
Experiment 5

Single-Stage MOS Amplifiers

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1 Objective

This is the first lab dealing with the use of transistors in amplifiers. We will be dealing with the MOS common-source (CS) amplifier in this experiment. You will measure the transfer curve and from it, determine the bias point. The voltage gain and output resistance will be measured. From these measurements, you should understand the trade-offs involved in biasing a CS amplifier.

2 Prelab

1. Reading H&S: Chapter 8.1, 8.5
2. You will now consider biasing issues with FETs. Below is an NMOS transistor that will be configured as a common source amplifier. For the circuit in Fig. 1, determine the DC bias voltage V_{IN} so that $V_{OUT} = 2.50$ V for $R_D = 5$ k Ω . Use the following MOS parameters for hand calculation and for SPICE, in which you should plot V_{OUT} vs. V_{BIAS} .
 $V_{TO} = 0.9$ V, $K_p = 86 \times 10^{-6}$ A/V², $\lambda = 0.08$ V⁻¹
3. Derive the expressions for the small-signal parameters g_m and r_o using the drain current in saturation; evaluate these parameters at this bias point.
4. In Fig. 2, the resistor has been replaced by an ideal 500 μ A current source. Using the above device parameters, find the DC bias voltage V_{IN} so that $V_{OUT} = 2.5$ V.

FIGURE 1.

NMOS transistor in the common source configuration with resistor current supply.

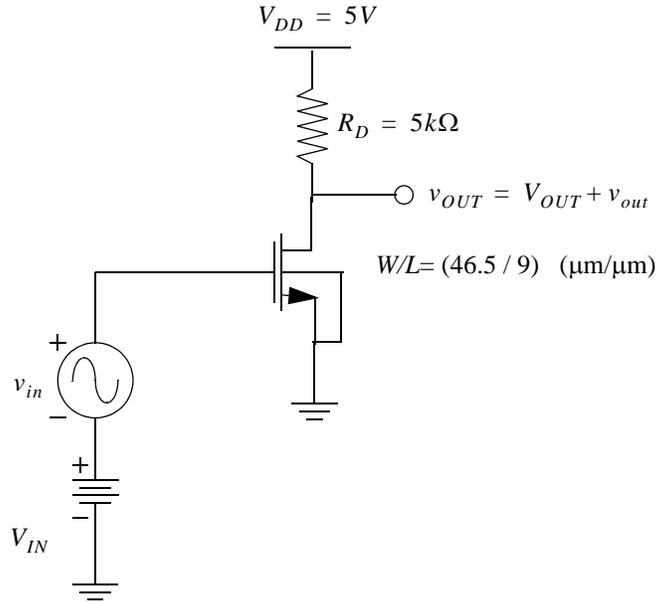
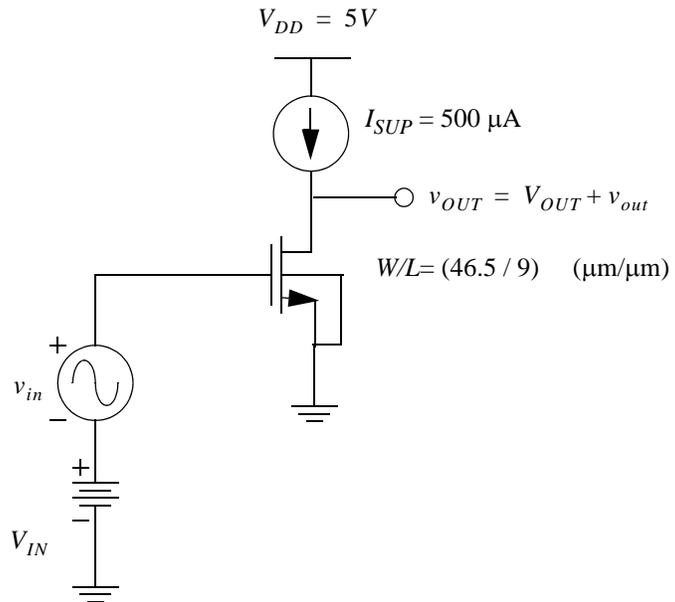


FIGURE 2.

NMOS transistor in the common source configuration with current-source supply.



