3: Transfer Functions, Parameters, and Equivalent Circuits of Linear Amplifiers: PART C

ECE 3200 Electronics II
updated 8 March 2021

Reference

1. S. Sedra and K. C. Smith, Microelectronic Circuits, 7th ed., Oxford University Press, 2015.

Objectives (cont'd)

5. To examine the effects of source and load resistance on the effective voltage and current gain of a linear amplifier.

6. To use an equivalent circuit representation for circuit analysis.

7. To improve and further develop an ability to effectively communicate technical information via written records and/or reports.

Procedures

Use your measured component values in your simulations.

1. AMPLIFIER OUTPUT RESISTANCE MEASUREMENT
   Use your SPICE engine to determine (in the linear operating region):
   a. The amplifier input resistance r_i for $R_L \approx$ 1M and $R_L \approx$ 100 to see if R_L affects r_i. Use a "DC transfer" analysis with ".tf V(vR) vS" and R_s set to a small value (e.g. 1mΩ)(otherwise R_s will affect the analysis).
   b. The amplifier output resistance r_o for $R_S \approx 10\, r_i$ and $R_S = 0$ to see if R_S affects r_o. Use a "DC transfer" analysis with ".tf V(vR) vS" and R_L set to a large value (e.g. 1000MEG)(otherwise R_L will affect the analysis).

2. AMPLIFIER OUTPUT RESISTANCE MEASUREMENT (method 1)
   Use your SPICE engine to determine the transfer function $v_R$vs. v_S (NOT v_I) for the case $R_S = r_i$ and $R_L = r_o$. Use a DC sweep of v_S to determine this transfer function. Identify the region of linear operation, the output offset voltage, and saturation voltages. Using this transfer function determine the effective small signal voltage gain v_r/v_s and the effective small signal current gain i_l/i_i in the linear region. Also find the power gain

   $$A_p = \text{(AC power delivered to the load)/(AC power delivered by the source)}$$

   Note that the AC power delivered to the amplifier does not include the power of R_S.

3. AMPLIFIER OUTPUT RESISTANCE MEASUREMENT (method 2)
   Measure the amplifier output resistance r_o for a 40Hz sinusoidal input signal (as usual, do so within the range of linear operation). Assume input and output resistances are the same as at DC.

Perform the following procedure once for $R_S \approx 10\, r_i$ and once for $R_S = 0$ to see if R_S affects r_o:

a. Measure v_{RL1} for $R_L = R_{L1} = 1$K and v_{RL2} for $R_L = R_{L2} =$ 1M. Use these measurements and the actual values of the two resistors to compute r_o (this is known as the varying R_L method):

$$r_o = -\frac{(v_{RL2} - v_{RL1})}{\left(\frac{v_{RL2}}{R_L} - \frac{v_{RL1}}{R_L}\right)}.$$

b. Compare to value found in Step 2.

4. SMALL SIGNAL AMPLIFIER MODEL (read, no other action needed)
The equivalent circuit of Figure 1 is used to model the **small signal operation** (i.e. in the LINEAR region) of the amplifier about its quiescent point at (V_I, V_R)=(0, V_{ROS}). A_{vo} is the open circuit voltage gain determined in procedure 6 of LAB 3 PART A.

