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

Lab Report – 7: Common Source Amplifier

Name: Chanda Akshay Kumar

Roll No 2024102014

Team Member Name: S V Santhosh

Team Member Roll.No 2024102054

1. Objectives

1. To analyze the effect of body bias on the gain of a Common Source (CS) amplifier.
2. To study the impact of bias voltage (VBIAS) on the amplifier's gain.
3. To observe the effect of input signal swing on amplifier gain and clipping behavior.
4. To analyze the frequency response of a CS amplifier with external coupling.

2. Equipment Used

1. Breadboard
2. NMOS transistor (CD4007BE)
3. DC power supply
4. Function generator
5. Digital Multimeter (DMM)
6. Oscilloscope
7. Resistors: RL=4.7 kΩ, RBIAS=few 100 Ω
8. Capacitors: CC=10 μF, CL=470 pF

3. Theory

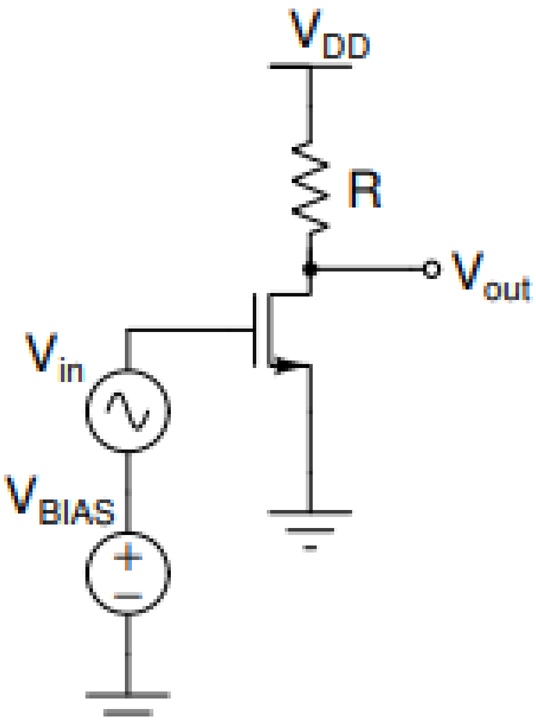
The Common Source (CS) amplifier is a fundamental MOSFET amplifier configuration. Key parameters include:

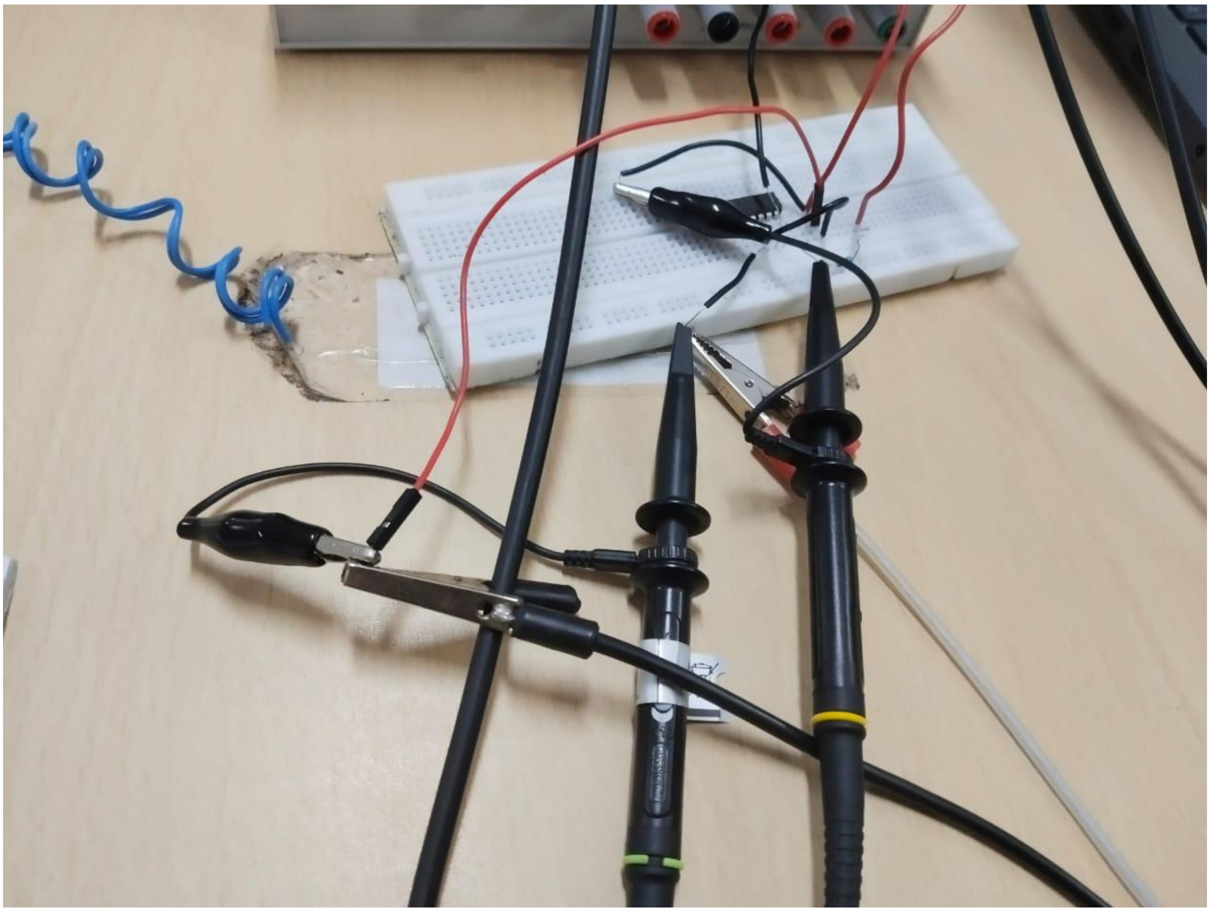
- **Voltage Gain (*Av*):** $A_v = -g_m R_L$

- **Transconductance (gm):** gm=μnCoxWL(VGS−VT)
- **Body Effect:** Changes in VSS*VSS* alter the threshold voltage (VT), affecting gm and gain.
- **Clipping:** Occurs when the output exceeds the linear range of the amplifier.
- **Frequency Response:** Determined by coupling and load capacitances.

4. Experimental Procedure & Observations

4.1 Effect of Body Effect on Gain





Circuit: CS amplifier with VDD=5V, VBIAS=2.5V, RL=4.7 kΩ.

(a) DC Measurements

- Measured VDS=3.5V
- Calculated IDS=(VDD−VDS)/RL=0.31mA
- Calculated μnCoxWL=1.27 A/V^2
- Calculated gm= mS

(b) AC Measurements

- Applied vin=50 mVpp, f=1 kHz
- Measured vout=200m Vpp
- Calculated Gain (Av) = vout/vin=4
- Calculated gm(effective)=0.91mS

LAB-7

(a) When we take V_{GS} as 2V we get V_{DS} = ~~180mV~~ ~~2.28V~~ 1.55V

$V_{DD} = 5V$

$\Rightarrow 5 - (I_D)(4.7k) = \cancel{2.28}\ 1.55V$

$= (I_D)(4.7k) = 3.45V$

$3.45 = I_D(4.7k)$

$I_D = \frac{3.45}{4.7} \times 10^{-3} = 0.734 \times 10^{-3} A$

$= 0.7 mA$

g_m

$I_D = \frac{\mu_n C_{ox} W}{2L} (V_{GS} - V_{TH})^2$ [Let $k = \frac{\mu_n C_{ox} W}{L}$]

$0.73 \times 10^{-3} = \frac{k}{2} (2 - 1.8)^2$

$= k(0.02) = 0.73 \times 10^{-3}$

$= k = \frac{0.73}{2} \times 10^{-1}$

$= 0.365 \times 10^{-1}$

$g_m = k(V_{GS} - V_{TH})$

$= 0.365 \times 10^{-1} (2 - 1.8)$

$= 0.73 \times 10^{-2}$

(b) $A_v = g_m R_L$

$= \cancel{(0.73 \times 10^{-2})(4.7 k\Omega)}$

$= \cancel{0.73 \times 10 \times 4.7}$

$= \cancel{34.31}$

$A_v = \frac{v_{out}}{v_{in}} = \frac{220 mV}{50 mV} = 4.4$

$A_v = g_m R_L$

$g_m = \frac{4.4}{4.7} \times 10^{-3} = 0.93 \times 10^{-3}$

(c) Body Effect Analysis

VSS(V)	vout(Vpp)	Gain (*Av*)	gm(effective)(mS)
0	220m	4	0.91
0.4	280m	4.67	1.04
-0.4	80m	1.6	0.47

gm(effective)=gm+gmb

Observation:

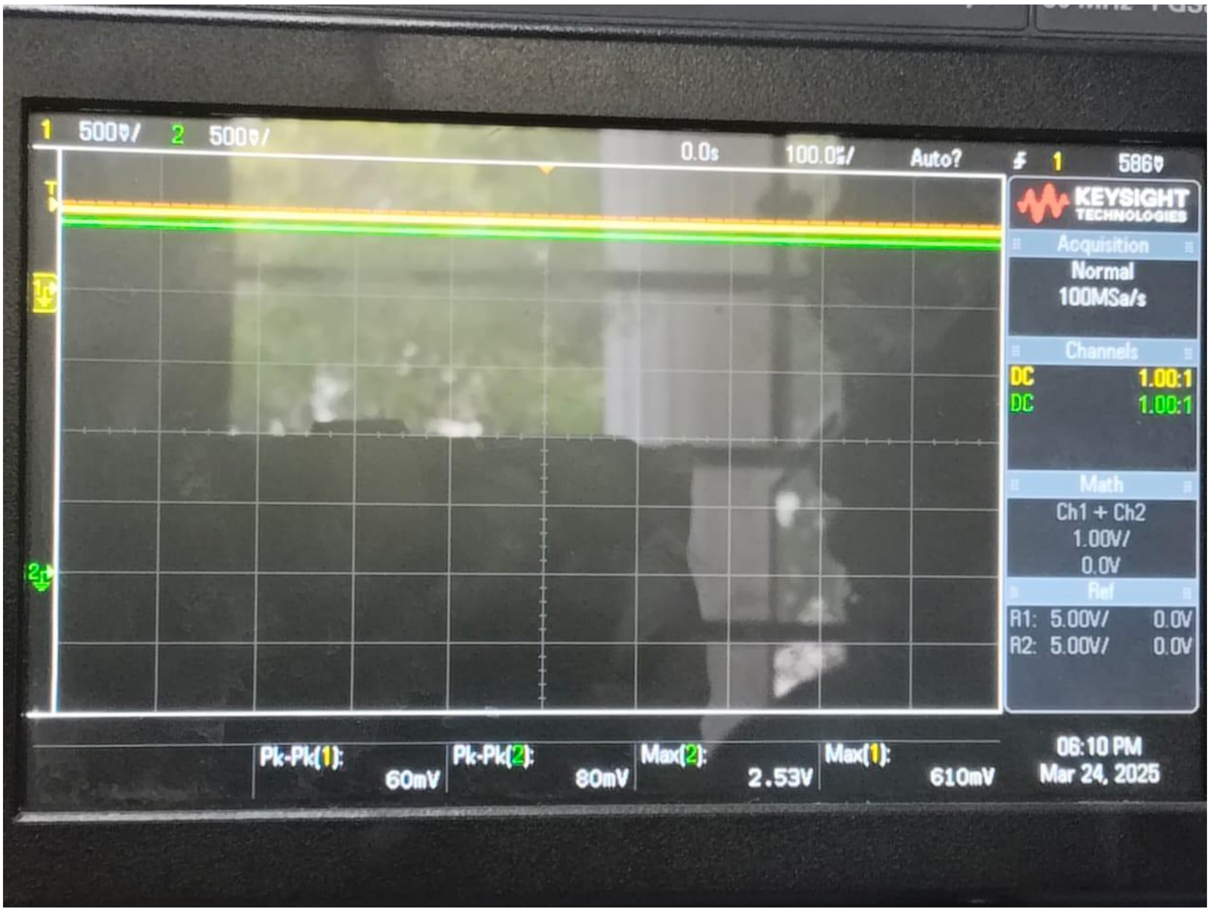
- As |VSS| increases, the gain changes due to the body effect (gmb).
- The equation of the Vth according to the body voltage will be given as
- **Vth=Vth0+(root(VSB+2(pie))- root(2(pie)))**
- Increasing the body voltage above zero raises the threshold voltage, which in turn lowers the output voltage.
- Decreasing the body voltage below zero reduces the threshold voltage, leading to a higher output voltage.
- gmb affected by bias voltage at body which changes VTH(threshold)

The initial bias voltage (Vbias) was set to 2.5V, but the MOSFET did not enter the saturation region as expected. This happened because Vds was too low, making it less than Vgs minus Vt. To fix this, the bias voltage was reduced to 2V, which increased Vds and ensured that the MOSFET operated in the saturation region. This adjustment was needed because Vgs was already less than Vt, preventing proper operation in the previous setup.

