ANALOG ELECTRONIC CIRCUITS

LAB REPORT-6

Name: Ande Karthik

Roll no: 2023102009

Team mate: Radheshyam.M

Roll no: 2023102032

MOSFET: I-V and Voltage Transfer characteristics (VTC)

1) ID vs VDS Characteristics :

The MOSFET we are going to use is an n-channel device (NMOS), having its Gate, Source, and Drain terminals available at pins 3, 4 and 5 of the IC.

All NMOS devices in the IC have a common substrate (pin 7). In the below figure, V2 = VDS and V0 = −I2 × R0 = −ID ×R0, where R0 = 1 kΩ (between node 2 and 6).

Therefore plot of ID will be proportional to V0. We will sweep V2 = VDS using the function generator and plot V0(∝−ID).

Potentiometer output verification:

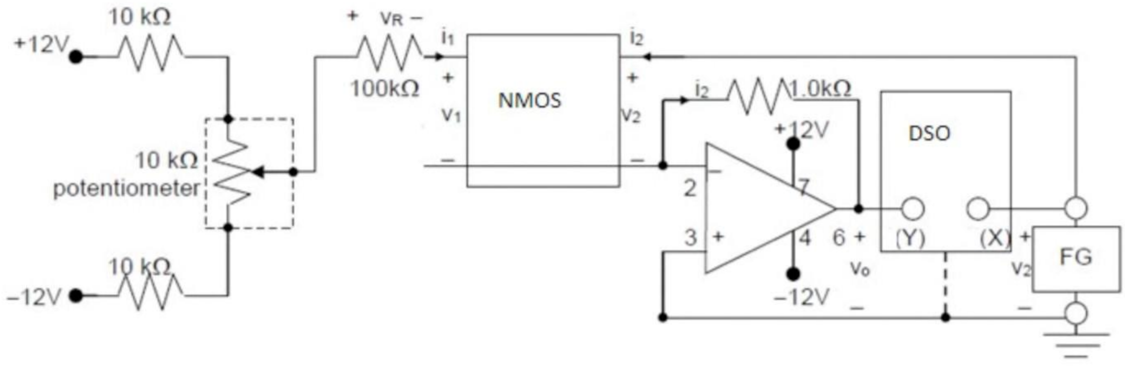
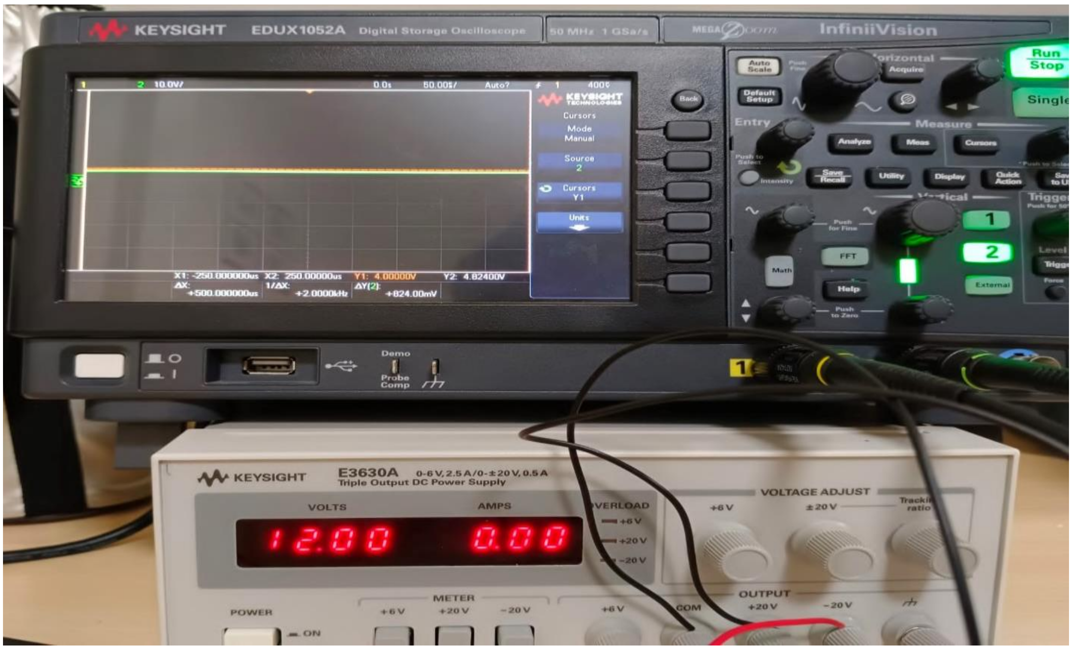


Figure 1: Circuit for displaying the output i-v characteristics of MOSFET

Max value=+4



<u>**Min value=-4**</u>

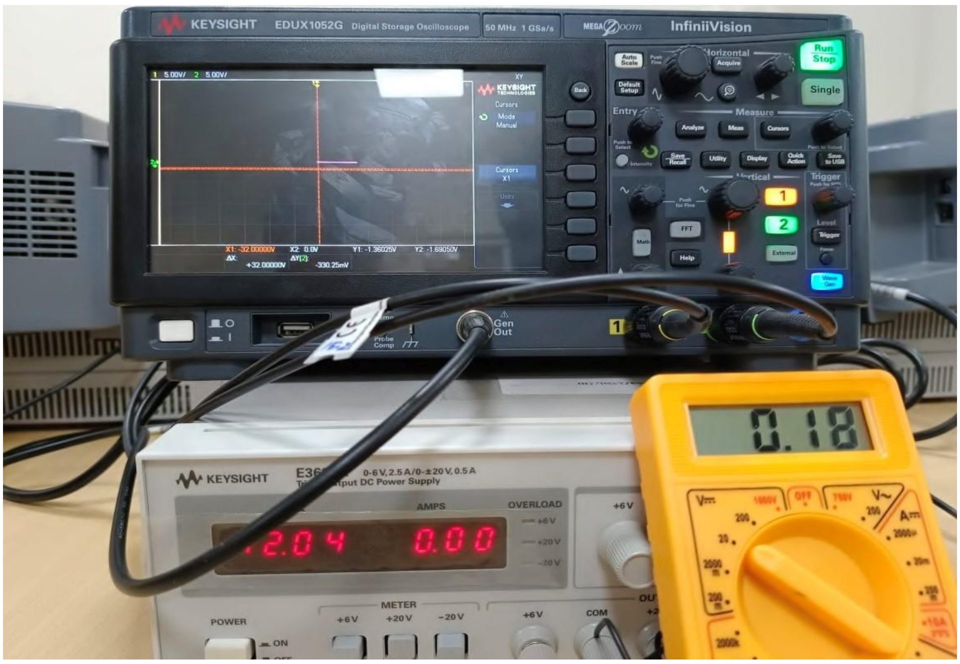
VGS	VDS	|Vo|	Io
0.2	All	107.5mV	107.5uA
0.3	All	107.5mV	107.5uA
0.4	All	129mV	129uA
0.5	All	150.5mV	150.5uA
0.6	All	150.5mV	150.5uA
0.7	All	150.5mV	150.5uA
0.8	All	150.5mV	150.5uA

1	All	150.5mV	150.5uA
1.2	All	150.5mV	150.5uA
1.4	All	150.5mV	150.5uA
1.6	All	150.5mV	150.5uA
1.8	All	330mV	330uA
2	500mV	333mV	333uA
2	4V	333mV	333uA
2	8V	333mV	333uA
2	12V	333mV	333uA
3	500mV	528mV	528uA
3	4V	627mV	627uA
3	8V	627mV	627uA
3	12V	627mV	627uA
4	500mV	1.1055V	1.1055mA
4	4V	1.716V	1.716mA
4	8V	1.764V	1.716mA
4	12V	1.764V	1.716mA

For VGS values up to 1.8V, the observed output voltage (Vo) remains relatively constant for different VDS values.

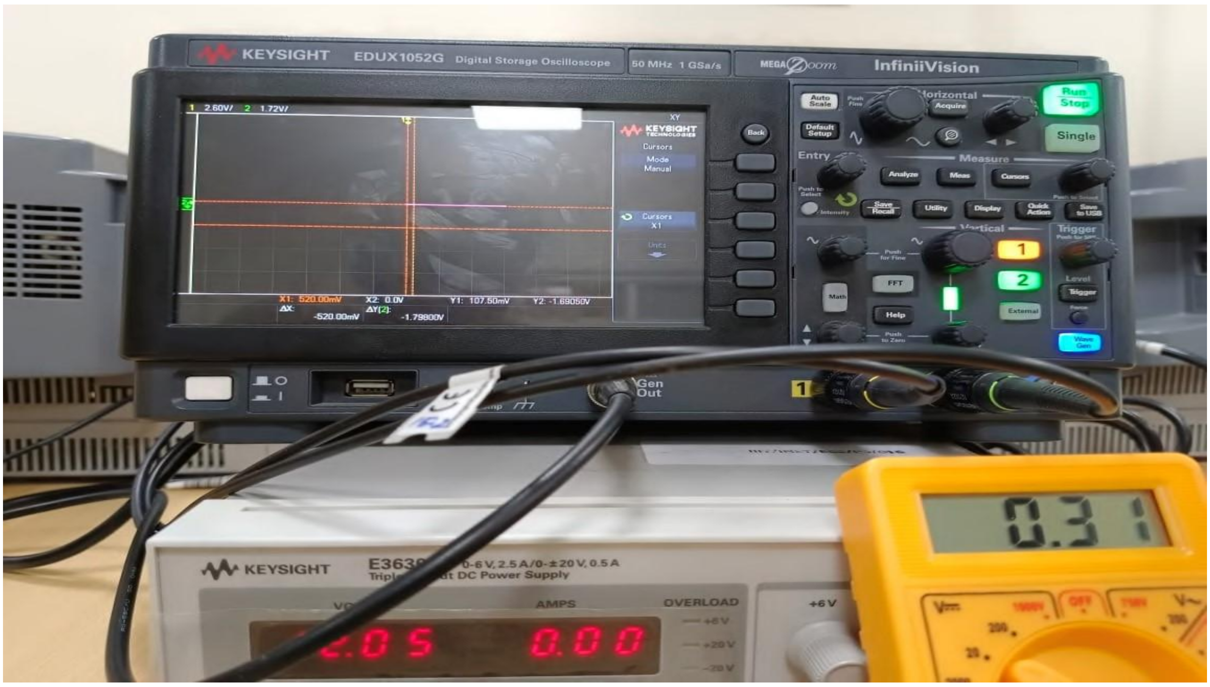
However, as VGS increases beyond 2V, the behavior of Vo starts to change. Specifically, between 2V and 4V of VGS, there is a noticeable variation in the value of Vo.

For VGS=0.2V



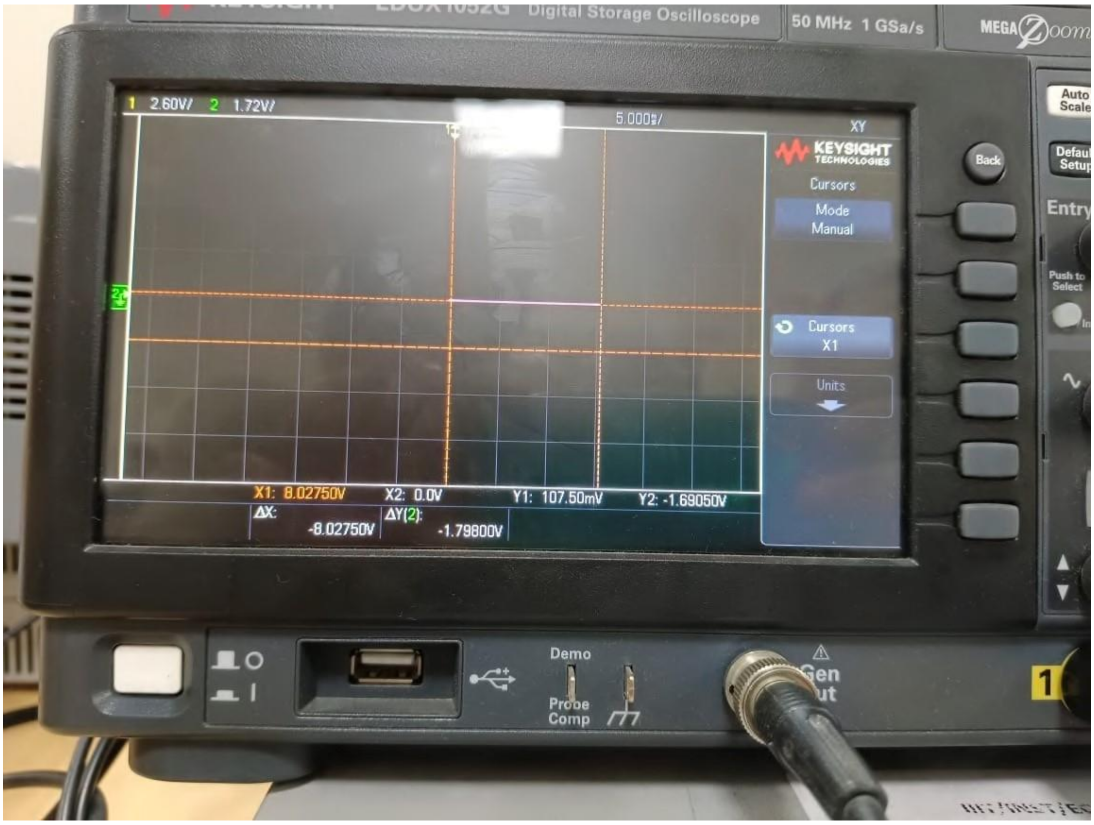
For VGS=0.3V

(VDS=500mV)



