

ECE3424 Electronic Circuits Laboratory

Experiment #1 Getting started with didactic labs: Opamps and signal transfer

vers 2.1

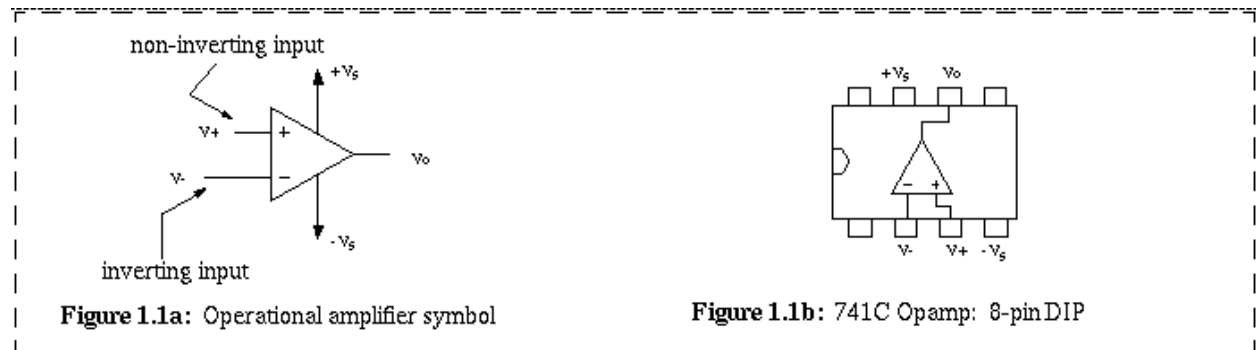
OBJECTIVE: (1) Become acquainted with the electronics lab equipment and environment. (2) Assess and characterize the transfer characteristics of the opamp (operational amplifier) for its standard resistance feedback configurations. The opamp will be used as a component in other lab experiments.

Background: The operational amplifier is qualified as a nearly ideal differential amplifier ($R_{in} = \text{high}$, $R_{out} = \text{low}$) and with voltage gain $A_V = \text{high}$, with values as follows

$$\begin{aligned} R_{in} & \quad (\text{typical} = 2\text{Meg}\Omega) \\ R_{out} & \quad (\text{typical} = 50 \Omega) \\ A_V & = v_L/v_I. \quad (\text{typical} = 10^5 \text{ V/V}) (= 100\text{dB}) \end{aligned}$$

The opamp is always used in a negative feedback mode. In this mode the high gain of the opamp pulls the input against the signal fed back through the feedback network. Therefore the transfer characteristics are forced to assume the characteristics of the feedback network. Linear transfer characteristics result and makes the opamp a very effective component for circuit design.

The symbol for the opamp is represented by figure 1.1a. The package and pin-out for the opamp used for this experiment, the 741C opamp, is represented by figure 1.1b. The 741C opamps and resistances needed for the experiment are part of your parts kit.



The amplitude gain (transfer gain) of output signal to input signal v_o/v_s is the inverse of the feedback ratio as represented by figure 1.2. The smaller the feedback v_f to the input, the larger the signal gain. The feedback usage of the opamp is represented by figure 1.2.

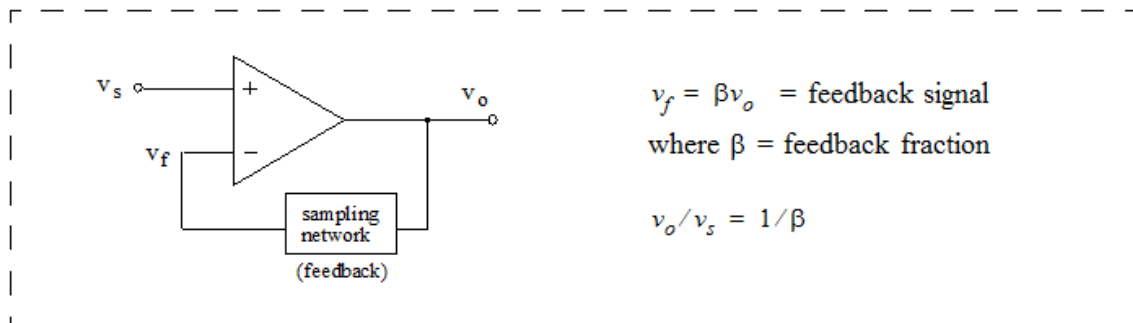


Figure 1.2. Negative feedback mode

PROCEDURE:

A-1. Survey your workstation site: Before doing anything, familiarize yourself with the workstation site and with your protoboard.