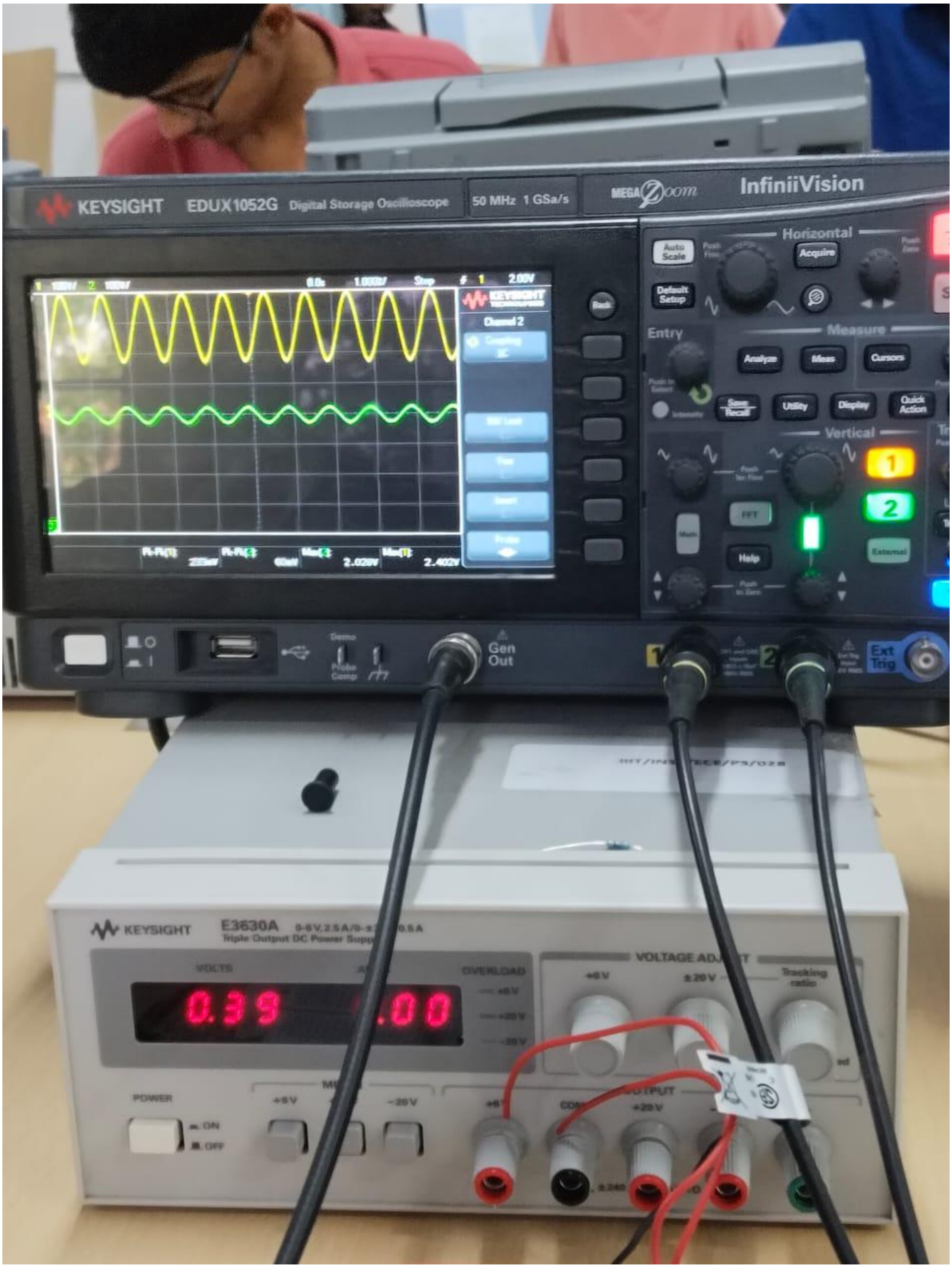
Vbias = 2V


KEYSIGHT
1 500mV/ 2 500mV/
0.0s 100.0s/ Auto?
1 1.52V
KEYSIGHT TECHNOLOGIES
Channel 1
Coupling DC
BW Limit
Fine
Invert
Probe
Pk-Pk(1): 60mV
Pk-Pk(2): 60mV
Max(2): 2.03V
Max(1): 1.55V
Demo
Probe Comp
Gen Out

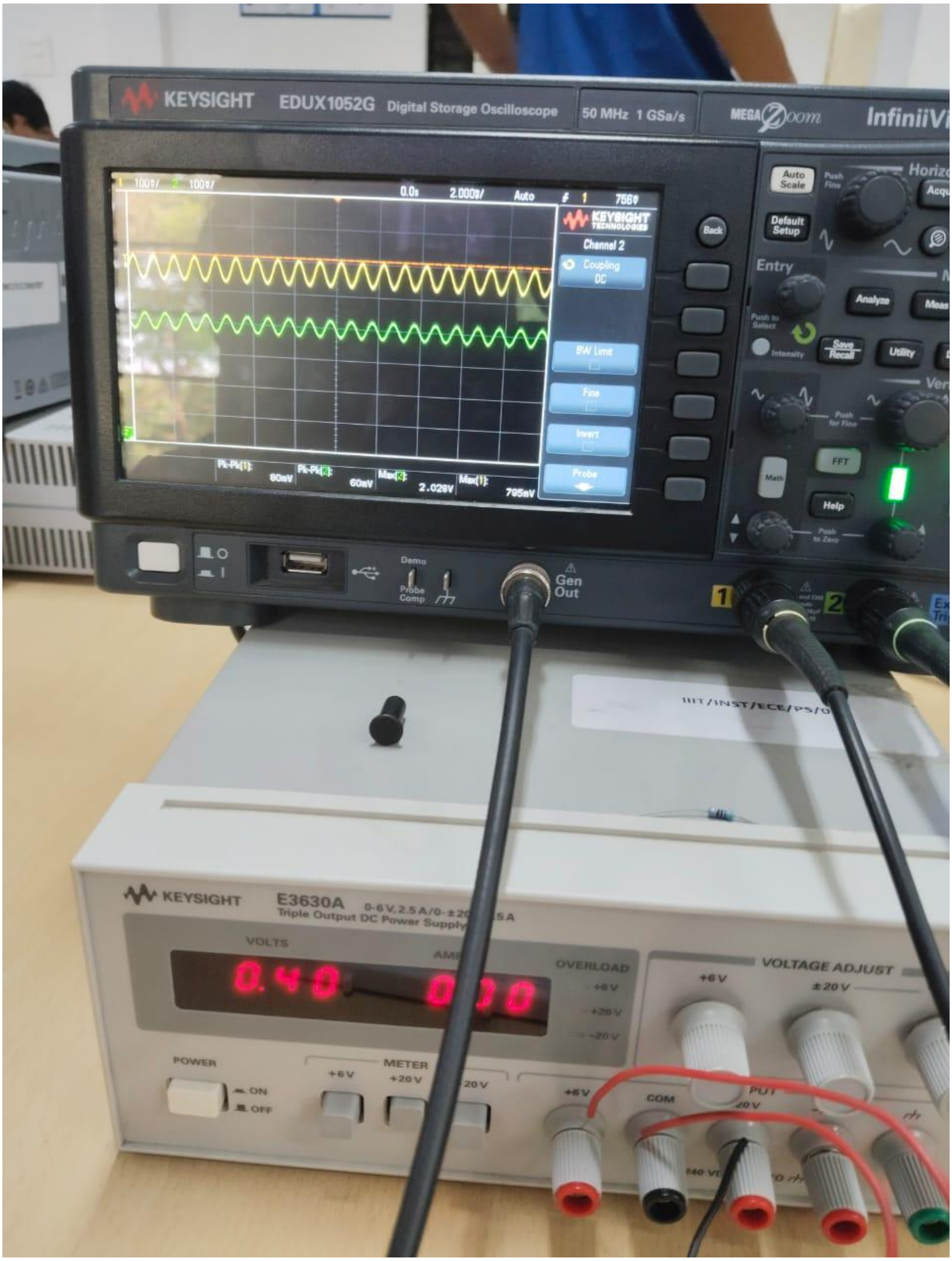
Vbias=2.5V



VBS=-0.4


KEYSIGHT
EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
InfiniiVision
Horizontal
Auto Scale
Acquire
Default Setup
Entry
Measure
Analyze
Meas
Cursors
Utility
Display
Quick Action
Vertical
1
2
FFT
Help
External
Channel 2
2.020V
2.402V
Gen Out
Ext Trig
KEYSIGHT
E3630A
VOLTS
OVERLOAD
0.39
.00
Tracking ratio
POWER
ON
OFF
+6V
±20V
-20V
+20V

VBS=+0.4



4.2 Effect of Bias Voltage on Gain

By changing vbias we need to observe what changes has occurred on the parameters vout,gain,gm etc,,,