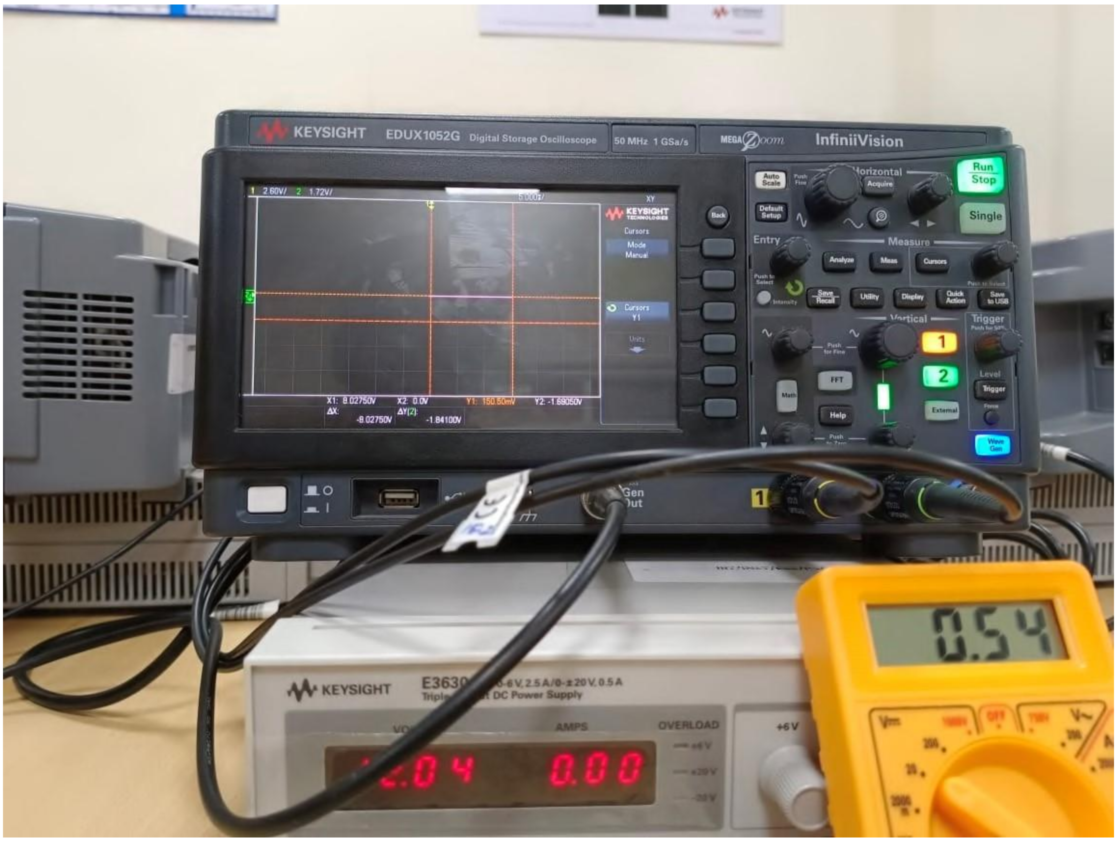
For VGS=0.4V

(VDS=4V)

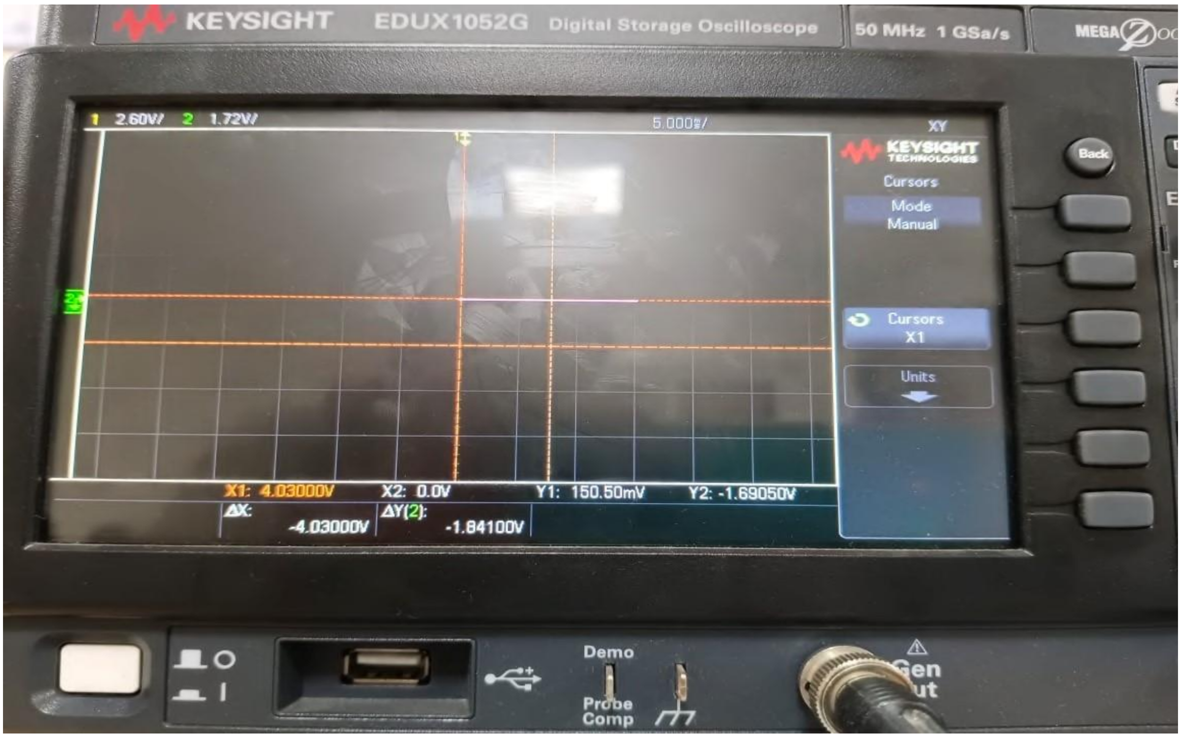


For VGS=0.5V

(VDS=8V)

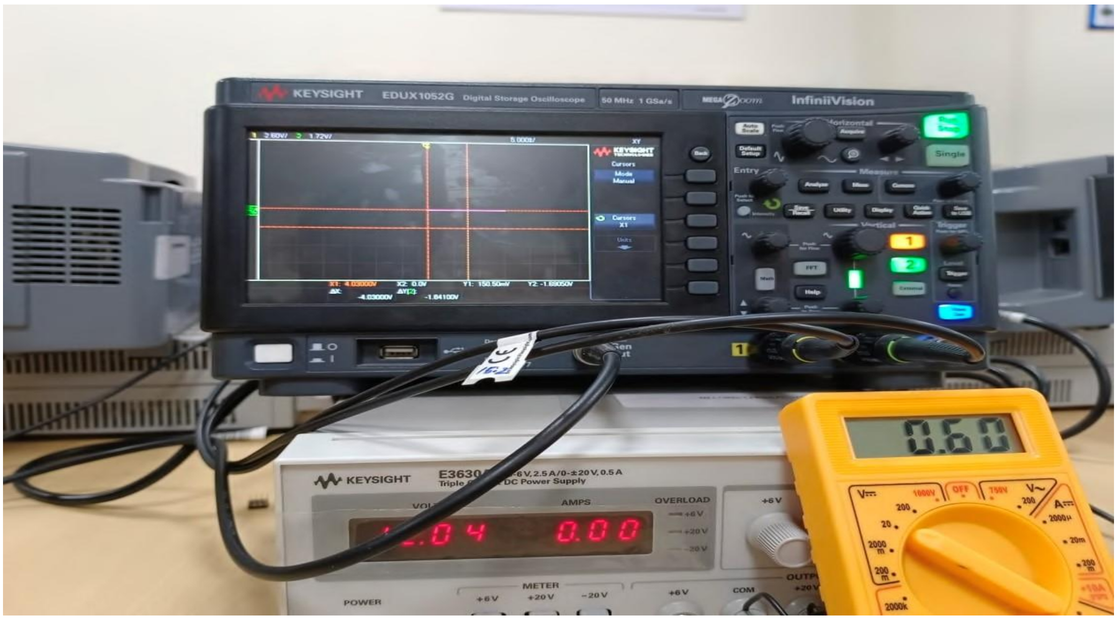


(VDS=4V)



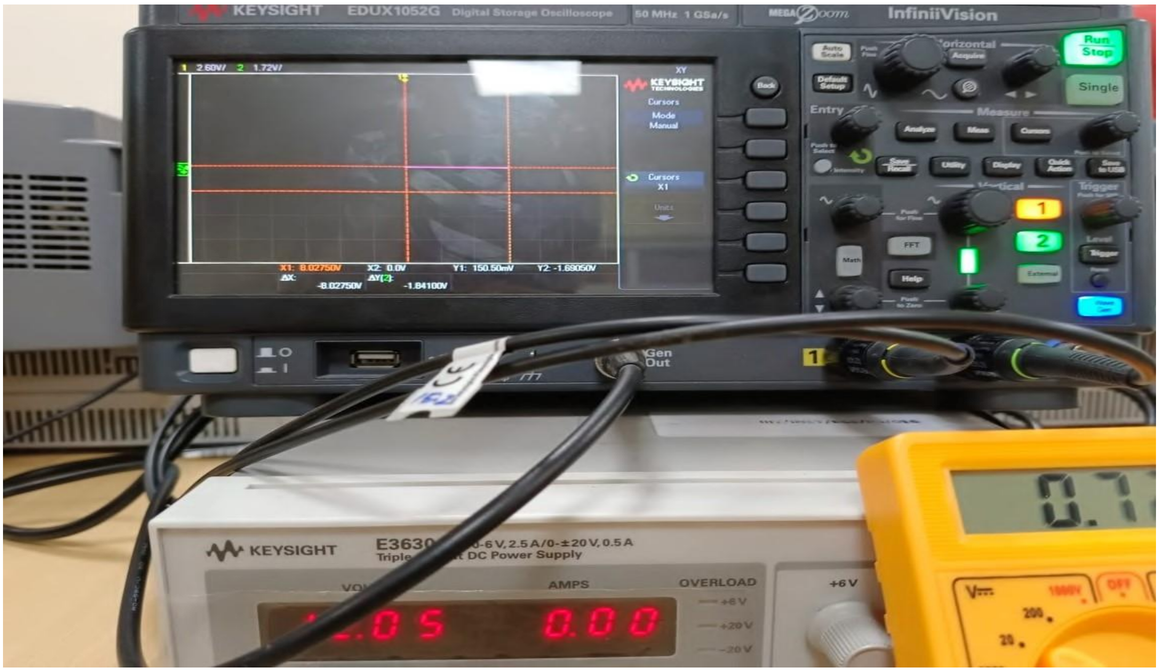
For VGS=0.6V

(VDS=4 V)

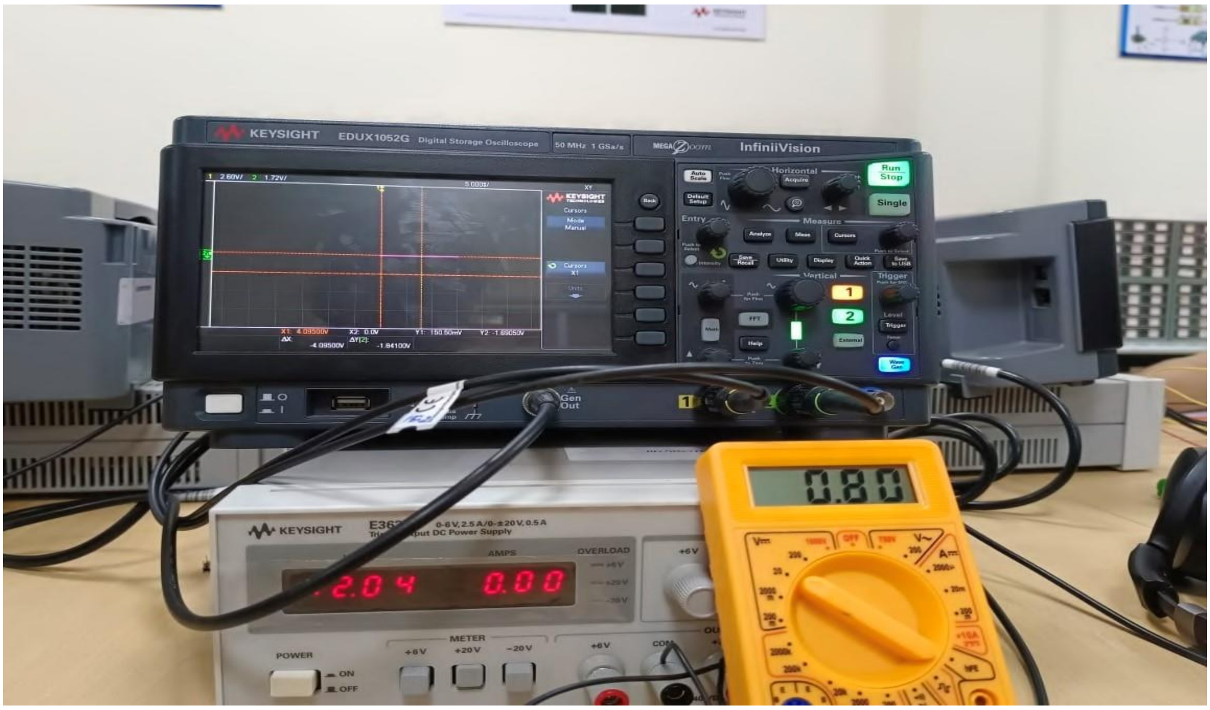


(VDS=8 V)

