ECGR 3131 Project 2: MOSFET Amplifier

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***Abstract*—This paper presents a comprehensive study of MOSFET (Metal-Oxide-Semiconductor Field-Effect Transistor) characteristics and applications. We conduct a detailed DC and AC analysis of MOSFETs, comparing theoretical calculations with simulations in Multisim and practical lab measurements. The DC analysis focuses on key parameters such as drain current, gate voltage, and power dissipation, while the AC analysis delves into frequency response and signal amplification. The results highlight the accuracy of simulations and the discrepancies in practical measurements, leading to a discussion on potential areas for future research and improvement in MOSFET technology. This study serves as a valuable resource for understanding MOSFET behavior in various electrical and electronic applications.**

I. INTRODUCTION

THe objective of this project is to design, build and calculate an amplifier using the CD4007UBE Dual Complementary Pair Plus Inverter IC Package under the specific conditions as follows:

- VT = 1.40 V
- μo Cox (W/L) = 600μA/V2
- VA — = 200V
- $AV = \frac{Vo}{Vi} \geq 10\,\text{V/V}$
- RL = 20 kOhms
- VDD = 10 V (rail voltage, single supply)
- Swing $\geq \pm 5\,\text{V}$ (pk to pk 10V)
- R_{INPUT} = any value
- R_{OUTPUT} = any value
- Power Consumption $= VDD \times IDD \leq 100\,\text{mW}$
- Perform within 5% of calculated values

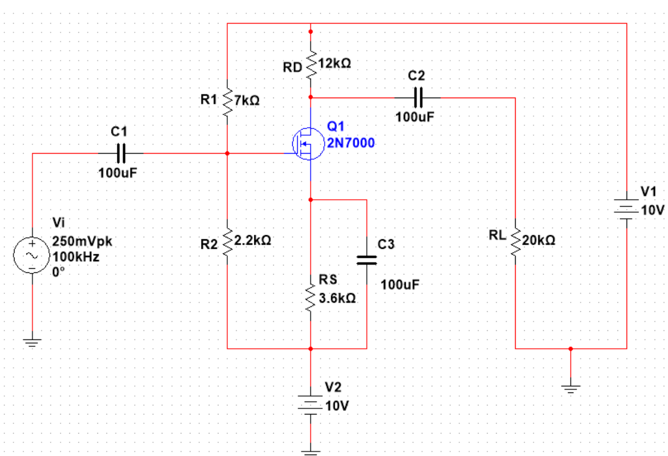

Fig 1-1: Simulated Circuit

Using the specifications mentioned above, hand calculations were made to determine the resistor values of R1, R2, Rd, and Rs and adjusted to values that were available in the lab while still keeping within the requirements. After the hand calculations, the circuit was simulated in Multisim shown in Figure 1-1.

II. DC ANALYSIS

To perform the DC Analysis of the amplifier circuit the DC bias values are found. The AC voltage source, the load resistor, and coupling and bypass capacitors were removed to produce the DC equivalent circuit. The following are the equations for analysis.

- Vgs = Vg - Vs
- Vg = -10 + [R2/(R1+R2)](Vdd - Vss)
- Vs = Rs*(Ids)
- Vgs = [R2/(R1+R2)](Vdd)-Rs (Ids)
- Ids = Kn(Vgds - Vtn)$\hat{2}$
- Q-Point = (VDSQ, IDSQ)

Figure 1-2 below shows the steps using the equations above to find the Voltages and Currents for the DC circuit.

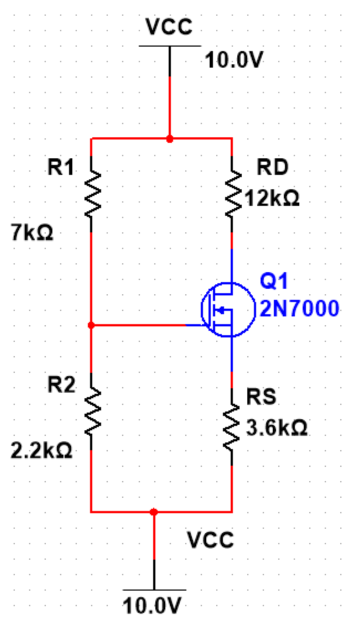

Fig 1-2: DC Analysis

Given constants:

$$V_T = 2.1\,V,$$
$$K_N = 0.32\,\frac{mA}{V^2}.$$

Calculating V_G:

$$V_G = -10 + (10 - (-10)) \cdot \frac{2.2}{(7 + 2.2)},$$
$$V_G = -5.23\,V.$$

Relating V_G and V_{GS}:

$$\begin{aligned} V_G - V_{GS} &= -10 + (I_{DS} \cdot 3.6\,k\Omega), \\ -5.23 - V_{GS} &= -10 + (I_{DS} \cdot 3.6\,k\Omega), \\ I_{DS} &= \frac{-4.77 - V_{GS}}{3.6\,k}. \end{aligned}$$

