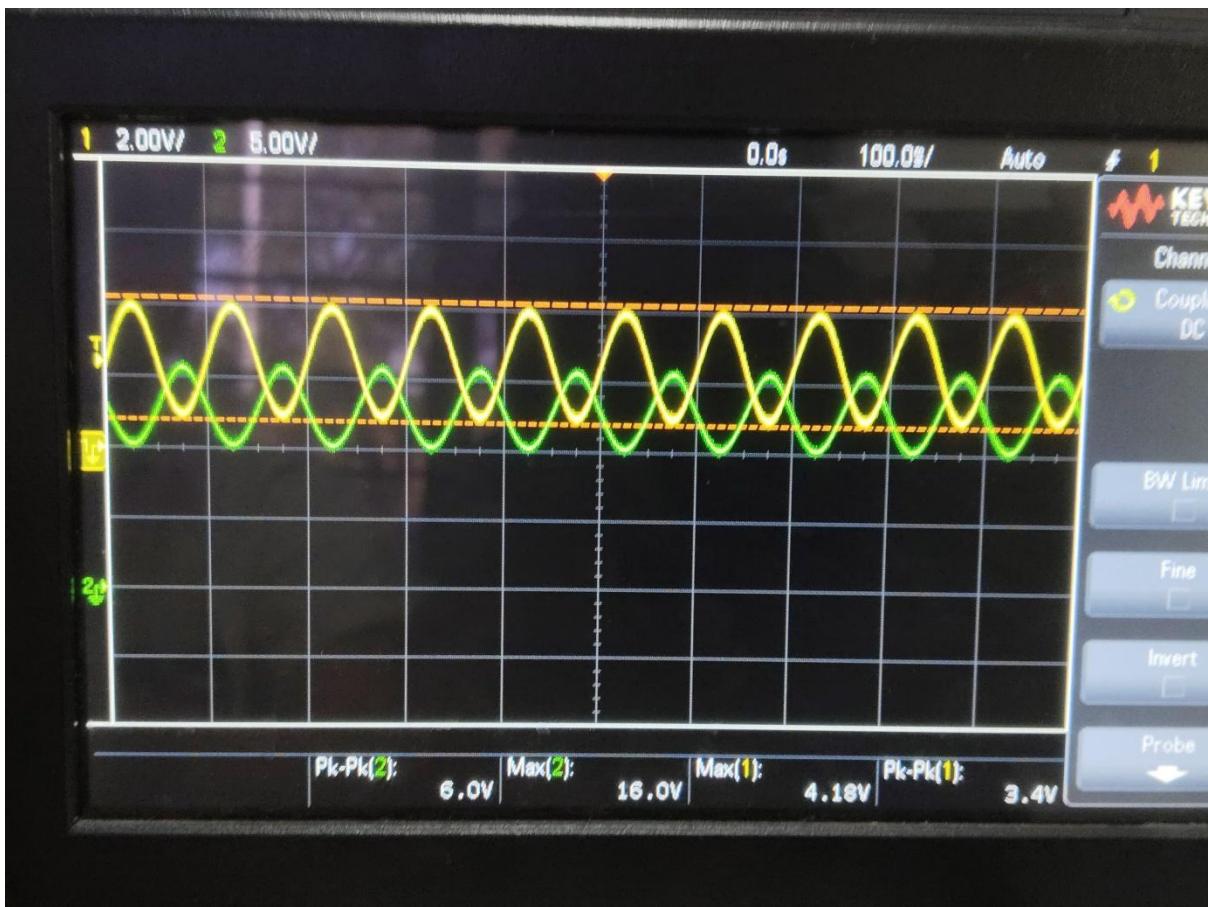
$V_{in}=5\text{V}$ => Linear/Triode mode