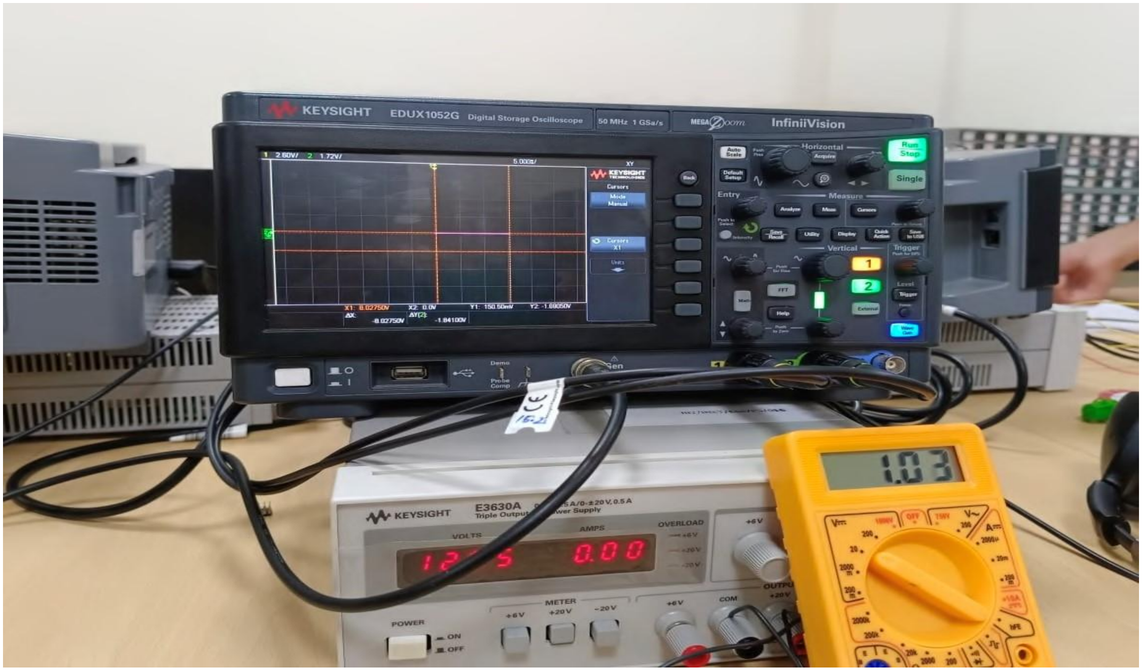
For VGS=0.7 V



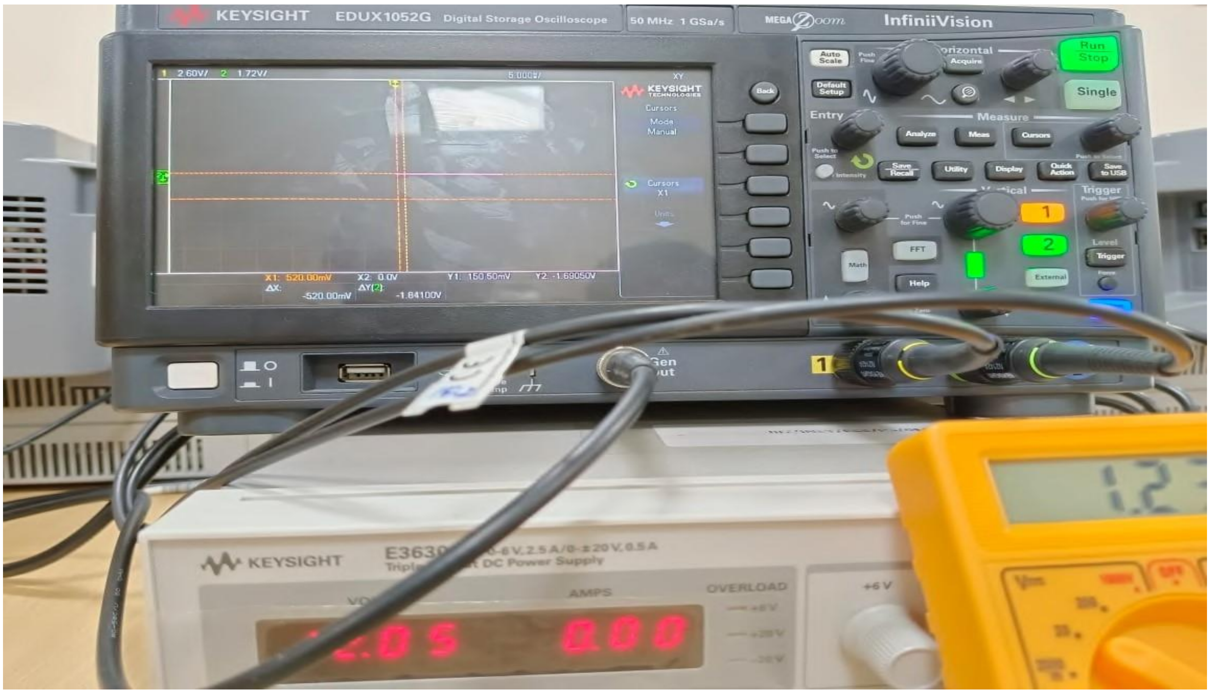
For VGS=0.8 V



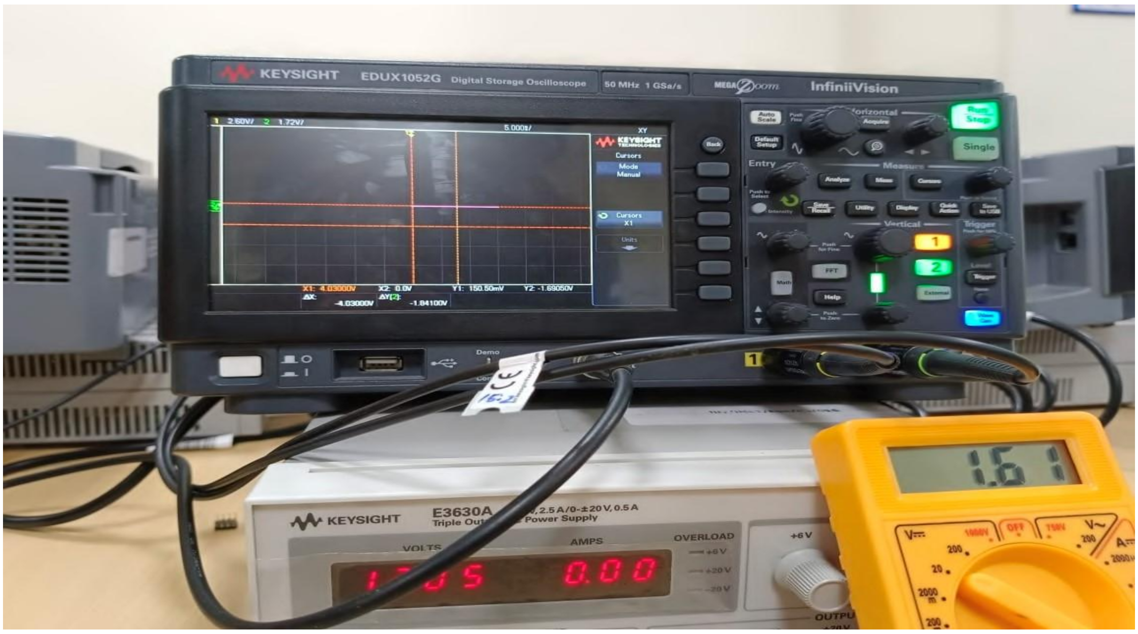
For VGS=1 V



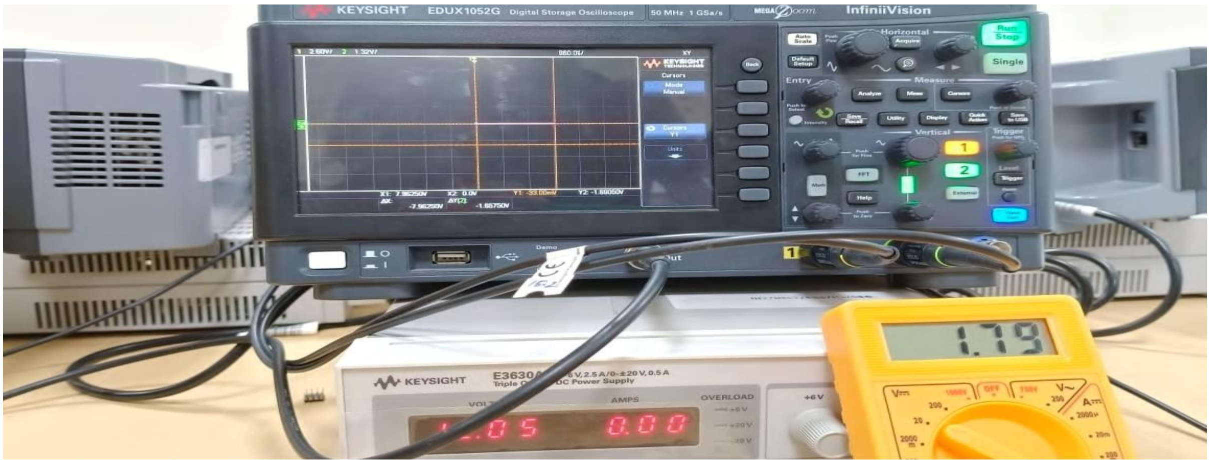
For VGS=1.2 V

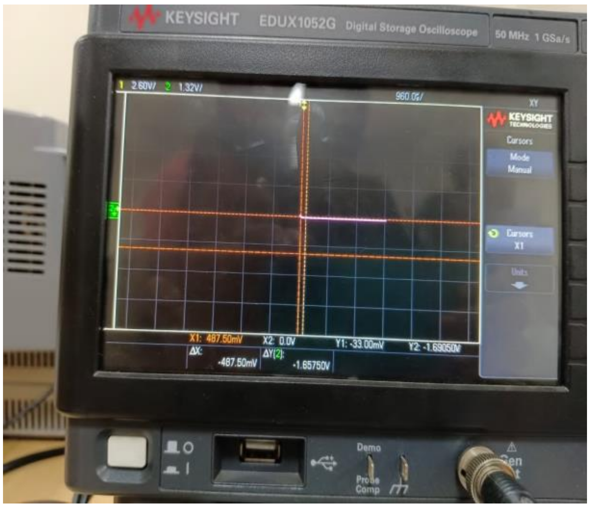


For VGS=1.6 V



For VGS=1.8 V





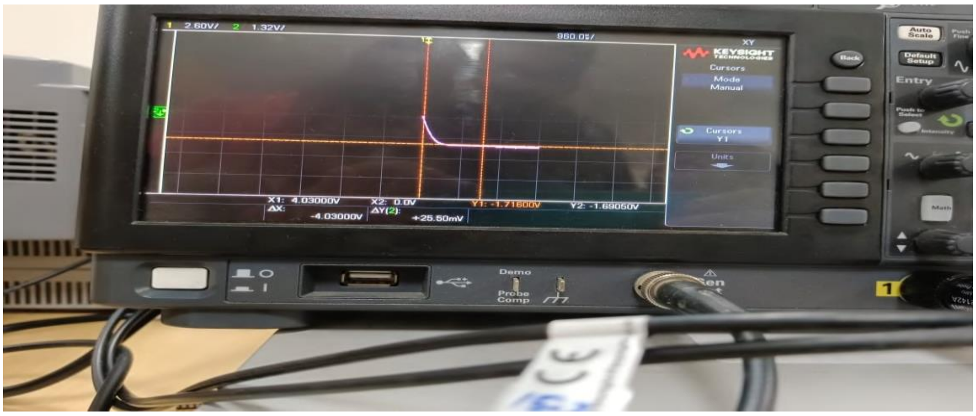
For VGS=2 V

(VDS=4V)