Using the transistor characteristic equation:

$$\begin{aligned} I_{DS} &= K_N \cdot (V_{GS} - V_{TN})^2, \\ I_{DS} &= 0.32 \cdot (V_{GS} - 2.1)^2. \end{aligned}$$

Solving for I_{DS} yields:

$$\begin{aligned} \frac{-4.77 - V_{GS}}{3.6\,k} &= 0.32 \cdot (V_{GS} - 2.1)^2, \\ -4.77 - V_{GS} &= 1.152 \cdot (V_{GS} - 2.1)^2, \\ -4.77 - V_{GS} &= 1.152 \cdot V_{GS}^2 - 4.83V_{GS} + 5.08, \end{aligned}$$

$$1.152V_{GS}^2 - 3.83V_{GS} + 9.85 = 0$$

The solutions for V_{GS}:

$$\begin{aligned} V_{GS} &= 2.9241\,V\angle 55.35^\circ, \\ V_{GS} &= 2.9241\,V\angle -55.35^\circ, \\ V_{GS} &= 2.9241\,V\angle 55.35^\circ. \end{aligned}$$

Calculating V_S:

$$\begin{aligned} V_{GS} &= V_G + V_S, \\ 2.9241\,V\angle 55.35^\circ &= -5.23 - V_S, \\ -V_S &= 2.9241\,V\angle 55.35^\circ + 5.23, \\ -V_S &= 6.8\angle 23.4, \\ V_S &= -6.85\,V. \end{aligned}$$

Calculating I_{DS}:

$$\begin{aligned} I_{DS} &= \frac{-10 + 6.8}{3.5\,k}, \\ I_{DS} &= 0.87\,mA. \end{aligned}$$

Calculating V_D and V_{DS}:

$$\begin{aligned} V_D &= 10 - (12\,k\Omega \cdot 0.87), \\ V_D &= -0.44\,V, \\ V_{DS} &= -0.44 + 6.85 = 6.41\,V. \end{aligned}$$

Calculating $Power$:

$$\begin{aligned} P &= V_{DD} \cdot I_{DD}, \\ P &= 20 \cdot (0.87 + 2), \\ P &= 77.4mW \end{aligned}$$

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After verifying that the hand calculations made were accurate, the circuit was simulated in Multisim to determine the simulation values for the voltages and current. By comparing the hand calculations, Multisim, and lab-measured values, percent errors were calculated. These values are shown in Table I

Results	Hand	Multisim	Lab	Error
Ig	0	0	0.02 mA	0%
Id	0.87 mA	1.09 mA	2.2 mA	8.62%
Is	0.87 mA	1.8 mA	2.1 mA	3.93%
Vg	-5.19 V	-5.22 V	-5.13 V	3.57%
Vd	-0.44 V	-1.05 V	-1.16 V	4.74%
Vs	-6.85 V	-7.27 V	-6.68 V	18.08%
Vdsq	6.41 V	6.22 V	5.52 V	2.15%
P	77.4 mW	78 mW	75 mW	2.97%

TABLE I: DC Voltages and Currents

III. AC ANALYSIS

For the AC Analysis, the DC source was removed and the capacitors were shorted. A pi-model was constructed to show the 10V pk-pk sweep and the gain of 10v/v. The hand calculations are shown below.

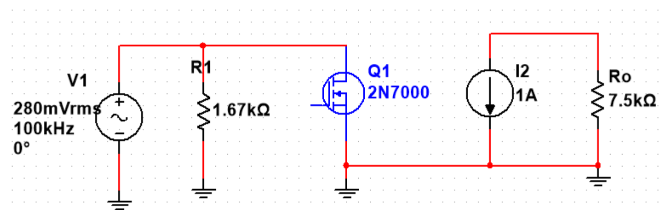

Fig 1-3: Pi-Model

$$\begin{aligned} g_m &= 2K_o(V_{GS} - V_{TN}) \\ &= 2 \times 0.392(2.92 - 2.1) \\ &= \mathbf{1.67mA/(V)^2} \end{aligned}$$

$$A_V = \frac{V_o}{V_{GS}} \cdot \frac{V_{GS}}{V_i}$$

$$\begin{aligned} V_{GS} &= g_m(7.5k)(1) \\ &= -1.67 \times (7.5k) \\ V_{GS} &= -12.5V \end{aligned}$$

$$\frac{V_{gs}}{V_i} = 1$$

$$AV = \frac{V_o}{V_i} = \textbf{-12.5 v/v}$$

$$\begin{aligned} P &= V_{DD} \cdot I_{DD} \\ &= 20(0.97 + 3) \\ &= \mathbf{77.4mW} \end{aligned}$$