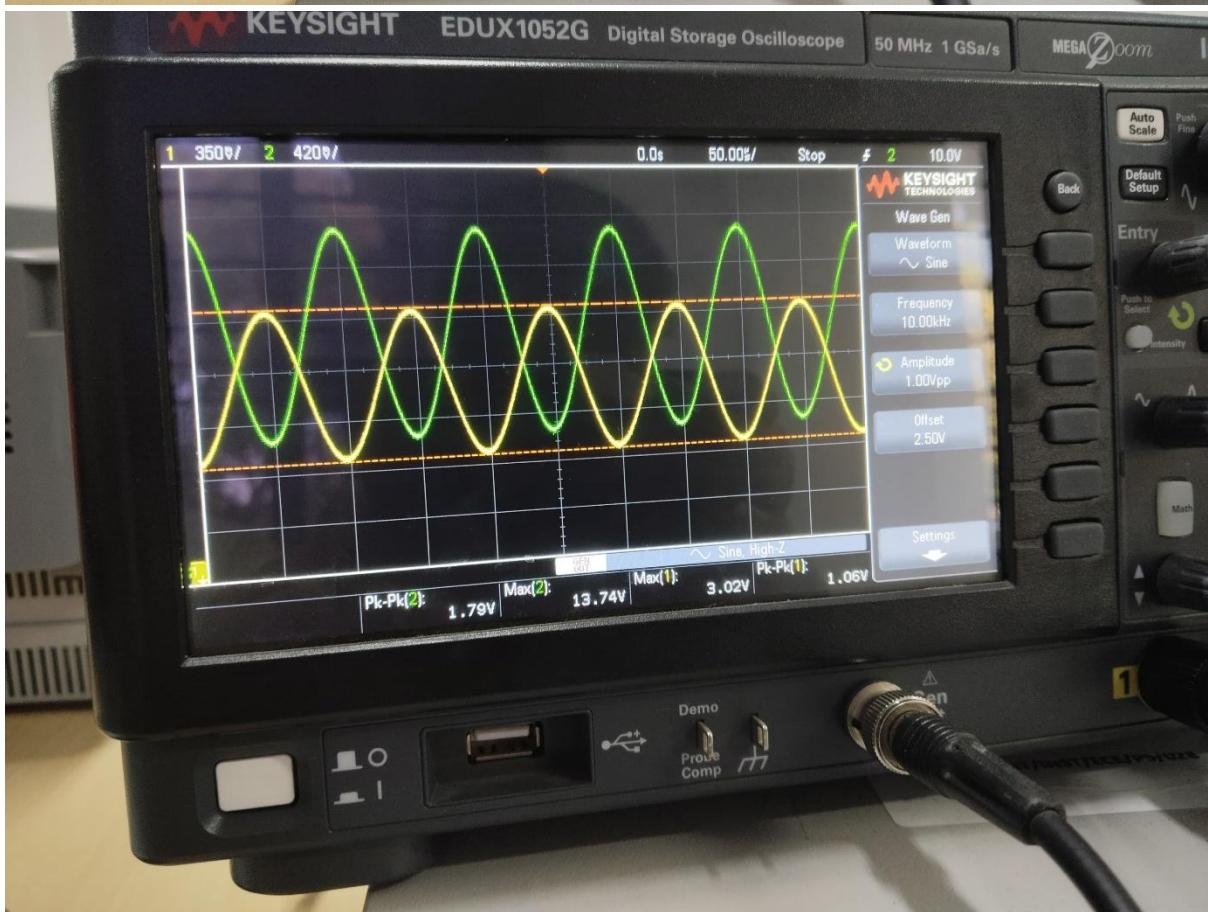
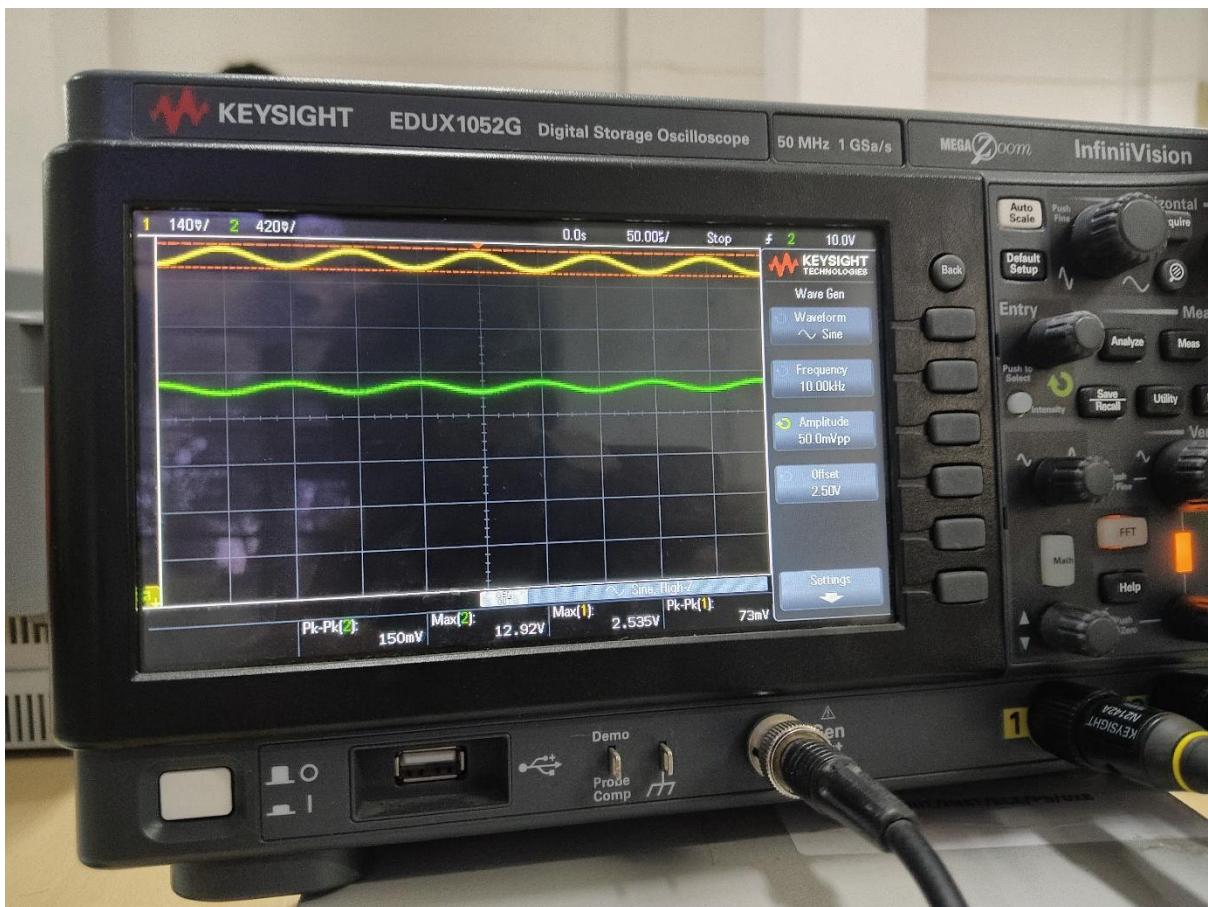
The NMOS-based amplifier with a 1 kOhm resistive load was analyzed. The input signal (V_{IN}) was swept from 0 to 5 V, and the output (V_{OUT}) was measured.