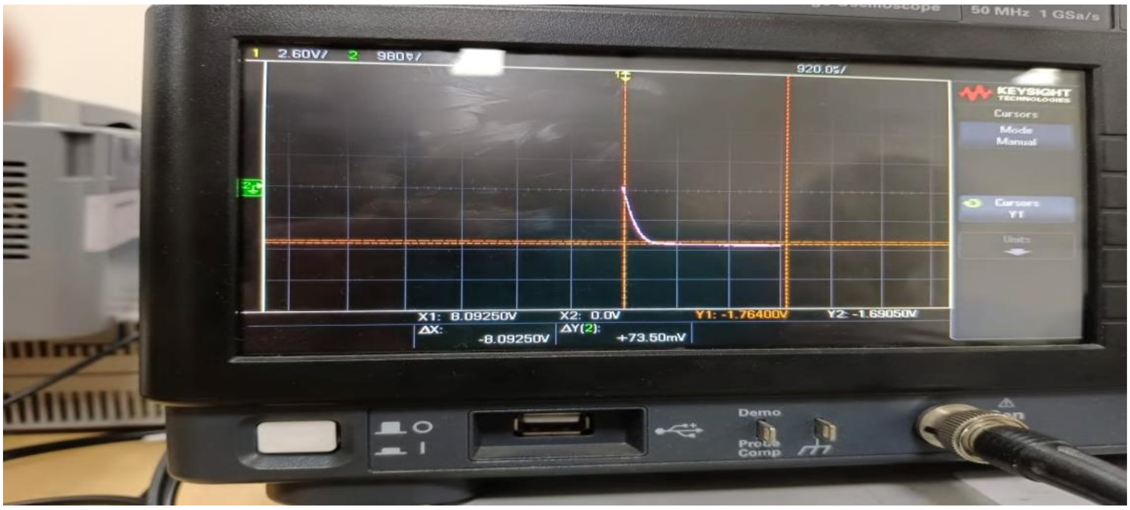
For VGS=4 V

(VDS=500mV)

(VDS=4V)

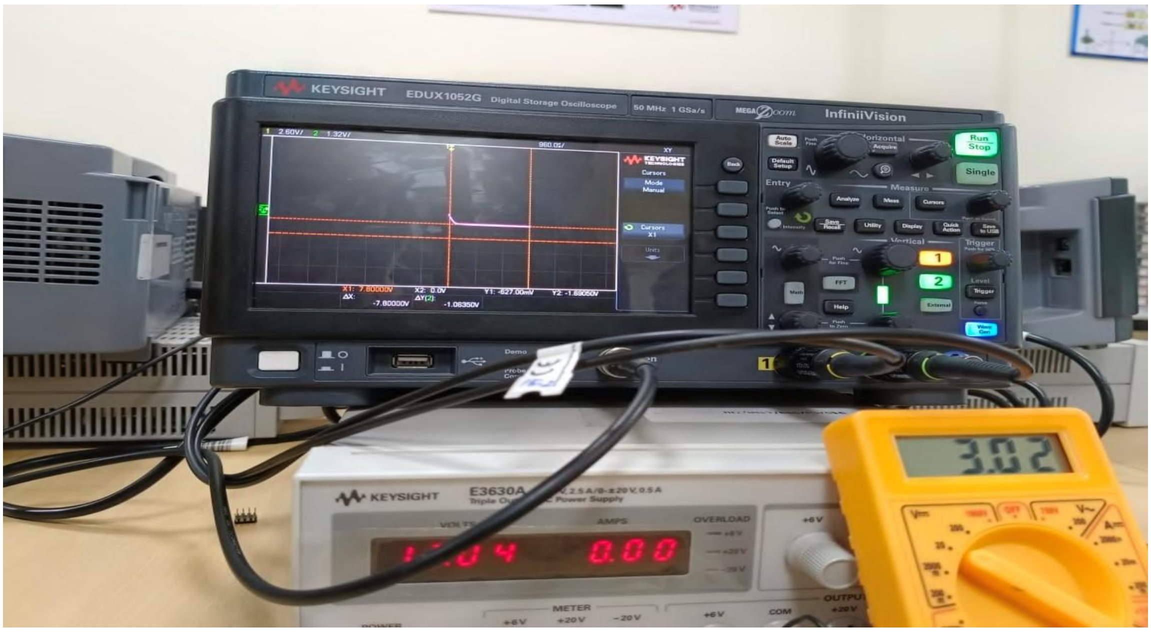


(VDS=8 V)

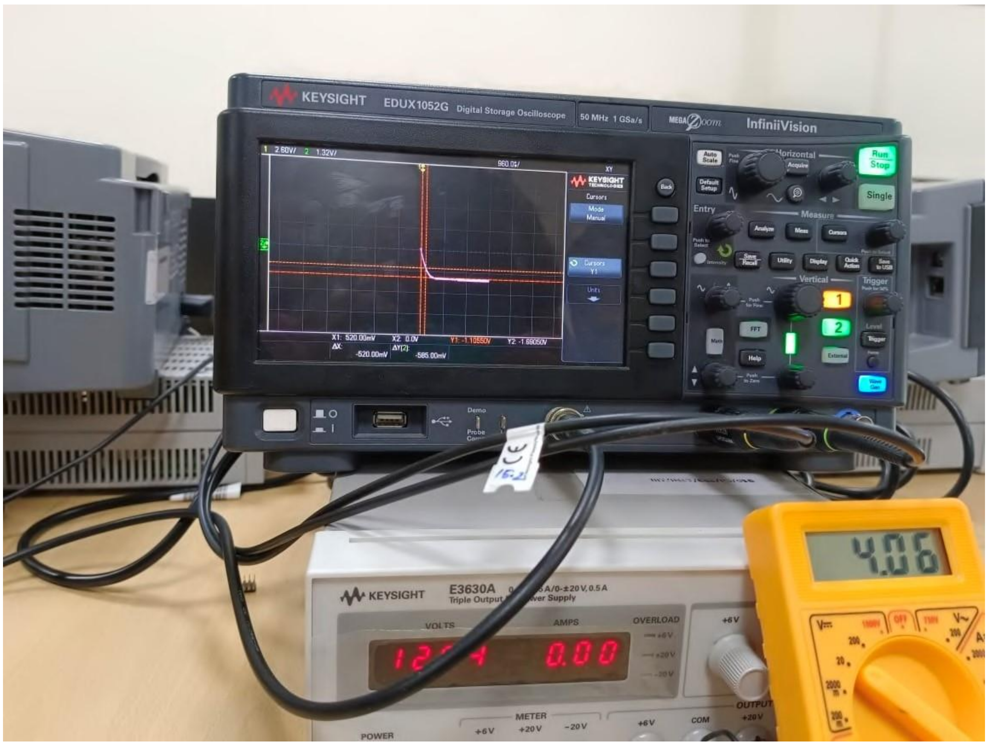


For VGS=8 V

(VDS=4V)



(VDS=8V)



for $V_{GS} < V_{Th}$ $\Rightarrow$ [MOSFET is in cutoff mode]

$\Rightarrow I_D = 0$ (close to zero)
$\Rightarrow V_O = 0$ (close to zero)

$\Rightarrow$ for $V_{GS} \geq V_T$ and $V_{DS} < V_{GS} - V_{th}$

$\rightarrow$ MOSFET is TRIODE | Linear mode

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

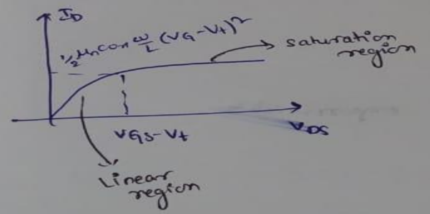
$$V_O = -R_O \mu C_{ox}\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)V_{DS} - \frac{V_{DS}^2}{2}\right]$$

$$V_O = -R_O I_D$$

$\Rightarrow$ for $V_{DS} > V_{GS} - V_{Th}$ & $V_{GS} > V_{th}$ [SATURATION MODE]

$$I_D = \frac{1}{2}\mu_n C_{ox}\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)^2\right]$$ { If channel length modulation is Not considered }

$= V_O = -R_O I_D$



Linear region:

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

Saturation region:

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

In linear region, the relation b/w I_D & V_{DS} $y = x - x^2$

In Saturation Mode, channel pinch off happens, This leads to narrowing of Channel's cross section.

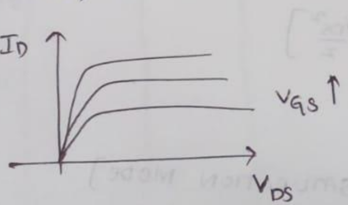
Consequently, The channel resistance ↑ses due to reduced effective channel width.

As voltage goes higher, resistance ↑ses & balances and leads to get a Constant current.

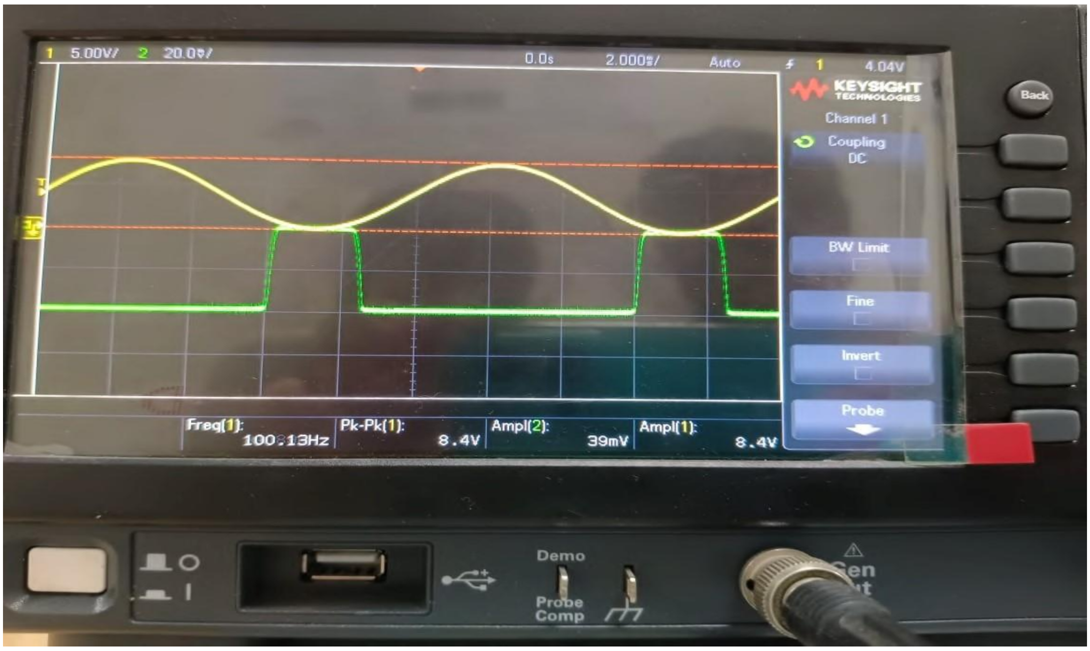
In eq^n mentioned above, I_D is independent of V_{DS}.

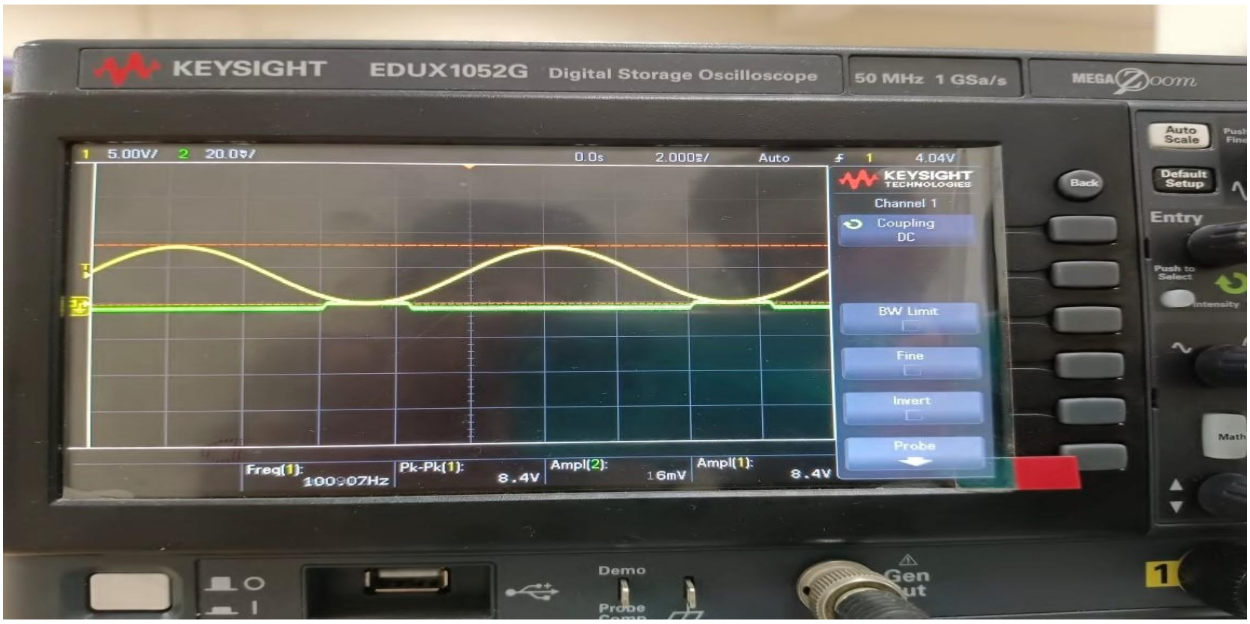
$\therefore I_D$ is constant if $V_{DS} > V_G - V_T$