After the AC and DC analysis, the load lines for the respective were calculated and plotted as shown in Fig 1-4 DCLL Calculations:

$$ID \times 15.6k + VDS = 20$$
$$IDS = 1.3\,\text{mA}$$
$$VDS = 20\,\text{V}$$

ACLL Calculations:

$$IDST \times 7.5k + VDST = 13.03$$
$$IDST = 1.7\,\text{mA}$$
$$VDST = 13.03\,\text{V}$$

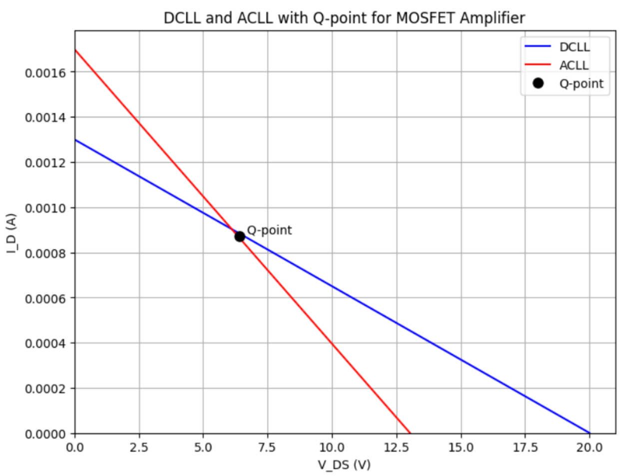

Fig 1-4: ACLL/DCLL

Then the input and output impedance calculations were performed as shown below

$$\mathrm{R_{in}} = \left(\frac{1}{7k\Omega} + \frac{1}{2.2k\Omega}\right)^{-1} = 1.8k\,\Omega$$

$$\mathrm{R_{in}} = 1.8k\,\Omega$$

$$\mathrm{R_{out}} = \left(\frac{1}{3.6k\Omega} + \frac{1}{12k\Omega}\right)^{-1} = 2.7\,\Omega$$

$$\mathrm{R_{out}} = 2.7k\,\Omega$$

IV. RESULTS

In Figure 2-1, is a great tool for analyzing the voltage gain for electronic circuits, particularly amplifiers, and filters. It graphically depicts the voltage gain against a range of frequencies on a logarithmic scale, allowing for ease of identification of characteristics such as maximum gain, bandwidth, and the frequencies at which the gain drops by 3dB from the peak, known as F_{-3dB}. The F_{-3dB} shows the limits of this effective range, marking the frequencies at which the gain begins to diminish significantly, serving as a practical measure of the system's frequency limits. The bandwidth shows the range of frequencies at which the amplifier can operate effectively.

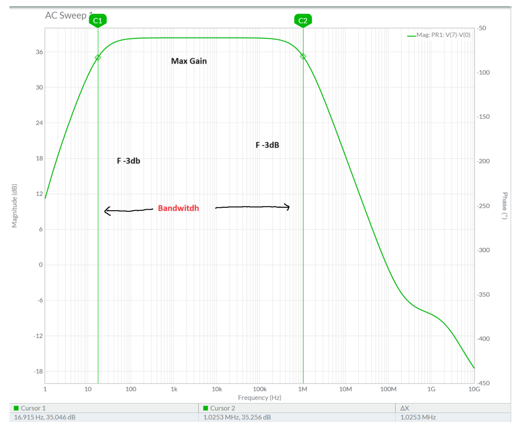

Fig 2-1: Gain V/V

- $F_{-3\text{dB}}$ High: 250 kHz
- $F_{-3\text{dB}}$ Low: 63 kHz
- Bandwidth = 187 kHz
- Peak Gain = 38.5 dB

Figure 2-2 shows the relationship between the phase shift between the voltage input (Vin) and the voltage output (Vout) across various frequencies.

