

Analog Electronic Circuits – Lab 7

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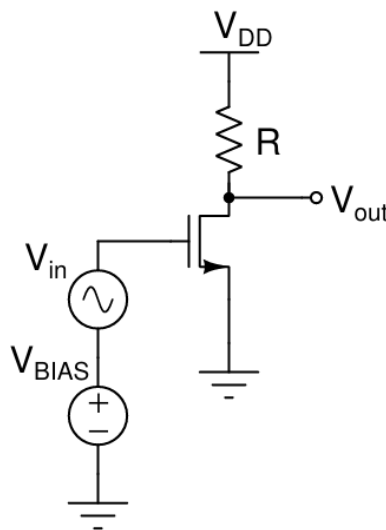
In all DSO plots, Green is Output response and Yellow is Input Response

Part 1:

- Objective:

To observe the effect of Body Effect on the gain of a MOSFET based Common Source Amplifier.

- Circuit Diagram:



- Parameters Used:

$$V_{BIAS} = 2V, V_{DD} = 5V, V_{TH} = 1.8V$$

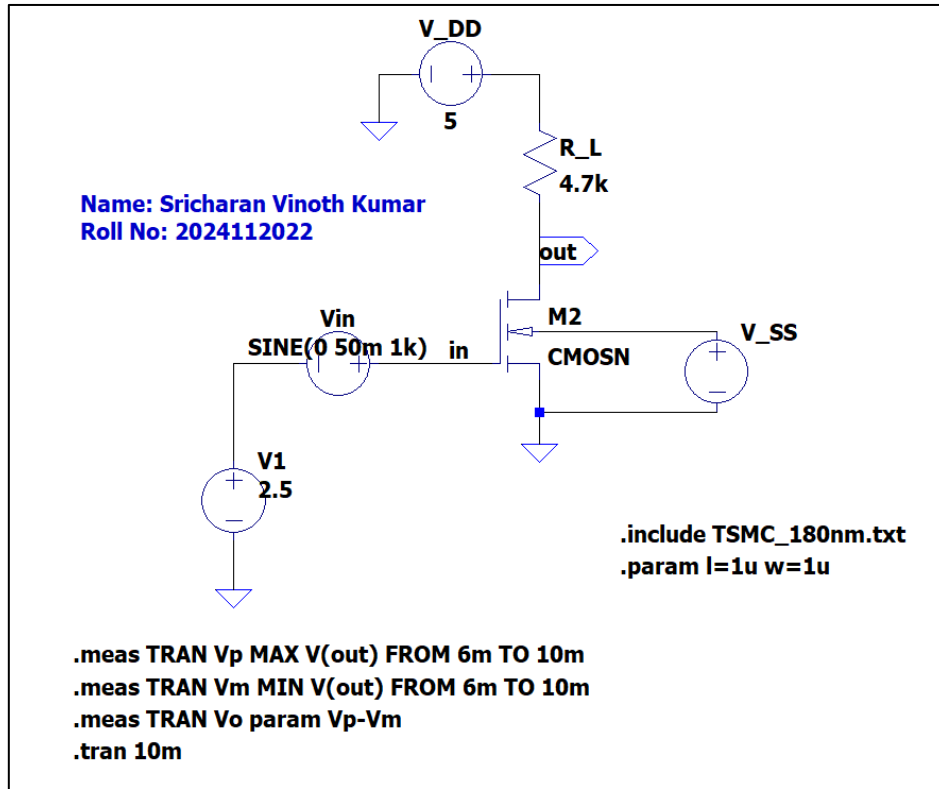
$$R = 4.7k\Omega$$

Input Signal:

- Amplitude = 50mV
- Frequency = 1kHz
- DC Offset = 0

Also, the negative sign of gain (since output is inverted) is ignored for simplicity.

- LTSpice Simulations:



LTSpice Schematic

DC Value of $V_{DS} = 3.85V$

To calculate g_m ,

$$I_{DSQ} = \frac{V_{DD} - V_{DS}}{R}$$

$$\Rightarrow I_{DSQ} = \frac{5 - 3.85}{4700} = 0.244mA$$

$$I_{DSQ} = \mu C_{ox} \frac{W}{L} (V_{TH} - V_{GS})^2$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{I_{DSQ}}{(V_{GS} - V_{TH})^2}$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{244 \times 10^{-6}}{(2.5 - 1.8)^2}$$

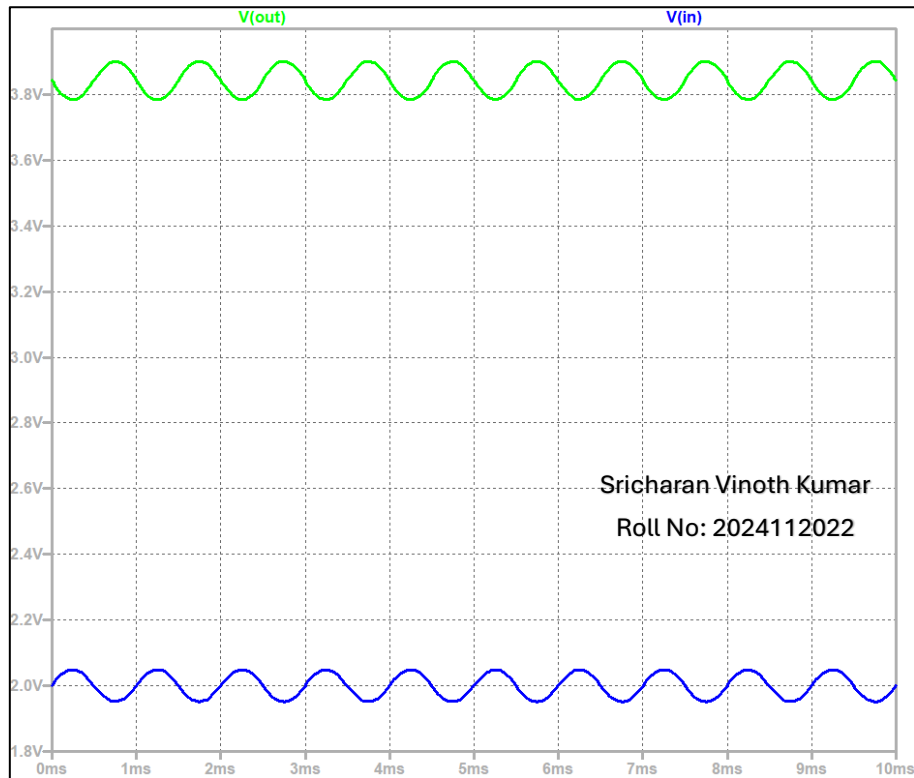
$$\Rightarrow \mu C_{ox} \frac{W}{L} = 348 \mu A/V^2$$

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

$$g_m = 348 * 10^{-6} * (2 - 1.8)$$

$$g_m = 69.71 \times 10^{-6} S$$

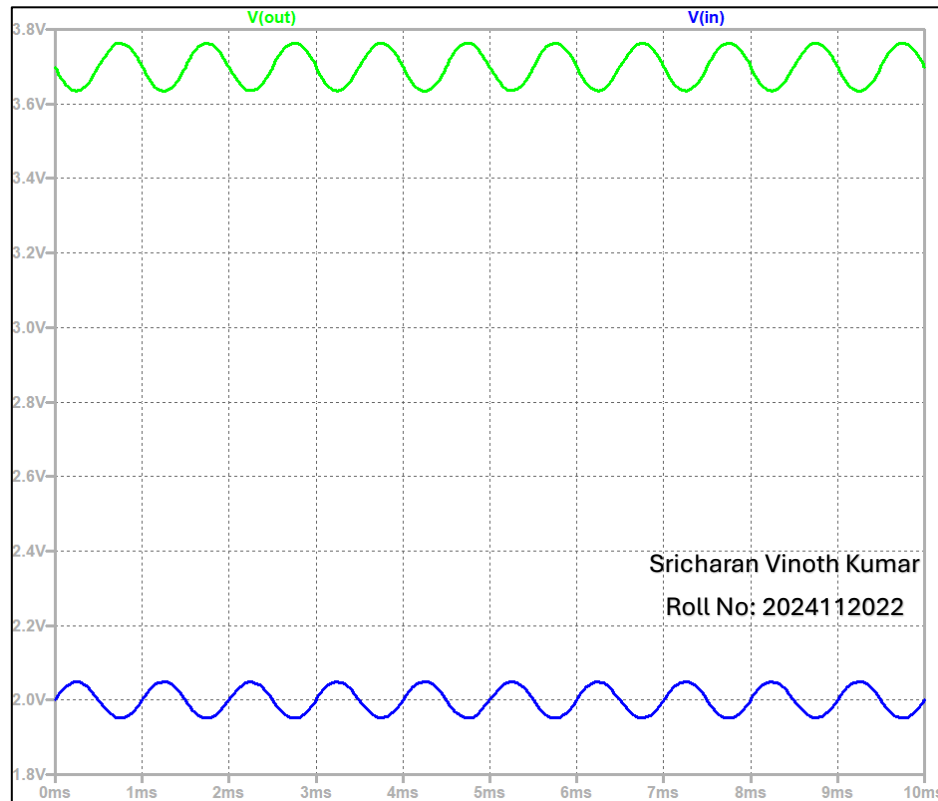
V_{SS}	V_{out}	$Gain = \frac{V_{out}}{V_{in}}$	$g_m = \frac{Gain}{R}$
0	0.11645	2.329	0.000496
0.4	0.12819	2.5638	0.000545
-0.4	0.10646	2.1292	0.000453



V(in) and V(out) vs t at $V_{SS} = 0$

Vp: MAX(V(out))=3.90072647962 FROM 0.006 TO 0.01
Vm: MIN(V(out))=3.78427188031 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.116454599306

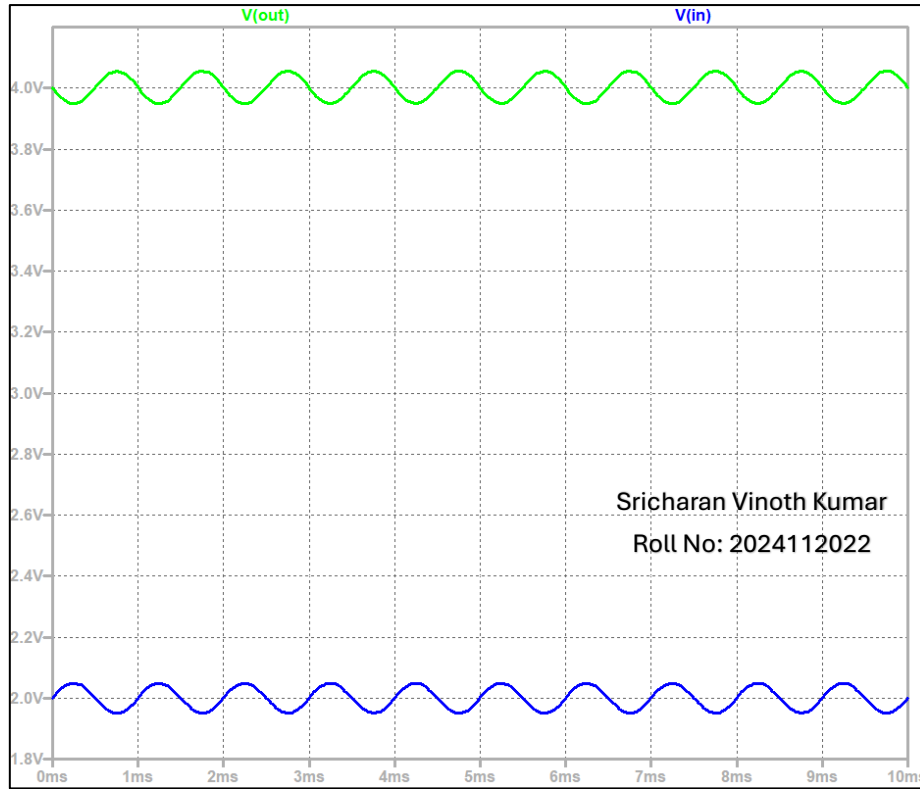
Amplitude of V(out) (represented as Vo) at $V_{SS} = 0$



V(in) and V(out) vs t at $V_{SS} = 0.4V$

Vp: MAX(V(out))=3.76310758446 FROM 0.006 TO 0.01
Vm: MIN(V(out))=3.63491210075 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.128195483708

Amplitude of V(out) (represented as Vo) at $V_{SS} = 0.4V$



V(in) and V(out) vs t at $V_{SS} = -0.4V$

Vp: MAX(V(out))=4.056059755 FROM 0.006 TO 0.01
Vm: MIN(V(out))=3.94959283993 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.106466915071

Amplitude of V(out) (represented as Vo) at $V_{SS} = 0.4V$

- Observations:

DC Value of $V_{DS} = 3.91V$

To calculate g_m ,

$$I_{DSQ} = \frac{V_{DD} - V_{DS}}{R}$$

$$\Rightarrow I_{DSQ} = \frac{5 - 3.91}{4700} = 0.232mA$$

$$I_{DSQ} = \mu C_{ox} \frac{W}{L} (V_{TH} - V_{GS})^2$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{I_{DSQ}}{(V_{GS} - V_{TH})^2}$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{232 \times 10^{-6}}{(2.5 - 1.8)^2}$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = 473 \mu A/V^2$$

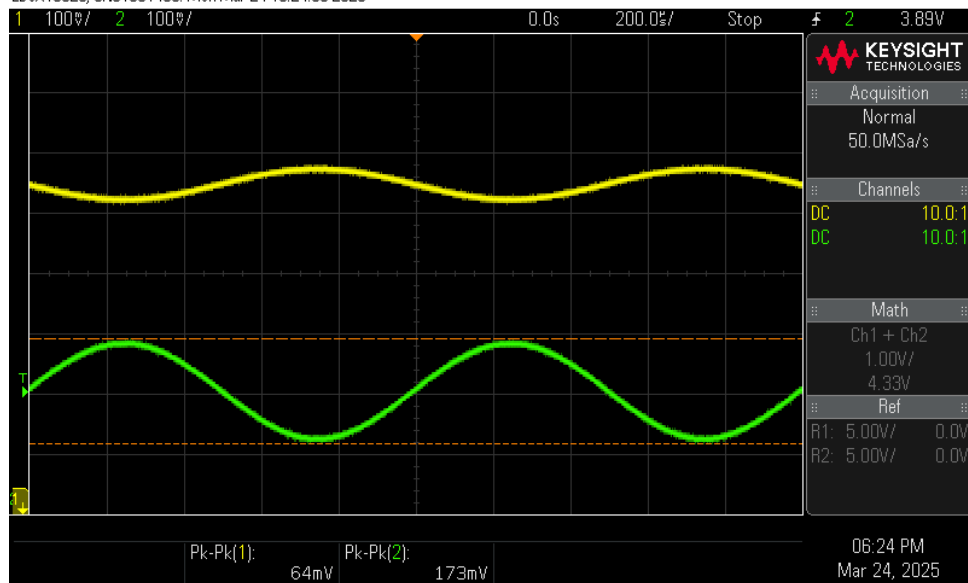
$$g_m = \mu C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$$

$$g_m = 473 * 10^{-6} * (2 - 1.8)$$

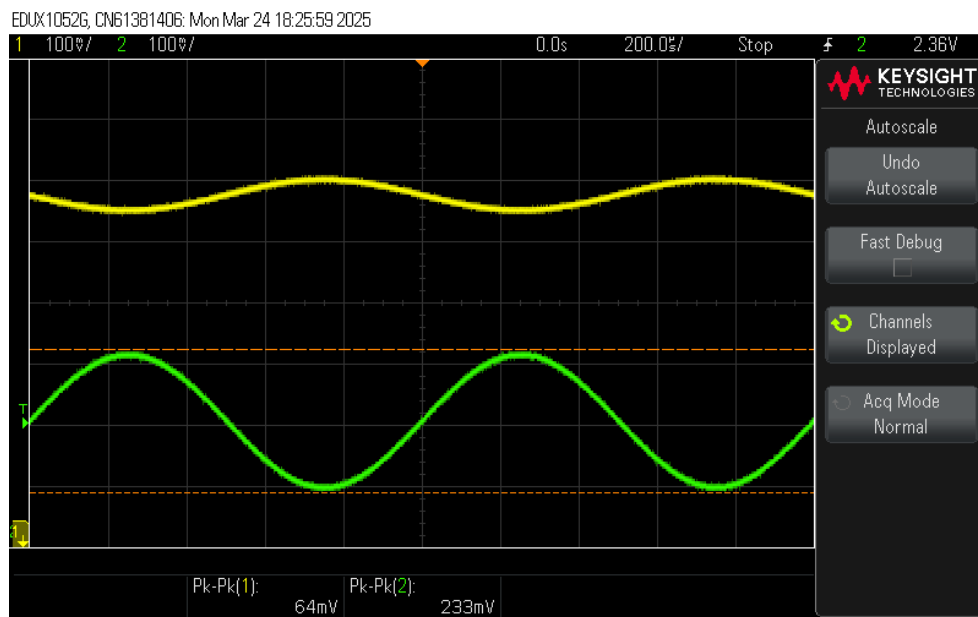
$$g_m = 94.6 \times 10^{-6} S$$

V_{SS} (V)	V_{out} (V)	$Gain = \frac{V_{out}}{V_{in}}$	$g_m = \frac{Gain}{R}$ (S)
0	0.173	3.46	0.000736
0.4	0.233	4.66	0.000991
-0.4	0.101	2.02	0.00043