With Fixed vin=100 mVpp , f=1 kHz

And also we need to plot gm vs VGS(bias) in notebook

Wkt,

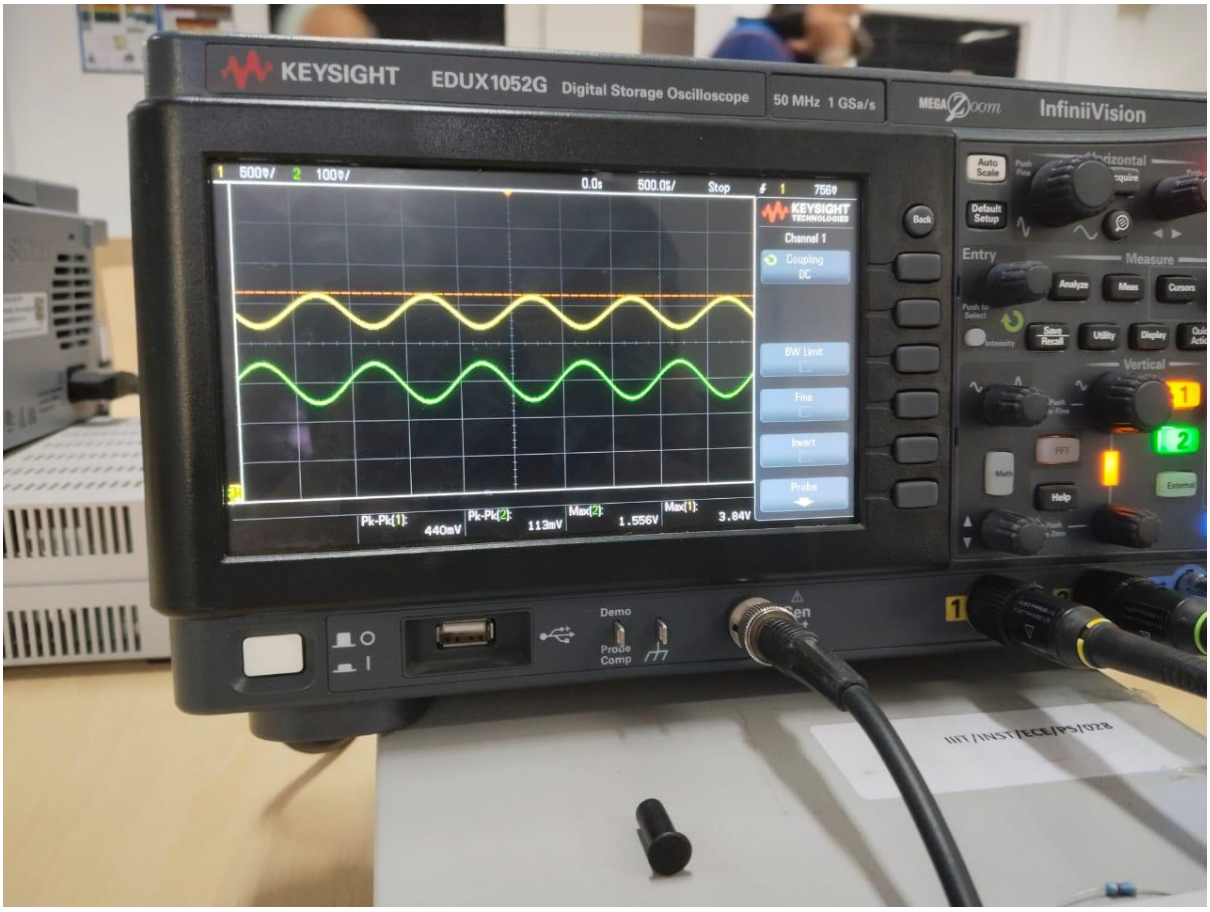
Av=Vout/vin

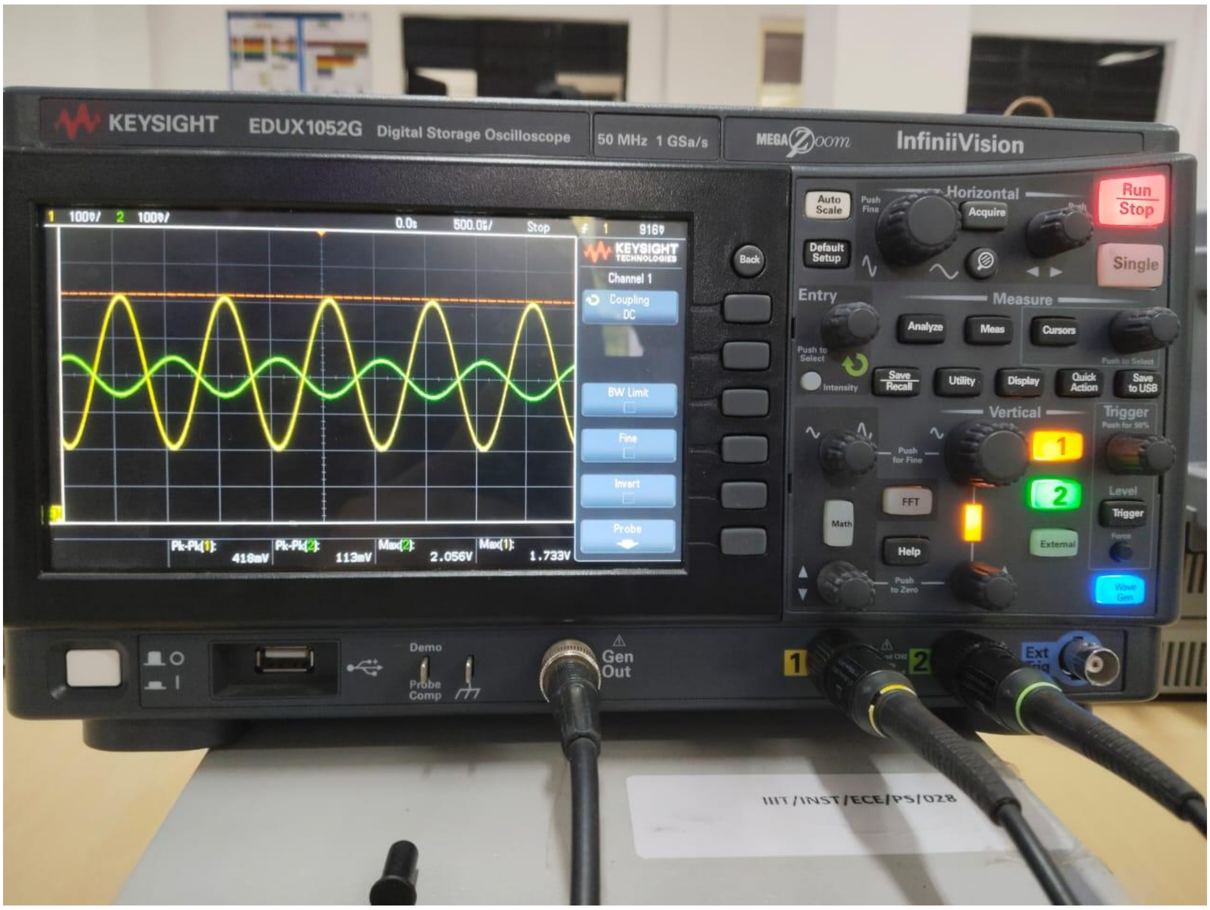
Av=(gm*RL*vin)/(vin)

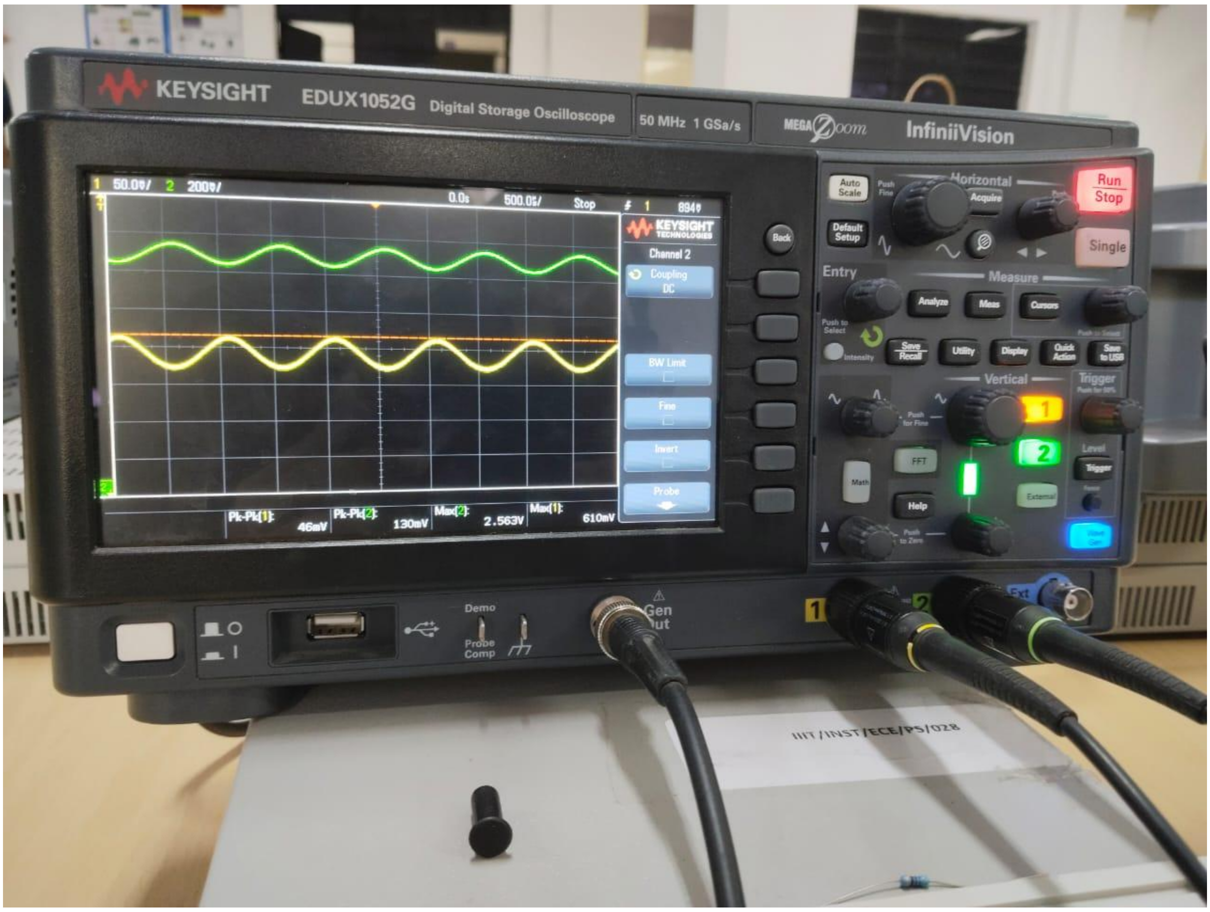
[vout=Vin*(outputimpedance)]

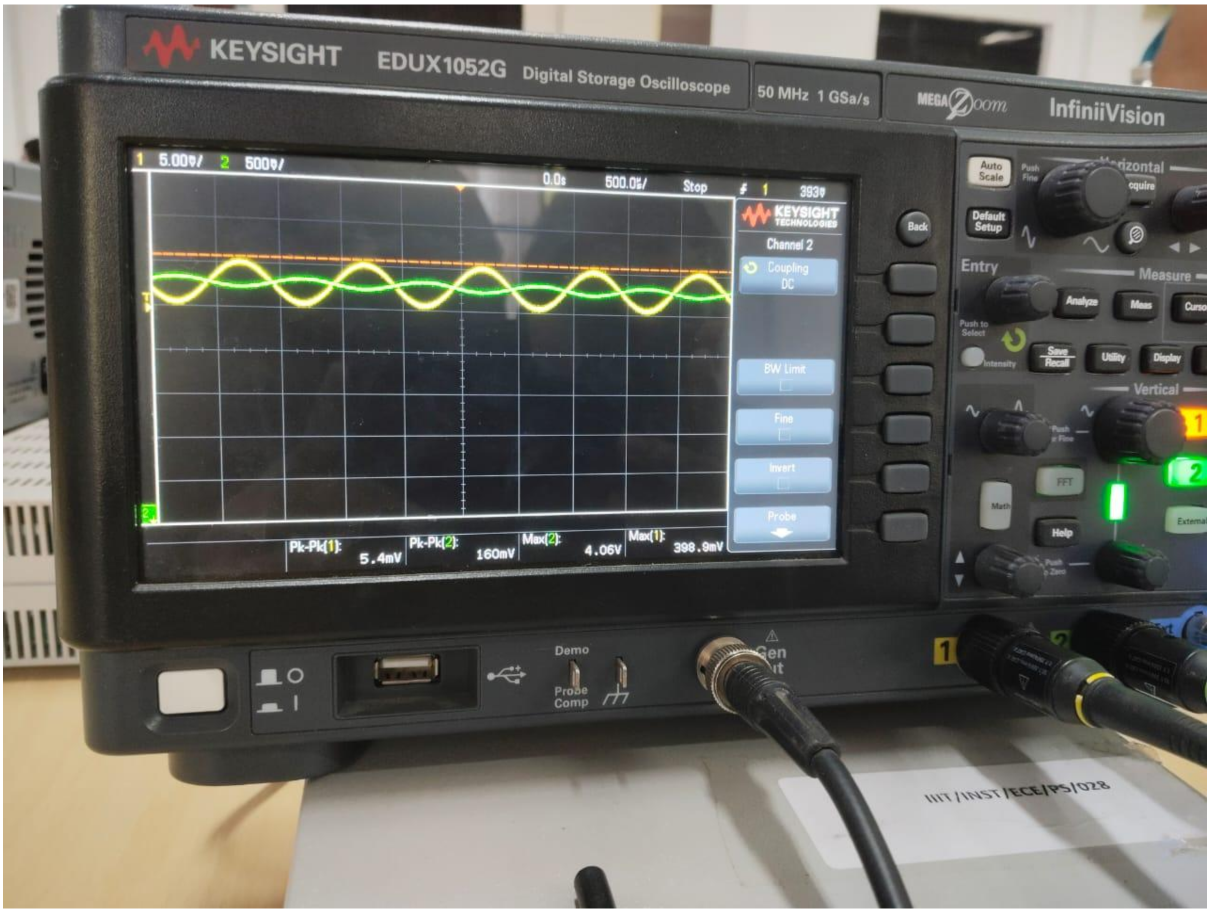
Av=-gm*RL

VBIAS(V)	**Vout(Vpp) mV**	**Gain (Av)**	**gm(mS)**
1.5	400	4	0.85
1.8	410	4	0.85
2.5	46	0.5	0.106
4.0	5.4	0.08	0.017