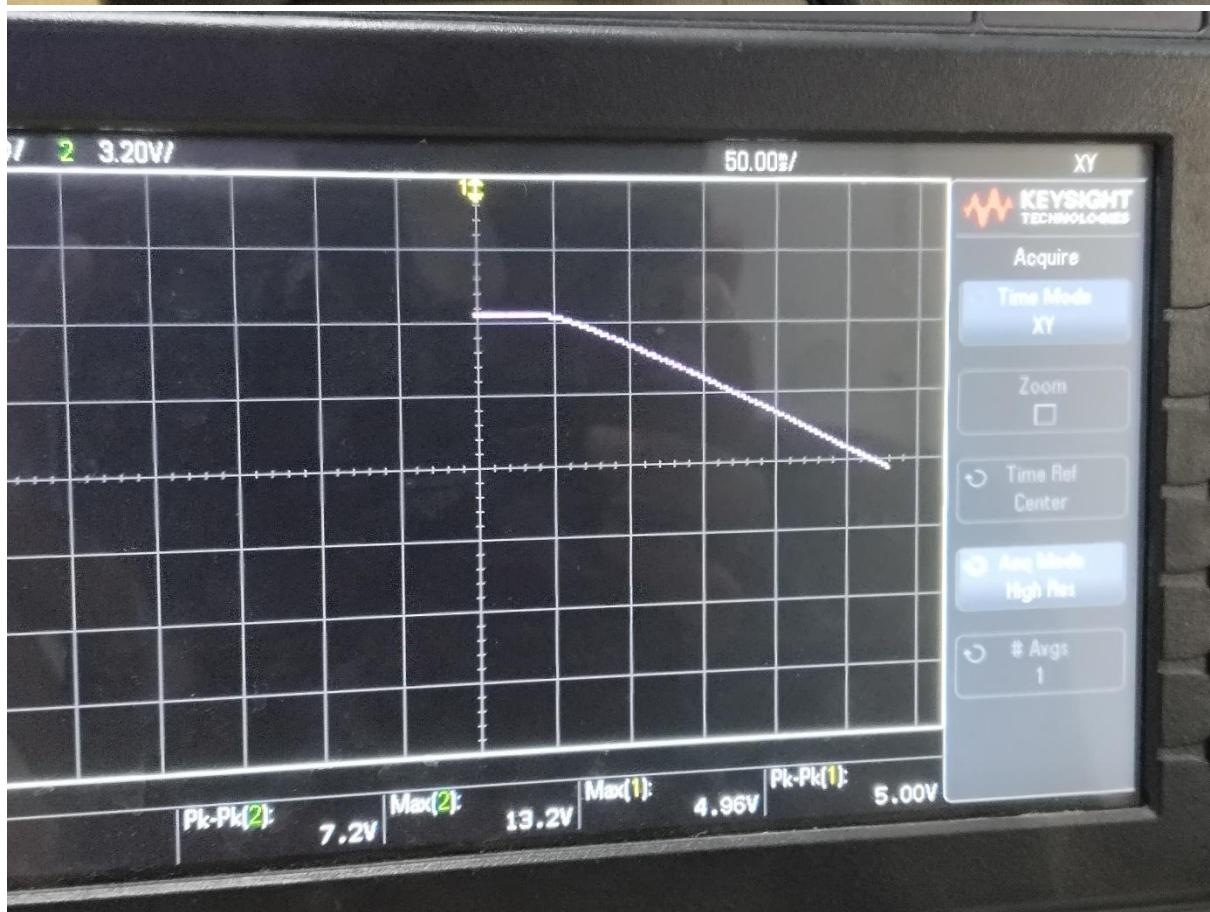