As V_{GS} ↑ses, I_D Increases in saturation region



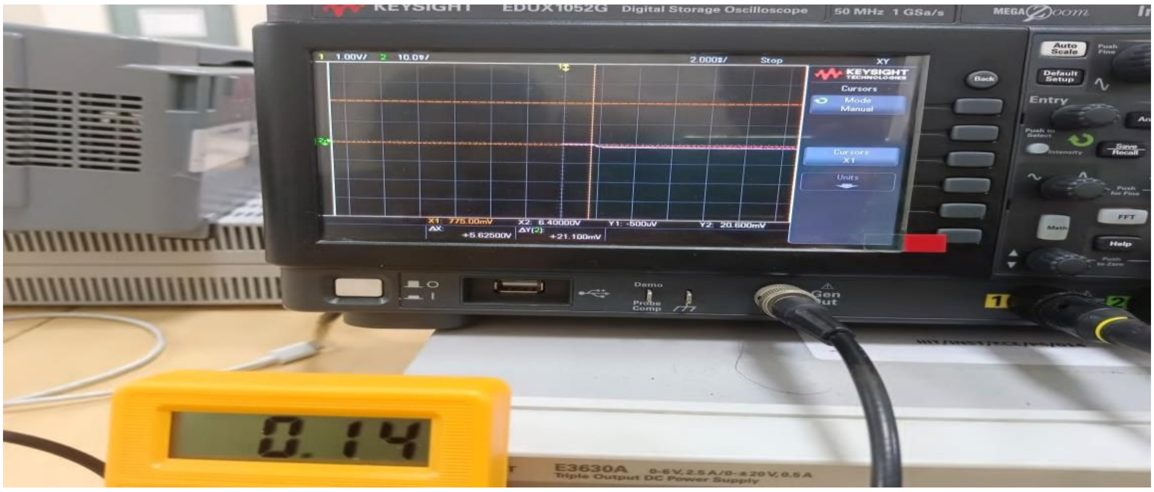
2) ID vs VGS Characteristics and Parameter Extraction:





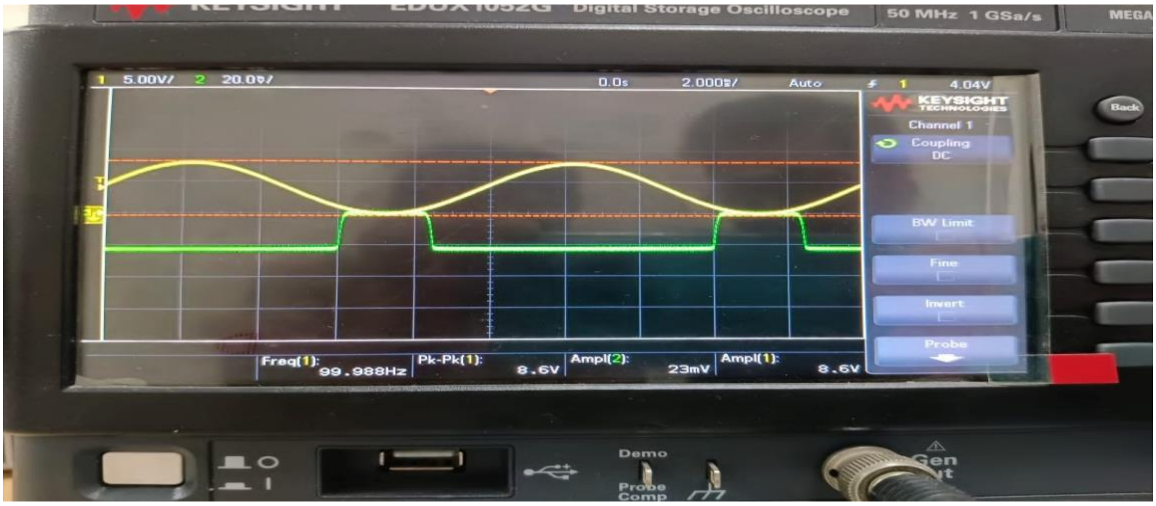
For VDS=0.1 V:

(VGS=775mV)

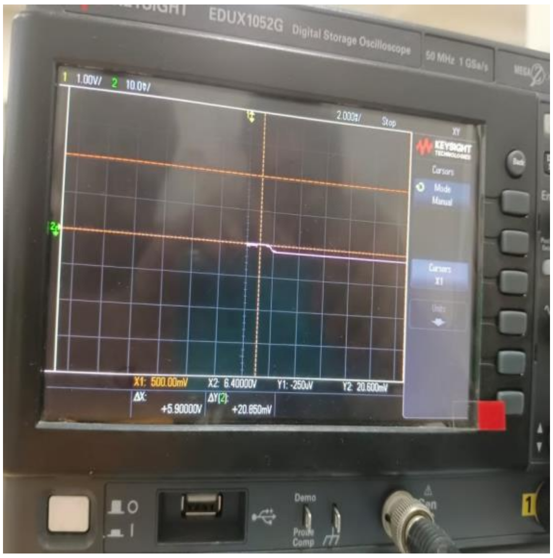


For VDS=0.2V:

(VGS=675mV)

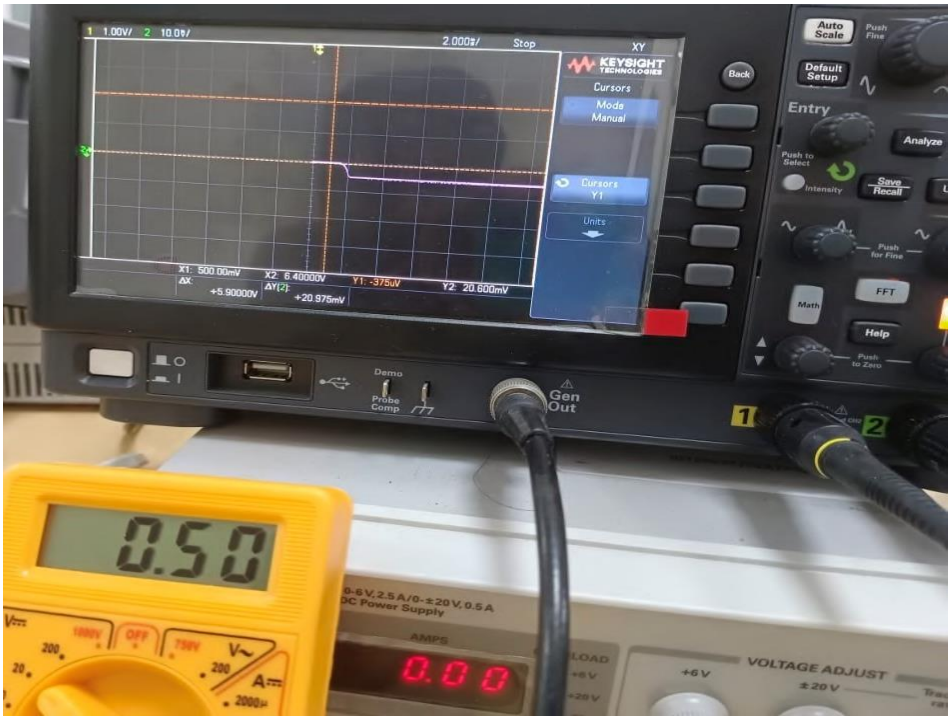


(VGS=2 V) (VGS=500 mV)

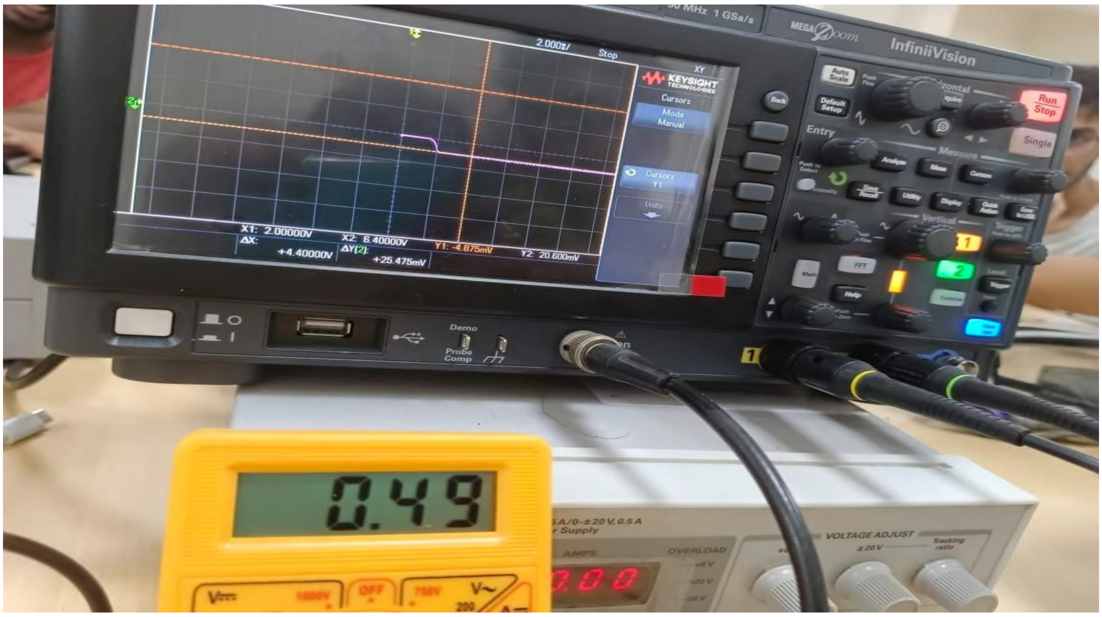


For VDS=0.5V:

(VGS=500mV)

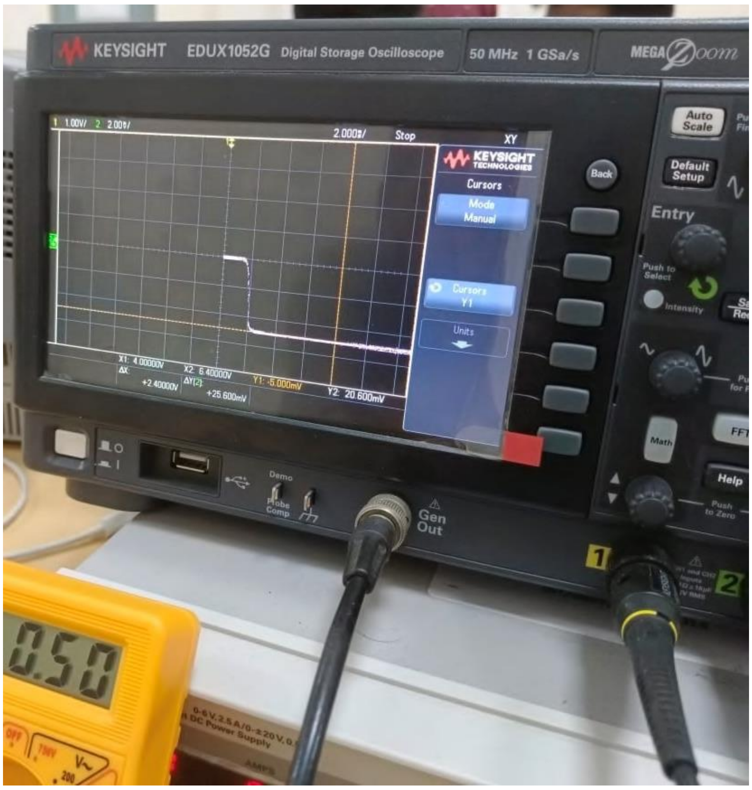


(VGS=2V)



InfiniiVision
KEYSIGHT TECHNOLOGIES
Cursors
Mode Manual
Cursors Y1
Units
X1: 2.00000V
X2: 6.40000V
ΔX: +4.40000V
ΔY(2): +25.475mV
Y1: -4.875mV
Y2: 20.600mV
0.49

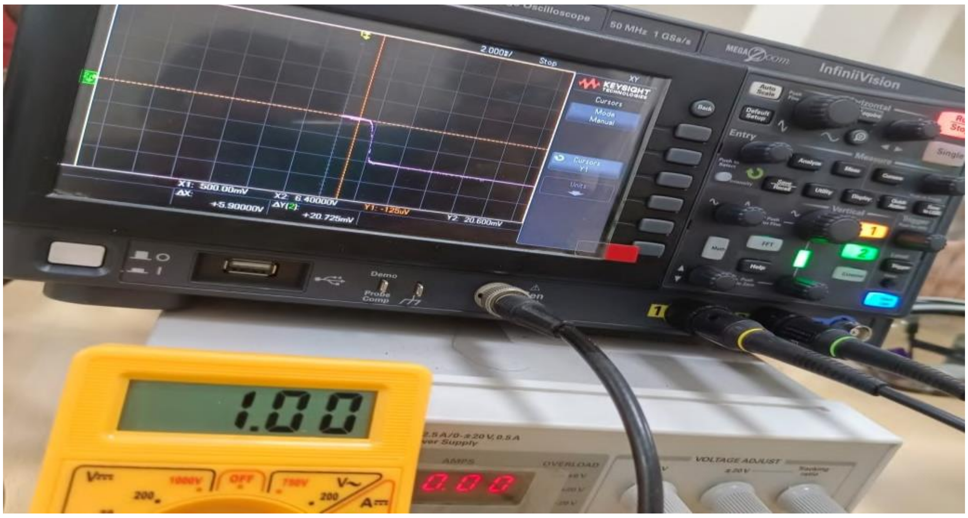
(VGS=4V)