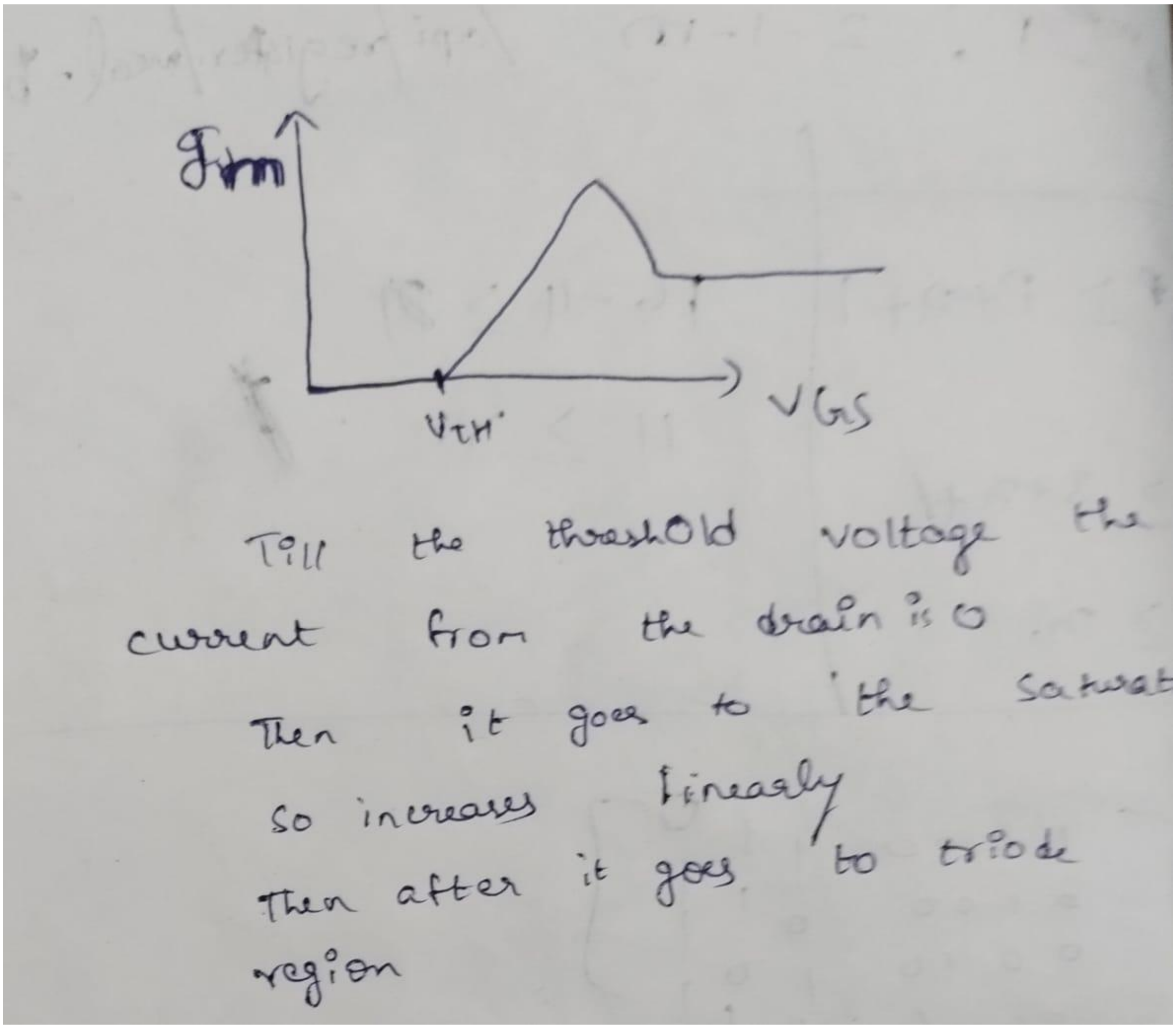

KEYSIGHT
EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
InfiniiVision
Channel 1
Coupling DC
BW Limit
Fine
Invert
Probe
Pk-Pk(1): 418mV
Pk-Pk(2): 113mV
Max(2): 2.056V
Max(1): 1.733V
IIIT/INST/ECE/PS/028


KEYSIGHT
EDUX1052G Digital Storage Oscilloscope
50 MHz 1 GSa/s
InfiniiVision
Channel 2
Coupling DC
BW Limit
Fine
Invert
Probe
Pk-Pk(1): 46mV
Pk-Pk(2): 130mV
Max(2): 2.563V
Max(1): 610mV
IIIT/INST/ECE/PS/028



Observation:

- Gain increases with VBIAS until saturation.
- After saturation slight increase with large increase in vbias because of channel length modulation
- Plot of gm vs Vgs

- 

4.3 Effect of Input Swing on Gain

Fixed VBIAS=2.5V, f=1 kHz

vin(mVpp)	vout(Vpp) mV	Gain (Av)	gm(mA/V)
100	400	4	0.85
200	960	4.2	0.98
300	1.23	5	1.06
400	1.56	5	1.06
500	1.89	4.8	1.02
600	2.21	3.4	0.72
700	2.45	3.2	0.68

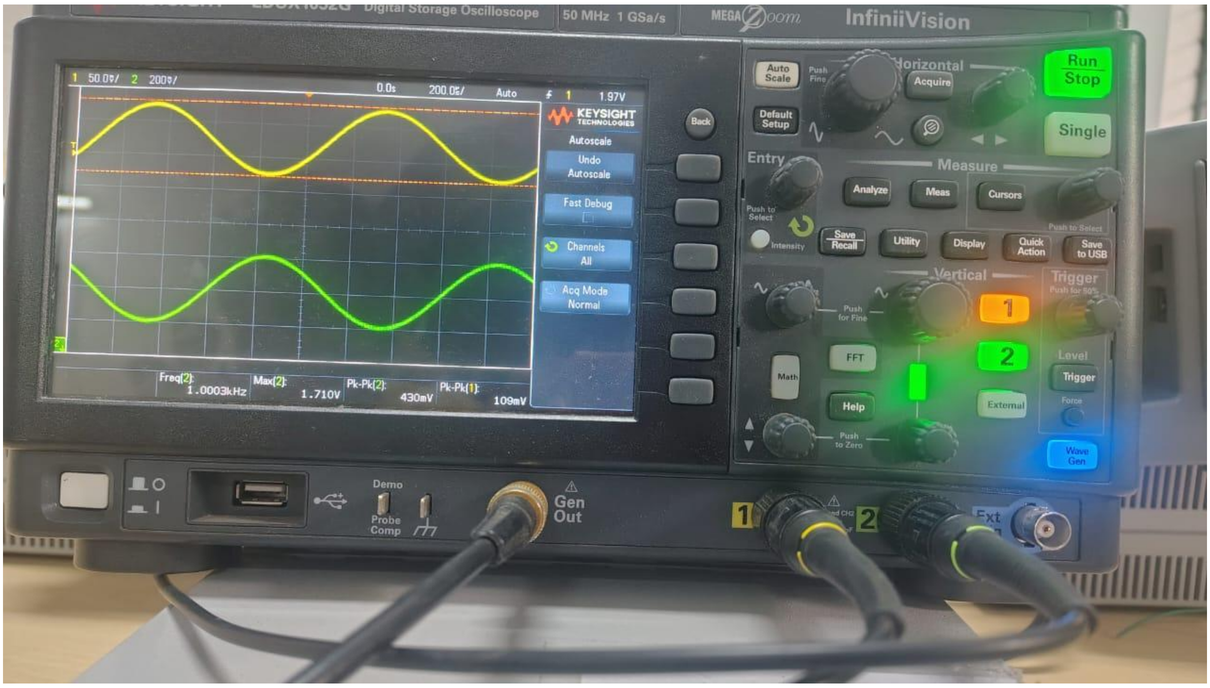
From above mentioned stat bias voltage is still 2V

Clipping observed after 700mv for v bias 2v

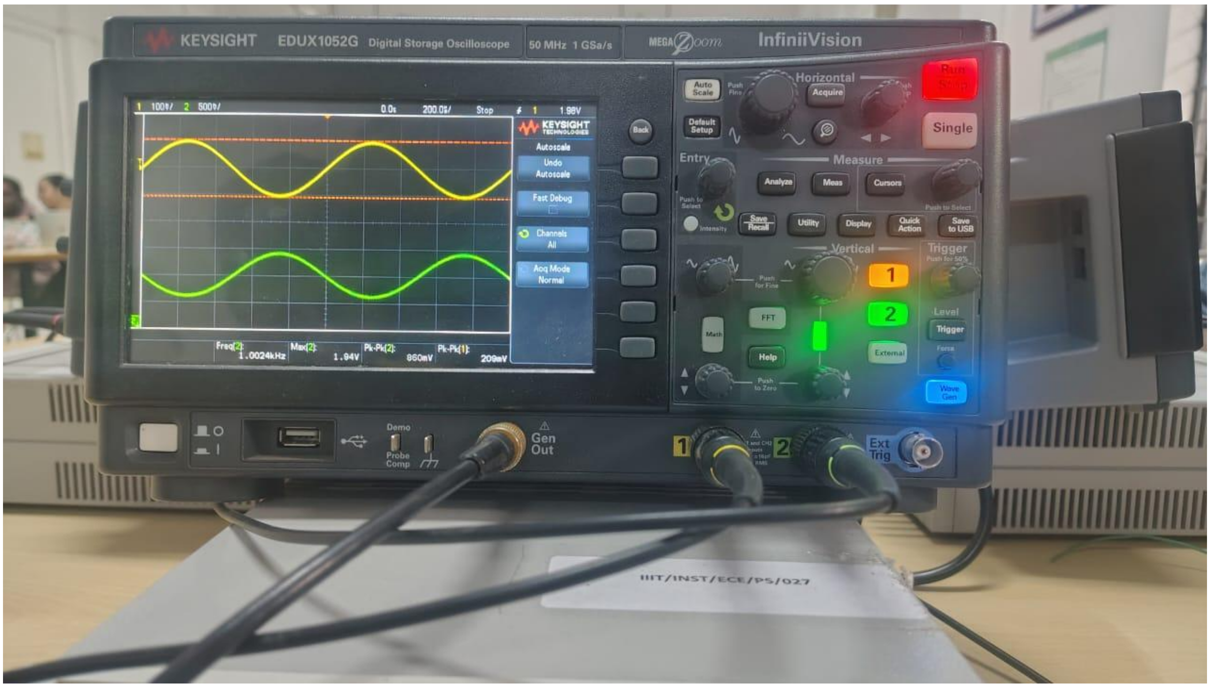
Observation:

- Clipping occurs when vin exceeds the linear range.

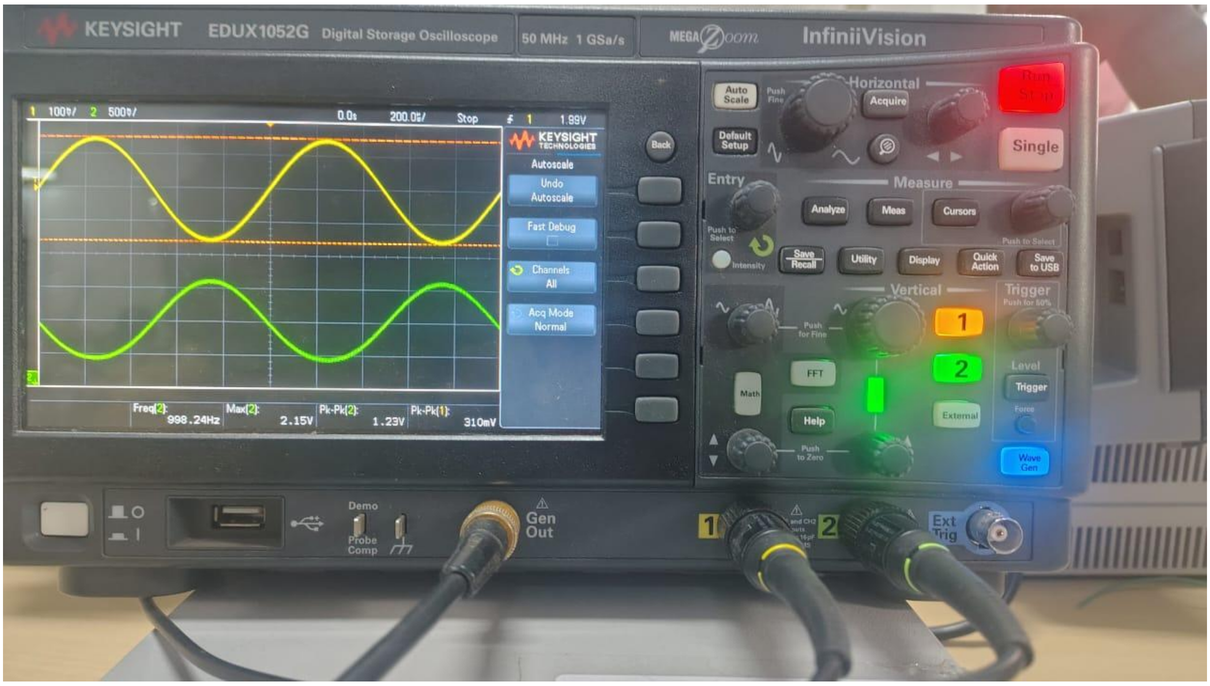
When the input voltage is 100mV(amplitude peak to peak)



