Transfer Functions, Parameters, and Equivalent Circuits of Linear Amplifiers: 
PART C
ECE 3200 Electronics II
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Reference

Objectives (cont’d)
5. To examine the effects of source and load resistance on the effective voltage, current, and power 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.

Pre-Laboratory Assignment

Use your measured component values in your simulations.

1. AMPLIFIER INPUT AND OUTPUT RESISTANCE
   Use LTspice® to determine (in the linear operating region):
   a. The amplifier input resistance \( r_i \) for \( R_L \approx 1\,\text{M}\Omega \) and \( R_L \approx 100\,\Omega \) 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. 1\,\mu\Omega; 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 EFFECTIVE VOLTAGE, CURRENT, AND POWER GAIN
   Report results in a table.
   a. Use LTspice® to determine the voltage transfer function \( v_L \) vs. \( v_S \) (NOT \( v_I \)) at 40Hz for the case \( R_S = r_i \) and \( R_L = r_o \). Set \( v_S \) to a 40Hz sinusoidal source with sufficient amplitude to drive the amplifier well into positive and negative saturation. Plot \( v_L \) vs. \( v_S \). Identify the region of linear operation, the output offset voltage, and saturation voltages. Use this graph to determine the effective small signal voltage gain \( A_{v eff} = \frac{v_L}{v_S} \) in the linear region.
   b. Plot \( i_L \) vs. \( i_I \). Identify the region of linear operation, the output offset current, and saturation currents. Use the graph to determine the effective small signal current gain \( A_{i eff} = \frac{i_L}{i_I} \) in the linear region.
   c. Compute the small signal power gain
\[ A_p = A_{veff} A_{ieff} = \frac{v_i l_i}{v_s i_i} \text{(Load power)/(Power supplied by source).} \]

Verify the small signal power gain using LTspice® as follows. First, zero the DC component of the output voltage by adding a suitable DC input offset voltage to \(v_S\). This is conveniently accomplished by setting the AC amplitude of \(v_S\) to zero and adjusting its DC offset to zero the amplifier output voltage. This moves the quiescent “Q” point of the amplifier so the output swings around zero! Then adjust the AC amplitude of \(v_S\) to maximize the output voltage without clipping. Plot \(V(vR)\times i(RL)\) and find the maximum load power. Plot \(V(vR)\times i(RL)\) and find the absolute value of the maximum source power. The ratio is the small signal power gain. If your plots are not smooth, decrease the step size.

**PROCEDURES (cont’d)**

12. **AMPLIFIER Q POINT ADJUSTMENT.** Set \(v_S\) to a 40Hz sinusoidal source. Adjust the AC amplitude of \(v_S\) to get a medium amplitude sinusoidal signal without distortion at the output. Adjust the DC offset of \(v_S\) to zero the amplifier DC output voltage as in the prelab. **ONCE ADJUSTED DO NOT ALTER THE INPUT DC OFFSET VOLTAGE.** Why is this step important?

13. **AMPLIFIER INPUT RESISTANCE MEASUREMENT.** Determine the amplifier input resistance \(r_i\) at 40Hz within the linear operating range. Measure it first with \(R_L=1M\Omega\) and then with \(R_L=100\Omega\). You can use your DMM in AC mode to measure the voltage drop across \(R_S\) in order to compute the RMS value of the input current. Be sure to use the RMS value of the input voltage \(v_s\) when computing \(r_i\) ! Monitor \(v_R\) with the oscilloscope to keep \(v_S\) small enough to prevent distortion of the output.

Compare result to prelab part 1(a). Resolve any discrepancies.
You will need these results to answer exercise 1 – read exercise 1 now.

**NOTE:** As always, with the aid of brief notes, simple circuit diagrams, enumerated, labeled and entitled graphs, tables and sketches, clearly but briefly describe methods that were used to measure the above parameters. Arrange your data in tables where appropriate. Briefly note any unusual or extenuating circumstances associated with the acquisition of the data.

14. **AMPLIFIER OUTPUT RESISTANCE MEASUREMENT.** Measure the amplifier output resistance \(r_o\) for a 40Hz sinusoidal input signal (as usual, do so within the range of linear operation). 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 \(R_L = R_{L1} = 1K\) 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):

\[
r_o = -\frac{(v_{RL2}-v_{RL1})}{(v_{RL2}/R_{L2} - v_{RL1}/R_{L1})}.
\]
b. Compare to the value found in prelab step 1(b). Resolve any discrepancies. You will need these results to answer exercise 2 – read exercise 2 now.

15. SMALL SIGNAL AMPLIFIER MODEL
We may now use the equivalent circuit of Figure 2 to model the low frequency 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 PART A procedure 6. Draw this circuit in your lab notebook. Include your measured values.

![Small Signal Amplifier Model](image)

**Figure 2. Small Signal Amplifier Model**

16. 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 \(r_o\) (you might use potentiometers or a resistor substitution box). Then display, in XY mode, the \(v_R\) vs. \(v_S\) (NOT \(v_I\)) dynamic voltage transfer function for a 40Hz input signal.

Observe, compute, or measure and record the following amplifier parameters. Put results in a table.

a. Region of linear operation, output offset voltage (should be zero due to procedure 12!), and saturation voltages.

b. Effective small signal voltage gain \(A_{veff} = v_i/v_s\) obtained from the transfer function in the linear region.

c. Measure the effective small current gain \(A_{ieff} = i_l/i_i\); a DMM is likely useful here.

d. Compute the small signal power gain \(A_p\).

e. Compare results of (a)-(d) with your prelab. Resolve any discrepancies (there will be one – why?).

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
\[ S = \frac{\Delta A_{\text{eff}}/A_{\text{eff}}}{\Delta R_L/R_L} \]

17. BE SURE ALL EQUIPMENT IS OFF.

**Exercises**

As always, use figures, graphs, circuit diagrams, and comparison of theoretical/experimental/simulation results, etc., to support your responses.

1. Refer to procedure 12. What effect does \( R_L \) seem to have on \( r_i \)? Is the equivalent circuit of Figure 2 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 \( r_i \). Verify these results by a circuit analysis of Figure 1.

2. Refer to procedure 13. 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 2, what effect would \( R_S \) have on \( r_o \)? Explain. Is the equivalent circuit of Figure 2 a reasonable approximation of the amplifier in this respect? Elaborate. Verify these results by a circuit analysis of Figure 1.

3. a. Compare (including finding % change) the effective voltage gain and effective current gain found in procedure 15 with the open circuit voltage/short circuit current gains found in procedures 6 (PART A) and 10 (PART B). Analyze the circuit of Figure 1 and use the amplifier small signal equivalent circuit of Figure 2 to verify these results.

   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.

   c. Using the amplifier equivalent circuit of Figure 2, verify the incremental sensitivity of the amplifier effective voltage gain to the value of \( R_L \) as determined in procedure 15f.

4. Analytically determine, using the equivalent circuit of Figure 2, the amplifier power gain for

   a. \( R_L = r_o \);
   b. \( R_L = r_o /10 \); and
   c. \( R_L = 10 \ r_o \).
   d. Verify (a)-(c) using LTspice®.
   e. What value of \( R_L \) yields maximum power gain?
   f. What value of \( R_S \) yields maximum power gain?

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