MOSFET Power Amplifiers: Class A, B and AB

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***Abstract*—In this lab, MOSFETs were used to create three different power amplifier output stages. The three different types were class A, B and AB. Class A consists of a NMOS transistor and a resistor. Class B consists of a PMOS transistor and an NMOS transistor. Class AB consists of a PMOS transistor, NMOS transistor, three resistors, and two capacitors. The three classes have different characteristics, which will result in having different voltage outputs. The different classes will be connected to the output of an amplifier with a gain of 10 V/V. The class A and class AB amplifier should have an output voltage greater or equal to 1 V. The B class amplifier is not able to reach a 1 V output. The input will be a sine wave with specific amplitude. The output will be recorded and the efficiency will be calculated. The different efficiencies will be compared with the different classes.**

I. INTRODUCTION

The purpose of this lab is to design power amplifiers that provide a signal gain without any loss by maintaining a low output resistance. Power amplifiers can produce high voltages and current and generate lots of heat. The requirement for these power amplifiers is for high conversion efficiency in order to reduce the temperature increase and prevent damage for the transistor. Power amplifiers are classified by their resulting output waveforms. This lab covers the design of Class A, B, and AB amplifiers. The theory discussed in this lab for power amplifiers uses BJTs; However, the lab uses MOSFETs in their design.

II. CIRCUIT THEORY

The most popular class A follower is the emitter follower constructed with BJTs shown in Fig. 1.

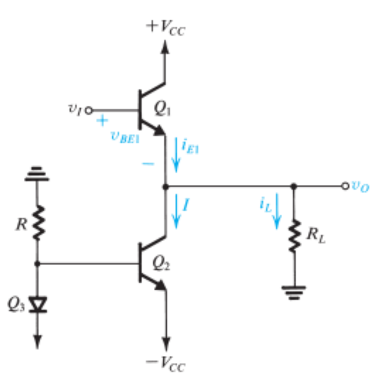

Fig. 1. Emitter follower circuit

The power-conversion efficiency is calculated by the following (1).

$$\eta = \frac{Load\ power(P_L)}{Supply\ power(P_S)} \quad (1)$$

In this lab, the output voltage is a sinusoid. The load power is calculated by the following (2).

$$P_L = \frac{(\hat{V}_O/\sqrt{2})^2}{R_L} = \frac{1}{2}\frac{\hat{V}_O{}^2}{R_L} \quad (2)$$

The average current passing through Q_1 and Q_2 is I, therefore the supply power is given by (3) and the efficiency can be found by (4).

$$P_S = 2V_{CC}I \quad (3)$$

$$\eta = \frac{1}{4}\left(\frac{\hat{V}_O}{IR_L}\right)\left(\frac{\hat{V}_O}{V_{CC}}\right) \quad (4)$$

The maximum efficiency from a class A is when $\hat{V}_O = IR_L = V_{CC}$ which is 25%. The same efficiency of our equivalent MOSFET circuit in Fig. 2 is expected.

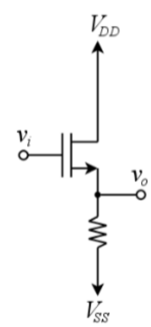

Fig. 2. A source follower circuit.

The class B amplifier is constructed using complementary BJTs as shown in Fig.3.

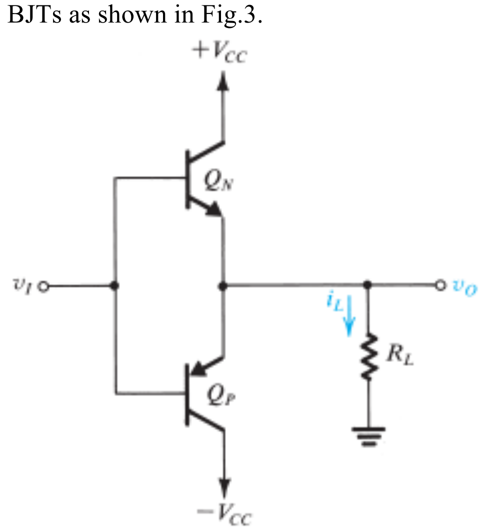

Fig. 3. A class B output stage.

The expected output of the class B amplifier will have cross over distortion shown in Fig. 4. because there is a point in which both transistors are off.