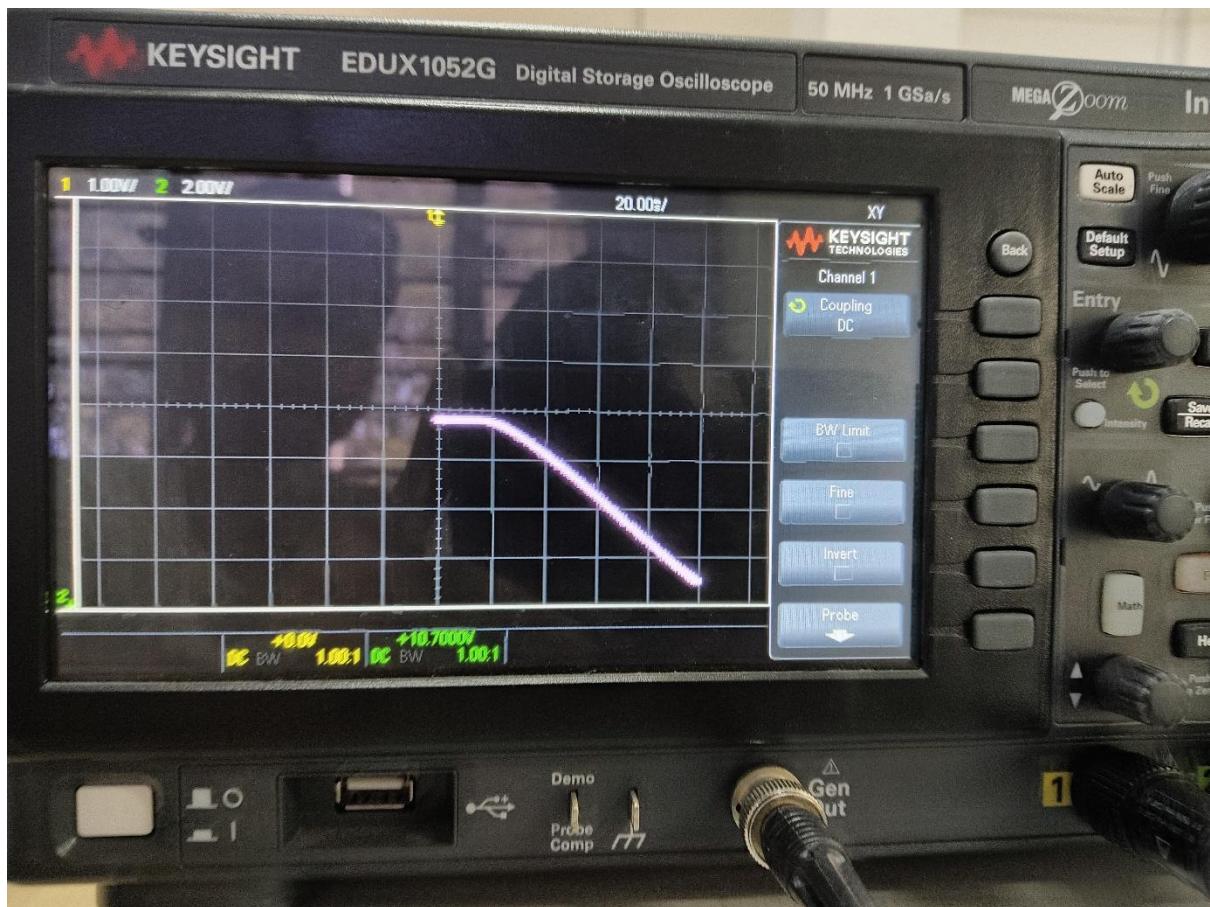


