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

ECE 3200 Electronics II
updated 14 February 2018

Reference


Objectives (cont’d)

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

7. To experimentally measure and use an equivalent circuit representation for circuit analysis.

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

Pre-Laboratory Assignment
(MUST BE COMPLETED INDIVIDUALLY)

Turn in a copy of your results for the items listed below. Use your measured component/voltage values. Make sure that your assignment meets the guidelines as outlined in the PARTIAL CHECK LIST FOR ANY SUBMITTED LABORATORY ASSIGNMENT document. Either record or paste/tape a copy of your results in your notebook.

1. Use your SPICE engine to determine the amplifier input resistance \( r_i \) and the amplifier output resistance \( r_o \) in the linear operating region under the conditions of procedures 8 and 9. Assume that these resistances are the same at 40Hz and at DC. This will be validated in lab. In LTspice, use a “DC transfer” analysis with “.tf V(vR) vS” and \( R_s \) set to a small value (e.g. 1mΩ; 1fΩ provided an incorrect result).

2. Use your SPICE engine to determine the transfer function \( v_R \text{ vs. } v_S \) (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 \( i_r/i_i \) in the linear region. Also find the power gain

\[
A_p = \frac{\text{(AC power delivered to the load)}}{\text{(AC power delivered by the source)}}
\]

Note that the AC power delivered to the amplifier does not include the power dissipated in \( R_S \).
Procedures (cont’d)

NOTE: IN THESE PROCEDURES YOU MAY NOT MAKE MEASUREMENTS “INSIDE” THE AMPLIFIER CIRCUIT. YOU ARE TO CONSIDER THE AMPLIFIER AS A BOX WITH INACCESSIBLE INTERNAL NODES. You may make measurements only at the input ($v_I$) and output ($v_R$) terminals of the amplifier.

8. AMPLIFIER INPUT RESISTANCE MEASUREMENT. Determine the amplifier’s input resistance $r_i$ at $f \approx 40$Hz within the linear operating region. Measure it first with $R_L \approx 1\,\text{M}$ and then with $R_L \approx 100$. Monitor $v_R$ with the oscilloscope being sure to keep $v_S$ small enough to prevent distortion of the output. You will need these results to answer exercise 1 — read exercise 1 now.

NOTE 1: As always, with the aid of brief notes, simple circuit diagrams, enumerated, labeled and entitled graphs, tables and sketches, clearly but briefly describe the methods that were used to measure the above parameters. Arrange your data in tables where appropriate. If measurements were to be made in the linear region, note how you insured such was the case. Briefly note any unusual or extenuating circumstances associated with the acquisition of the data.

9. AMPLIFIER OUTPUT RESISTANCE MEASUREMENT. Measure the amplifier output impedance $r_o$ for a 40Hz input signal (as usual, do so within the range of linear operation). Proceed as follows. Measure $v_R$ for $R_L = 1\,\text{K}$ and for $R_L = 100$. Use these measurements and the actual values of the two resistors to compute $r_o$ (this is known as the varying $R_L$ method). Do this for $R_S \approx 10 \, r_i$ and $R_S = 0$. Remember to monitor the output with the oscilloscope to avoid distortion. You will need these results to answer exercise 2 — read exercise 2 now.

SMALL SIGNAL AMPLIFIER MODEL. Use the equivalent circuit of Figure 1 to represent 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 4 of LAB 4 PART A.

Draw this circuit in your lab book. Include your measured values.

![Figure 1. Small Signal Amplifier Model](image)
10. 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 transfer function for a 40Hz input signal.

Observe/measure/determine and record the following amplifier parameters (the DMM may be more useful for current and power gains, be sure and keep operation in the linear region during DMM measurements):

a. Region of linear operation (print out or record the transfer function for your notebook, **YES, DO IT NOW!!**), 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 ($i_I/i_I$).

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 $\eta$. NOTE: In order to measure the power drawn from the supplies, use small sampling resistors. The RMS value of the current is given by

\[
    i_{\text{RMS}} = \sqrt{I_{\text{DC}}^2 + I_{\text{AC}}^2}
\]

where $I_{\text{DC}}$ and $I_{\text{AC}}$ are obtained by measuring the DC and AC RMS components of the voltage across the sampling resistors and dividing by the resistance values. The power is obtained by multiplying this by the magnitude of the supply voltage (15V).

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

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

11. DO NOT DISASSEMBLE YOUR CIRCUIT UNTIL INSTRUCTED TO DO SO. YOU MAY NEED TO REPEAT PARTS OF THIS EXPERIMENT.

**Exercises**

As always, use figures, graphs, circuit diagrams, theoretical analysis, etc., to support your responses.
1. Refer to procedure 8. What effect does $R_L$ seem to have on $r_i$? Is the equivalent circuit of Figure 1 a reasonable approximation of the real amplifier in this respect? Explain. To do so you might attach a “source” and a “load” and use analysis to show the effect of $R_L$ on $r_i$ for the equivalent and real circuits.

2. Refer to procedure 9. 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 real amplifier in this respect? Elaborate.

3. Using the results of procedures 5, 8, and 9, draw the small signal equivalent circuit of the experimental amplifier for operation about its quiescent point and use it in answering the following questions.
   a. Compare (including finding % change) the effective voltage gain and effective current gain found in procedure 10 with the voltage/current gains found in procedures 4 and 7 (make a table).
   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 circuit analysis showing theoretically determined numeric results.
   c. Use the results of procedure 10f, determine the experimental sensitivity of the effective voltage gain to the load resistor. Then, using the amplifier equivalent circuit, verify that the experimental value is consistent with the theoretical value.

4. Analytically determine, using the equivalent circuit of exercise 3, what the amplifier power gain would be if
   a. $R_L = r_o/10$, and
   b. if $R_L = 10r_o$?
   c. Compare (numerically and qualitatively) these with the experimental 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 $R_L$ would yield maximum power gain?
   e. What value of $R_S$ would yield maximum power gain? Again, substantiate your answers via engineering science.

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