

## LAB 5.5

# NMOS Common-Source Amplifier

[See Section 5.8.2, p. 316 of Sedra/Smith]

### OBJECTIVES:

To study an NMOS-based common-source (CS) amplifier by:

- Completing the DC and small-signal analysis based on its theoretical behavior.
- Simulating it to compare the results with the paper analysis.
- Implementing it in an experimental setting, taking measurements, and comparing its performance with theoretical and simulated results.
- Measuring its output resistance.
- Qualitatively seeing the impact of transistor-to-transistor variations.

### MATERIALS:

- Laboratory setup, including breadboard
- 1 enhancement-type NMOS transistor (e.g., MC14007)
- 3 large (e.g., 47- $\mu$ F) capacitors
- Several resistors of varying sizes
- Wires

### PART 1: DESIGN AND SIMULATION

Consider the circuit shown in Figure L5.5:

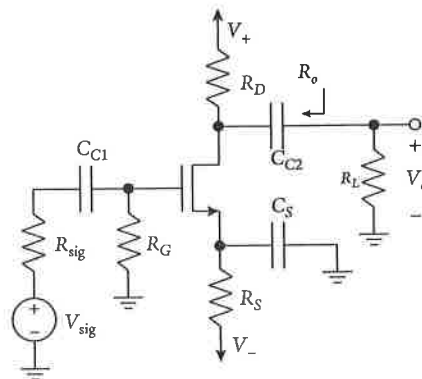


FIGURE L5.5: Common-source amplifier circuit, with coupling capacitors, and resistor  $R_G$  for DC-biasing purposes. Based on Fig. 5.57 p. 317 S&S.

Design the amplifier to achieve a small-signal gain of at least  $A_v = -5$  V/V. Use supplies of  $V_+ = -V_- = 15$  V,  $R_{sig} = 50 \Omega$ ,  $R_L = 10$  k $\Omega$ ,  $R_G = 10$  k $\Omega$ , and design the circuit to have  $I_D = 1$  mA. Obtain the datasheet for the NMOS transistor that will be used. In your lab book, perform the following:

#### DC Operating Point Analysis

- Sketch a DC model of the circuit in your lab book, replacing the three “large-valued” coupling capacitors  $C_{C1}$ ,  $C_{C2}$ ,  $C_S$  by open circuits (for simplicity you may also omit  $v_{sig}$ ,  $R_{sig}$ , and  $R_D$ ). What is the DC current through  $R_G$ ?
- Based on the information just given, you have enough information to calculate  $V_{OV} = V_{GS} - V_{in}$ . What is its value? What is the value of  $g_m$ ? What is  $V_{GS}$ ? Remember: Your actual transistor will have a value of  $V_{in}$  that will vary from its nominal value, which will alter your measurement results slightly!
- Calculate  $r_o$ .
- You now have enough information to calculate  $R_S$ . Show your calculations. Is the value you calculate for  $R_S$  available in your kit? Can you achieve this value by combining several resistors? Comment.
- *Note:* At this stage we know neither  $V_{DS}$  nor  $R_D$ .

#### AC Analysis

- Sketch a small-signal model of the circuit in your lab book, replacing the transistor with its small-signal model, replacing the capacitors with short circuits (what happens to  $R_S$ ?), and replacing  $V_+$  with an AC ground. What happens to  $V_-$ ? Label the gate of the transistor as  $v_i$ , i.e., the small-signal voltage at the input.
- What is the ratio of  $v_o/v_{sig}$ ? How would you approximate it in further calculations?
- Derive an expression for  $A_v = v_o/v_i$ . What is the value of  $R_D$  that produces a small-signal voltage gain of *at least*  $A_v = -5$  V/V? Is the value you calculated for  $R_D$  available in your kit? Can you achieve this value by combining several resistors? Comment.
- What is the DC voltage at the drain? Does this satisfy the assumption that the transistor should be operating in the saturation region? Explain.
- What is the output resistance,  $R_o$ ?

#### Simulation

- Simulate your circuit. Use capacitor values  $C_{C1} = C_{C2} = C_S = 47 \mu\text{F}$ , and the values of  $R_S$  and  $R_D$  based on your preceding calculations. Use a 10-mV<sub>pk-pk</sub>, 1-kHz sinusoid with no DC component applied at  $v_{sig}$ .
- From your simulation, report the DC values of  $V_{GS}$ ,  $V_{DS}$ , and  $I_D$ . How closely do they match your calculations? (Remember: The simulator has its own more-complex model of the real transistor, so there should be some small variations.)
- From your simulation, report  $A_v$ . How closely does it match your calculations?

## PART 2: PROTOTYPING

- Assemble the circuit onto your breadboard using the specified component values and those just calculated. Note that  $R_{sig}$  represents the output

resistance of the function generator, and therefore you should *not* include it in your circuit.

### PART 3: MEASUREMENTS

- *DC bias point measurement:* Using a digital multimeter, measure the DC voltages of your circuit at the gate ( $V_G$ ), source ( $V_S$ ), and drain ( $V_D$ ) of your transistor.
- *AC measurement:* Using a function generator, apply to your circuit a 10-mV<sub>pk-pk</sub>, 1-kHz sinusoid with no DC component. (*Note:* Some function generators allow only inputs as small as 50 mV<sub>pk-pk</sub>. If this is the case, use that value instead.)
- Using an oscilloscope, generate plots of  $v_o$  and  $v_i$  vs.  $t$ .
- *Output resistance  $R_o$ :* Replace  $R_L$  with a 1-M $\Omega$  resistor and repeat the AC measurement. What is the amplitude of the output waveform? Adjust  $R_L$  until you find a value such that the amplitude of the output waveform is approximately 50% of what it was for the 1-M $\Omega$  load. This new value of  $R_L$  is the output resistance  $R_o$ . How does it compare to the value you calculated earlier in Step 2? *Hint:* It cannot be greater than the value of  $R_D$ .
- *Further exploration:* What happens to the shape of the output signal as you increase the amplitude of the input signal, e.g., to 1 V<sub>pk-pk</sub>? At what input amplitude do you begin to see significant distortion? Can you explain this?
- Using a digital multimeter, measure all resistors to three significant digits.

### PART 4: POST-MEASUREMENT EXERCISE

- Calculate the values of  $V_{GS}$  and  $V_{DS}$  that you obtained in the lab. How do they compare to your pre-lab calculations? Explain any discrepancies.
- Based on the measured values of  $V_D$  and  $V_S$  and your measured resistor values, what is the real value of  $I_D$  based on your lab measurements?
- What is the measured value of  $A_v$ ? How does it compare to your pre-lab calculations? Explain any discrepancies.
- *Hint:* The single biggest source of variations from your pre-lab simulation results will be due to variations in the transistor threshold voltage  $V_{in}$ . Remember: Its value will be somewhere within the range indicated on the transistor datasheet.

### PART 5 [OPTIONAL]: EXTRA EXPLORATION

- Instead of tying  $R_G$  to ground, try tying it to the drain terminal of the transistor. Repeat the DC bias point measurement and the small-signal gain measurement. What has changed? Do  $R_D$  and  $R_S$  need to be altered to meet design specifications?