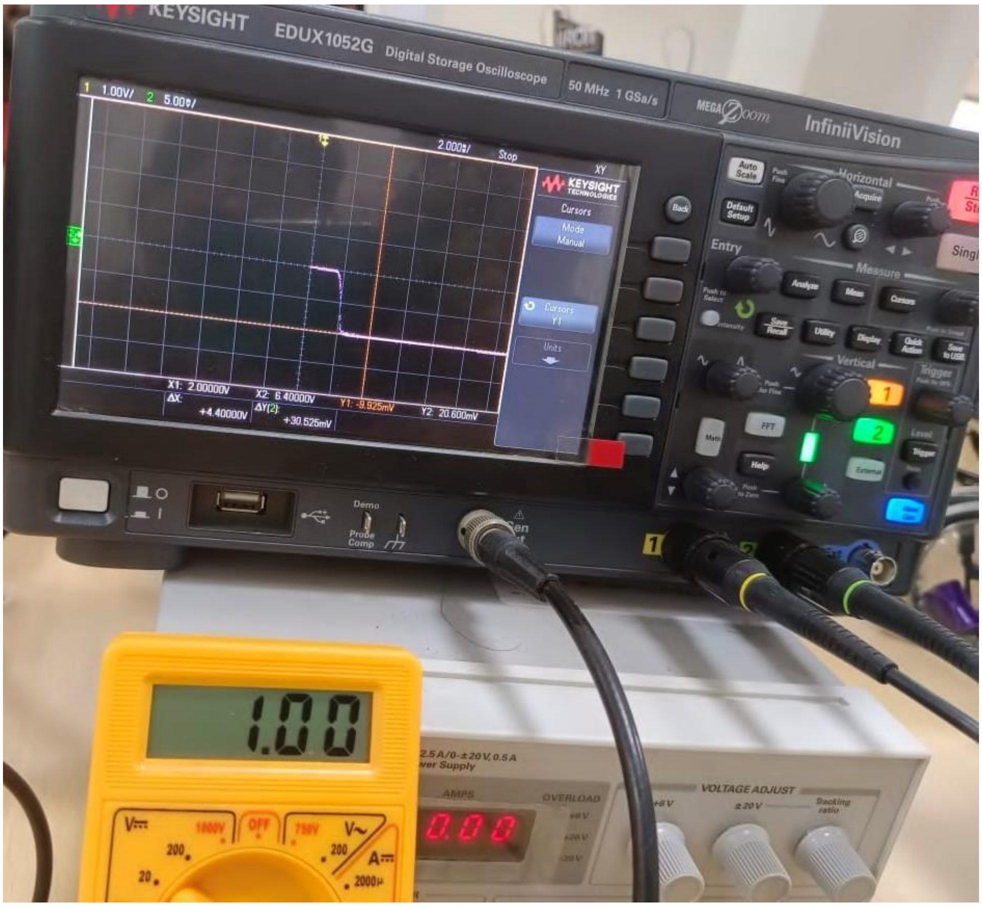
KEYSIGHT EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
Cursors
Mode Manual
Cursors Y1
Units
X1: 4.00000V
X2: 6.40000V
ΔX: +2.40000V
ΔY(2): +25.600mV
Y1: -5.000mV
Y2: 20.600mV
Auto Scale
Default Setup
Entry
Help
Gen Out
0.50

For VDS=1V

(VGS=500mV)



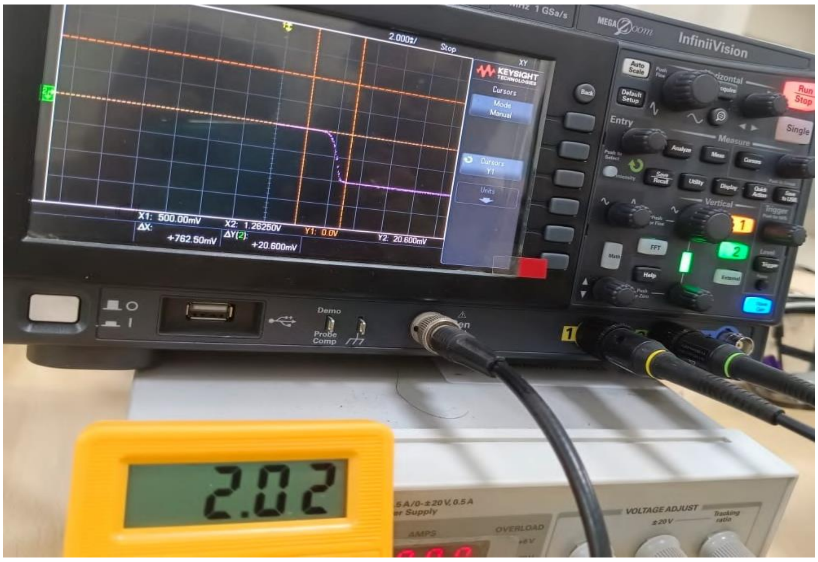
(VGS=2V)



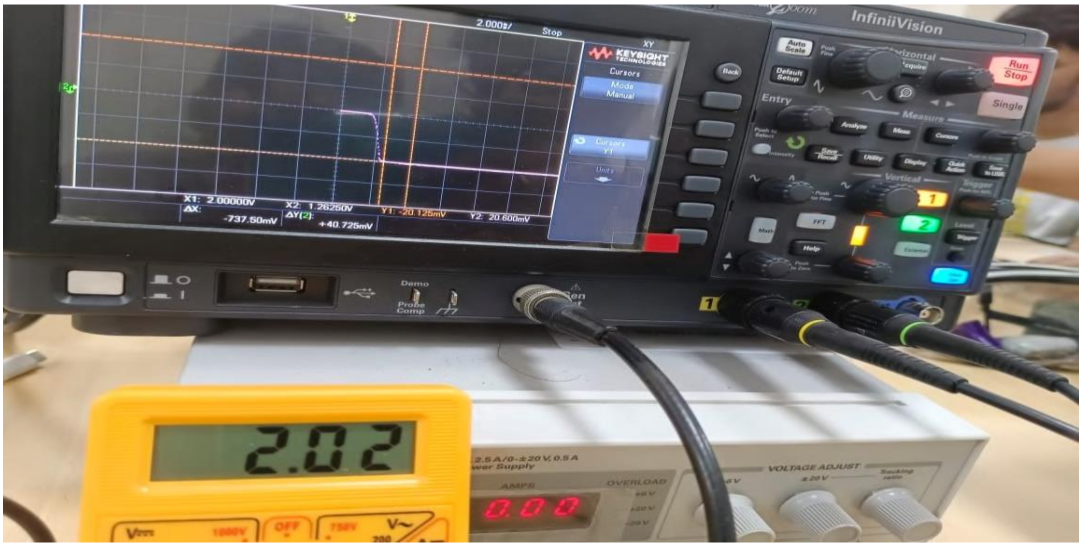
(VGS=1V)

FOR VDS=2V

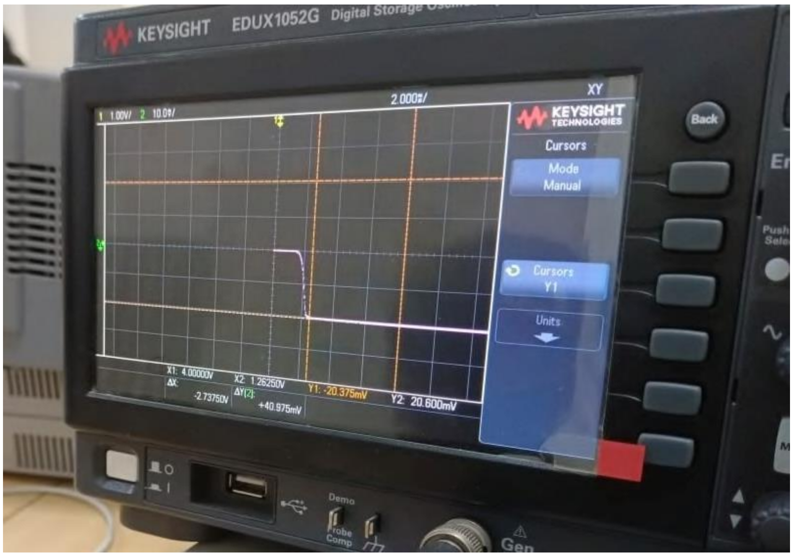
(VGS=500mV)



(VGS=2V)

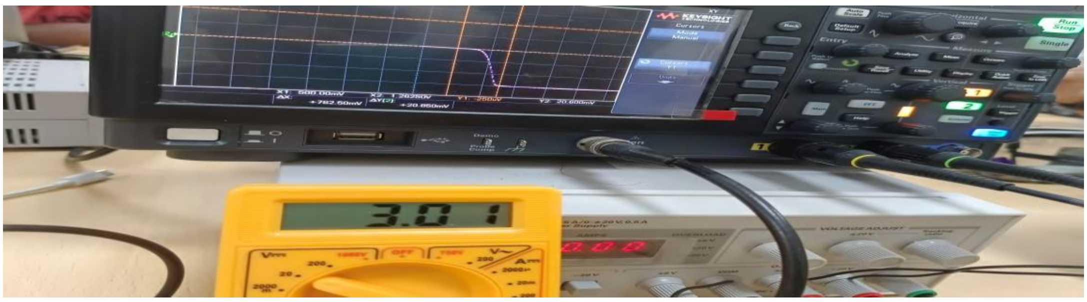


(VGS=4V)

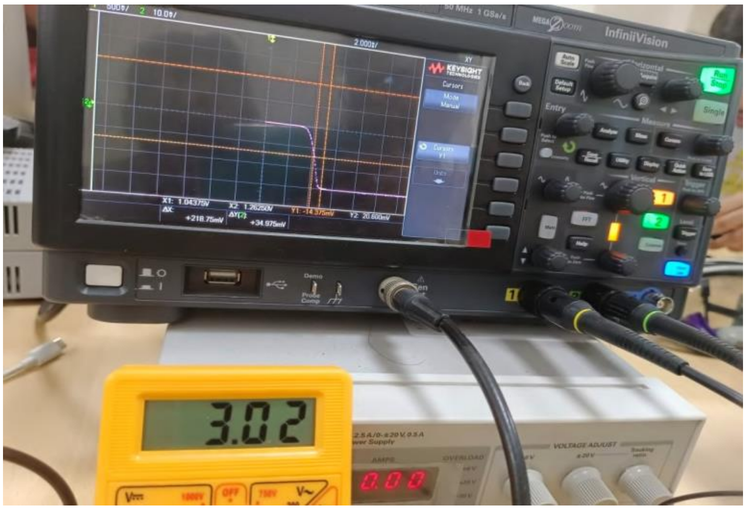


For VDS=3V

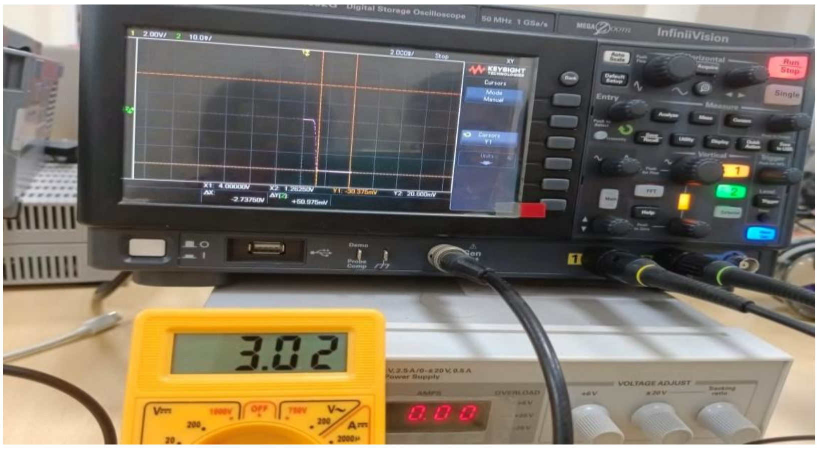
(VGS=500mV)



(VGS=1V)



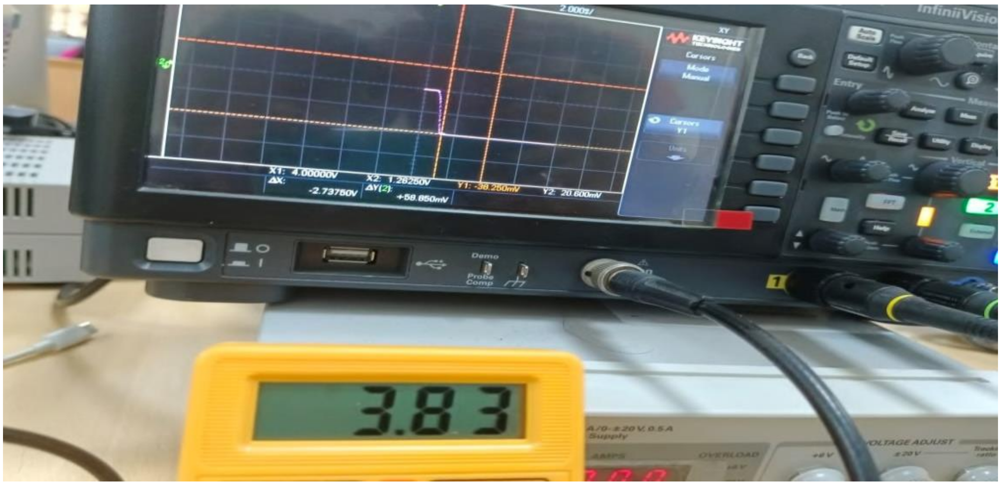
(VGS=4V)



For VDS=4V

(VGS=1V)

(VGS=4V)



VDS	VGS	Vo	ID
0.1	775mV	-500uV	0 A
0.1	1.5V	-1.5mV	-1.5uA
0.2	675mV	-200uV	0 A
0.2	2V	-2mV	-2uA
0.5	500mV	-375uV	0 A
0.5	2V	-4.875mV	-4.875uA
0.5	4V	-5mV	-5uA
1	500mV	-125uV	0 A
1	2V	-9.925mV	-9.925uA
1	1V	-4.925mV	-4.925uA
2	500mV	0V	0A
2	2V	-20.125mV	-20.125uA
2	4V	-20.375mV	-20.375uA
3	500mV	-250uV	0 A
3	2V	-30.125mV	-30.125uA
3	1V	-14.375mV	-14.375uA
3	4V	-30.375mV	-30.375uA
4	1V	-20.750mV	-20.750uA
4	2	-38.250mV	-38.250uA
4	4	-38.500mV	-38.500uA

b)

To determine the threshold voltage (VT), we examine the maximum slope of the curve.