First open the left-hand drawer under the table.



Figure A1-1: Left-hand drawer.

In this drawer there are few short wires with stripped ends. These wires are for connection of alligator clip leads or for use as jumper wires, as reflected by the example of figure A1-2. They are NOT for protoboard interconnects, which must be supplied by the student.

Close the left-hand drawer and open the right-hand drawer.



Figure A1-2: Right-hand drawer.

In this drawer there should be three paired alligator clip leads for use in experiment connections as needed.

Close both drawers and take a look at your components and your protoboard. Figure A1-3 tells the story that you need to know. Emphasis: Keep leads short and layout concise.

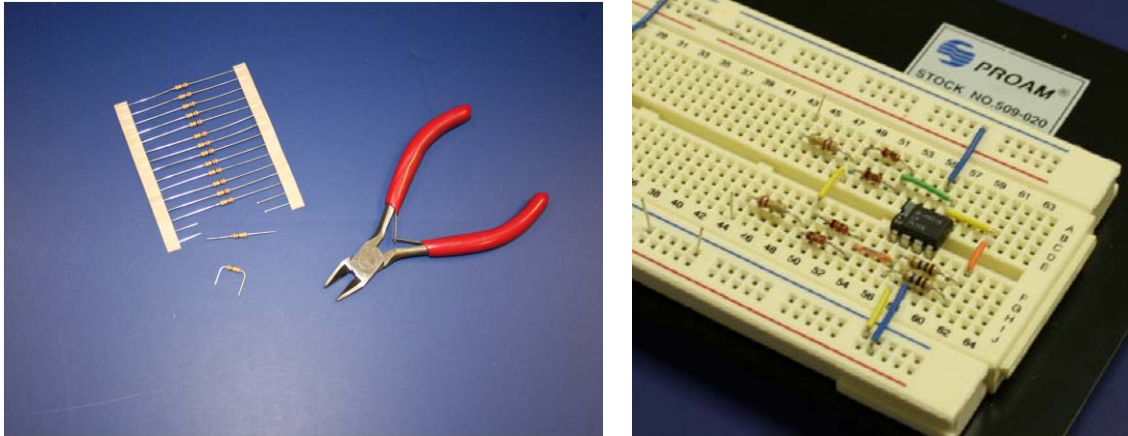


Figure A1-3. Technique. It is essential that your circuit be well-ordered and component leads kept short. You will need to clip all resistances and diodes leads with a pair of nippers to approximately the lengths shown and then bend to fit between 4-5 spaces of your protoboard.

Now take a look at your instrument cluster. If your predecessor followed correct protocols (as you are expected to do) you will be able to make a quick confirmation of the status of all of these instruments in a glance. The O-scope is the principal measurement instrument, so give it the most emphatic scrutiny. As you march through the various lab exercises you will become very acquainted with the O-scope, and learn what each menu setting does by experience and by necessity.

MESUREMENTS:

B-1. Non-inverting configuration: The input is applied to the (+) input. The feedback network is a resistance voltage divider. The basic circuit is shown by figure 1A-1.

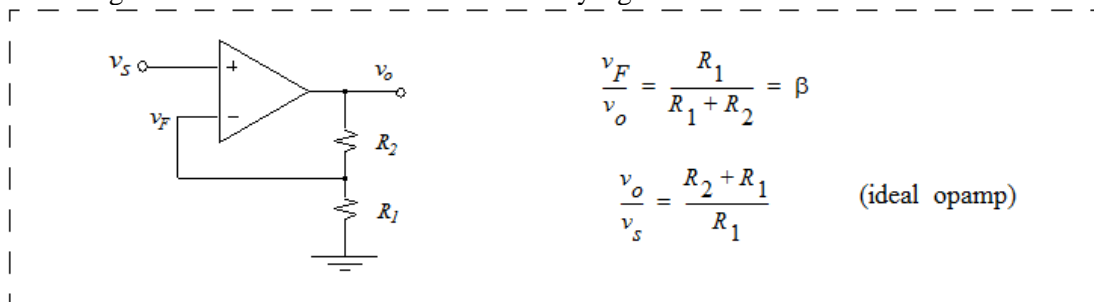


Figure 1B-1. Non-inverting configuration using resistance voltage divider as feedback.

B-2. Construct the configuration of figure 1B-1 on your proto-board with $R_1 = 10\text{k}\Omega$ and $R_2 = 180\text{k}\Omega$. Suggestions about component placement and wiring are shown by figures 1B-2a and 1B-2-b.