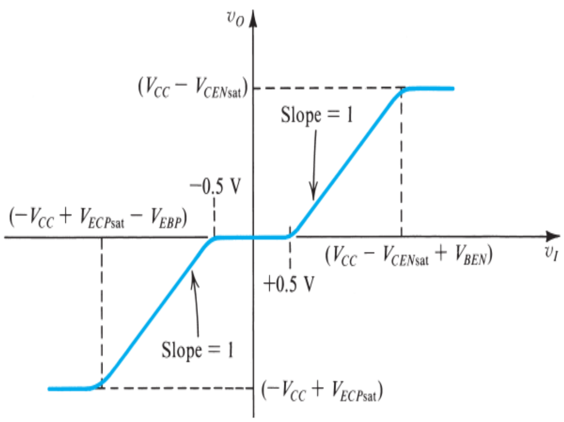

Fig 4. The transfer characteristic of the class B output stage.

The load power is still calculated by (2). The current drawn by the two transistors will be have sine waves, so the supply power is calculated by (5). Using these equations, the resulting efficiency is seen in (6).

$$P_S = \frac{2}{\pi}\frac{\hat{V}_O}{R_L}V_{CC} \quad (5)$$

$$\eta = \frac{\pi}{4}\left(\frac{\hat{V}_O}{V_{CC}}\right) \quad (6)$$

The maximum power of the class B output stage is 78.5%. Fig. 5. shows the class B output stage using CMOS, which should not have any cross over distortion because they cannot be off at the same time.

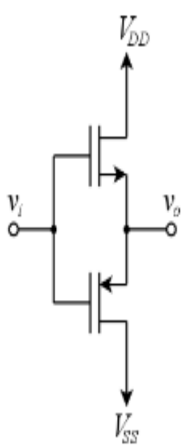

Fig. 5. The equivalent class B output stage in CMOS

Fig.6 shows a class AB output stage which is like the class B, only that the transistors are biased to ensure that they are never off at the same time.

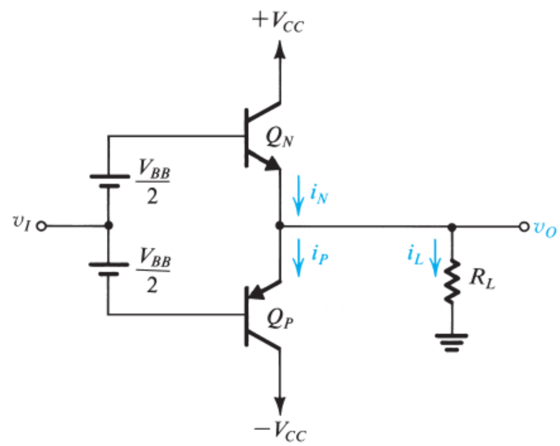

Fig. 6. The class AB output stage

Looking at the transfer characteristic in Fig. 7. The cross over distortion is eliminated resulting in the benefits of a high efficiency without distortion.

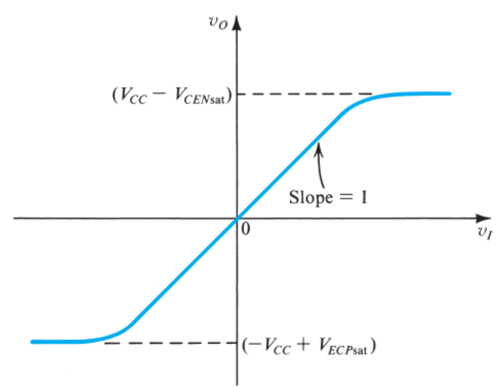

Fig . 7. Transfer characteristic of the class AB stage.

The equivalent circuit for CMOS is shown in Fig. 8. The MOSFET transistors are biased using three resistors allowing the NMOS on top to have a high gate voltage and the PMOS down below to have a low gate voltage.

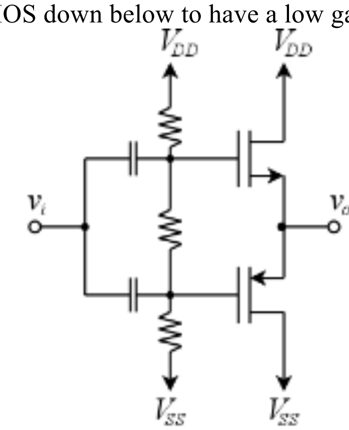

Fig . 8. The CMOS class AB output stage.

III. SIMULATION AND EXPERIMENTAL RESULTS

A common source amplifier was created to produce a gain of 10 V/V. This amplifier is shown in Fig. 9. The values calculated were R_3= 600 kΩ, R_4= 450 kΩ, R_5= 5 MΩ, C_2= 1 uF, and C_3= 100 uF. The value of R_5 is so great so that the output voltage can be measured with a voltage probe. The gain to this circuit is 11 V/V.