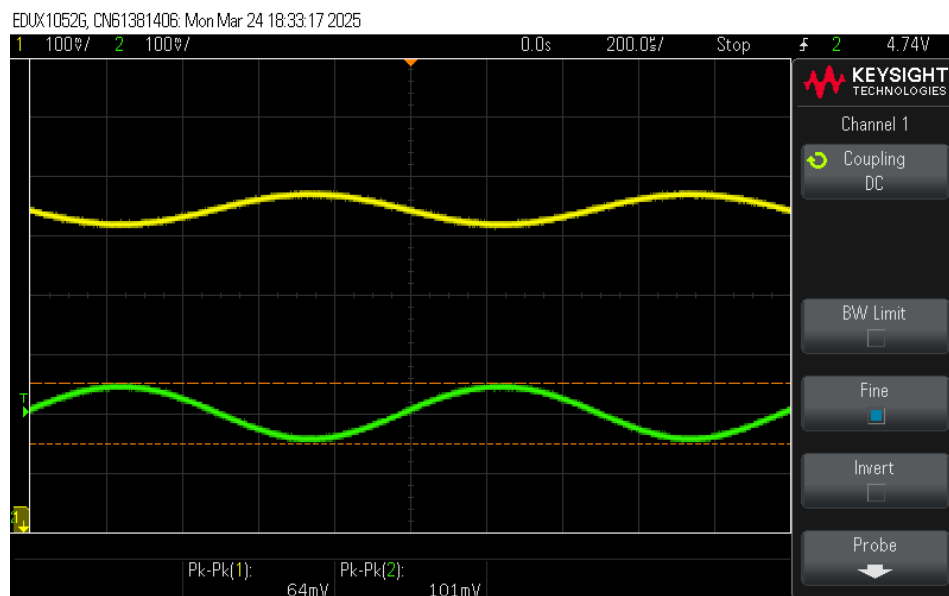
EDUX10526, CN61381406: Mon Mar 24 18:24:56 2025



$$\underline{V_{SS} = 0}$$



$$\underline{V_{SS} = 0.4V}$$



$$\underline{V_{SS} = -0.4V}$$

- Inferences:

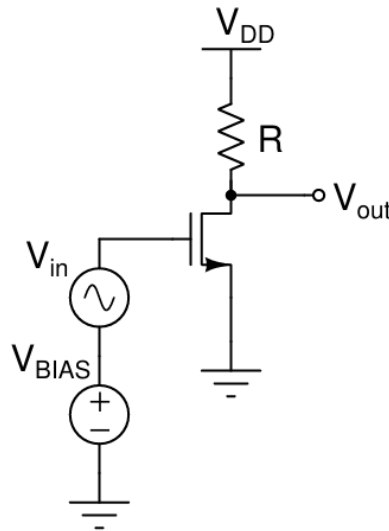
Based on the observations, we can clearly see that gain increases with increase in V_{BS} , i.e., body effect. This can be attributed to the fact that an increase in V_{BS} decreases V_{TH} , which increases $V_{GS} - V_{TH}$, which increases g_m and consequently the Gain increases.

Part 2:

- Objective:

To observe the effect of Bias point voltage on the Gain of a MOSFET based Common Source Amplifier.

- Circuit Diagram:



- Parameters Used:

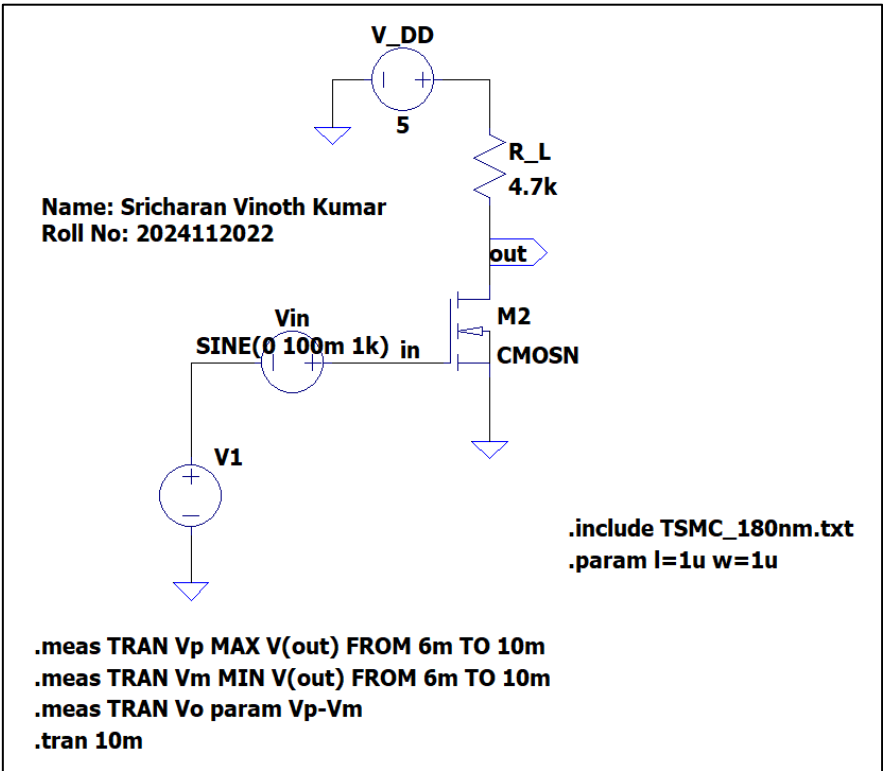
$V_{DD} = 5V$, $R = 4.7k\Omega$, $V_{TH} = 1.8V$

Input Signal:

- Amplitude = 100mV
- Frequency = 1kHz
- DC Offset = 0V

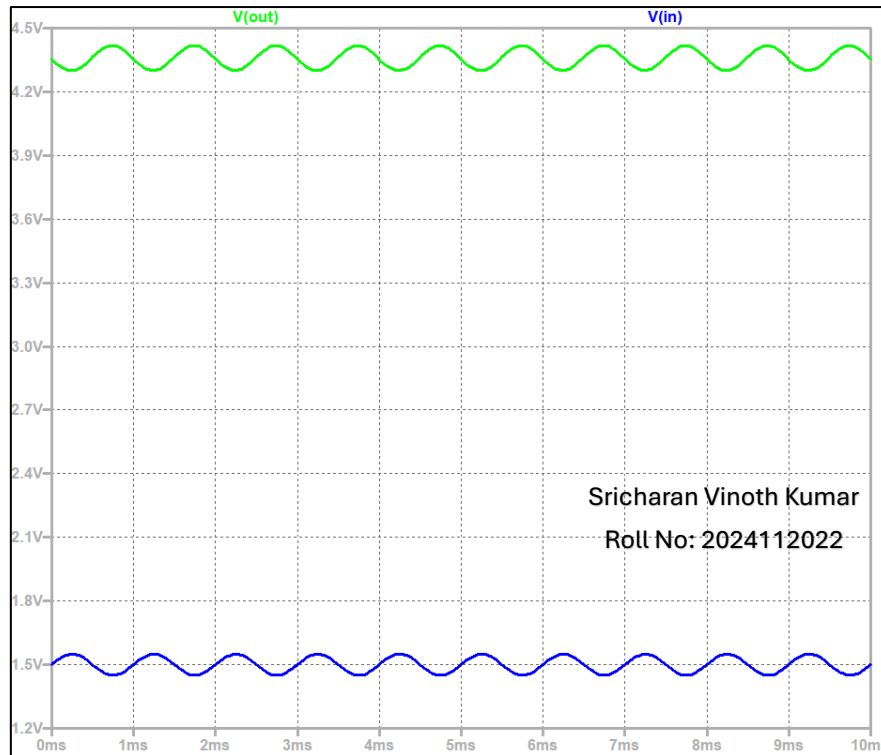
Also, the negative sign of gain (since output is inverted) is ignored for simplicity.

- LTSpice Simulations:



LTSpice Schematic

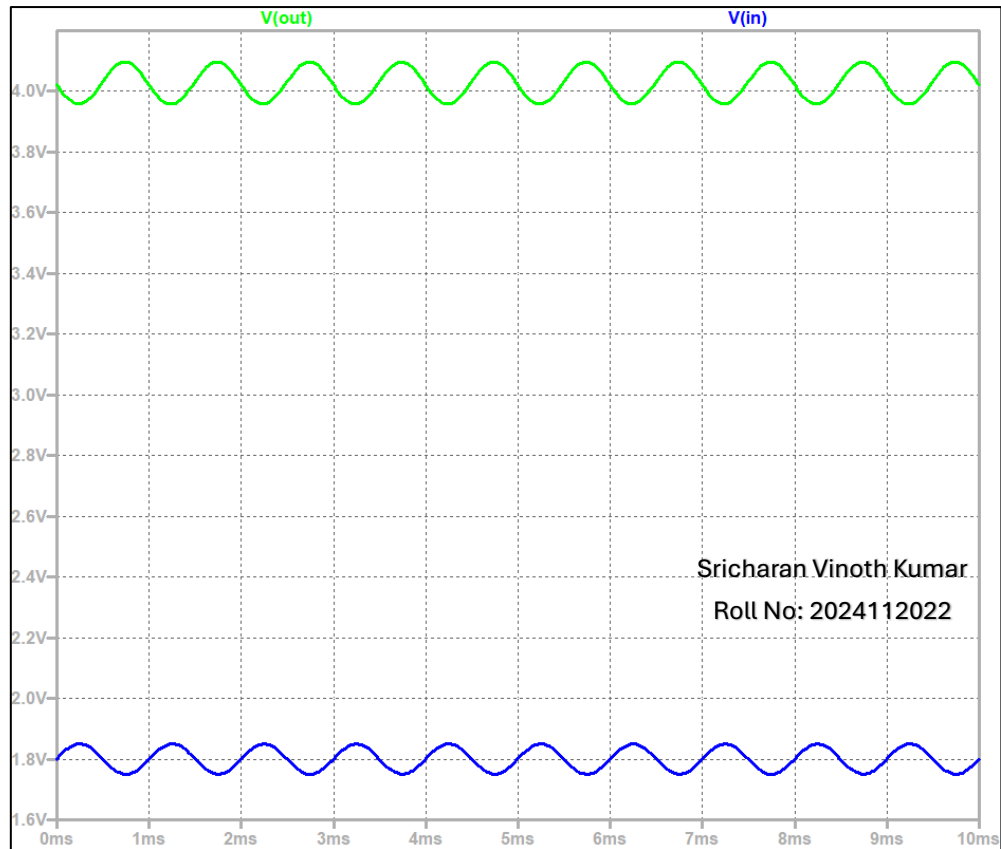
V_{bias} (V)	V_{out} (V)	$\text{Gain} = \frac{V_{\text{out}}}{V_{\text{in}}}$	$g_m = \frac{\text{Gain}}{R} (S)$
1.5	0.11747	1.1747	0.00025
1.8	0.13861	1.3861	0.000295
2.5	0.18038	1.8038	0.000384
3.1	0.14915	1.4915	0.000317
4	0.04726	0.4726	0.000101



V(in) and V(out) vs t at $V_{BIAS} = 1.5V$

Vp: MAX(V(out))=4.41743137076 FROM 0.006 TO 0.01
Vm: MIN(V(out))=4.29995735806 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.117474012703

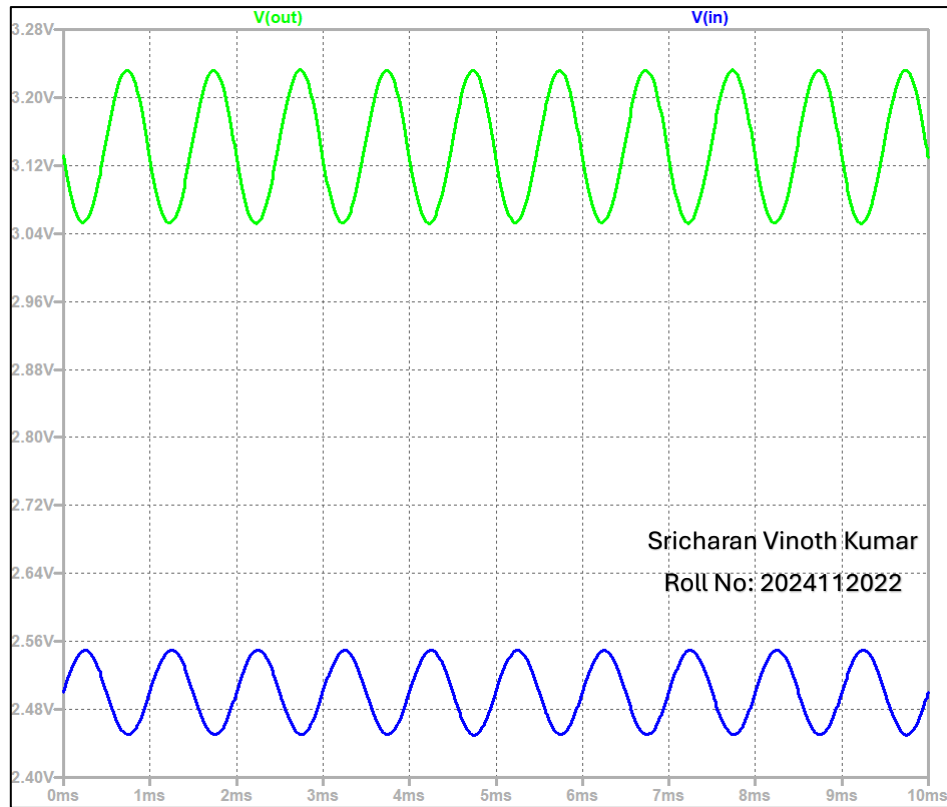
Amplitude of V(out) (represented as Vo) at $V_{BIAS} = 1.5V$



V(in) and V(out) vs t at $V_{BIAS} = 1.8V$

Vp: MAX(V(out))=4.09701191879 FROM 0.006 TO 0.01
Vm: MIN(V(out))=3.95840445827 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.138607460523