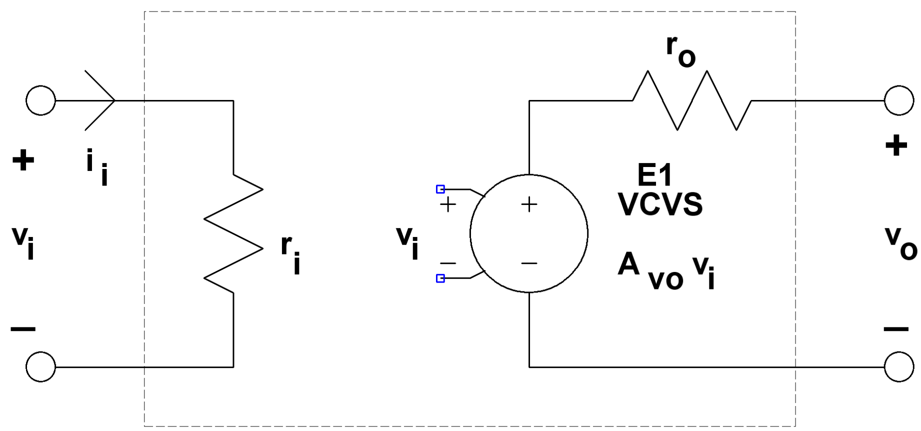

Figure 1. Small Signal Amplifier Model

5. AMPLIFIER PERFORMANCE WITH MATCHED SOURCE AND LOAD RESISTANCE
Change R_s to a value approximately equal to r_i and change R_L to a value approximately equal to r_o. Use your SPICE engine to plot v_R vs. v_S (NOT v_I), the dynamic transfer function for a 40Hz input signal. Be sure your circuit is in the sinusoidal steady-state.

Observe/measure/determine and record the following amplifier parameters:

a. Region of linear operation, output offset voltage, and saturation voltages.

b. Effective small signal voltage gain (v_r/v_s), obtained from the transfer function in the linear region.

c. Effective small current gain (i_l/i_i).

d. Adjust v_s to get a medium amplitude 40Hz sinusoidal signal at the output. Measure the power gain A_p and the amplifier efficiency η. The SPICE .MEAS command can be used to find RMS values of the power supply currents. You need those values to compute power of the voltage supplies.

e. Adjust v_s to give the maximum amplitude 40Hz sinusoidal signal at the output (without noticeable distortion) and measure the amplifier efficiency under these conditions.

f. Determine an estimate of the incremental sensitivity of the amplifier effective voltage gain to the value of R_L by measuring the effective voltage gain first with R_L increased by about 5% and then decreased by about 5%. The incremental sensitivity is

$$S = \frac{\Delta A_{veff}/A_{veff}}{\Delta \mathrm{R_L}/\mathrm{R_L}}$$

Exercises

As always, use figures, graphs, circuit diagrams, theoretical analysis, etc., to support your responses.

1. Refer to procedure 1. What effect does R_L seem to have on r_i? Is the equivalent circuit of Figure 1 a reasonable approximation of the amplifier in this respect? Explain. To do so you might attach a "source" and a "load" to the model and use analysis to show the effect of R_L on r_i.

2. Refer to procedure 2. Using an approach similar to that of exercise 1, determine the effect R_S has on r_o. Is it significant? In a near ideal amplifier such as that shown in Figure 1, what effect would R_S have on r_o? Explain. Is the equivalent circuit of Figure 1 a reasonable approximation of the amplifier in this respect? Elaborate.

3. Using the small signal equivalent circuit of the amplifier for operation about its quiescent point from procedure step 4 to answer the following questions:

    a. Compare (including finding % change) the effective voltage gain and effective current gain found in procedure 5 with the open circuit voltage/short circuit current gains found in procedures 5 (PART A) and 2 (PART A).

    b. What effect(s) (both quantitative and qualitative) do R_S and R_L have on the effective voltage gain and effective current gain? Explain with the aid of the small signal equivalent circuit of the amplifier. Substantiate your results with simulation and circuit analysis showing theoretically determined numeric results.

    c. Using the amplifier equivalent circuit, verify the incremental sensitivity of the amplifier effective voltage gain to the value of R_L as determined in procedure 5f.

4. Analytically determine, using the equivalent circuit, what the amplifier power gain would be if
    a. $R_L = r_o/10$, and

    b. if $R_L = 10\ r_o$.

c. Compare (numerically and qualitatively) these with the simulated value obtained with $R_L = r_o$. Are the results expected? Explain. As always, substantiate your argument with circuit analysis showing theoretically determined numeric results.

d. What value of R_L yields maximum power gain?

e. What value of R_S yields maximum power gain? Again, substantiate your answers via engineering science.

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