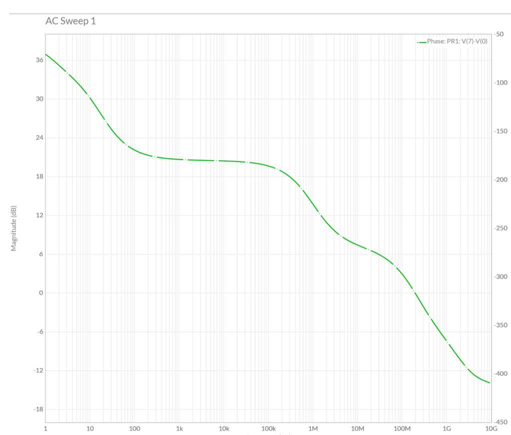

Fig 2-2: Phase Angle

The transient response is shown in Figure 2-3. The amplitude of the voltage is shown in the time domain.

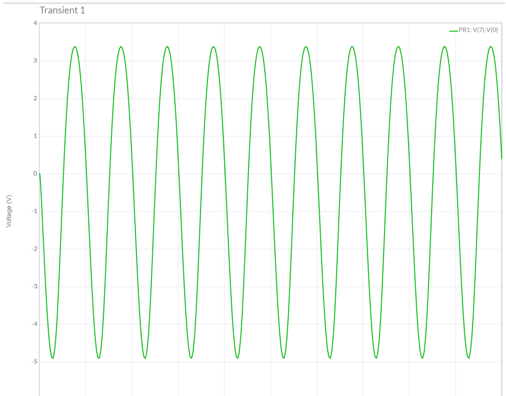

Fig 2-3: Transient Response

The input impedance AC sweep shown in Figure 2-4 was determined by measuring the voltage input and current going into the circuit. Using Ohm's Law, we divide the voltage over the current to obtain the impedance. The AC sweep allows us to view the frequency response.

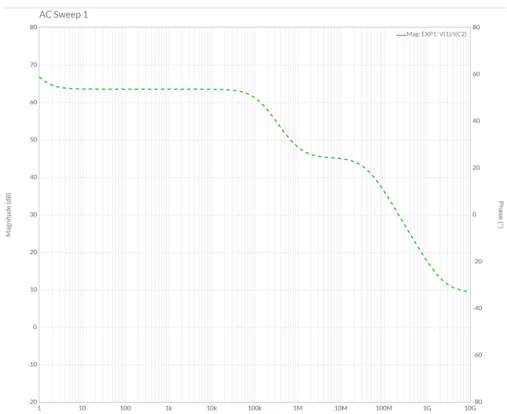

Fig 2-4: Input Impedance

Figure 2-5 shows the frequency response of the output impedance, which was found using Ohm's Law. This shows how the output impedance drops drastically after 500kHz.

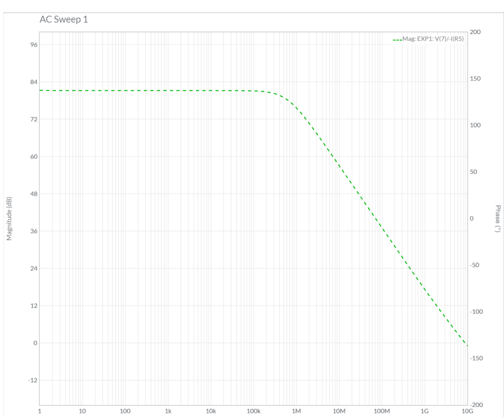

Fig 2-5: Output Impedance

Results	Hand	Multisim	Lab	Error
Rin	1.8 kohm	1.67 kohm	1.4 kohm	20%
Rout	2.7 kohm	1.4 kohm	0.9 kohm	10%
Gain	12.4 V/V	10.2 V/V	37 V/V	60%

TABLE II: AC Impedance and Gain

V. LAB MEASUREMENTS

The measurements obtained in the practical lab are depicted below. The figures are labeled with the corresponding image/plot of the lab measurement. The graphs contain the Gain, Input/Output Impedance, Phase Angle, and Transient response.