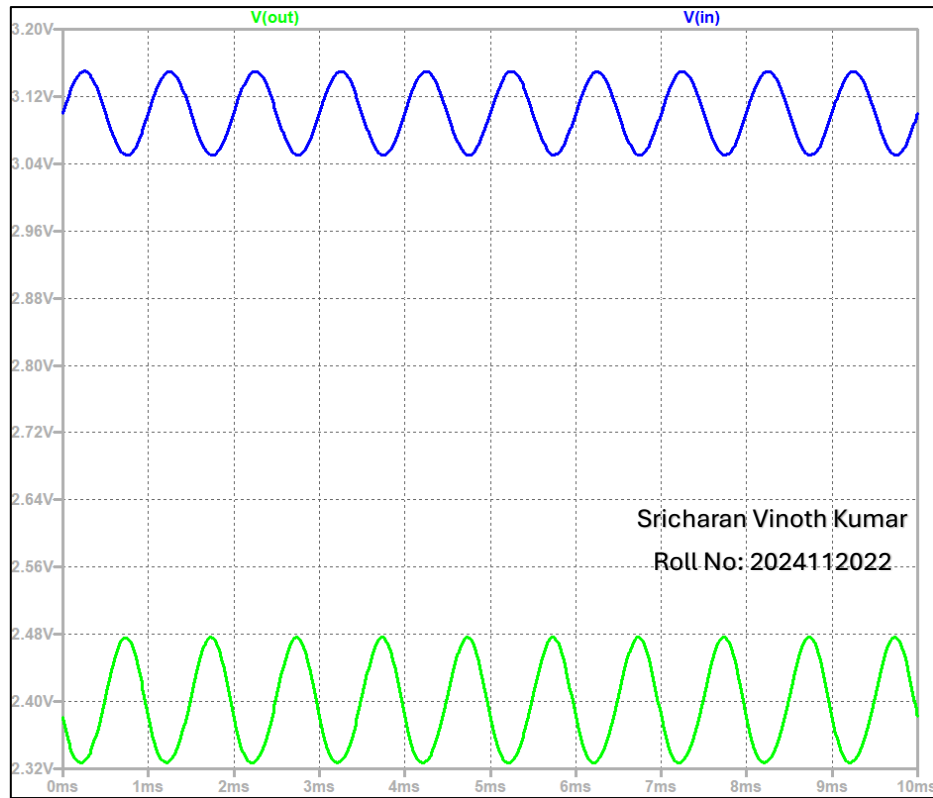
Amplitude of V(out) (represented as Vo) at $V_{BIAS} = 1.8V$



V(in) and V(out) vs t at $V_{BIAS} = 2.5V$

Vp: MAX(V(out))=3.23234295845 FROM 0.006 TO 0.01
Vm: MIN(V(out))=3.05196288096 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.18038007749

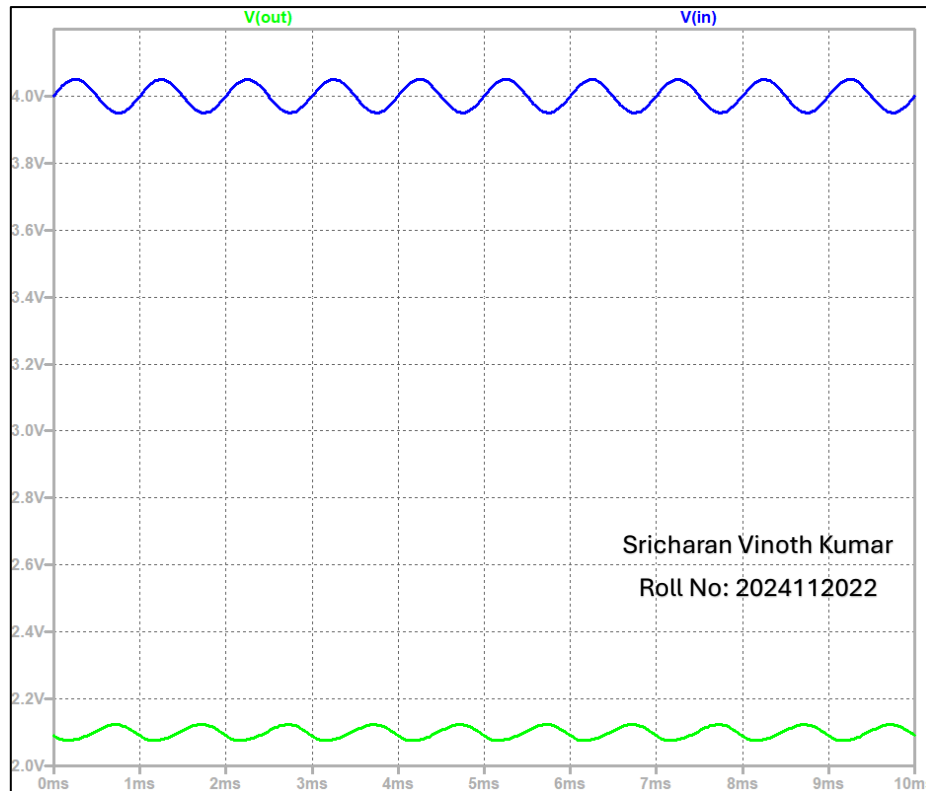
Amplitude of V(out) (represented as Vo) at $V_{BIAS} = 2.5V$



V(in) and V(out) vs t at $V_{BIAS} = 3.1V$

Vp: MAX(V(out))=2.47639775276 FROM 0.006 TO 0.01
Vm: MIN(V(out))=2.32723907025 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.149158682516

Amplitude of V(out) (represented as Vo) at $V_{BIAS} = 3.1V$

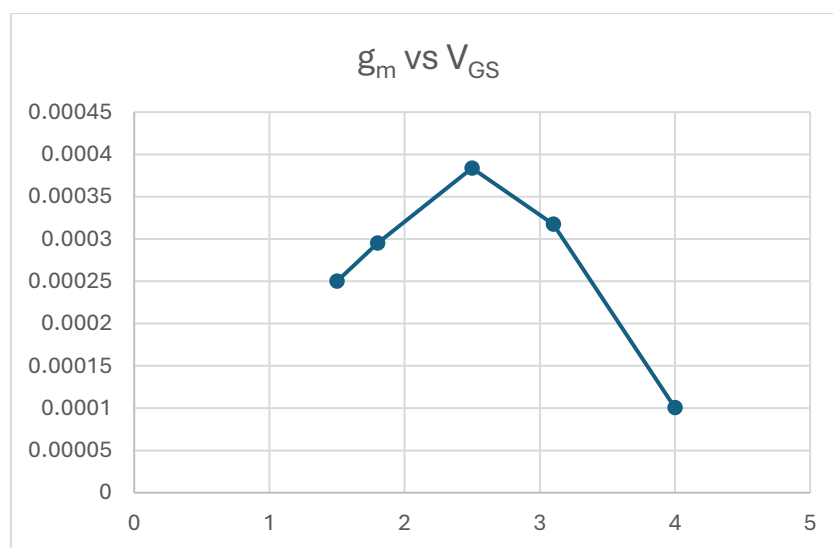


V(in) and V(out) vs t at $V_{BIAS} = 4V$

Vp: MAX(V(out))=2.12331628799 FROM 0.006 TO 0.01
Vm: MIN(V(out))=2.07604789734 FROM 0.006 TO 0.01
Vo: Vp-Vm=0.0472683906555

Amplitude of V(out) (represented as Vo) at $V_{BIAS} = 4V$

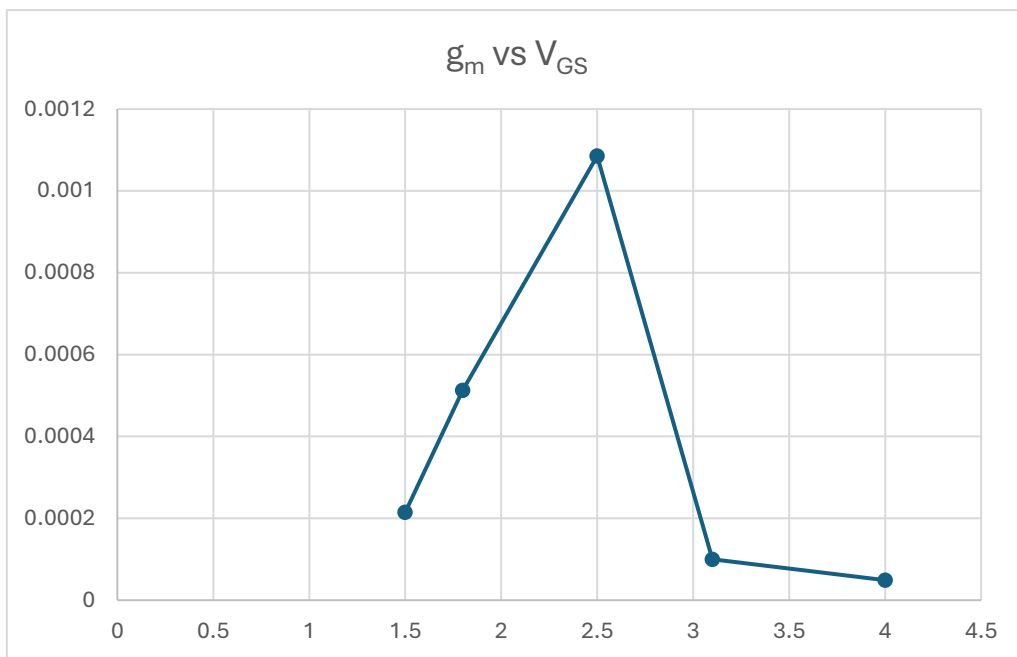
Plot of g_m vs V_{GS} :

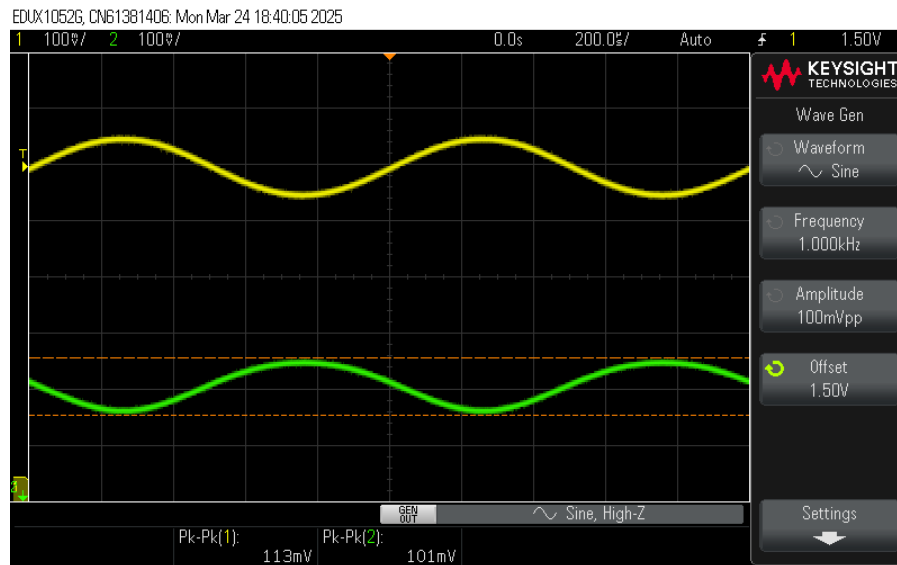


- Observations:

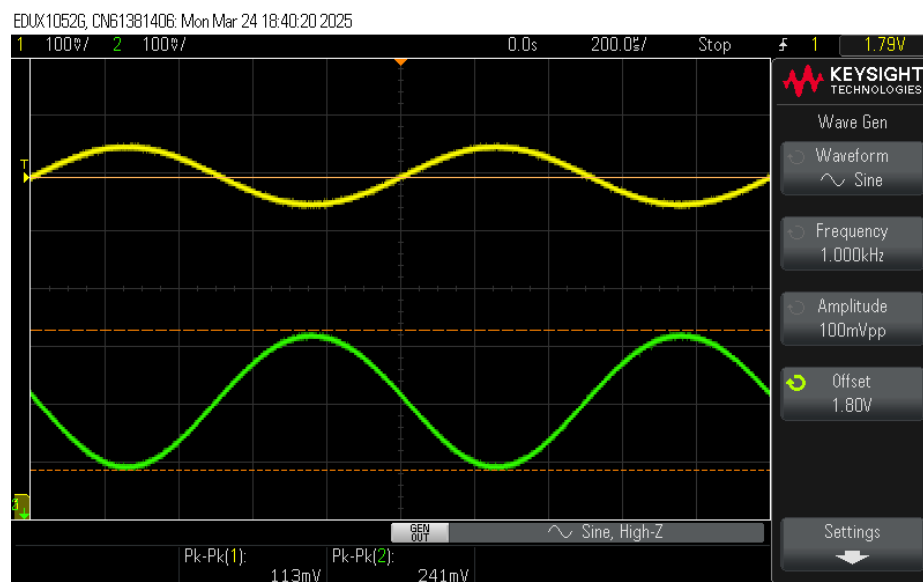
V_{bias} (V)	V_{out} (V)	$\text{Gain} = \frac{V_{\text{out}}}{V_{\text{in}}}$	$g_m = \frac{\text{Gain}}{R} \text{ (S)}$
1.5	0.101	1.01	0.000215
1.8	0.241	2.41	0.000513
2.5	0.51	5.1	0.001085
3.1	0.047	0.47	0.0001
4	0.023	0.23	4.89E-05

Plot of g_m vs V_{GS} :

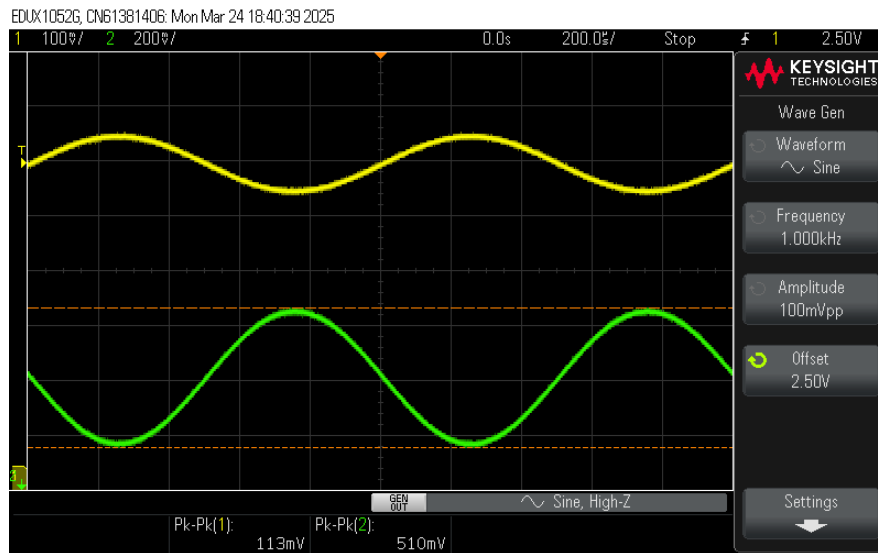




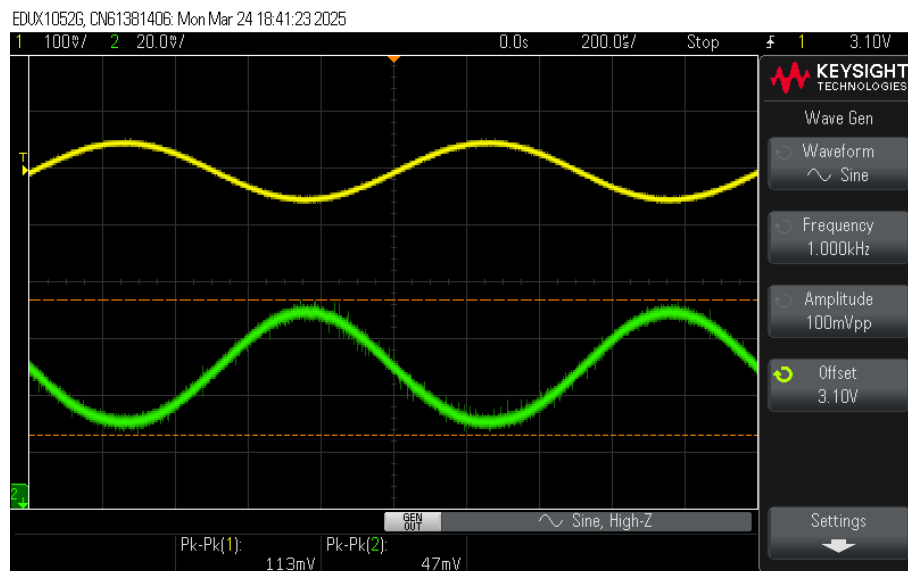
$$\underline{V_{BIAS} = 1.5V}$$



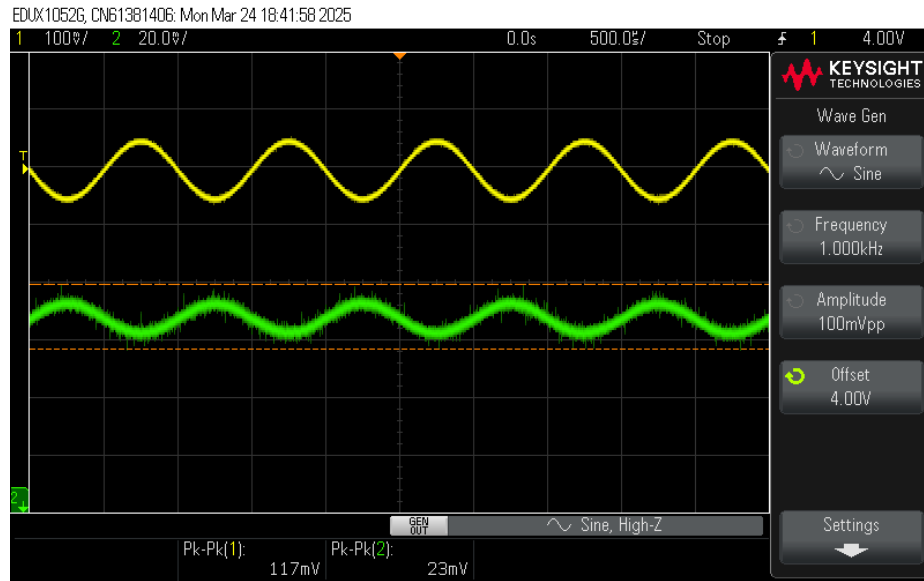
$$\underline{V_{BIAS} = 1.8V}$$



$$V_{\text{BIAS}} = 2.5\text{V}$$



$$V_{\text{BIAS}} = 3.1\text{V}$$



$$\underline{V_{BIAS} = 4V}$$

- Inferences:

The Gain of the amplifier peaks at around $V_{BIAS} = 2.5\text{ V}$, this can be attributed to the following facts:

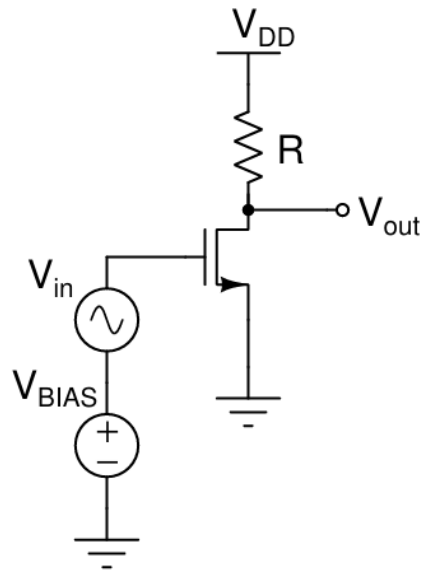
1. At $V_{BIAS} = 1.5\text{V}$ and 1.8V , the MOSFET will be in cutoff region, since $V_{GS} < V_{TH}$.
2. At $V_{BIAS} = 3.1\text{V}$ and 4V , the MOSFET will be in linear region due to high V_{GS} , and gain will be negatively affected.

Part 3:

- Objective:

To observe the effect of small signal input swing on the gain of the MOSFET based Common Source Amplifier.

- Circuit Diagram:



- Parameters Used:

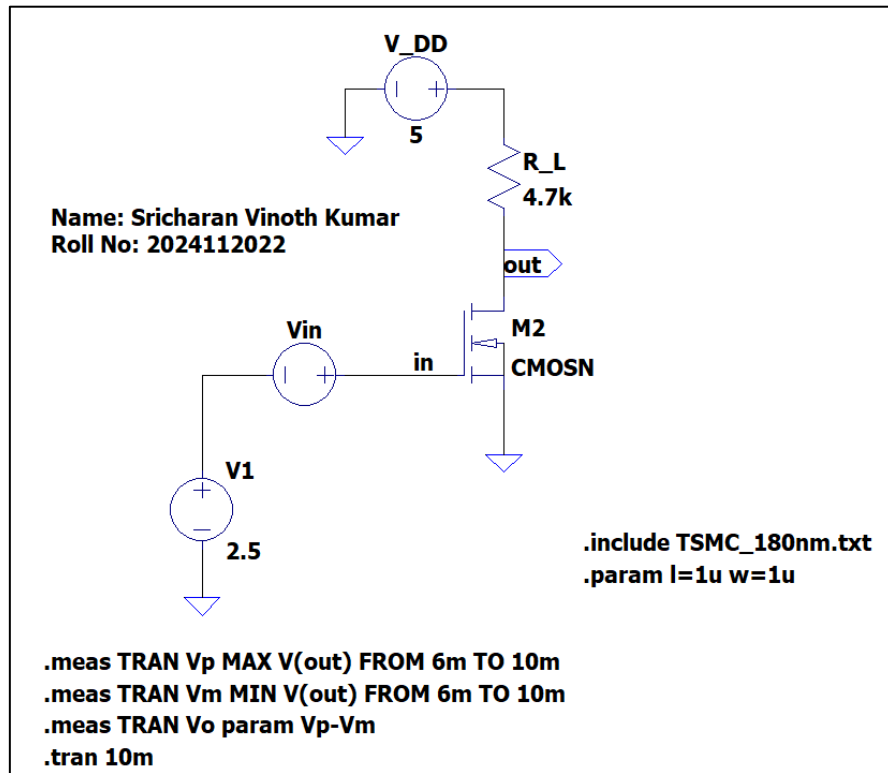
$V_{DD} = 5V$, $R = 4.7k\Omega$, $V_{BIAS} = 2.5V$, $V_{TH} = 1.8V$

Input Signal:

- Amplitude = Varying
- Frequency = 1kHz
- DC Offset = 0V

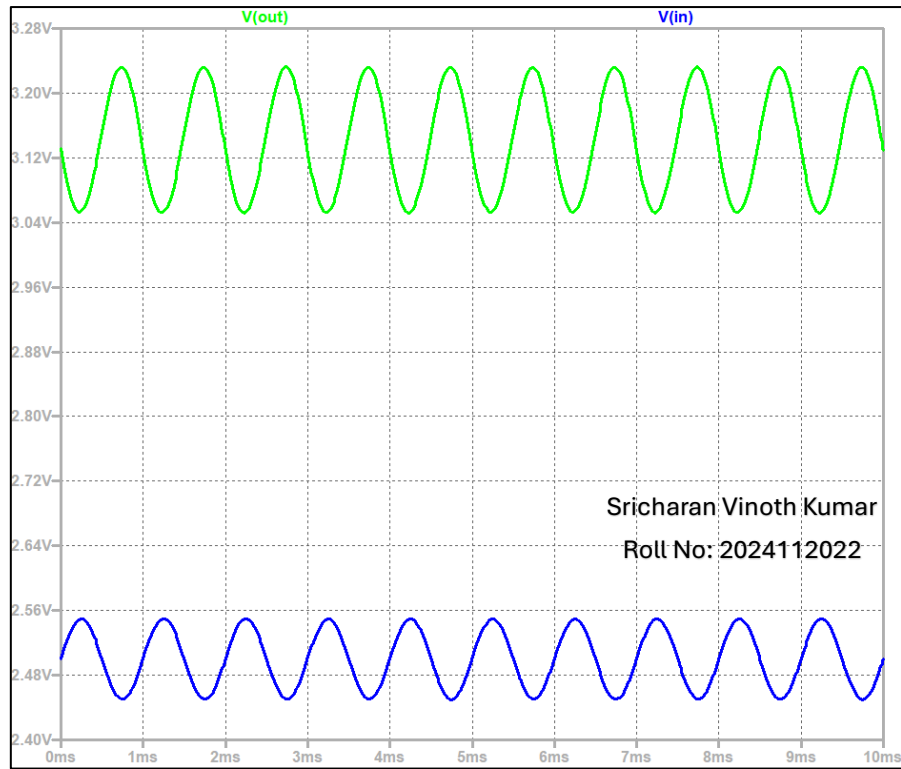
Also, the negative sign of gain (since output is inverted) is ignored for simplicity.

- LTSpice Simulations:



LTSpice Schematic

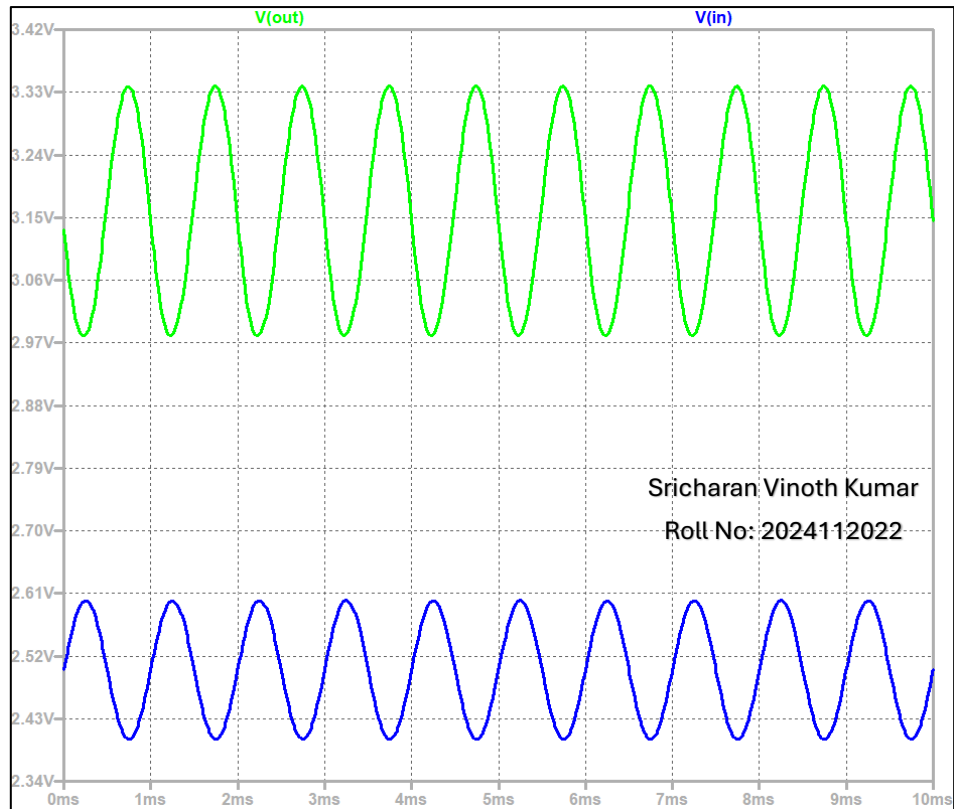
V_{bias} (V)	V_{out} (V)	$Gain = \frac{V_{out}}{V_{in}}$	$g_m = \frac{Gain}{R} (S)$
0.1	0.18038	1.8038	0.000384
0.2	0.35869	1.79345	0.000382
0.3	0.53275	1.775833	0.000378
0.4	0.7011	1.75275	0.000373
0.5	0.86425	1.7285	0.000368
0.6	1.0239	1.7065	0.000363
0.7	1.17966	1.685229	0.000359
0.8	1.3296	1.662	0.000354
1	1.60751	1.60751	0.000342
1.5	2.14136	1.427573	0.000304
2	2.51502	1.25751	0.000268
2.5	2.76987	1.107948	0.000236
3	2.91486	0.97162	0.000207
3.5	3	0.84322	0.000179



V(in) and V(out) vs t at Amp(V_{in}) = 100mV

V_p: MAX(V(out))=3.23234295845 FROM 0.006 TO 0.01
V_m: MIN(V(out))=3.05196288096 FROM 0.006 TO 0.01
V_o: V_p-V_m=0.18038007749

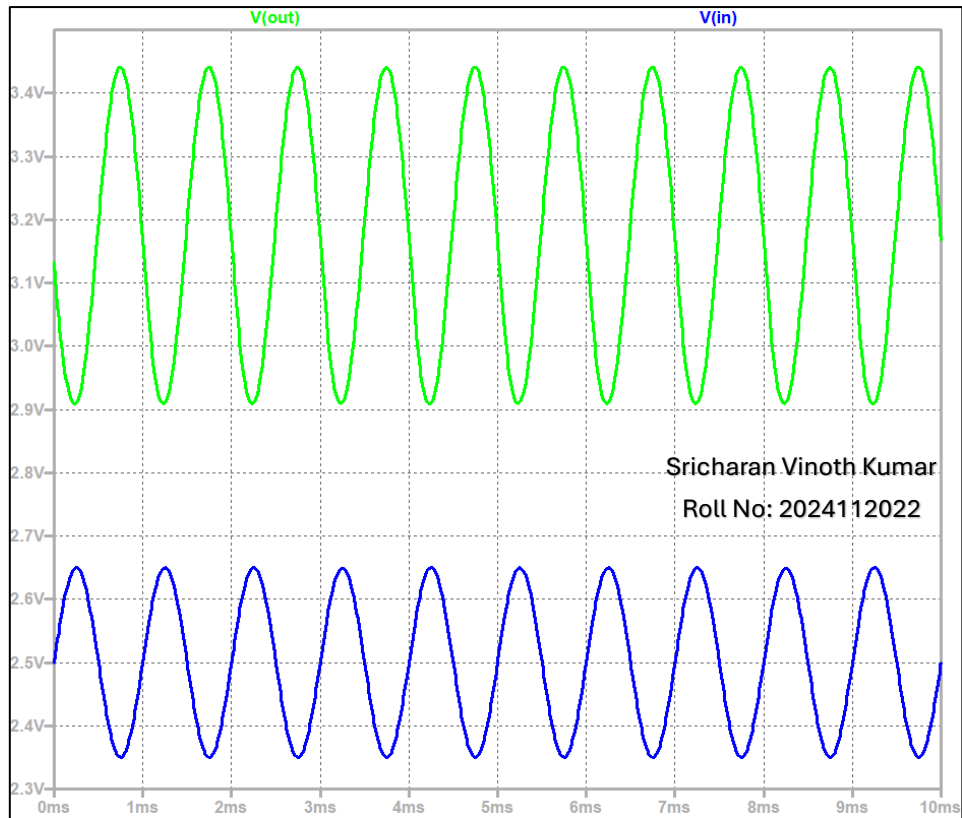
Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 100mV



V(in) and V(out) vs t at Amp(V_{in}) = 200mV

V_p: MAX(V(out))=3.33880972862 FROM 0.006 TO 0.01
V_m: MIN(V(out))=2.98011150697 FROM 0.006 TO 0.01
V_o: V_p-V_m=0.358698221648

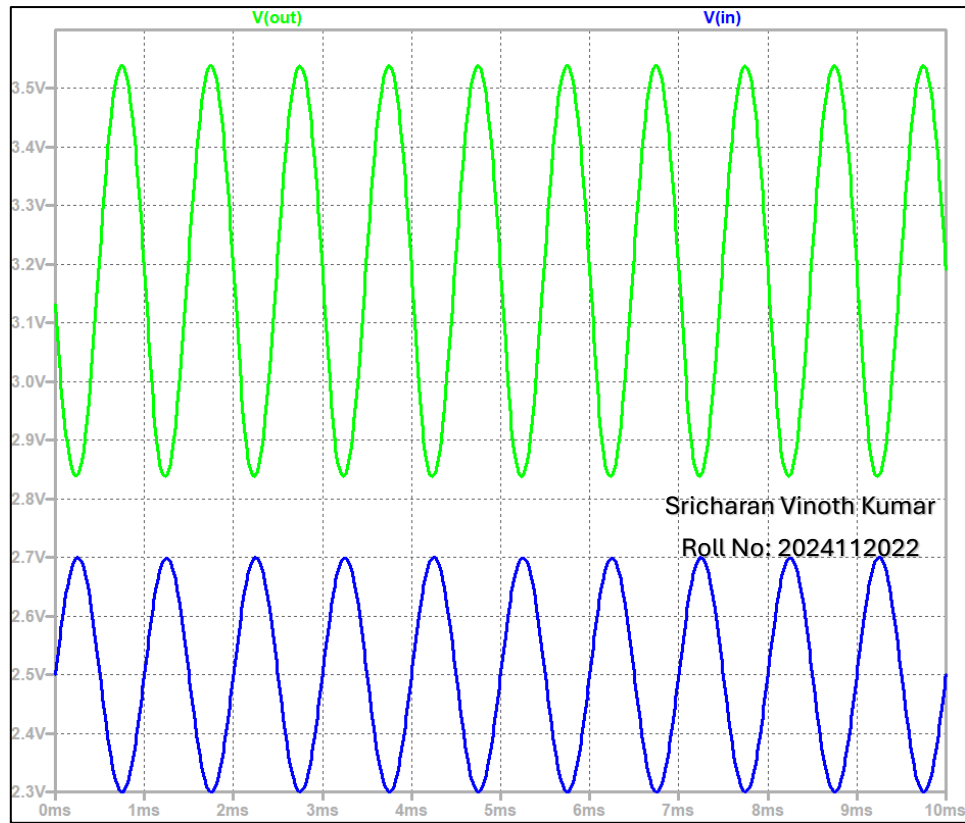
Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 200mV