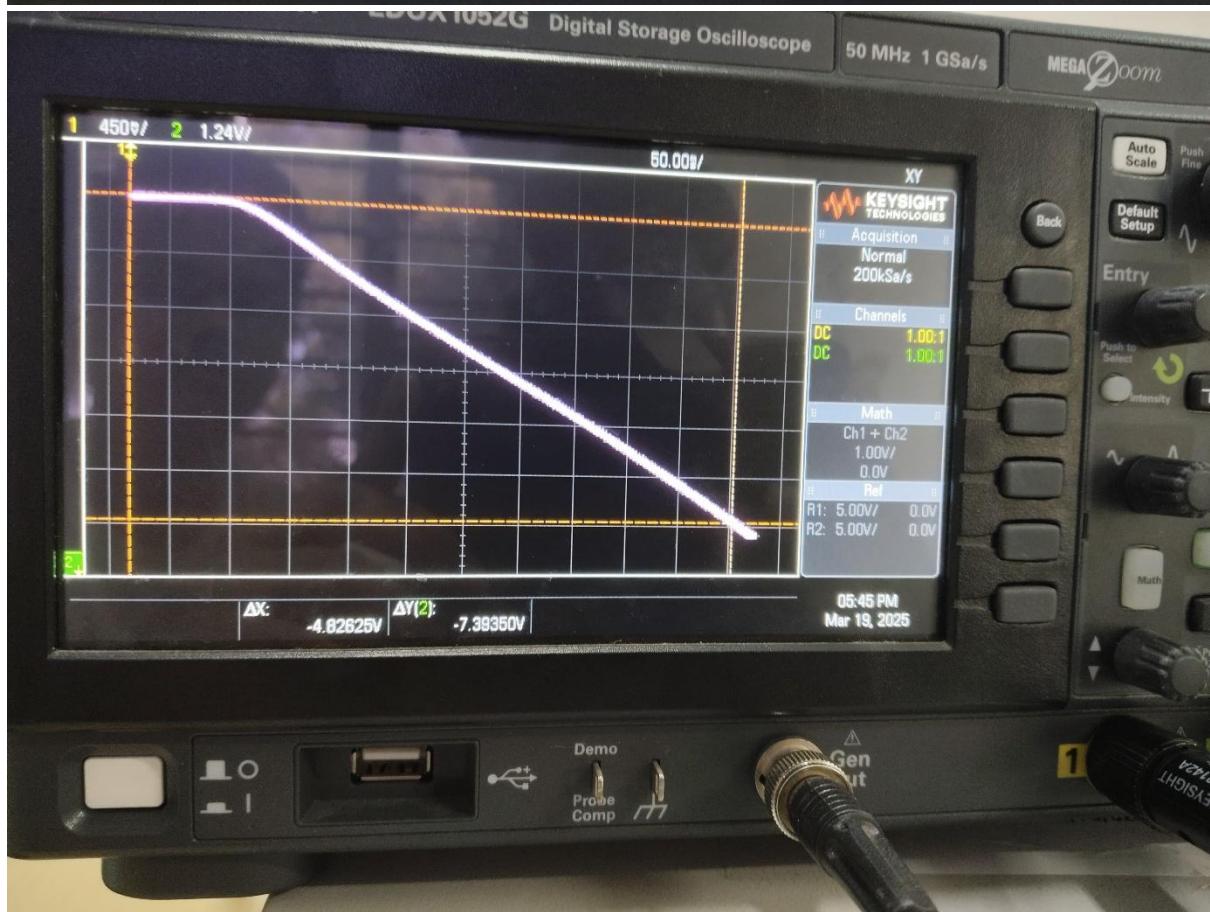


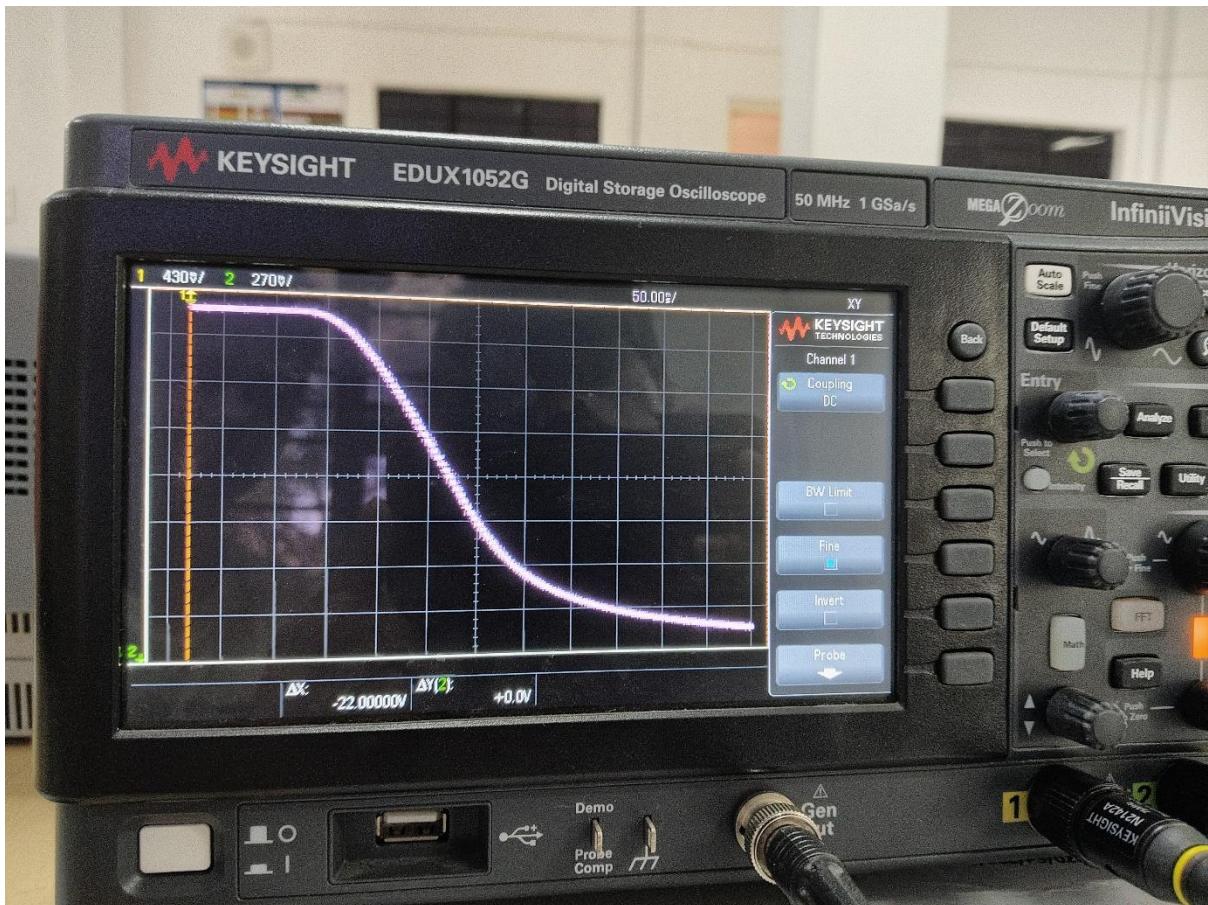












Observations:

	V_{DD}	V_{in}	ΔV_{out}	Gains
V_{DD}	V_{DD}	V_{in}	ΔV_{out}	Gains
18	2.5	80mV	130mV	2.6
16	2.5	100mV	230	2.3
16	$V_{out} = V_{DD} - IR$	800mV	910mV	1.82
16	2.8			
16	2.5	1000mV	1.79V	1.79

Analysis:

- **Cut-off Mode ($V_{IN} = 0.68$ V):** $V_{GS} < V_T$, so $I_D = 0$, and $V_{OUT} = V_{DD}$. Gain is low (< 1).
- **Saturation Mode ($V_{IN} = 2.5$ V):** $V_{GS} > V_T$ and $V_{DS} > V_{GS} - V_T$, yielding maximum gain (> 1).
- **Trends:** Gain peaks in saturation, decreases in linear mode, and is minimal in cut-off. Voltage swing is limited by V_{DD} and MOSFET operation.
-

When the input voltage (V_{in}) is significantly smaller than $2(V_{GS}-V_{TH})$ and much smaller than V_{DS} , we can observe a proper gain in the MOSFET.

However, when V_{in} becomes comparable to V_{DS} , the MOSFET enters the triode mode on one side of the operational point.

As a result, the gain is not uniform and varies. This occurs because the MOSFET's behavior changes as the input voltage crosses the operational point, leading to non-uniform amplification characteristics.

Gain is greater than 1 only in saturation region.

MOSFET acts as closed switch in cut off region. MOSFET acts as an amplifier only in Saturation region because a voltage dependent current source can be obtained in this region. MOSFET acts as a voltage dependent resistor in Linear region.

Conclusion

This experiment successfully characterized the NMOS transistor's I_D - V_{DS} and I_D - V_{GS} behavior, extracted $V_T = 0.8$ V and $\mu_n C_{ox} W/L = 16.67 \mu\text{S}/\text{V}$, and analyzed the VTC of an NMOS amplifier. The MOSFET effects through cut-off, saturation, and linear regions, with optimal amplification in saturation.