When the input voltage is 200mV

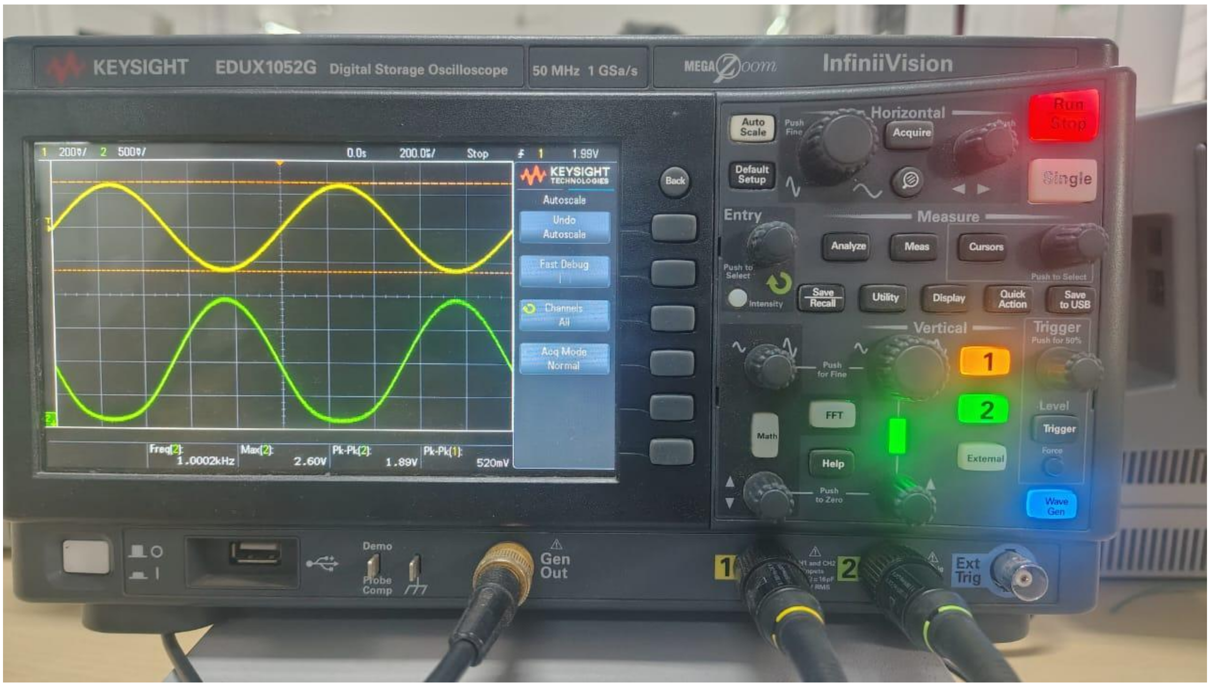


When the input voltage is 300mV

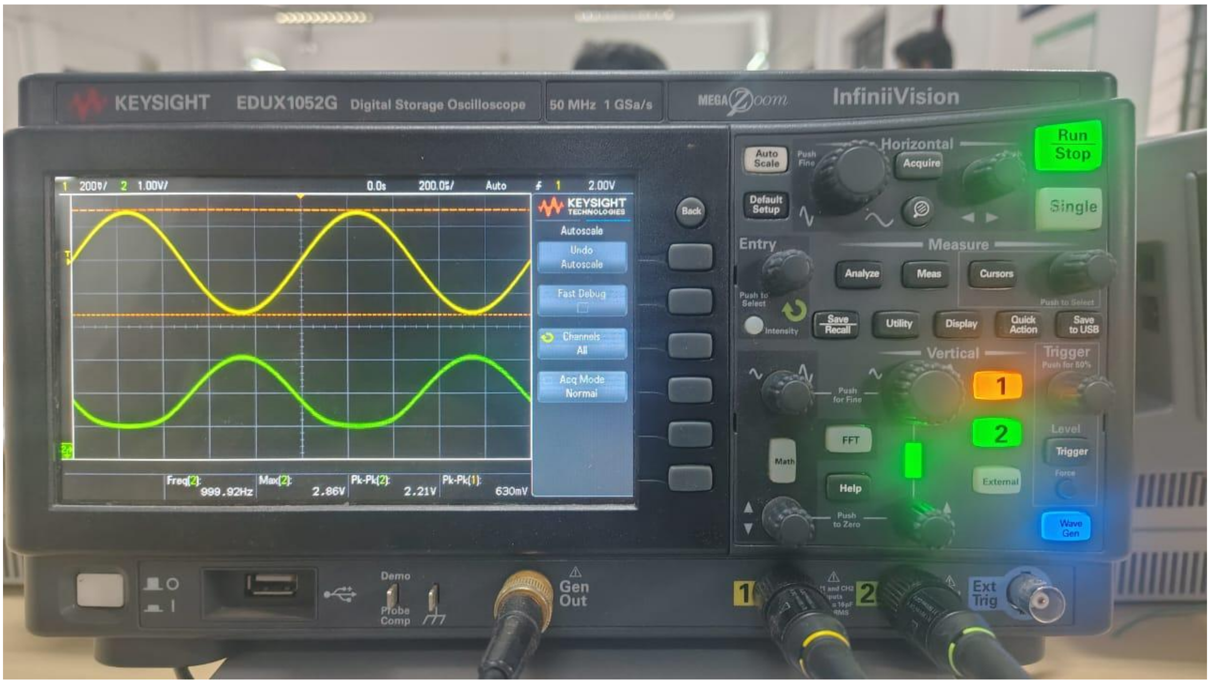


Input voltage is 400mV

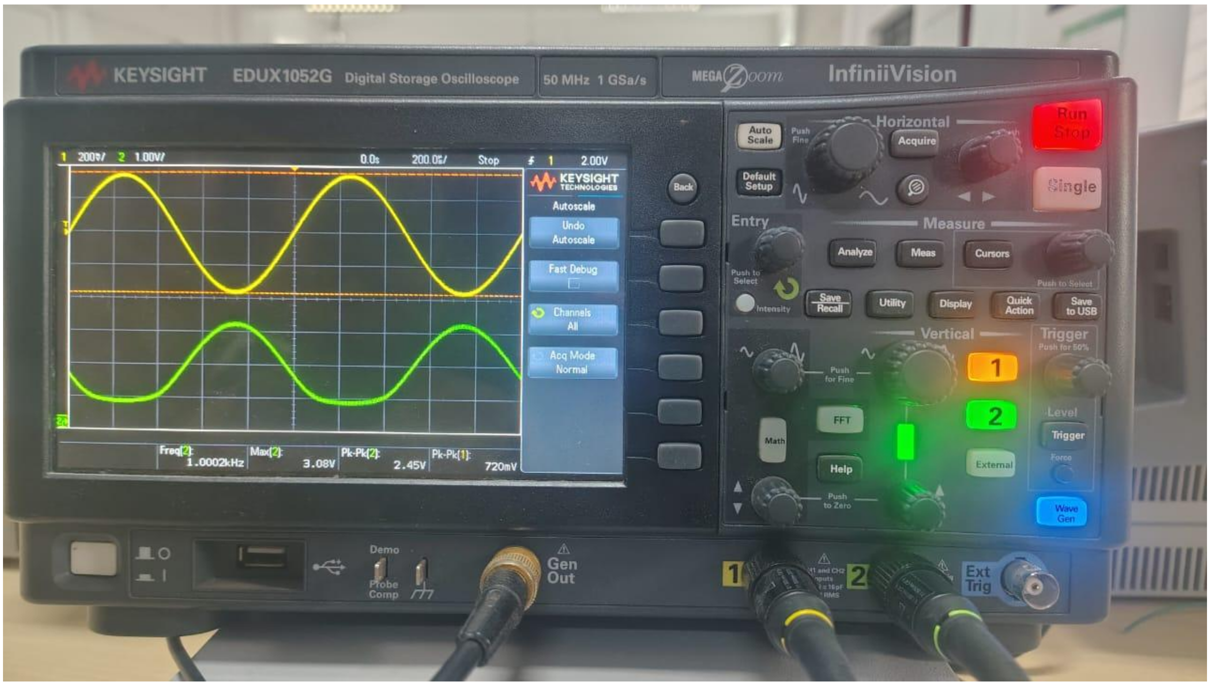
Input voltage is 500mV



Input voltage is 600mV



Input voltage is 700mV



- The output clips when the input amplitude exceeds 700 mV, as the peak Vgs becomes 2.35V (2V + 700mV/2). This pushes the MOSFET into the triode region since increasing Vgs increases Id.
- Since Vds = Vdd - Id * R, as Id increases, Vds decreases. When Vds becomes less than Vgs - Vth, the MOSFET exits saturation and enters the triode region.
- Further increase in amplitude causes clipping on both sides of the sine wave, as the MOSFET moves into the subthreshold region.
- When the input amplitude reaches 1Vpp, Vgs at some points drops below Vth, reducing conduction and leading to clipping.

We can observe the clipping started due to vin exceeds the linear range that means mosfet is in triode region

4.4 CS Amplifier with External Coupling

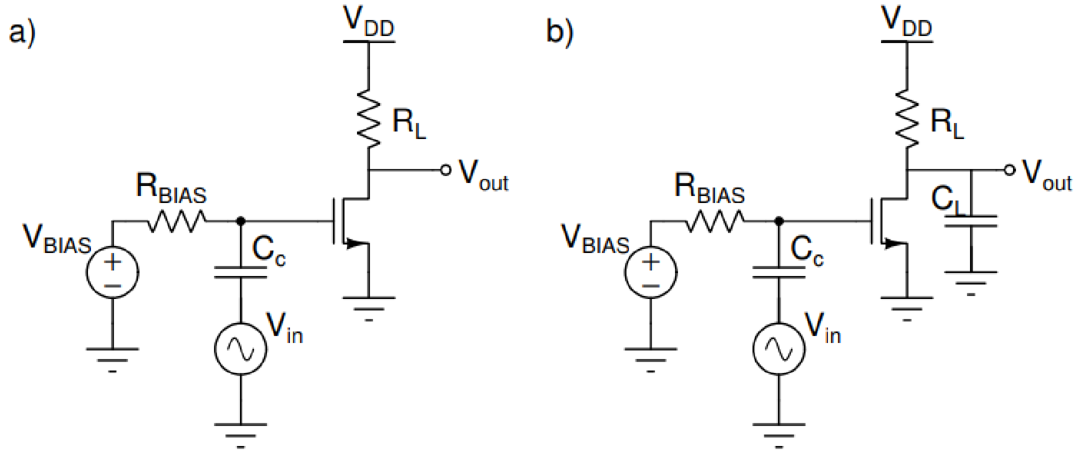


Figure 22: CS amplifier with external coupling capacitance and resistor

- **Gain with coupling:** Av=6
- **Input vin = 50mv Vpp**
- **Rbias=100ohm**
- **gm=6/RL=1.**27mA/V
- 500 1.84V
  600 2.81
  700 2.45V.

  (4) gain = $\frac{V_{out}}{V_{in}} = \frac{300}{50} = 6$

  gain = $A_v = g_m R_L$

  $g_m = \frac{6}{R_L}$

  $= \frac{6}{4.7} \times 10^{-3}$

  $= 1.27 \times 10^{-3}$
- **Measured VDS=300m V**
- **Calculated IDS=((5-0.3)/4.7)*10^-3)mA**=1mA

- $g_m = 1.27 \times 10^{-3}$

  $I_D = \frac{1}{2}(g_m)(V_{GS} - V_{TH})$

  $\Rightarrow g_m = \left(\frac{\mu C_{ox} W}{L}\right)(V_{GS} - V_{TH})$

  $g_m = \frac{\mu C_{ox} W}{L}(2 - 1.8)$

  $= 1.27 \times 10^{-3} = \frac{\mu C_{ox} W}{L}(0.2)$

  $\Rightarrow \boxed{\frac{\mu C_{ox} W}{L} = \frac{1.27}{2} \times 10^{-2} = 6.35 \times 10^{-2}}$

- By above calculations muCox*W/L=6.35*0.01 is calculated using VDS come IDS
- **Vbias=2.5V**
- Connected a load capacitor (CL) of 470 pF to check the frequency response.
- Set start frequency to 100 Hz and stop frequency to 20 MHz.
- Input amplitude is 10 mV, output load is High-Z, and 50 points are taken.
- Selected the gain channel and moved the marker to get the 3-dB bandwidth.
- Compared the measured bandwidth with the estimated pole of the transfer function Vout/Vin(s).
- Used the frequency response analysis chart in the DSO for plotting.
- **Frequency Response:**

- 3-dB Bandwidth frequency responses are

  fL=300Hz,fH=80kHz

then

so increases linearly

Then after it goes to triode region

Calculation of ~~gain~~ poles

$$H_1(s) = \frac{V_{gate}}{V_{in}} = \frac{R_{Bias}}{R_{Bias}+Z_C} = \frac{sC_c R_{Bias}}{1+sC_c R_{Bias}}$$

$$H_2(s) = \frac{V_{out}}{V_{gate}} = \frac{R_{Bias}}{R_{Bias}+Z_C} = \frac{sC_c R_{Bias}}{1+sC_c R_{Bais}}$$

$$\cancel{H_2(s)} = Z_{load} = \frac{R_C \frac{1}{sC_c}}{R_C + \frac{1}{sC_c}}$$

$$V_{out} = \frac{-i_d R_c}{1+sR_cC_c}$$

$i_d = g_m V_{gate}$

$$V_{out} = \frac{-g_m V_{gate} R_L}{1 + sR_L C_L}$$

$$\frac{V_{out}}{V_{gate}} = \frac{-g_m R_L V_{gate}}{1 + sR_L C_L}$$

$$\frac{V_{out}}{V_{gate}} = \frac{-g_m R_L}{1 + sR_L C_L} = H_2(s)$$

$$H(s) = H_1(s) + H_2(s)$$

$$H(s) = \frac{(-g_m R_L)}{(1 + sR_L C_L)} \quad \frac{(sC_c R_{Bias})}{1 + sR_{Bias} C_L}$$