V(in) and V(out) vs t at Amp(V_{in}) = 300mV

V_p: MAX(V(out))=3.44105696678 FROM 0.006 TO 0.01
V_m: MIN(V(out))=2.90830397606 FROM 0.006 TO 0.01
V_o: V_p-V_m=0.532752990723

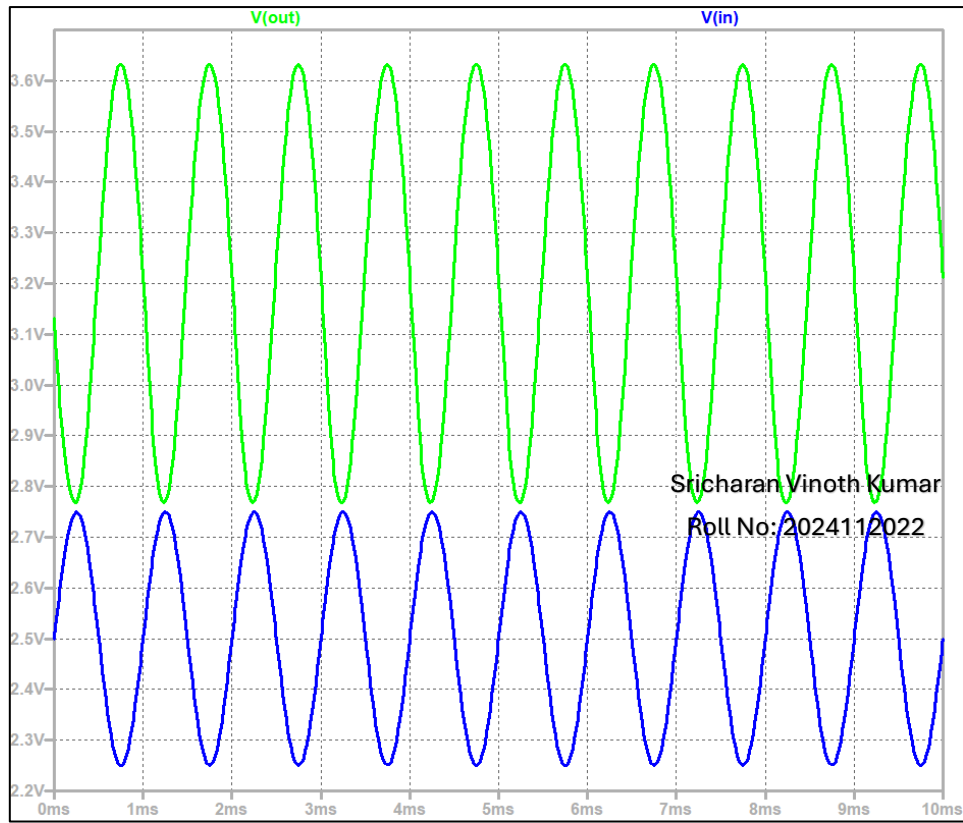
Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 300mV



V(in) and V(out) vs t at Amp(V_{in}) = 400mV

V_p: MAX(V(out))=3.53888702393 FROM 0.006 TO 0.01
V_m: MIN(V(out))=2.8377840519 FROM 0.006 TO 0.01
V_o: V_p-V_m=0.701102972031

Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 400mV



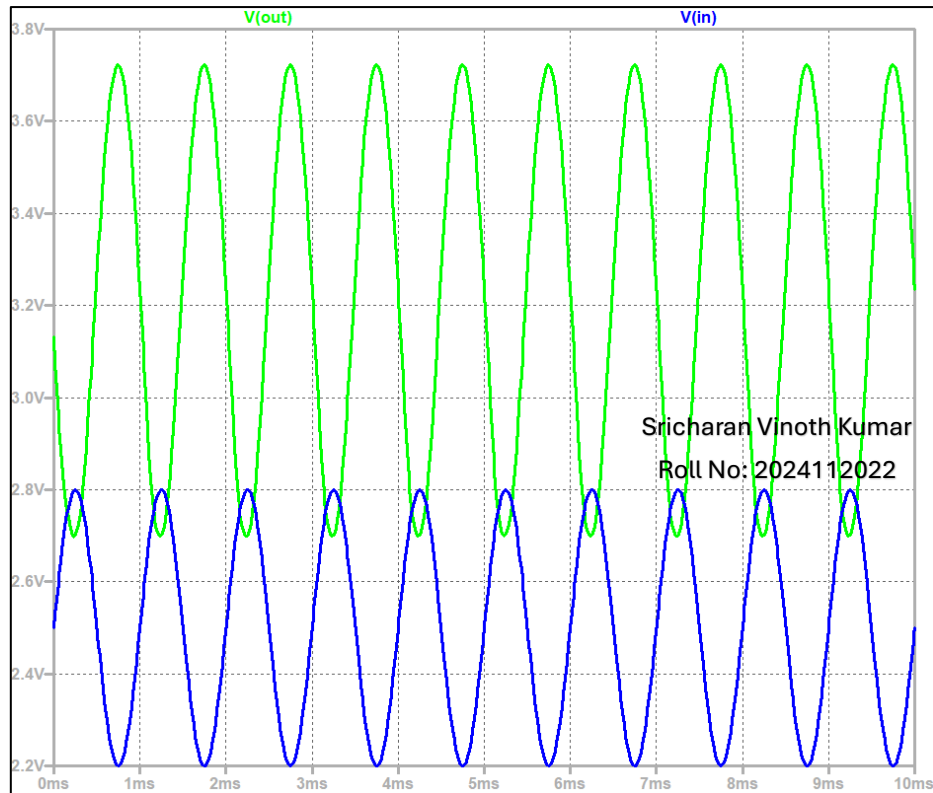
V(in) and V(out) vs t at Amp(V_{in}) = 500mV

V_p: MAX(V(out))=3.63258218765 FROM 0.006 TO 0.01

V_m: MIN(V(out))=2.76832818985 FROM 0.006 TO 0.01

V_o: V_p-V_m=0.864253997803

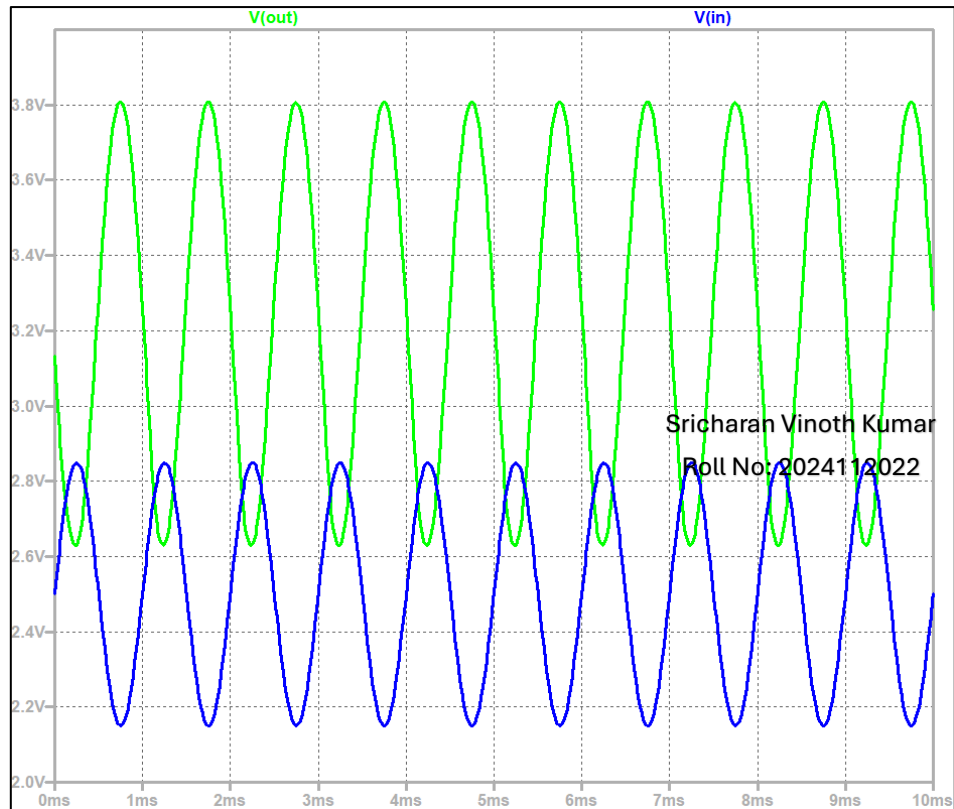
Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 500mV



V(in) and V(out) vs t at Amp(V_{in}) = 600mV

V_p: MAX(V(out))=3.7223610878 FROM 0.006 TO 0.01
V_m: MIN(V(out))=2.69845485687 FROM 0.006 TO 0.01
V_o: V_p-V_m=1.02390623093

Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 600mV



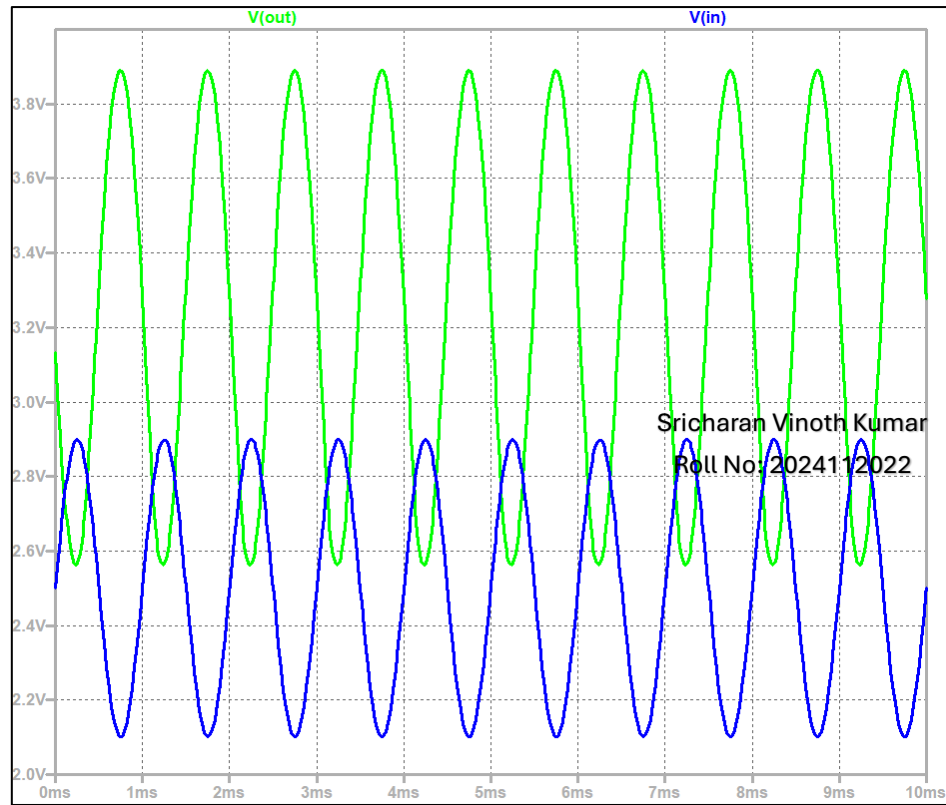
$V(in)$ and $V(out)$ vs t at $Amp(V_{in}) = 700mV$

Vp: MAX(V(out))=3.80839729309 FROM 0.006 TO 0.01

Vm: MIN(V(out))=2.62873601913 FROM 0.006 TO 0.01

Vo: $V_p - V_m = 1.17966127396$

Amplitude of $V(out)$ (represented as V_o) at $Amp(V_{in}) = 700mV$



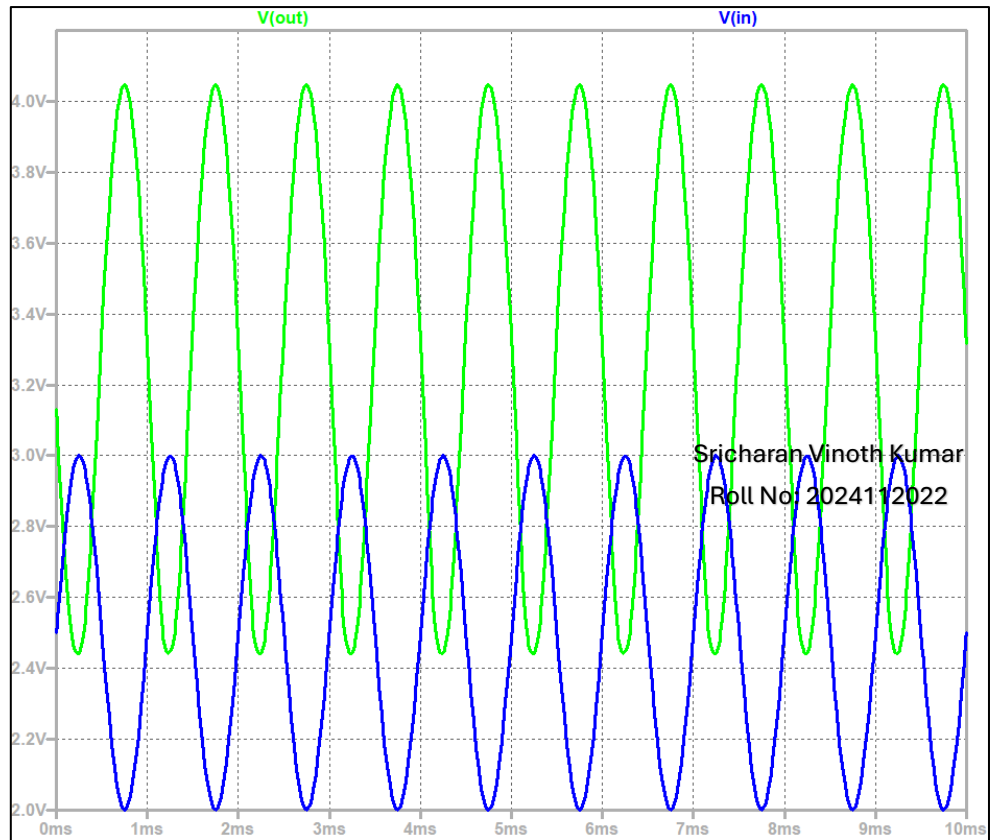
V(in) and V(out) vs t at Amp(V_{in}) = 800mV