3 Static Measurements using HP 4155

3.1 Finding the Transfer Curve

The goal of this section is to bias the common-source amplifier in Fig. 3 properly. Using the HP 4155, we can sweep V_{IN} and see how the DC output voltage varies. In addition, we can use the slope function to find how the magnitude of the small-signal gain

$$|A_v| = \left| \frac{dv_{OUT}}{dv_{IN}} \right| \quad (\text{EQ 1})$$

varies with the DC input bias voltage V_{IN} .

3.2 Circuit and HP 4155 Measurement Set Up

To make measurements of the output voltage, we need to use a VMU (voltage measurement unit), which functions as a voltmeter. Set up the circuit in Fig. 3 and make the appropriate HP 4155 channel definitions.

Sweep the voltage v_{IN} from 0 V to 5 V, using a 25 mV step size. Plot the output voltage v_{OUT} versus v_{IN} , which is called the transfer curve.

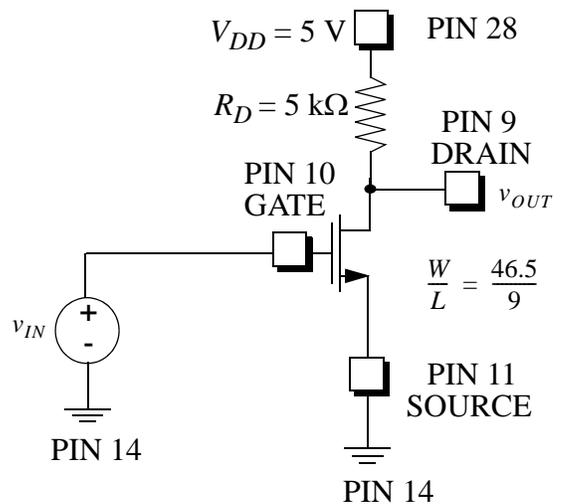
In order to plot the magnitude of the small-signal gain versus the DC input bias voltage V_{IN} , a user definition similar to the following should be made:

$$\text{ABS}(\text{DIFF}(\text{Var1}, \text{Var2})) \quad (\text{EQ 2})$$

What are Var1 and Var2 in this case?

FIGURE 3.

Common Source Amplifier (Lab Chip 1)



3.3 Triode/Saturation Boundary

By moving the cursor on your transfer curve, find the value of V_{IN} at which the transistor enters the triode region; call this value V_1 . Printout your transfer curve.

Recall that the test for a MOSFET to be in the saturation region is

$$V_{DS} \geq V_{GS} - V_{Tn} = V_{DS(SAT)} \quad \text{which implies that} \quad V_{OUT} - V_{IN} \geq V_{Tn} \quad \text{(EQ 3)}$$

An alternative approach is to plot $V_{OUT} - V_{IN}$ versus V_{IN} . If you use this approach, use a 5 mV step size and make a printout of your plot. What happens to the small-signal gain once the transistor enters the triode region?

3.4 Maximum Gain Bias Point

Find the input voltage V_{IN} for maximum small-signal gain; call this value V_2 . Are V_1 from setp 3.3 and V_2 far apart? If we need to amplify a sinusoidal signal-signal input voltage v_{in} with an amplitude of 100 mV, can we bias this CS amplifier with $V_{IN} = V_2$? Hint: consider the range of the total input voltage $v_{IN} = V_{IN} + v_{in}(t)$.

3.5 Gain versus DC Output Voltage Curve

Plot the magnitude of the small-signal voltage gain versus V_{OUT} . Find the output voltage range for which the amplifier's gain is greater than 50% of the maximum gain. On what side of the maximum does the gain decrease sharply? Explain why.

3.6 Bias Point for 1 V Output Swing

Find a DC output bias point V_{OUT} for which the small-signal voltage gain is greater than 2.5 and that allows an output swing of 1 V peak-to-peak, without severe distortion of $v_{out}(t)$. The amplitude of the output voltage v_{OUT} 's time-varying component, in other words, could be as large as 1 V.

3.7 Increased Drain Resistance

Now replace the drain resistor with $R_D = 100 \text{ k}\Omega$ and repeat steps 3.3 - 3.6. How did the gain and the values of V_1 and V_2 change? Are the results consistent with the DC and small-signal models for this amplifier?