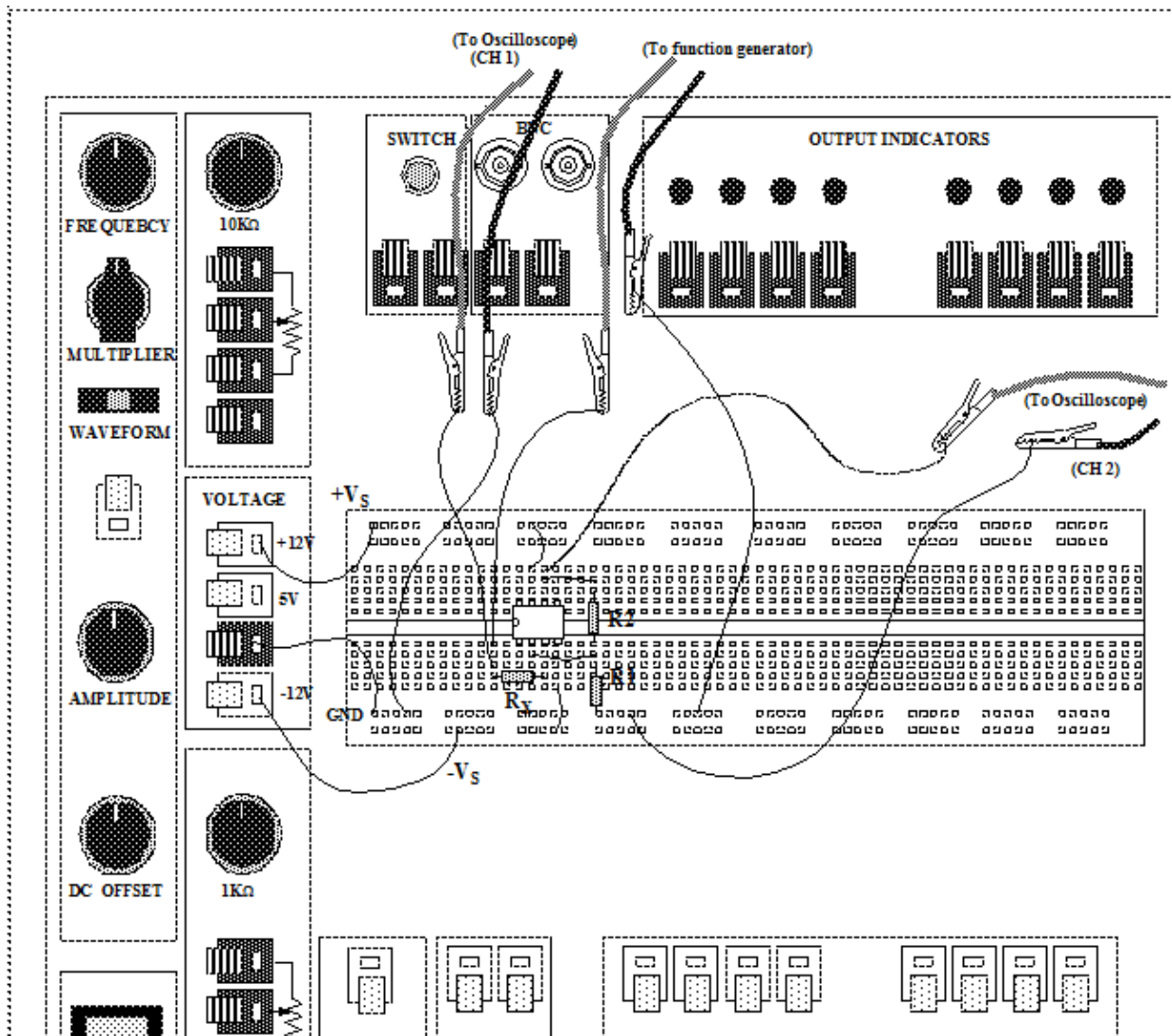


Figure 1B-2a: Suggestions for component placement and wiring.