V_p: MAX(V(out))=3.89101028442 FROM 0.006 TO 0.01

V_m: MIN(V(out))=2.56140589714 FROM 0.006 TO 0.01

V_o: V_p-V_m=1.32960438728

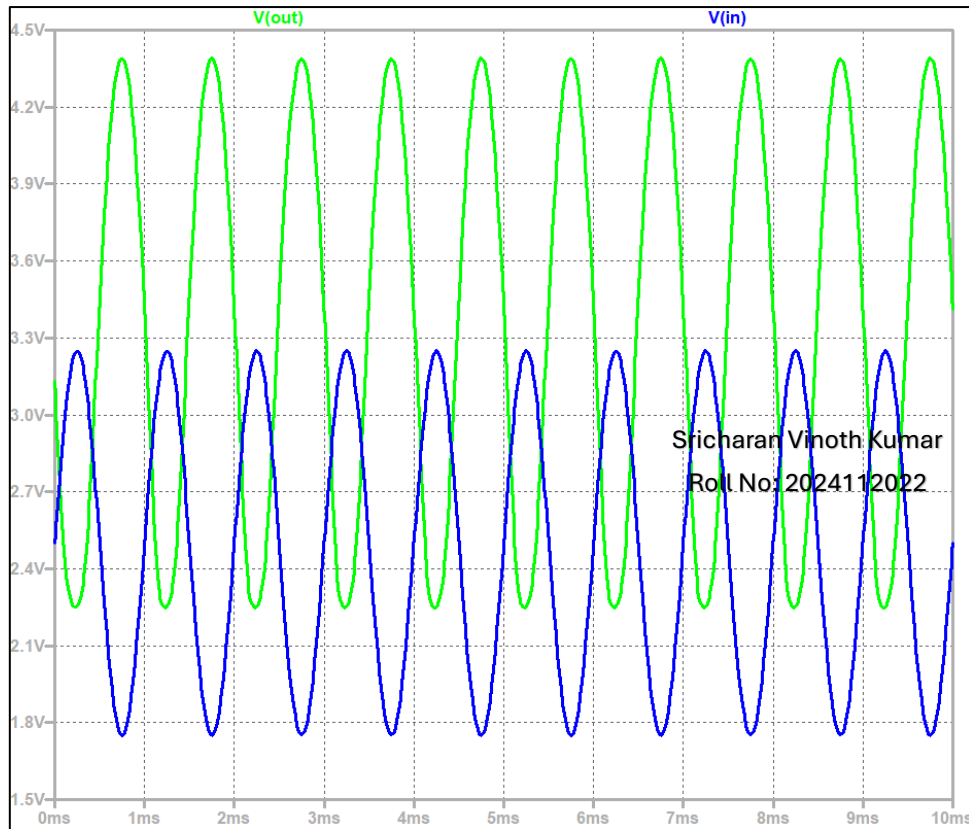
Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 800mV



V(in) and V(out) vs t at Amp(V_{in}) = 1V

V_p: MAX(V(out))=4.04796695709 FROM 0.006 TO 0.01
V_m: MIN(V(out))=2.44044756889 FROM 0.006 TO 0.01
V_o: V_p-V_m=1.6075193882

Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 1V



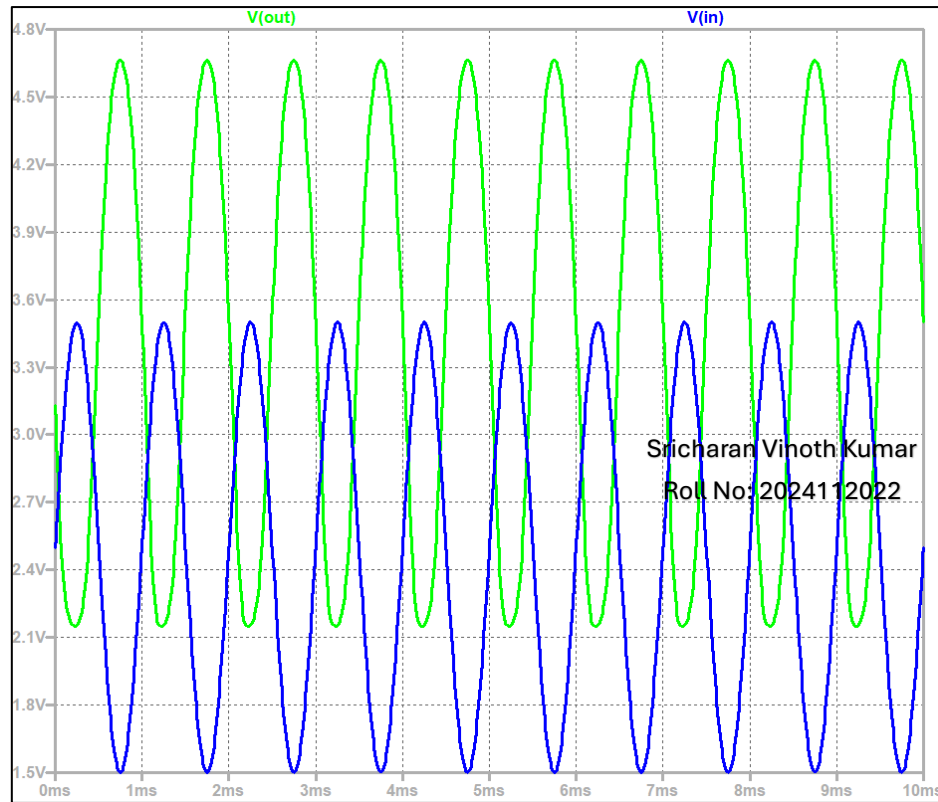
V(in) and V(out) vs t at Amp(V_{in}) = 1.5V

Vp: MAX(V(out))=4.39014720917 FROM 0.006 TO 0.01

Vm: MIN(V(out))=2.2487783432 FROM 0.006 TO 0.01

Vo: Vp-Vm=2.14136886597

Amplitude of V(out) (represented as Vo) at Amp(V_{in}) = 1.5V



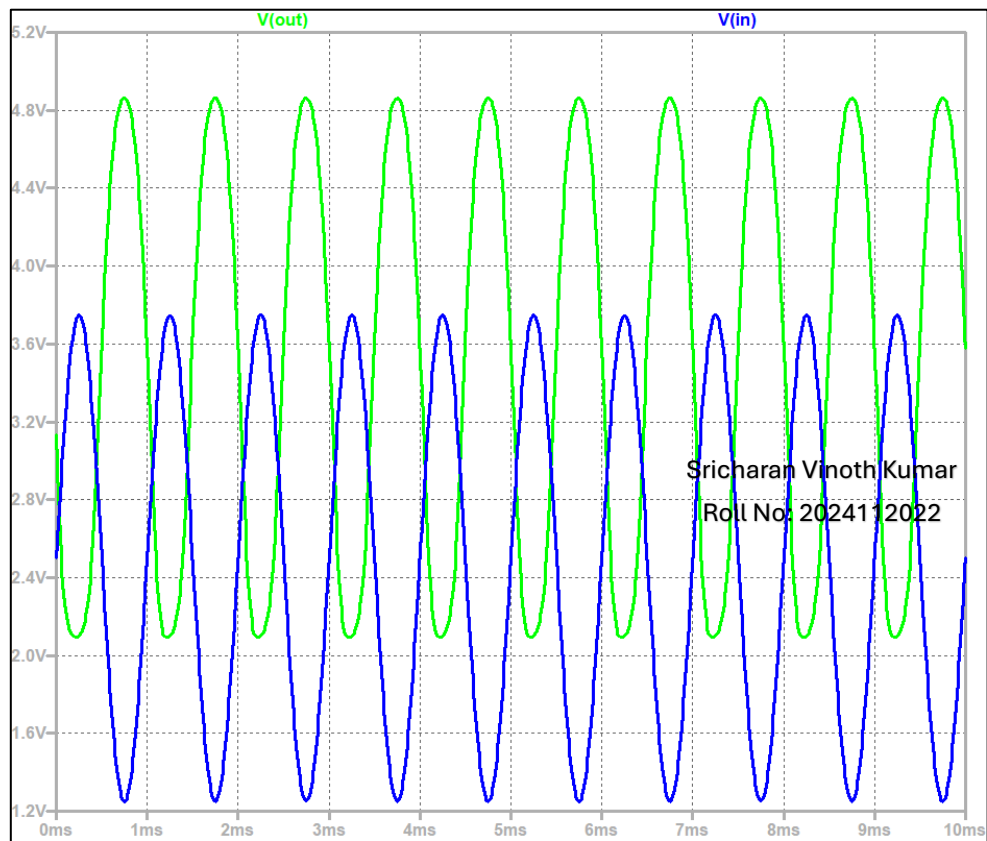
V(in) and V(out) vs t at Amp(V_{in}) = 2V

V_p: MAX(V(out)) = 4.66380119324 FROM 0.006 TO 0.01

V_m: MIN(V(out)) = 2.14877653122 FROM 0.006 TO 0.01

V_o: V_p - V_m = 2.51502466202

Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 2V



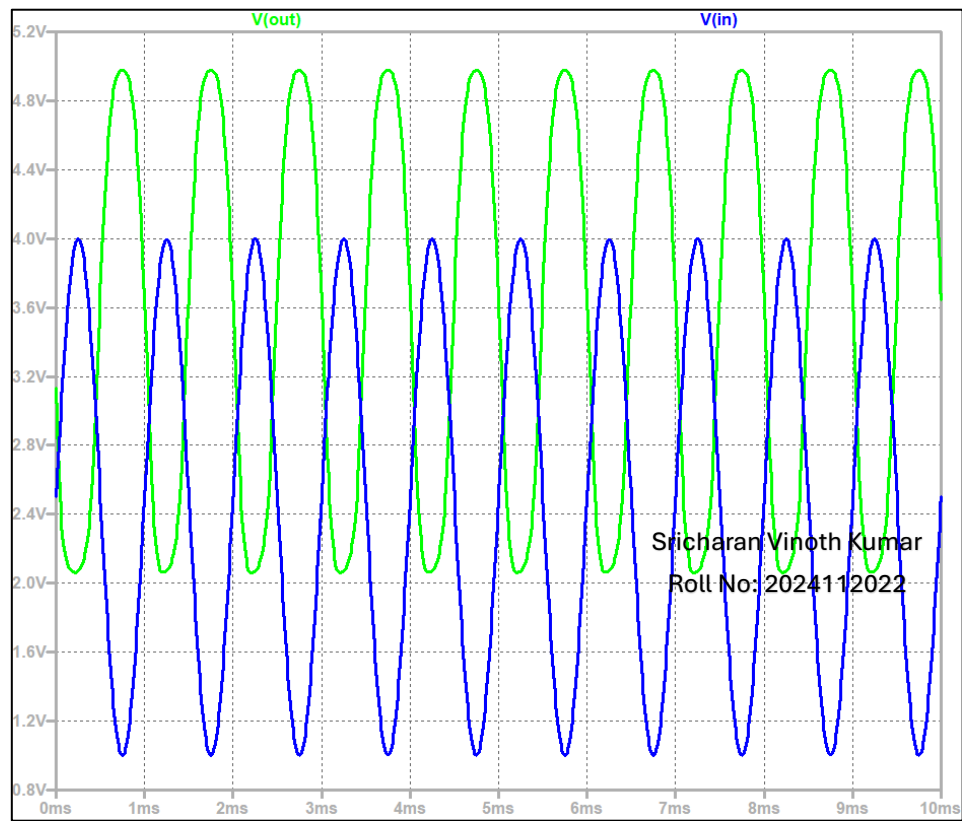
V(in) and V(out) vs t at Amp(V_{in}) = 2.5V

V_p : MAX(V(out)) = 4.86303091049 FROM 0.006 TO 0.01

V_m : MIN(V(out)) = 2.09315752983 FROM 0.006 TO 0.01

V_o : $V_p - V_m = 2.76987338066$

Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 2.5V



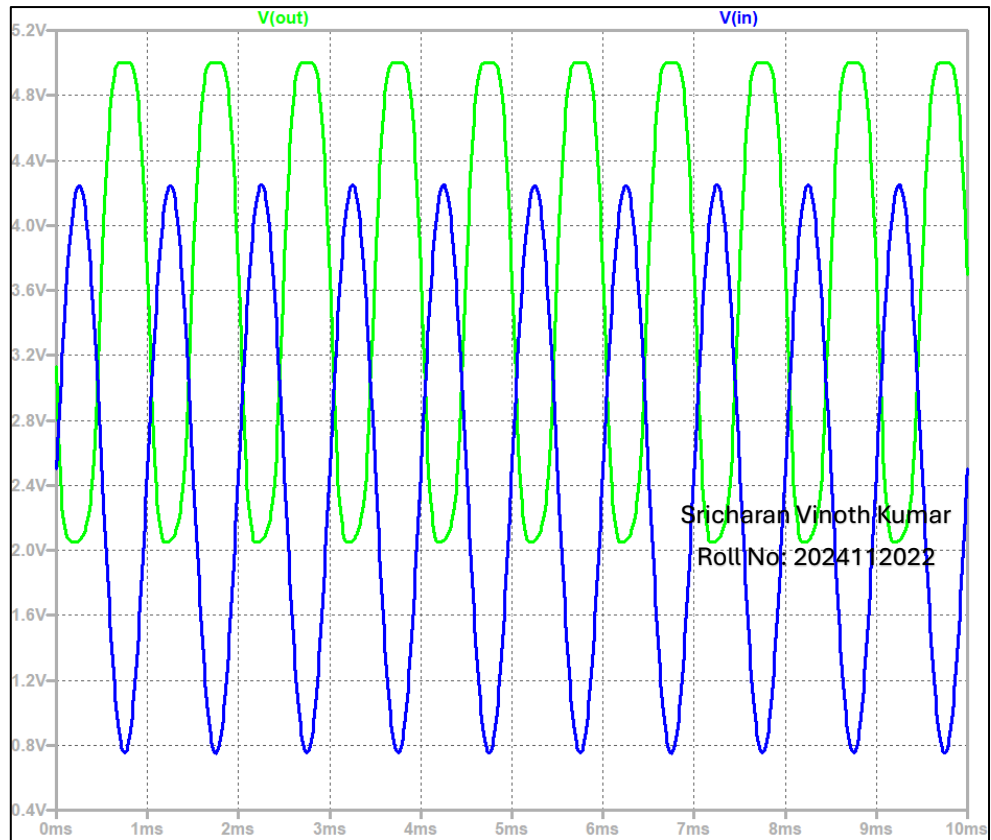
V(in) and V(out) vs t at Amp(V_{in}) = 3V

V_p: MAX(V(out))=4.97806882858 FROM 0.006 TO 0.01

V_m: MIN(V(out))=2.06320595741 FROM 0.006 TO 0.01

V_o: V_p-V_m=2.91486287117

Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 3V



V(in) and V(out) vs t at Amp(V_{in}) = 3.5V

V_p: MAX(V(out))=4.99996566772 FROM 0.006 TO 0.01
V_m: MIN(V(out))=2.04868769646 FROM 0.006 TO 0.01
V_o: V_p-V_m=2.95127797127

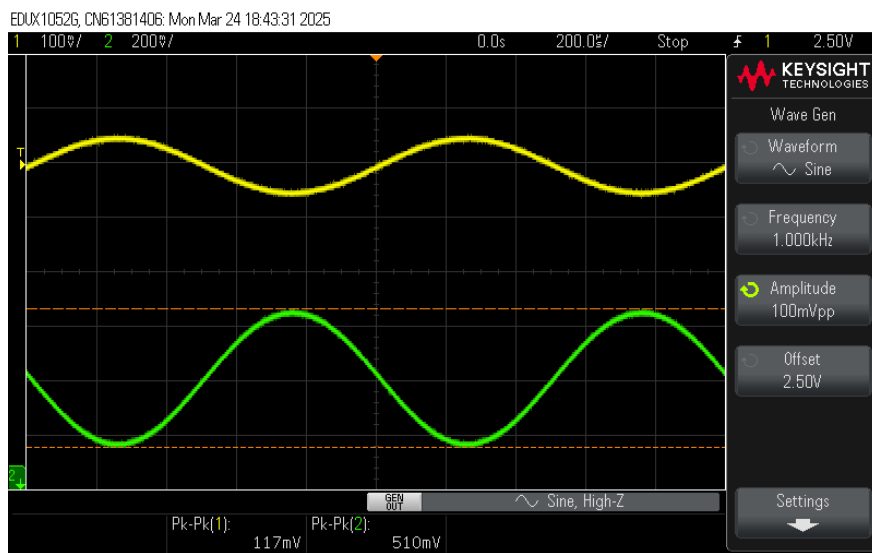
Amplitude of V(out) (represented as V_o) at Amp(V_{in}) = 3.5V

- Inference From LTSpice:

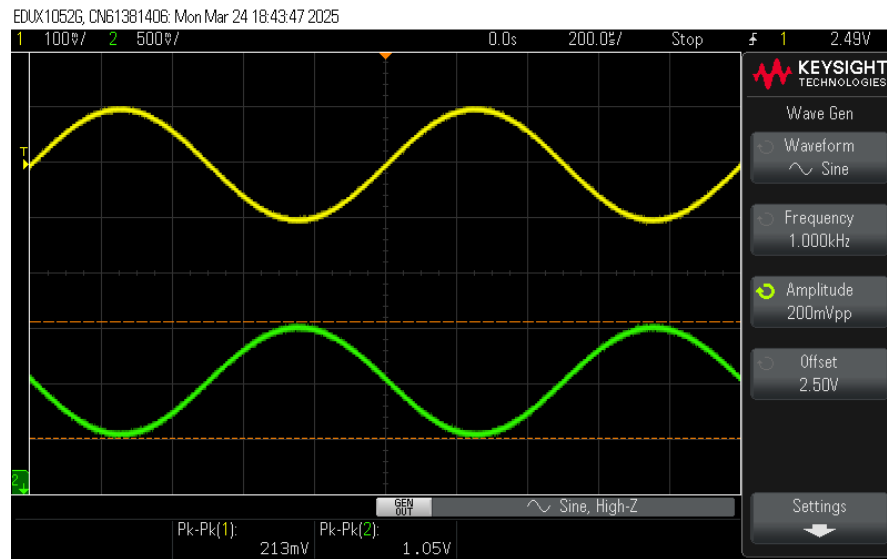
There is a clear decrease in gain at Amplitude = 700mV, and there is very visible clipping at Amplitude = 3.5V

- Observation:

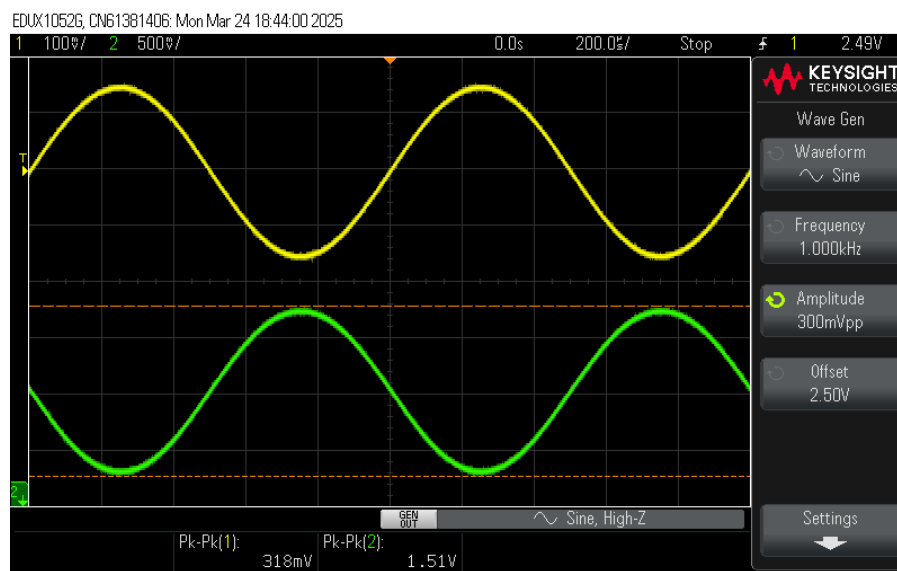
V_{bias} (V)	V_{out} (V)	$Gain = \frac{V_{out}}{V_{in}}$	$g_m = \frac{Gain}{R} (S)$
0.1	0.51	5.1	0.001085
0.2	1.03	5.15	0.001096
0.3	1.51	5.033333	0.001071
0.4	1.97	4.925	0.001048
0.5	2.33	4.66	0.000991
0.6	2.61	4.35	0.000926
0.7	2.85	4.071429	0.000866
0.8	3.06	3.825	0.000814



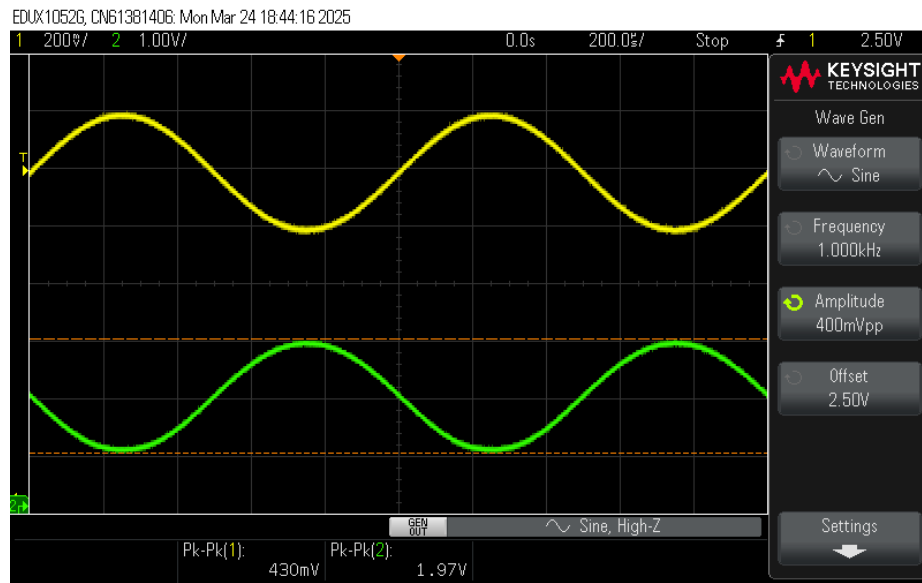
Amplitude = 100mV



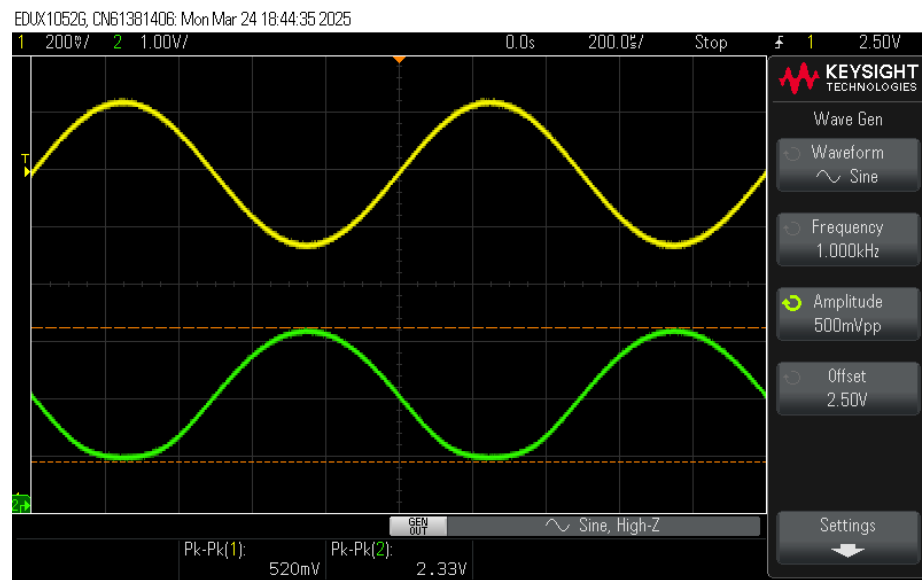
Amplitude = 200mV



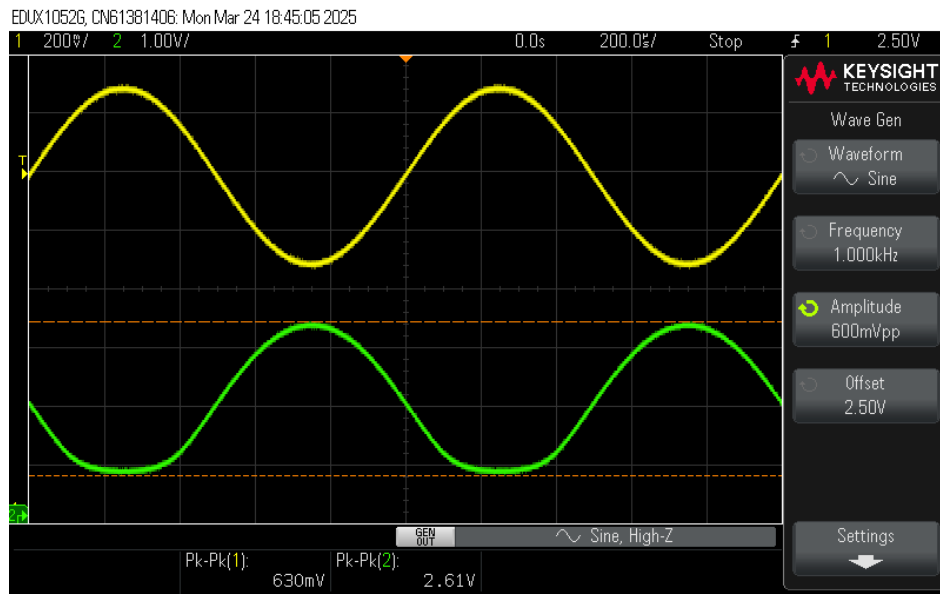
Amplitude = 300mV



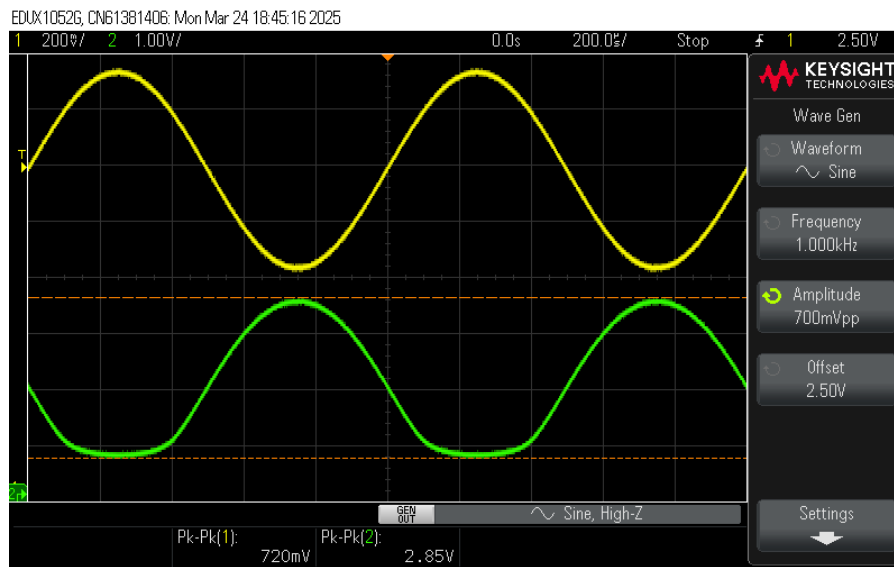
Amplitude = 400mV



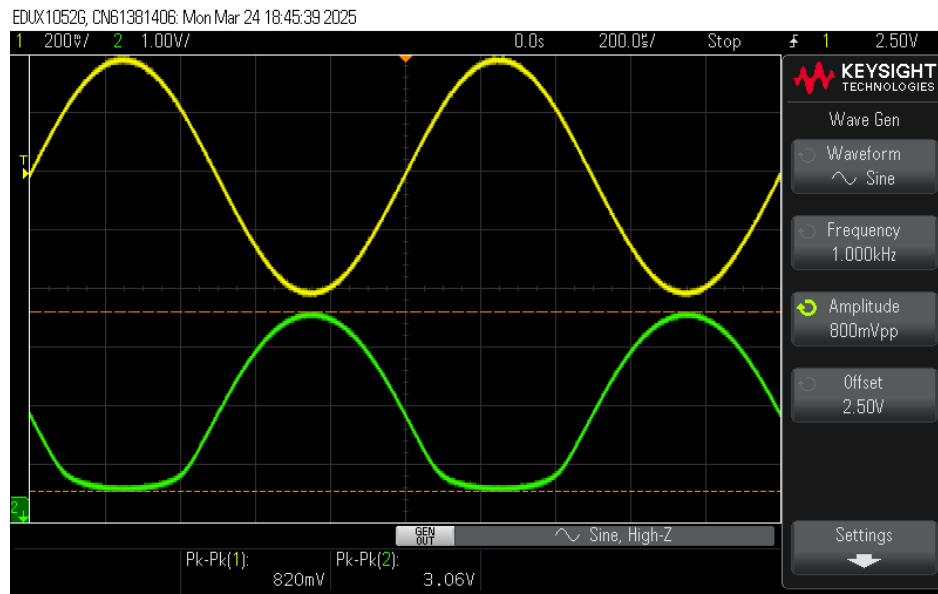
Amplitude = 500mV



Amplitude = 600mV



Amplitude = 700mV



Amplitude = 800mV

- Inference:

From the observations, we can see that the output is being clipped at Amplitude greater than 600mV, due to a significant decrease in gain and also distortion in the output sinusoid.

This clipping is due to the Amplifier exiting small-signal operation and exhibiting non-linear behaviour.

Possible explanations can be:

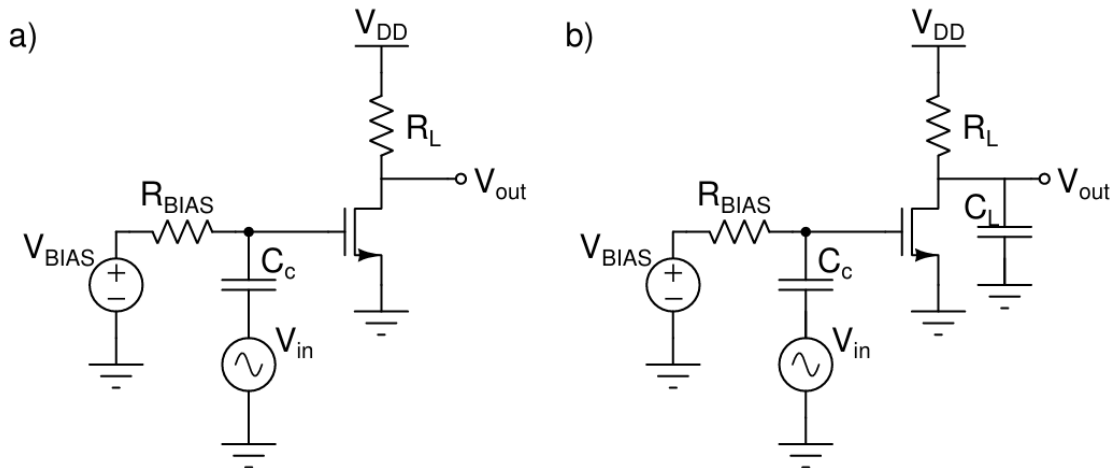
- When V_{GS} is too small, the MOSFET enters cutoff region ($V_{GS} < V_{TH} = 1.8V$), which clips the negative half of the output.
- When V_{GS} is too high, the MOSFET enters triode region ($V_{DS} < V_{GS} - V_{TH}$) which clips the positive half of the output. If even higher, then the output is clipped due to it exceeding V_{DD} .

Part 4:

- Objective:

To analyse the behaviour of a MOSFET based Common Source Amplifier with external coupling.