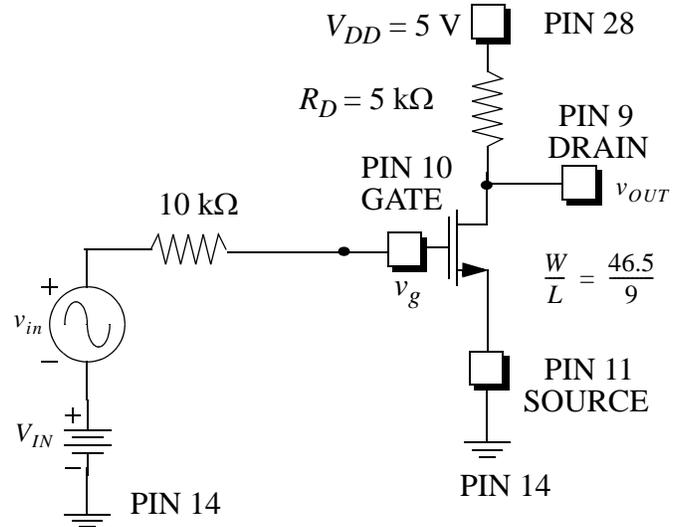
4 Common-Source Amplifier Two-Port Parameters

Figure 4 shows a common source amplifier. Let $R_D = 5 \text{ k}\Omega$. Set your function generator such that it gives $V_{IN} + v_{in}(t)$. Use the input bias value V_{IN} you found in 3.6 above.

4.1 Small-signal voltage gain measurement

Let v_{in} be a sinusoid with an amplitude of 100 mV at a frequency of 5 kHz. Use the oscilloscope to measure the the small-signal gain v_{out} / v_{in} . Compare the value you find to that which you measured in section 3.6.

FIGURE 4. Common Source Amplifier (Lab Chip 1)



4.2 Output resistance measurement

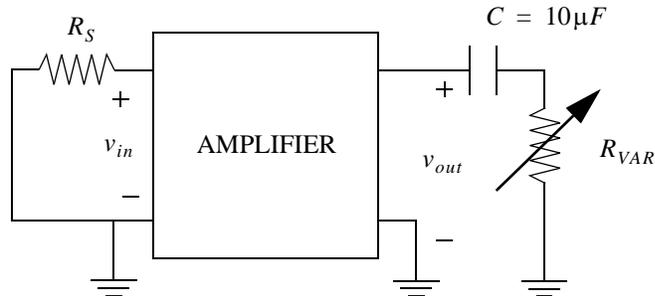
The output resistance R_{out} can be measured using the standard approach described in Fig. 5. The technique uses the fact that the very large capacitor is an effective short circuit for sinusoidal signals at the measurement frequency, whereas it is an open circuit as far as the DC bias of the amplifier is concerned. This useful property of capacitors allows us to vary the load resistor (R_{VAR}) without altering the bias point of the transistor.

Measure the amplitude at v_{out} . Connect the capacitor and the variable resistor to the output of the circuit as depicted in Fig. 4. Adjust the resistance until the amplitude at v_{out} is reduced by one-half. The value of the variable resistor is equal to the output resistance. Explain why this procedure finds the output resistance by applying the voltage form of the 2-port model of the common-source.

Compare your measurement to the predicted value of R_{out} from the small-signal model; the channel-length modulation parameter is $\lambda = 0.08 \text{ V}^{-1}$ for this MOSFET. Calculate the DC drain current by using the bias point of V_{OUT} and the measured value of R_D .

FIGURE 5.

2-Port Representation of Amplifier to find R_{out}



4.3 Clipping of the Output Voltage Waveform

Increase the amplitude of $v_{in}(t)$ until the output waveform $v_{out}(t)$ starts to become significantly distorted by “clipping.” What is the maximum amplitude of $v_{out}(t)$ before clipping is significant? Does it agree with the value you found in section 3.5? Explain briefly the reason for clipping. Hint: consider why the lower portion of the waveform is distorted before the upper portion.

5 Optional Experiment

5.1 Modified drain resistance

Repeat section 4 with a drain resistance $R_D = 10\text{ k}\Omega$. What are the differences between the measurements on the original amplifier and the one with the higher drain resistance?