$H(s)$ poles

$$s = \frac{-1}{R_L C_L}, \frac{-1}{R_{Bias} C_L}$$

$$2\pi f = \frac{-1}{R_L C_L}, \frac{-1}{R_{Bias} C_L}$$

$$2\pi f = -\frac{1}{R_L C_L}, -\frac{1}{R_{Bias} C_L}$$

$$f = \frac{1}{2\pi R_L C_L}, \frac{1}{2\pi R_{Bias} C_L}$$

$$f_L = \frac{1}{(2\pi)(50)(10^{-5})}$$

$$= \frac{10^4}{10\pi}$$

$$= \frac{1000}{\pi}$$

$$= 318.47$$

$$f_H = \frac{1}{(2\pi)(4.7\times10^3)(4.7\times10^{-10})}$$

$$= \frac{10^7}{(2\pi)(4.7)(4.7)}$$

$$= 72k\,Hz$$

5. Results & Discussion

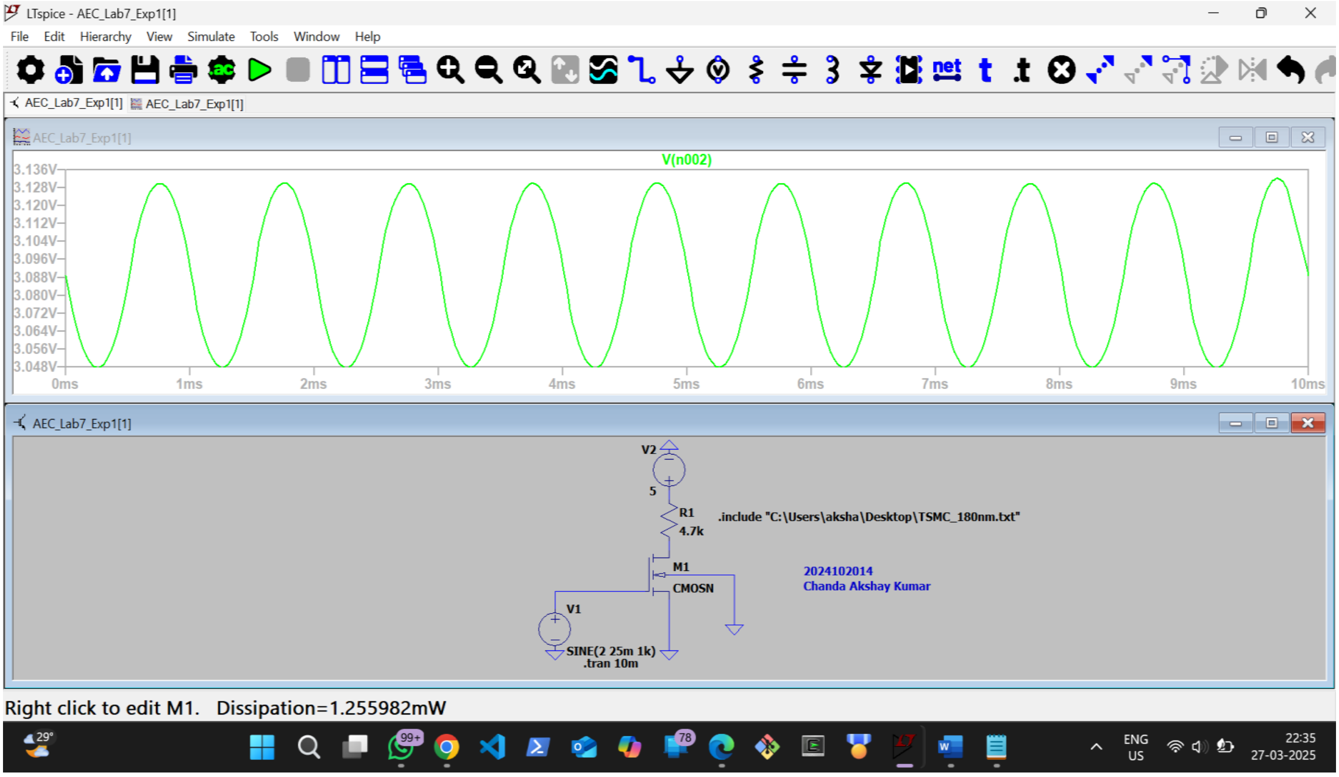
1. **Body Effect:** Changes in VSS alter gm and gain.
2. **Bias Voltage:** Higher VBIAS increases gain until saturation.
3. **Clipping:** Occurs due to MOSFET entering cutoff or triode region.
4. **Coupling Capacitor:** Blocks DC but allows AC signal, improving stability.

6. Conclusion

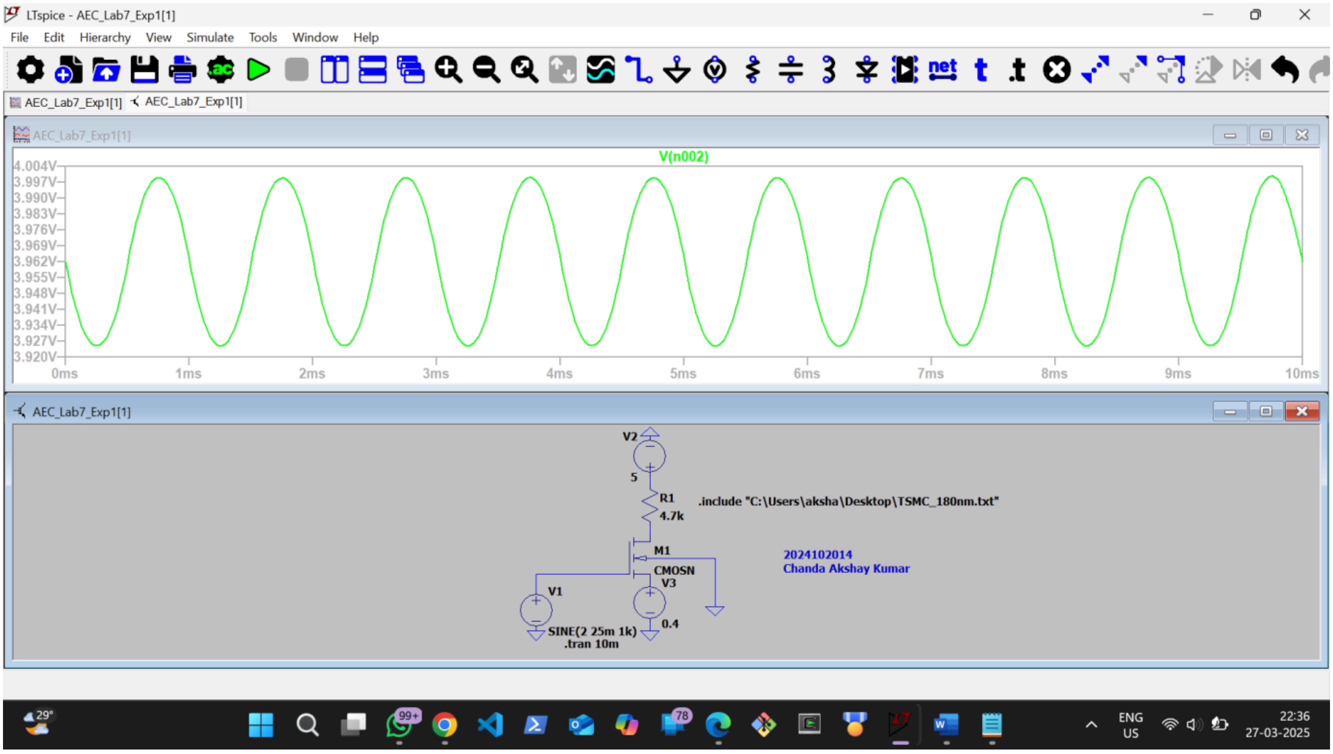
- The experiment showed the main features of a CS amplifier, like how body bias, bias voltage, and input signal swing affect gain.
- The frequency response confirmed bandwidth limits caused by capacitive effects.