- Circuit Diagrams:



- Parameters Used:

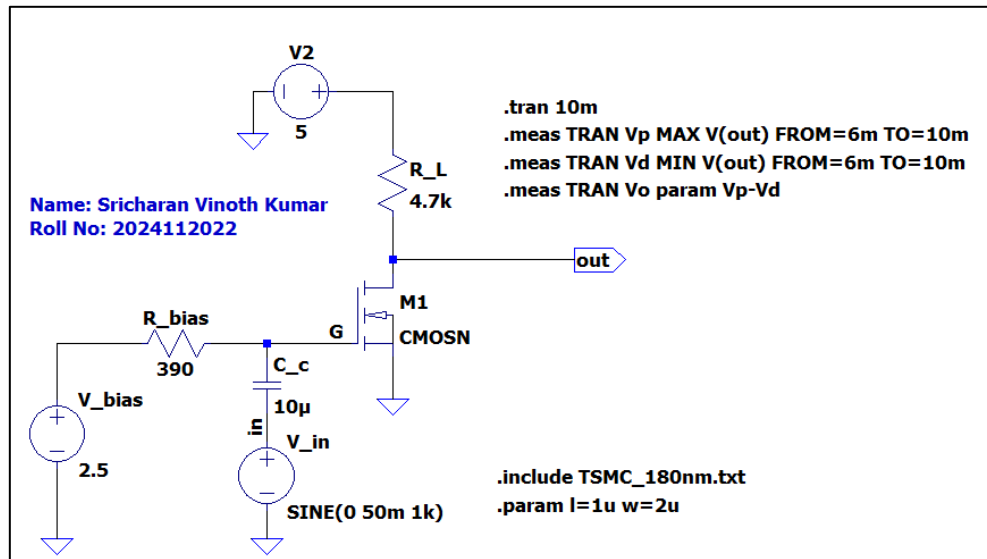
$V_{DD} = 5V$, $V_{BIAS} = 2.5V$, $R_{BIAS} = 390\Omega$, $R_L = 4.7k\Omega$, $C_C = 10\mu F$, $C_L = 470pF$, $V_{TH} = 1.8V$

Input Signal:

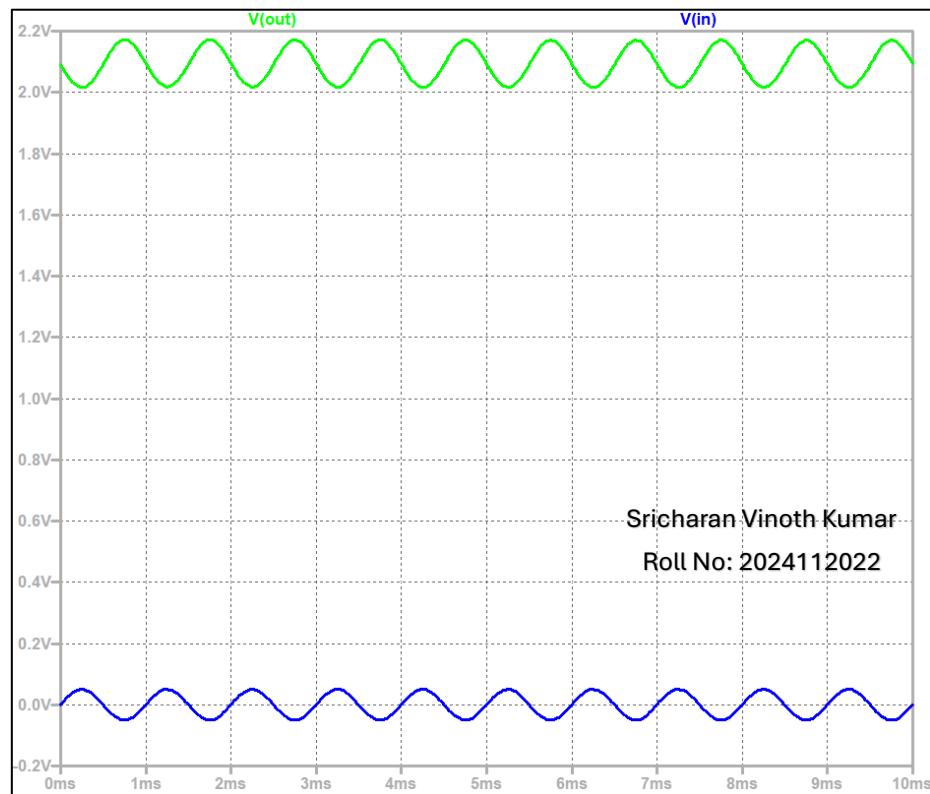
- Amplitude = 100mV
- Frequency = 1kHz
- DC Offset = 0V

- LTSpice Simulation:

1. Without Load Capacitance,



LTSpice Schematic



V(in) and V(out) vs t

Vp: MAX(V(out))=2.17006111145 FROM 0.006 TO 0.01
Vd: MIN(V(out))=2.0163371563 FROM 0.006 TO 0.01
Vo: Vp-Vd=0.153723955154

Amplitude of V(out) (represented as Vo)

$$Gain = \frac{V_o}{V_{in}}$$

$$\Rightarrow Gain = \frac{0.15372}{0.1} = 1.5372$$

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

$$g_m = \frac{1.5372}{4700} = 3.27 \times 10^{-4} \text{ S}$$

To measure V_{DS} ,

Using Operating Point Analysis,

V(g) :	2.5	voltage
V(n003) :	0.206582	voltage
V(in) :	0	voltage
V(n002) :	2.5	voltage
V(out) :	2.09027	voltage
V(n001) :	5	voltage

$V_{DS} = 2.09 \text{ V}$ (V(out) is V_{DS})

$$I_{DS} = \frac{V_{DD} - V_{DS}}{R_L}$$

$$\Rightarrow I_{DS} = \frac{5 - 2.09}{4700} \approx 619.148 \mu\text{A}$$

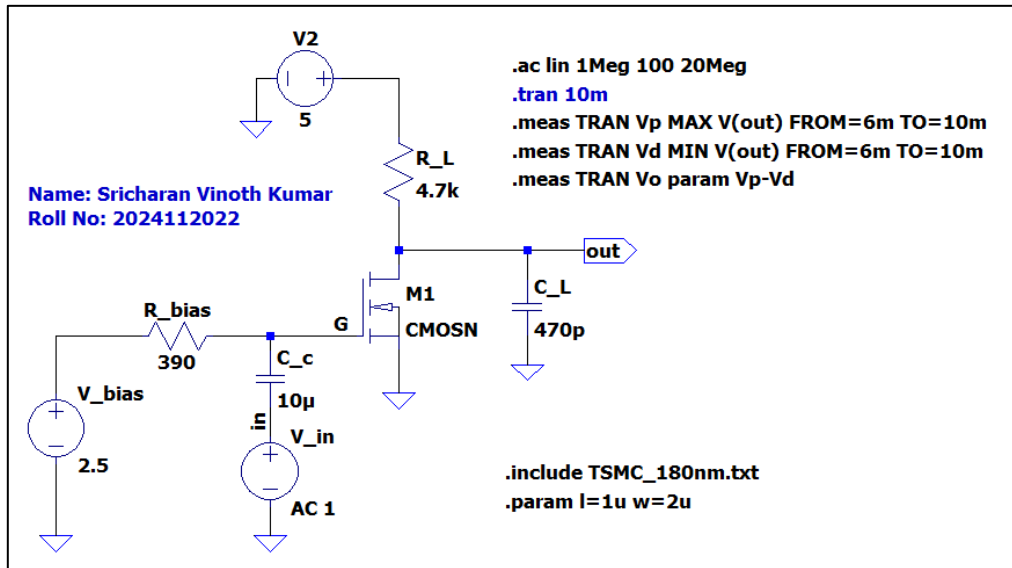
$$I_{DS} = \mu C_{ox} \frac{W}{L} (V_{TH} - V_{GS})^2$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{I_{DS}}{(V_{GS} - V_{TH})^2}$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{619.148 \times 10^{-6}}{(2.5 - 1.8)^2}$$

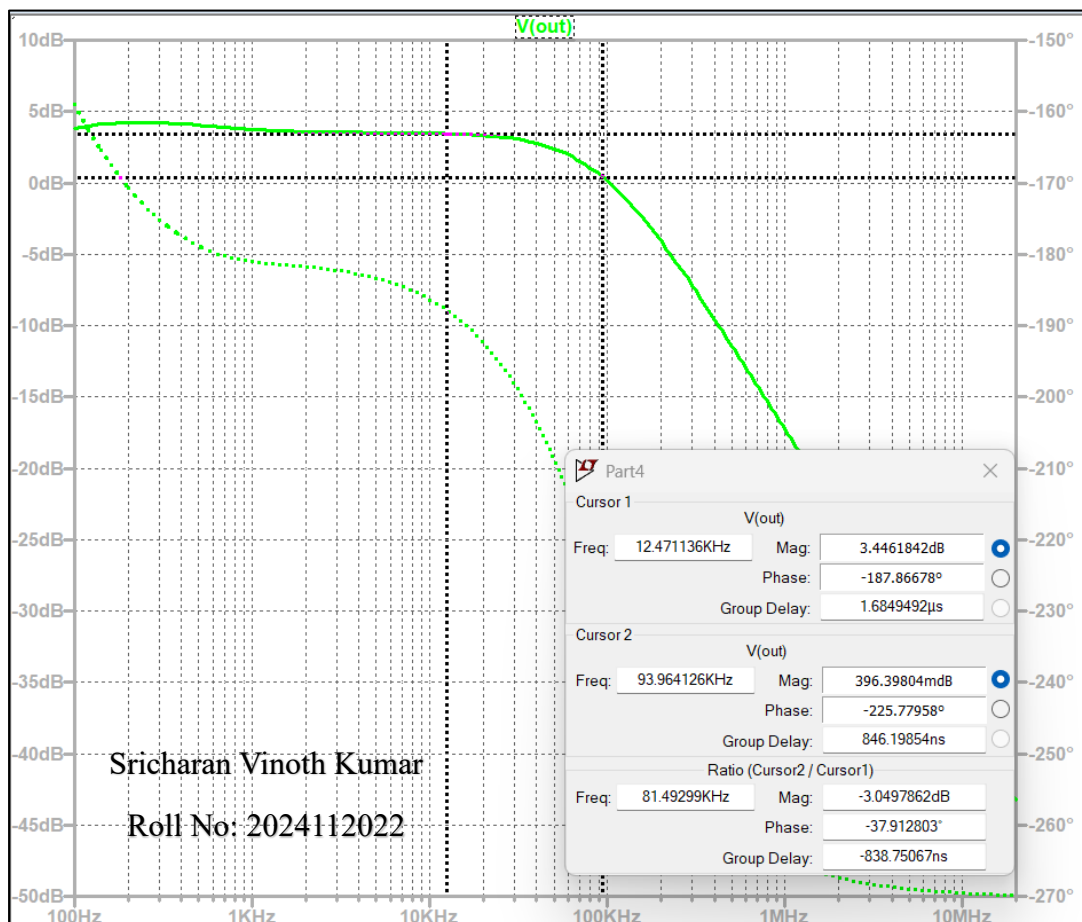
$$\Rightarrow \mu C_{ox} \frac{W}{L} = 1263 \mu\text{A/V}^2$$

2. With Load Capacitance



LTSpice Schematic

Result of FRA,



-3db Frequency = 81.492 kHz

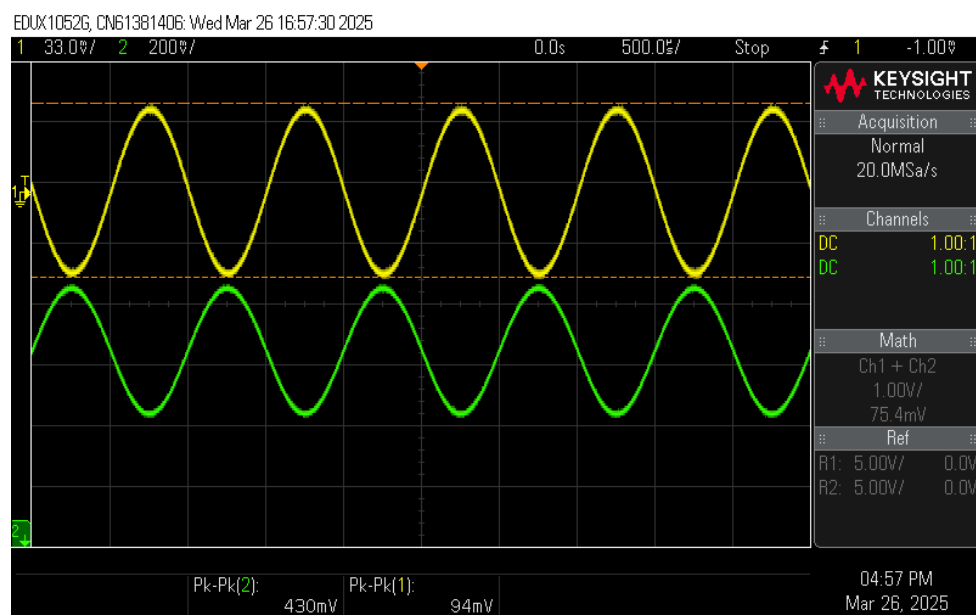
Theoretically,

We know that the gain of the Amplifier is given by,

$$\begin{aligned} Gain &= g_m(R_L \parallel \frac{1}{sC}) \\ \Rightarrow Gain &= g_m \frac{R_L}{1 + sC_L R_L} \\ \Rightarrow Pole\ frequency &= \frac{1}{R_L C_L} = 72.048\text{ kHz} \end{aligned}$$

The calculated pole/3db frequency is about the same as the observed frequency

- Observations:



$$V_{out} = 430\text{mV}$$

$$\begin{aligned} Gain &= \frac{V_{out}}{V_{in}} \\ \Rightarrow Gain &= \frac{0.43}{0.1} = 4.3 \end{aligned}$$

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

$$\Rightarrow g_m = \frac{4.3}{4700} = 9.14 \times 10^{-4} \text{ S}$$

$$V_{DSQ} = 1.86 \text{ V}$$

$$I_{DS} = \frac{V_{DD} - V_{DS}}{R_L}$$

$$\Rightarrow I_{DS} = \frac{5 - 1.86}{4700} \approx 668.085 \mu\text{A}$$

$$I_{DS} = \mu C_{ox} \frac{W}{L} (V_{TH} - V_{GS})^2$$

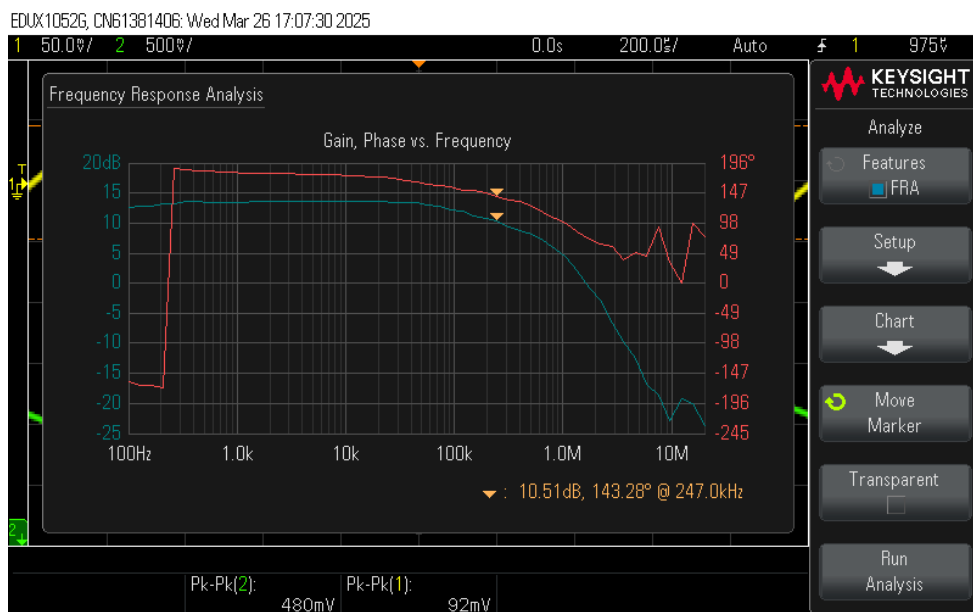
$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{I_{DS}}{(V_{GS} - V_{TH})^2}$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} = \frac{668.085 \times 10^{-6}}{(2.5 - 1.8)^2}$$

$$\Rightarrow \mu C_{ox} \frac{W}{L} \approx 1363 \mu\text{A}/\text{V}^2$$

Using Load Capacitance,

Result of FRA:



-3db frequency = 247 kHz

Theoretically, from the LTSpice calculations, we know that theoretical 3db frequency is 72.048 kHz.

The theoretical and observed 3db frequency are in the same order.

Also, there is a substantial decrease in the gain of the amplifier in this configuration, even without load capacitance. This can be possibly attributed to the presence of R_{BIAS} , which prevents the full effect V_{BIAS} on the input signal, and due to the presence of the coupling capacitance C_C , which will offer some impedance (attenuation) to the input signal.