This occurs at the point (VGS, VOUT) = (2, -1.95).

By considering the points (2, -1.95) and (1.95, -2), we calculate the approximate slope to be -1.8V.

The next step involves drawing a tangent at the point of maximum slope and determining its intersection with the x-axis (VGS). This intersection point represents the threshold voltage (VT). Therefore, in this case, the threshold voltage is approximately 0.75V.

c)

Given the following known parameters:

VDS = 0.1V

VGS = 2V

Vout = -1.95V

VT = 0.75V

ID ≈ 2mA

To determine the mode of operation of the MOSFET, we calculate:

VGS - VTH = 2 - 0.75 = 1.25V

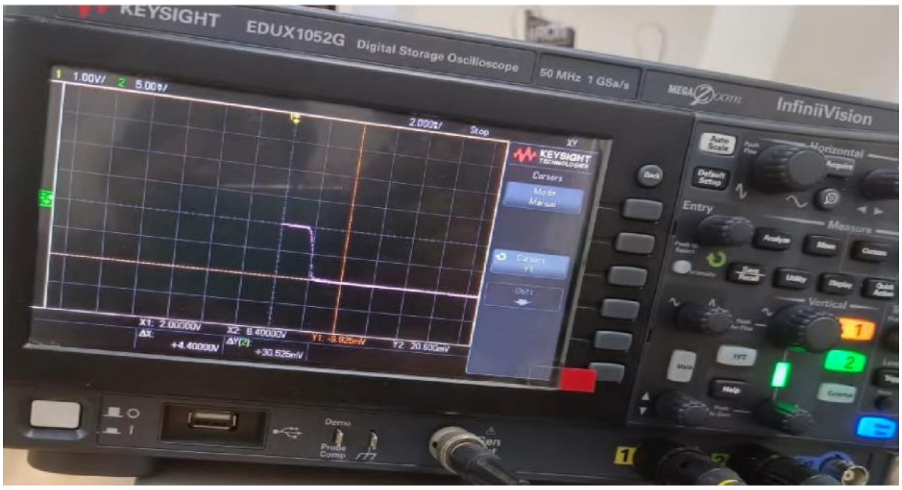
Since VDS is less than 1.25V, the MOSFET is operating in the triode or linear region.

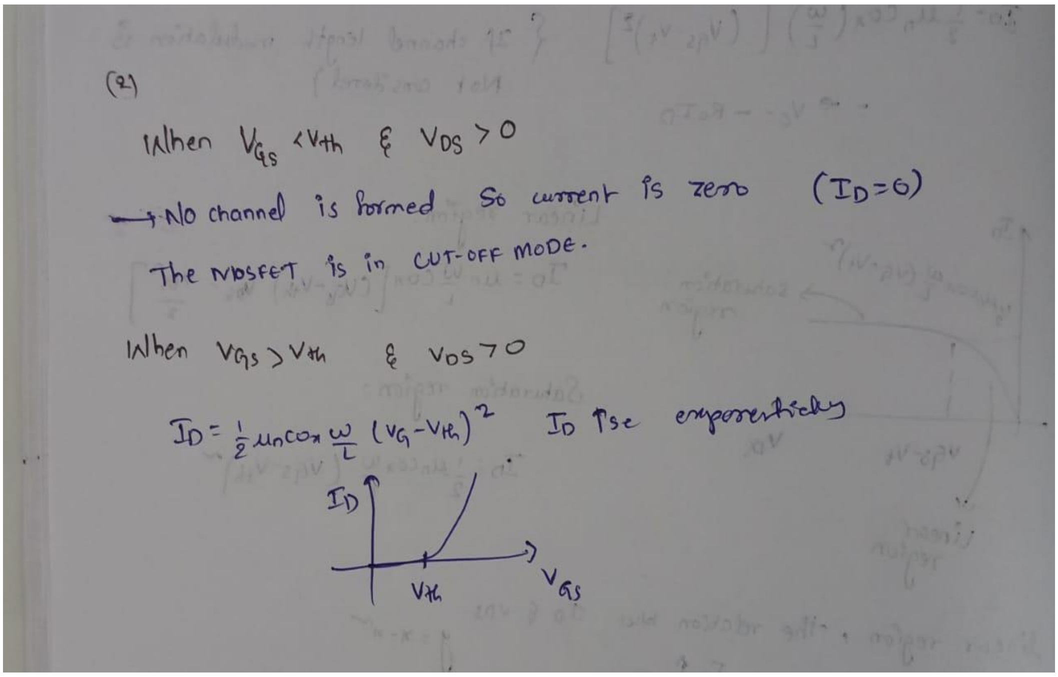
To further analyze the MOSFET's behavior, we can utilize the characteristic equation:

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

ID = (µnCox/2) * [(VGS - VTH) * VDS - (VDS^2 / 2)]

Using the above equation we got µnCox(W/L)= 18 mS/V





(2)

When $V_{GS} < V_{th}$ & $V_{DS} > 0$

→ No channel is formed So current is zero ($I_D = 0$)

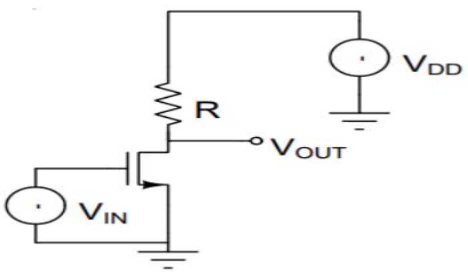
The MOSFET is in CUT-OFF MODE.

When $V_{GS} > V_{th}$ & $V_{DS} > 0$

$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_G - V_{th})^2$ I_D ↑se exponentially

3) Large signal Analysis and other Voltage Transfer Characteristics of MOS based Amplifier :

Consider the NMOS based amplifier with a resistive load as shown below:

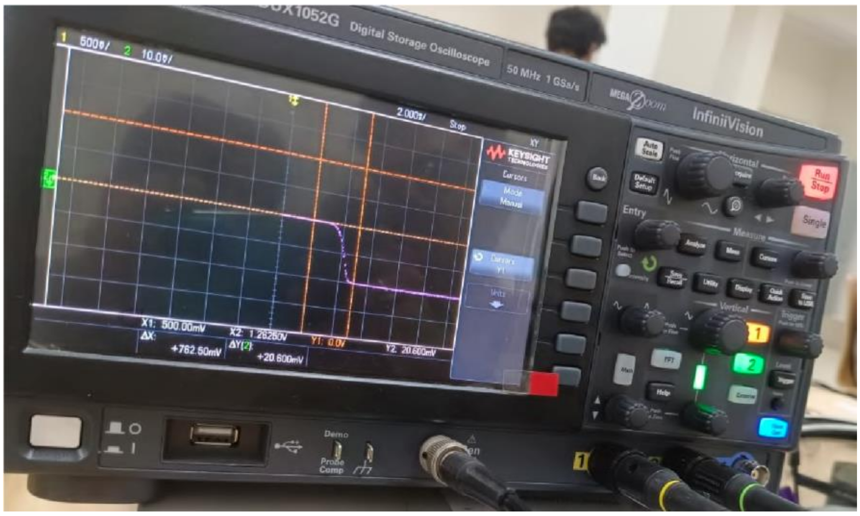


Modes of Operation of MOSFET:

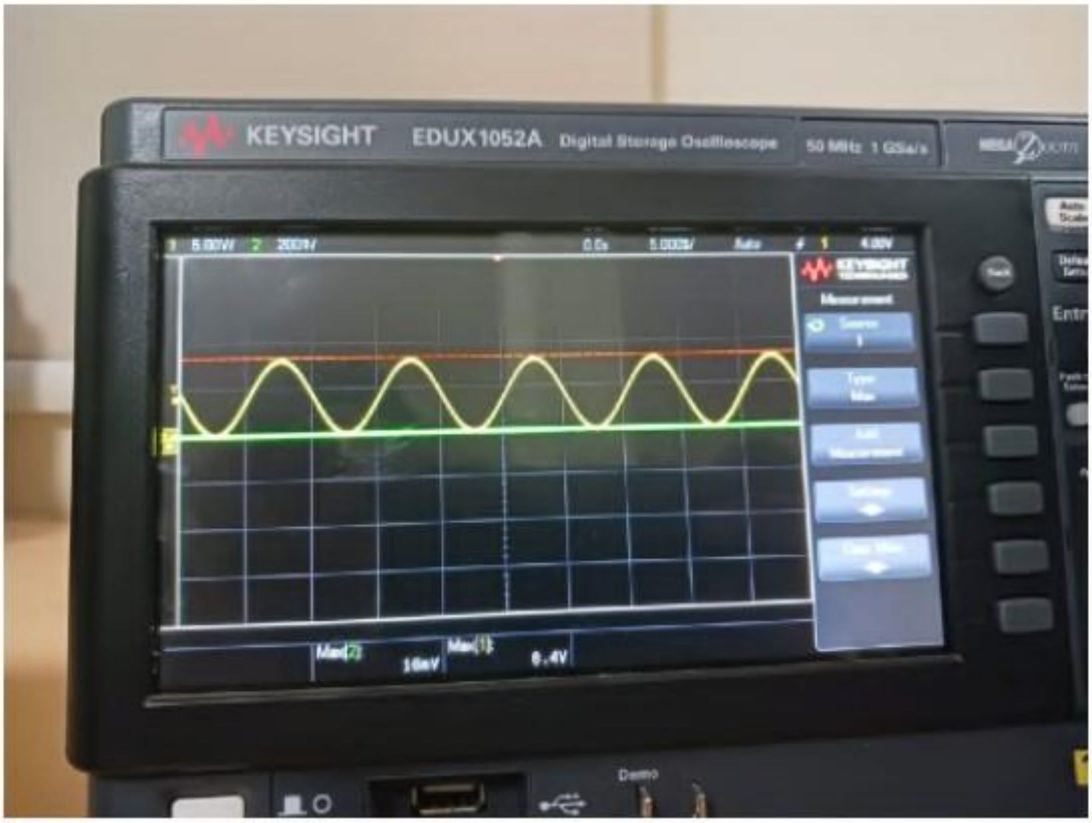
Vin=500mv => cut off mode

Vin=2.5v => saturation mode

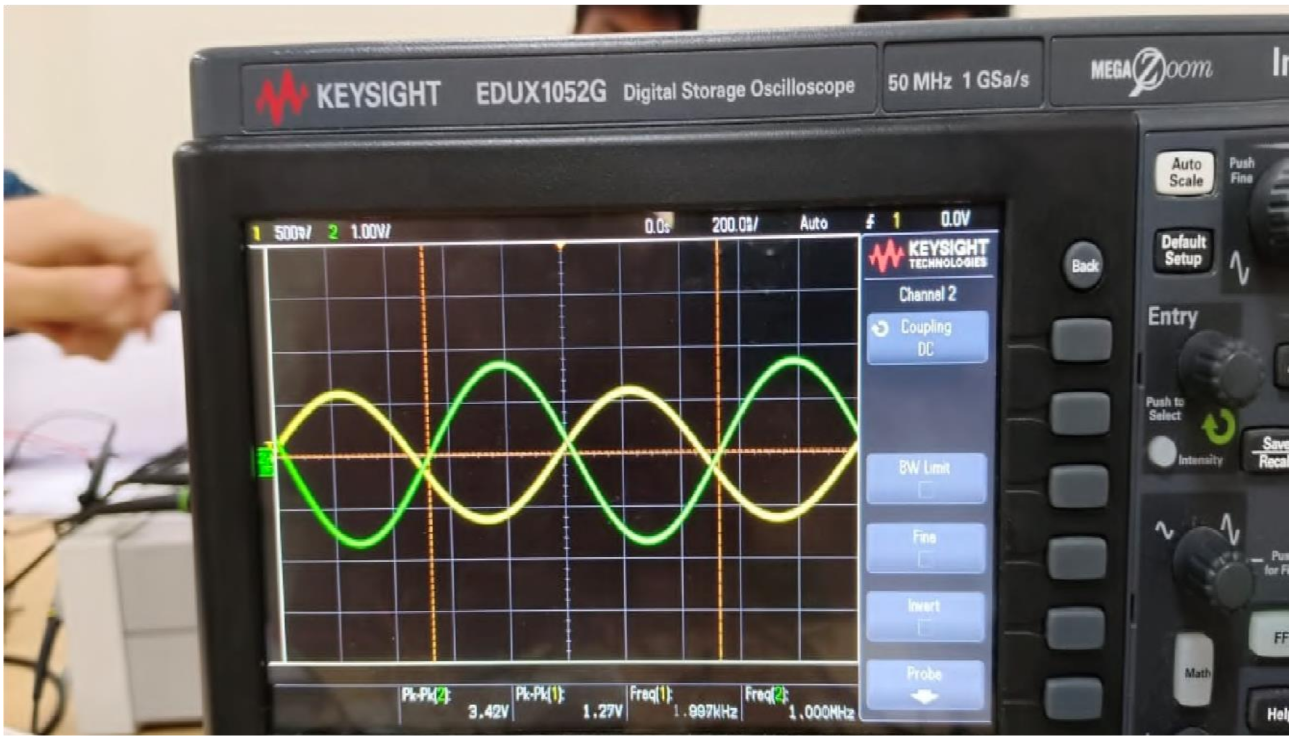
Vin=4v => Linear/Triode mode

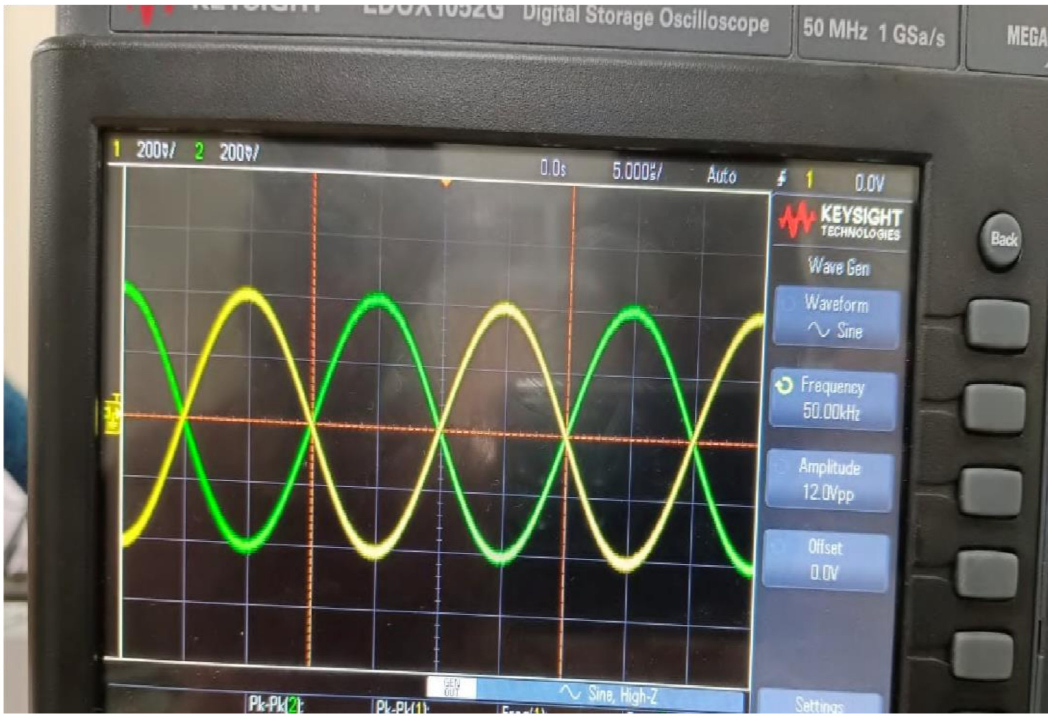

Digital Storage Oscilloscope
50 MHz 1 GSa/s
InfiniiVision
KEYSIGHT

At Vin=500mV

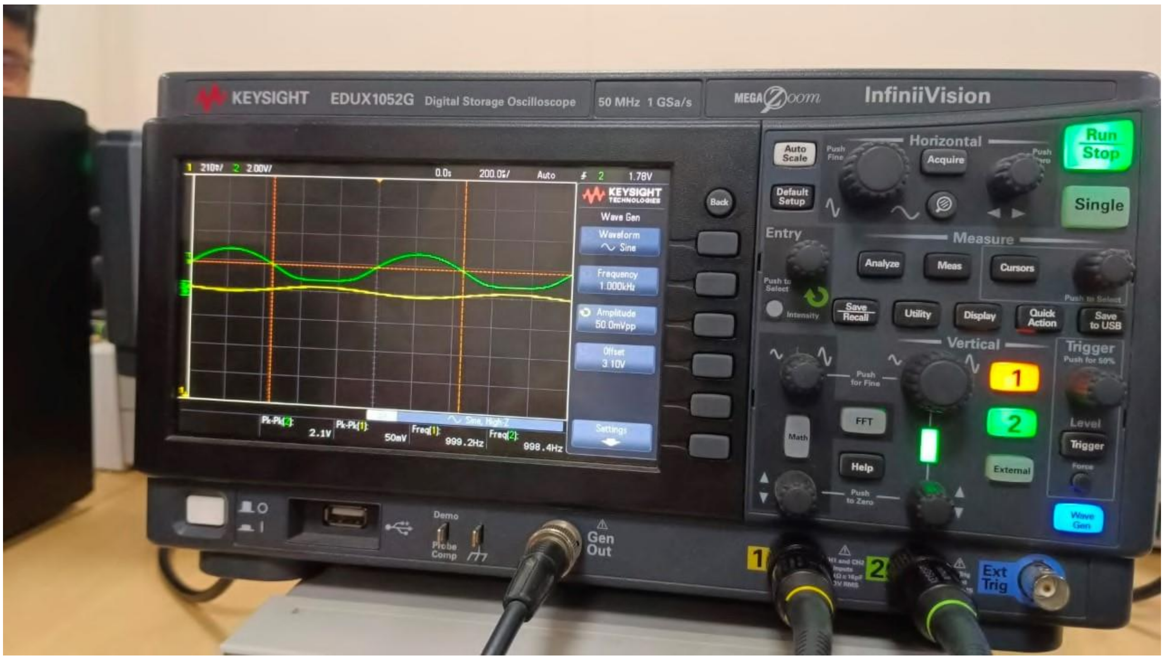

KEYSIGHT
EDUX1052A
Digital Storage Oscilloscope
50 MHz 1 GSa/s
KEYSIGHT

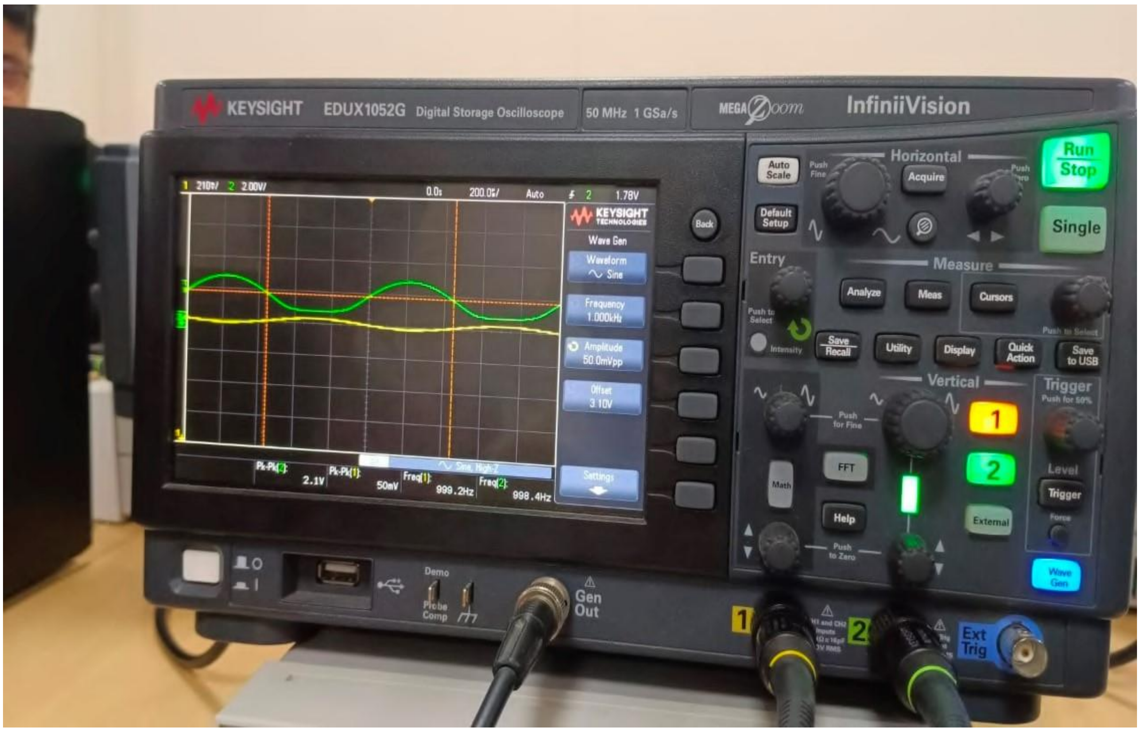
At Vin=2.5mV


KEYSIGHT
EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
Channel 2
Coupling
DC
BW Limit
Fine
Invert
Probe
Pk-Pk(2): 3.42V
Pk-Pk(1): 1.27V
Freq(1): 1.997kHz
Freq(2): 1.000kHz
Auto Scale
Default Setup
Entry
Back

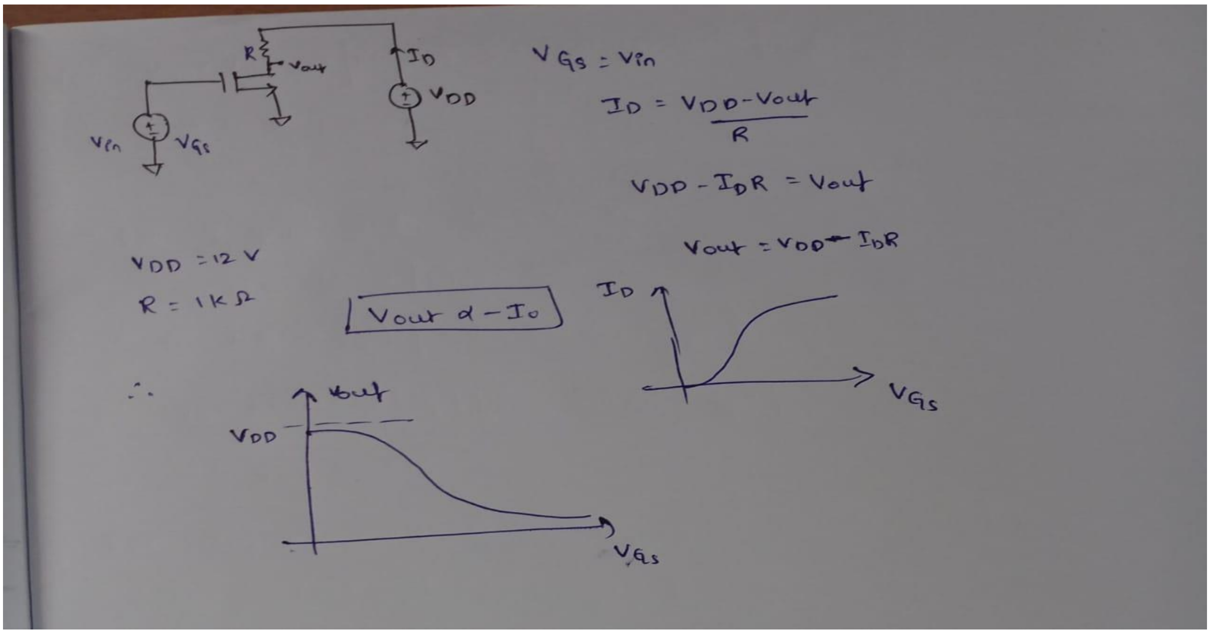

Digital Storage Oscilloscope
50 MHz 1 GSa/s
KEYSIGHT
Wave Gen
Waveform
Sine
Frequency
50.00kHz
Amplitude
12.0Vpp
Offset
0.0V
Sine, High-Z
Back

At Vin=4V


KEYSIGHT
EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
InfiniiVision
Horizontal
Run Stop
Single
Measure
Vertical
Trigger
Gen Out
Ext Trig


KEYSIGHT
EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
InfiniiVision
Horizontal
Run Stop
Single
Measure
Vertical
Trigger
Gen Out
Ext Trig

MODE	VDS	Vin	Vout	Gain
Cutoff-mode	500mv	40mv	22mv	~0.5
		120mv	15mv	0.125
		1v	40mv	0.04
		500mv	16mv	0.032
Linear/Triode	4v	40mv	21mv	~0.5
		19.7mv	19mv	0.96
		120mv	45mv	0.375
		500mv	120mv	0.24
		1v	300mv	0.3
saturation	2.5	27mv	38mv	1.407
		120mv	155mv	1.2917
		570mv	765mv	1.34
		1 V	1.42V	1.42



When the input voltage (Vin) is significantly smaller than 2(VGS-VTH) and much smaller than VDS, we can observe a proper gain in the MOSFET.

However, when Vin becomes comparable to VDS, 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.