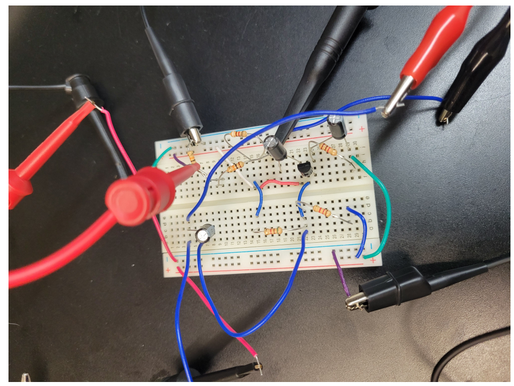

Fig 3-1: MOSFET Amplifier Circuit

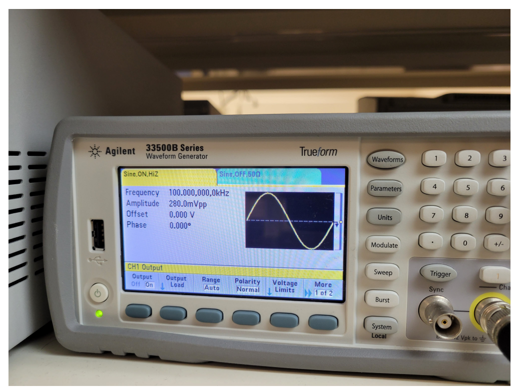

Fig 3-2: AC Power Supply

Fig 3-3: DC Power Supply

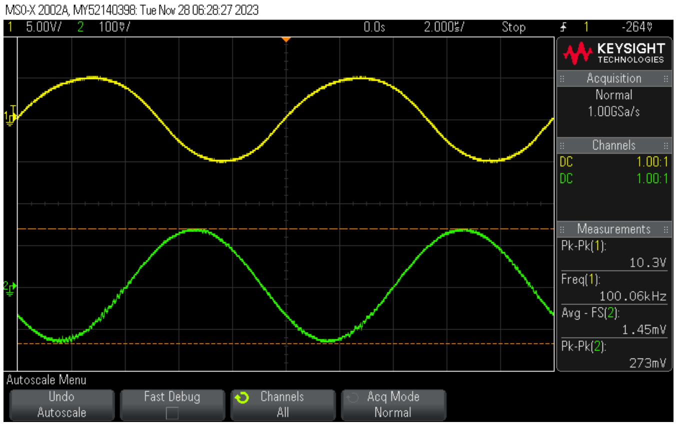

Fig 3-4: Oscilloscope

VI. AREAS FOR FUTURE RESEARCH/IMPROVEMENT

There is definitely room for improvement. One major improvement would be to find better values for an optimal operating point (Q point). By obtaining better values for the operating point, the swing would be more aligned and symmetrical along the Y-axis. Using less wire, such as clipping the resistor excess wire along with the actual wires themselves would reduce the resistance that may cause some noise in the signal output.

Much time was spent on finding the value of the transconductance parameter (Kn) and values that were not given in the project. There were some unclear instructions in the project that led to the delay in the completion of the project. Some issues were out of our control for example the quality of the components, such as the capacitors, resistors, power supply, function generator, and the list goes on. With that said, the circuit behaved correctly and met the requirements.

VII. CONCLUSION

The purpose of this lab was to design, build, and test a Metal-Oxide-Semiconductor-Field-Effect-Transistor (MOSFET) Amplifier circuit. Hand calculations were compared to the simulation and the values obtained in the practical lab. From prior knowledge, it was known that the values obtained in each experiment were not going to be exact.

The simulation, hand calculations, and lab values are not the same. There is a small discrepancy between the three measurements. The main reason is that the theoretical (simulation/calculations) assumes ideal conditions. Of course in practice ideal conditions are don't exist. As mentioned before this affected not only the values but the quality of the signal. In order to resolve these issues, various tests were performed. Adjusting the R1 and R2 values for biasing, as well as trying different capacitor values. This helped in achieving in the desired voltage peak-to-peak output, and a symmetrical sine wave.

Increasing the voltage input above 290mV would result in an unsymmetrical sine wave, this would result in a gain above 11 Vpp. Having the optimal operating point (Q-point) is crucial as well, as it allows for more room for error in the input signal. If your Q-point is not centered it will result in clipping in the signal output.

The practical values were within 10 percent in the error range and an outlier of 18 percent. The MOSFET Amplifier circuit met all the requirements and fell within the constraints mentioned. The hand calculations provided the foundation of a starting point for the circuit. The theoretical values found did not provide the best results, where the circuit would clip slightly. This was solved by adjusting the input AC voltage. The DC Voltage remained constant. With these slight modifications, the desired result of the signal output was achieved. With an input AC signal of 280 mVpp and DC power supply of 20 V, resulted in an output of 10.3 Vpp with a gain of 37 V/V with a power consumption of 75 mW.

VIII. REFERENCES

[1] Abasifreke Ebong, Chapter 5: MOSFET Transistors (BJT), Oct 2021.

[2]. ECGR 3131 Fall 2023 Project 2 – MOSFET Amplifier. (2023) [eBook]. Charlotte: UNCC. [Accessed 26 November. 2023]