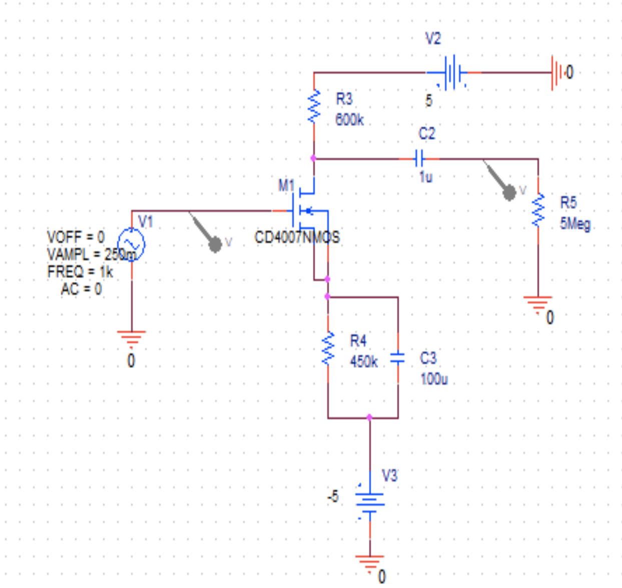

Fig. 9. A common source amplifier with an 11 V/V gain.

The amplifier was connected to a Class A amplifier output stage. The values were calculated to be R_7= R_8= R_{10}= R_{11}= 3 MΩ, and R_5= R_9= 1 kΩ. This can be seen in Fig 10.

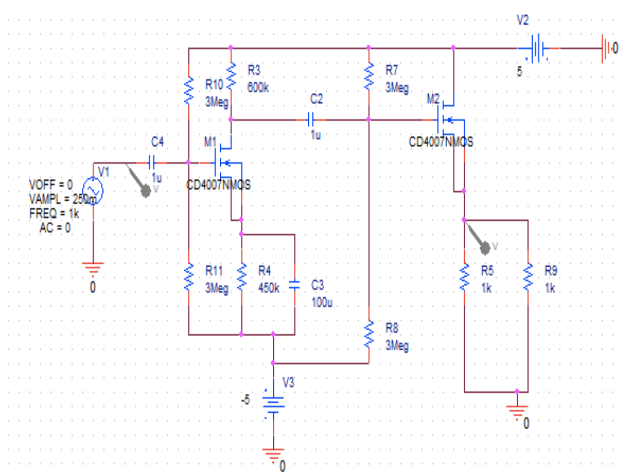

Fig 10. Class A amplifier output stage circuit.

The output of the Class A circuit can be seen in Fig. 11. A sine output voltage with amplitude of 2.3 V is received when a 250 mV amplitude sine wave is inputted. The efficiency for this Class A circuit can be calculated to be 5.3%.

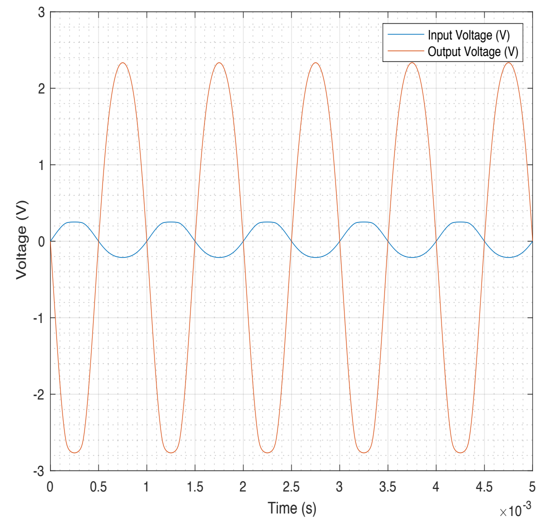

Fig. 11. Class A amplifier output stage results.

The Class A amplifier output stage was replaced for a Class B one. The values calculated were R_7= R_8= 1.2 MΩ, R_5= 1 kΩ, and C_3= 10 uF. This can be seen in Fig. 12.

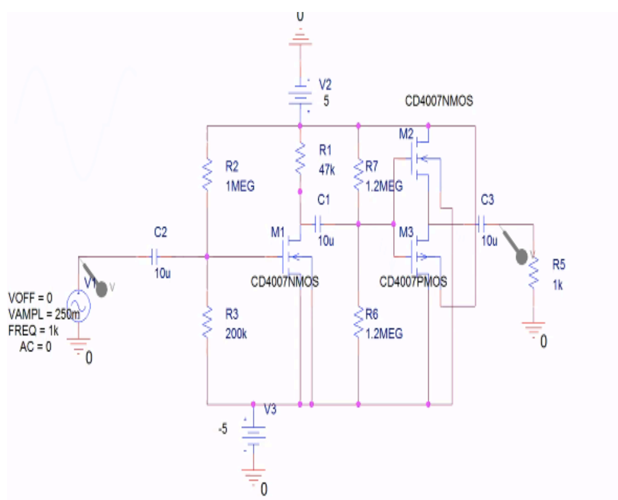

Fig. 12. Class B amplifier output stage circuit.