7. LTSPICE

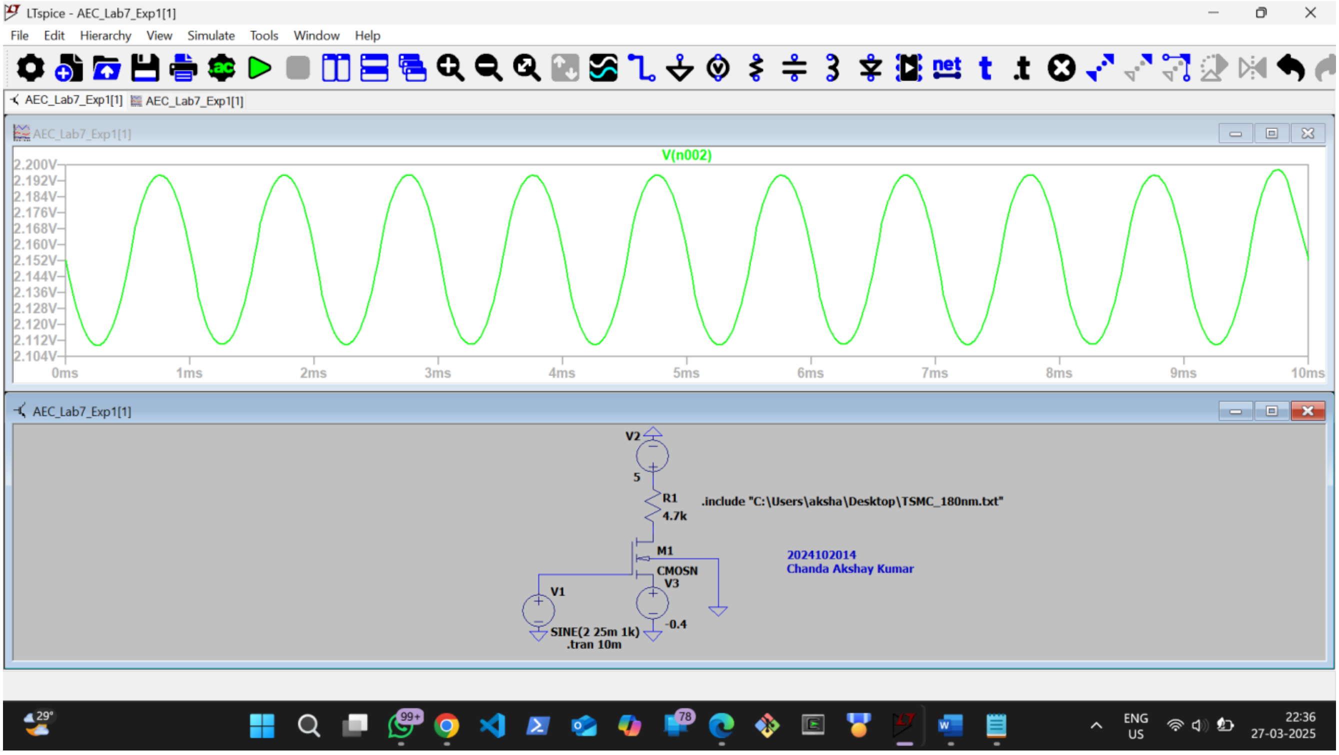
at vbody 0 V



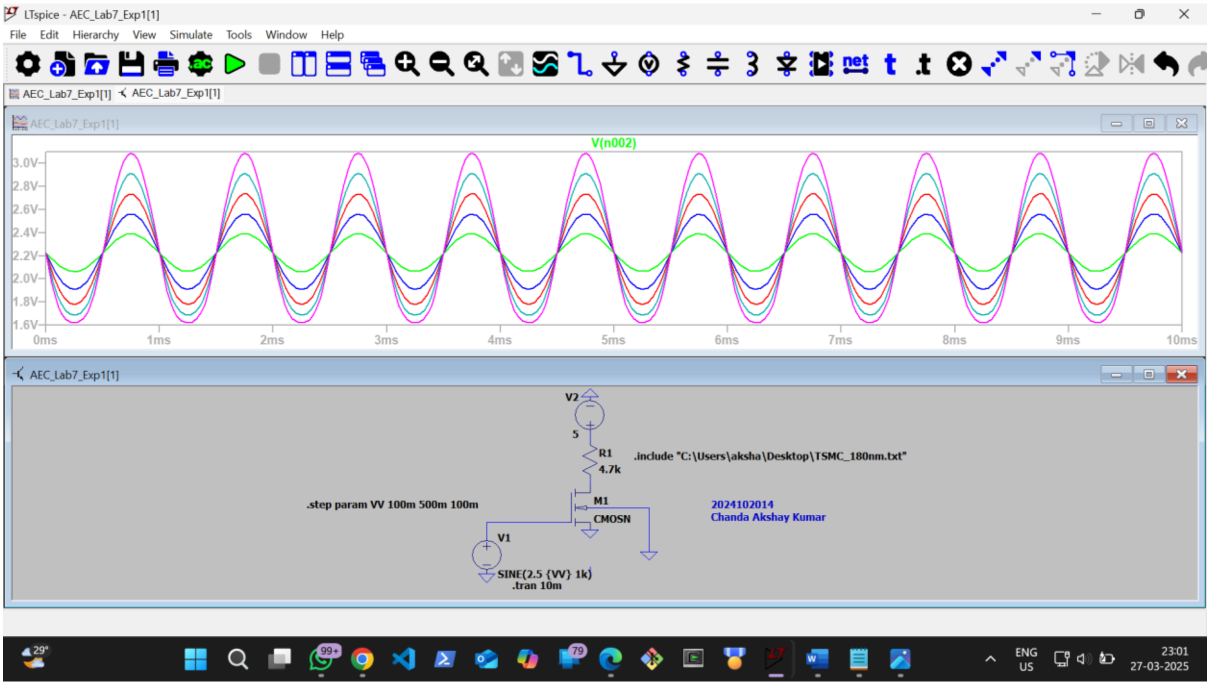
at vbody 0.4 V

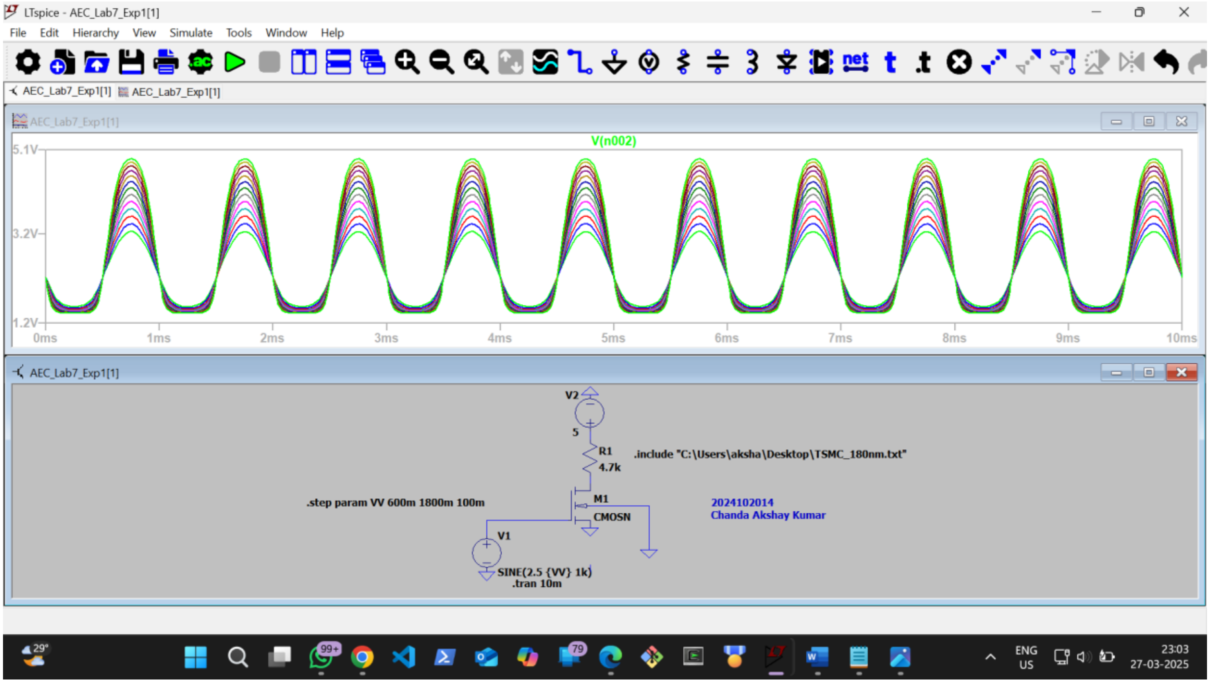


at vbody -0.4 V

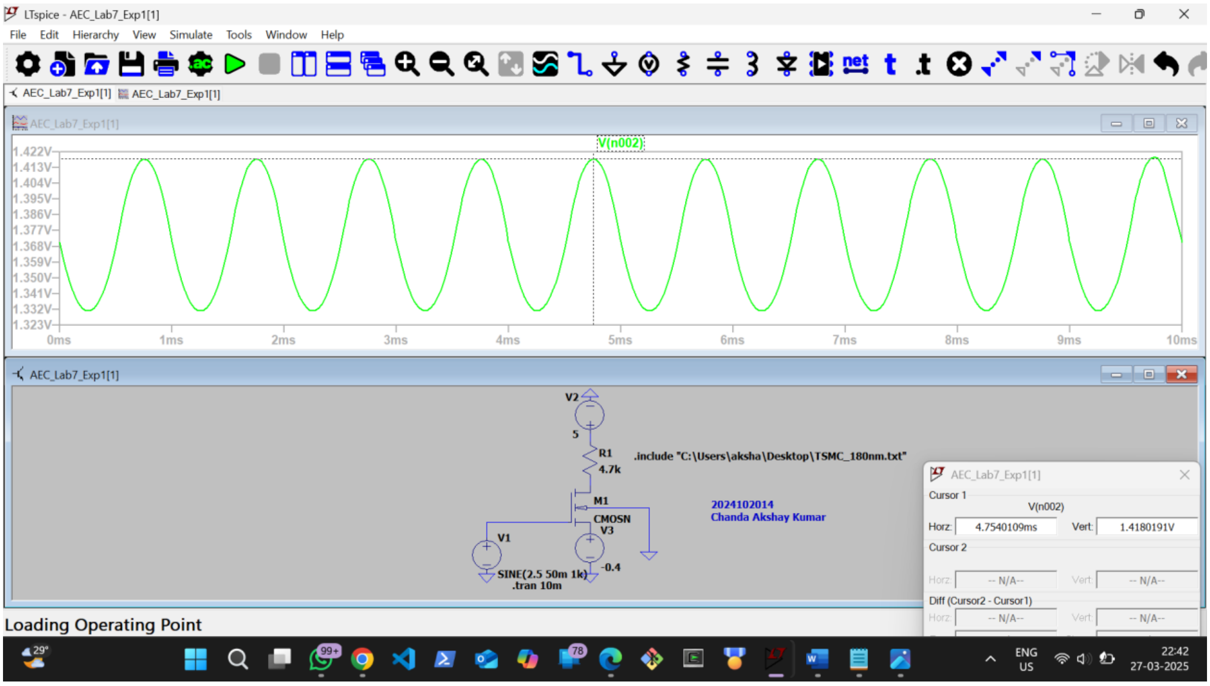

LTspice - AEC_Lab7_Exp1[1]
V(n002)
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
M1
CMOSN
V3
V1
-0.4
SINE(2 25m 1k)
.tran 10m
2024102014
Chanda Akshay Kumar

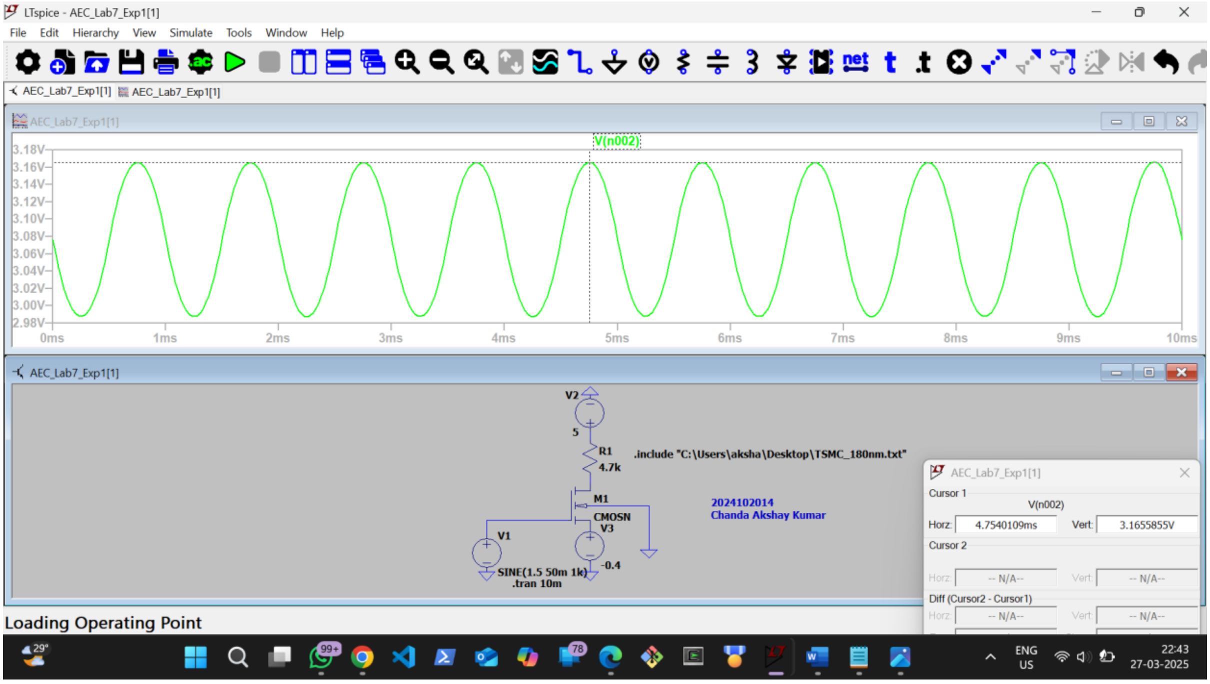
3rd exp

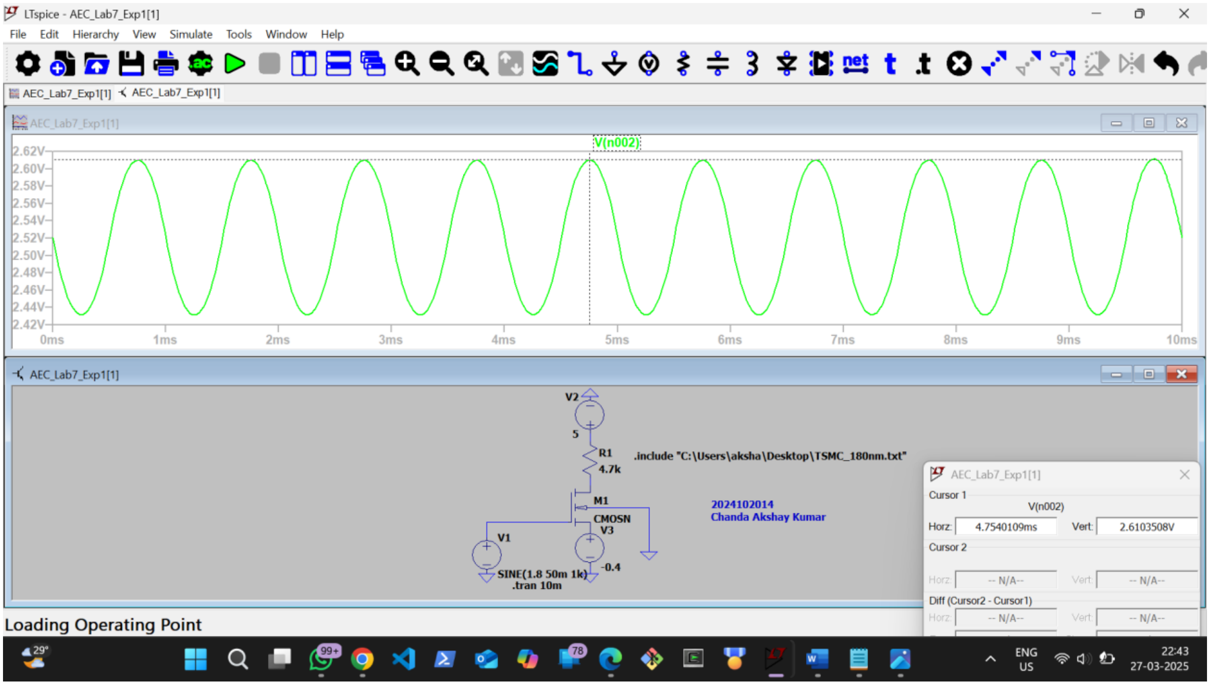

LTspice - AEC_Lab7_Exp1[1]
V(n002)
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
.step param VV 100m 500m 100m
M1
CMOSN
V1
SINE(2.5 {VV} 1k)
.tran 10m
2024102014
Chanda Akshay Kumar