The output can be seen for the Class B amplifier output stage in Fig. 13. The output is looks different due to the crossover distortion. This is due to the fact that both transistors are cut off and the output voltage is zero where the input voltage is zero. The efficiency for this Class B circuit is 36%.

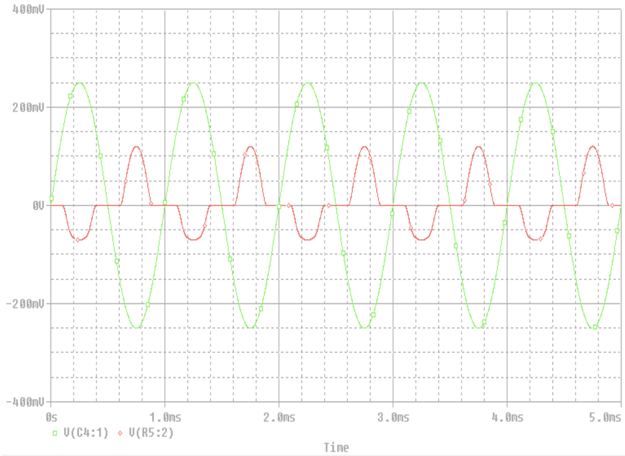

Fig. 13. Class B amplifier output stage results. Input voltage (green), output voltage (red).

A Class AB amplifier output stage is inserted to get rid of the distortion caused by Class B. Class AB can be seen in Fig. 14. The values were R_7= 2 MΩ, R_8= 5 MΩ, R_{13}= 100 GΩ, R_{14}= 100 MΩ, R_5= 1 kΩ, and C_8= 10uF.

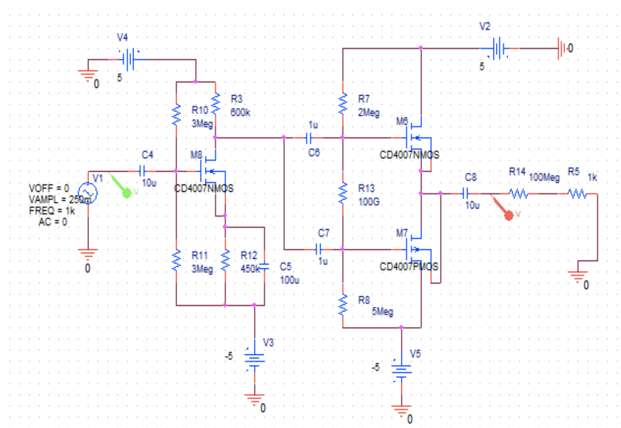

Fig. 14. Class AB amplifier output stage circuit.

The results can be seen in Fig. 15. The output voltage can be seen to be 2.1 V. The efficiency for this Class AB circuit is 33%.

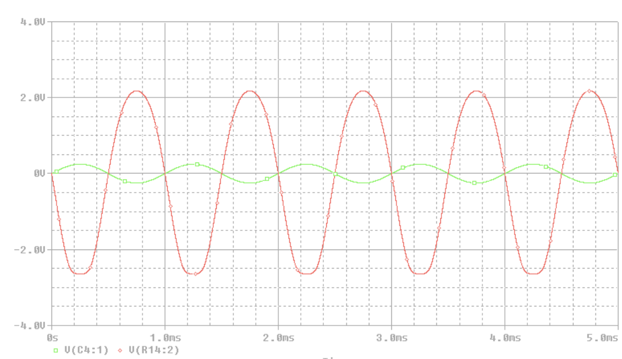

Fig. 15. Class AB amplifier output stage results. Input voltage (green), output voltage (red).

IV. DISCUSSION AND CONCLUSION

A power amplifier was built for this lab and different amplifier output stages were being connected to it. The power amplifier had a gain of 11 V/V and Classes A, B, and AB. These circuits were simulated and received an efficiency of 5.3%, 36%, and 33%. The Class A amplifier output stage was the simplest to build but had the least efficiency. The Class B output was more complicated and had a greater efficiency but had distortion due to both CMOS transistors being turned off at a certain time. To get the efficiency from Class B and get rid of the distortion, resistors and capacitors were added to create Class AB.

There is some distortion in the results for our circuit. This can be traced back to the 11 V/V gain amplifier. This is caused by the resistor values that were chosen and causing the CMOS transistors to act different. Another observation is that the csv file for the Class B and Class AB didn't download correctly. The results come directly from PSPICE.

ACKNOWLEDGEMENTS

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Ridge- 50% Lab, Introduction and Circuit Theory, Simulation and Results

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