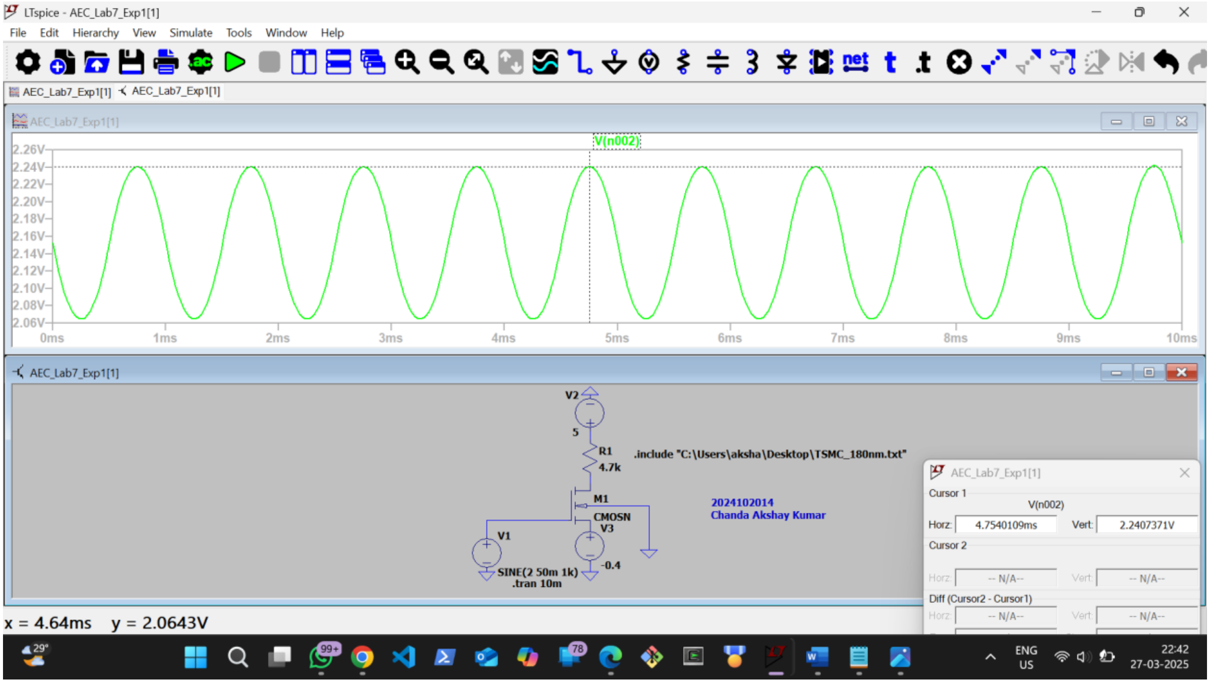

LTspice - AEC_Lab7_Exp1[1]
V(n002)
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
.step param VV 600m 1800m 100m
M1
CMOSN
2024102014
Chanda Akshay Kumar
V1
SINE(2.5 {VV} 1k)
.tran 10m

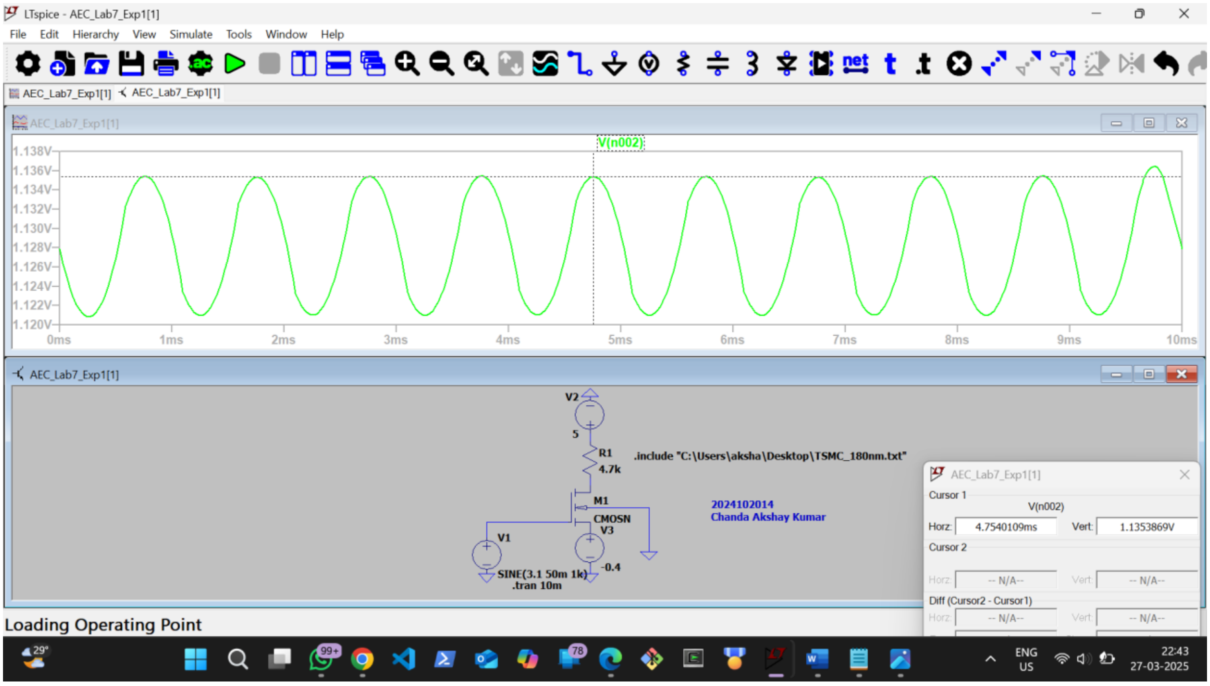
2nd exp

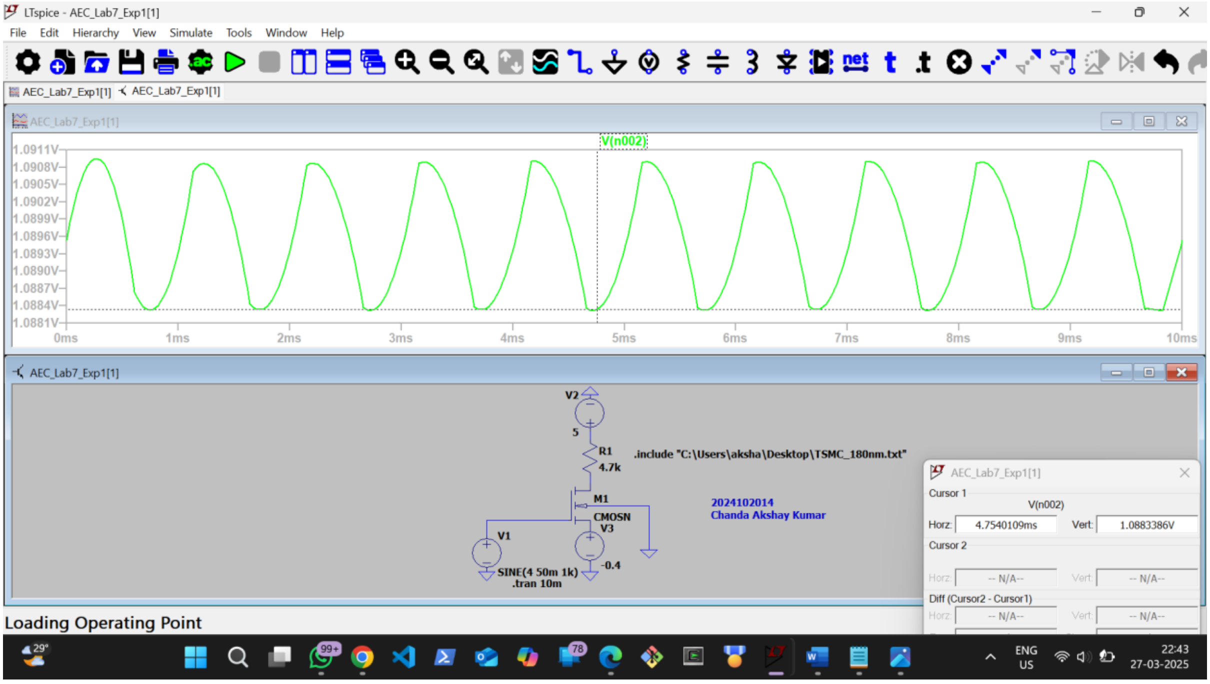

LTspice - AEC_Lab7_Exp1[1]
V(n002)
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
M1
CMOSN
V3
2024102014
Chanda Akshay Kumar
V1
SINE(2.5 50m 1k)
.tran 10m
-0.4
Cursor 1
Horz: 4.7540109ms
Vert: 1.4180191V
Loading Operating Point


LTspice - AEC_Lab7_Exp1[1]
File Edit Hierarchy View Simulate Tools Window Help
V(n002)
3.18V
3.16V
3.14V
3.12V
3.10V
3.08V
3.06V
3.04V
3.02V
3.00V
2.98V
0ms 1ms 2ms 3ms 4ms 5ms 6ms 7ms 8ms 9ms 10ms
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
M1
CMOSN
V3
V1
-0.4
SINE(1.5 50m 1k)
.tran 10m
2024102014
Chanda Akshay Kumar
Cursor 1
V(n002)
Horz: 4.7540109ms
Vert: 3.1655855V
Cursor 2
Diff (Cursor2 - Cursor1)
Loading Operating Point
22:43
27-03-2025

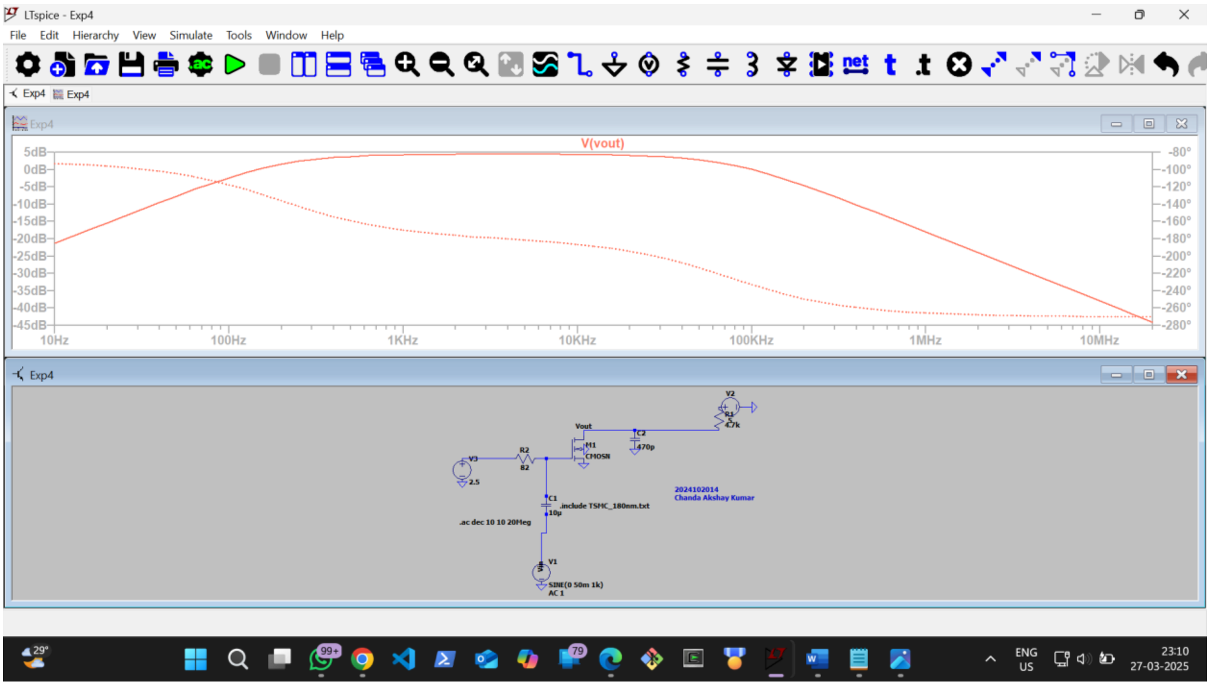

LTspice - AEC_Lab7_Exp1[1]
File Edit Hierarchy View Simulate Tools Window Help
V(n002)
2.62V
2.60V
2.58V
2.56V
2.54V
2.52V
2.50V
2.48V
2.46V
2.44V
2.42V
0ms 1ms 2ms 3ms 4ms 5ms 6ms 7ms 8ms 9ms 10ms
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
M1
CMOSN
V3
V1
-0.4
SINE(1.8 50m 1k)
.tran 10m
2024102014
Chanda Akshay Kumar
Cursor 1
V(n002)
Horz: 4.7540109ms
Vert: 2.6103508V
Cursor 2
Diff (Cursor2 - Cursor1)
Loading Operating Point
22:43
27-03-2025


LTspice - AEC_Lab7_Exp1[1]
V(n002)
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
M1
CMOSN
V3
V1
-0.4
SINE(2 50m 1k)
.tran 10m
2024102014
Chanda Akshay Kumar
Cursor 1
Horz: 4.7540109ms
Vert: 2.2407371V
x = 4.64ms y = 2.0643V


LTspice - AEC_Lab7_Exp1[1]
V(n002)
V2
5
R1
4.7k
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
M1
CMOSN
V3
V1
-0.4
SINE(3.1 50m 1k)
.tran 10m
2024102014
Chanda Akshay Kumar
Cursor 1
Horz: 4.7540109ms
Vert: 1.1353869V
Loading Operating Point


LTspice - AEC_Lab7_Exp1[1]
V(n002)
.include "C:\Users\aksha\Desktop\TSMC_180nm.txt"
2024102014
Chanda Akshay Kumar
SINE(4 50m 1k)
.tran 10m
Cursor 1
Horz: 4.7540109ms
Vert: 1.0883386V
Loading Operating Point

4th exp


LTspice - Exp4
V(vout)
.include TSMC_180nm.txt
2024102014
Chanda Akshay Kumar
.ac dec 10 10 20Meg
SINE(0 50m 1k)
AC 1