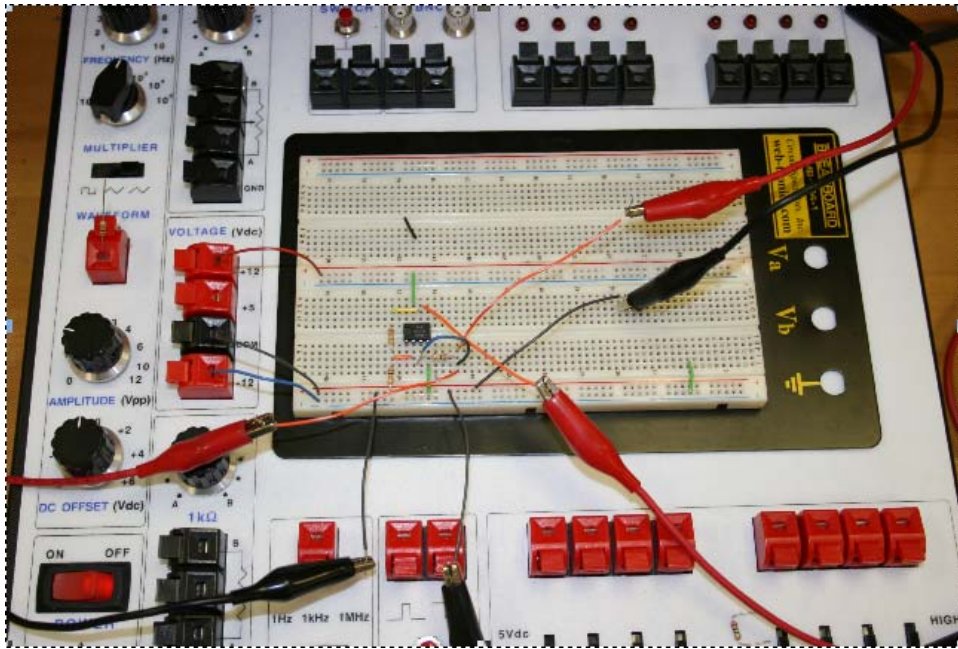


Figure 1B-2a: Suggestions for component placement and wiring.

Proto-board layout: As indicated by figure 1A-3 use short wires and nip your resistance leads to approximately ½ inch. Although it is not much of a concern with this experiment, if you do not keep your wiring tight and leave it looking like a bird nest it becomes fairly difficult to debug. Keep in mind that later experiments will be more complex.

The requirement of the experiment is to evaluate the transfer characteristics R_{in} , R_{out} and v_O/v_S . The test configuration for measurement of (1) transfer gain and (2) measurement of R_{in} is shown by figure 1B-3.

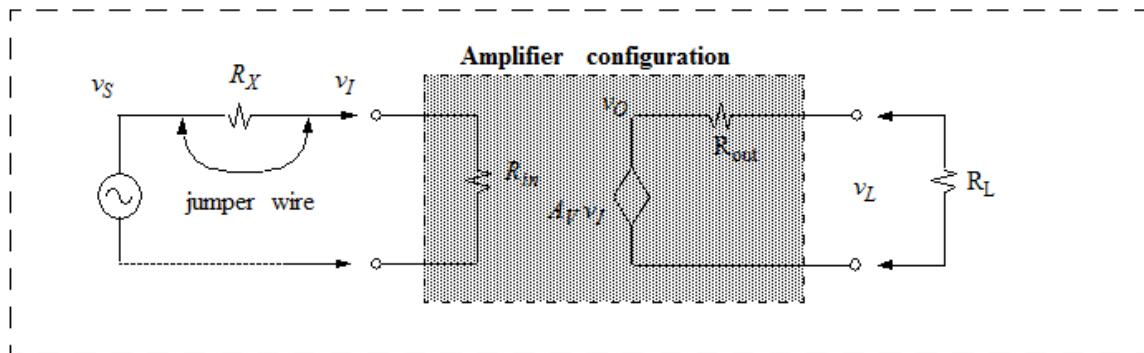


Figure 1B-3. Measurement of input resistance and transfer gain

Measurement of transfer gain is a ratio of v_L and v_I and is straightforward. The 'measure' button on your O-scope will display the pk-pk values of whatever signals are fed into CH1 and CH2. Use it.

Measurement of input and output resistances is accomplished by insertion of resistances in series for which you will have voltage-division of the signal amplitudes of

$$\frac{v_I}{v_S} = \frac{R_{in}}{R_{in} + R_X} \quad (1-1a)$$

$$\frac{v_L}{v_O} = \frac{R_L}{R_L + R_{out}} \quad (1-1b)$$

As long as R_X is consistent in magnitude with R_{in} and R_L consistent in magnitude with R_{out} , you will be able to identify R_{in} and R_{out} from the measurement of the voltage ratios

B-3. The opamp requires three voltage rails, $+V_S$, $-V_S$, and GND. Connect power rails first, but do not turn power on until the inputs and feedback network are connected. Supply voltages of $+V_S = +12$, and $-V_S = -12$ are sufficient and the (+, -12) power taps on the MFJ box are recommended, as reflected by figure 1B-2.

Let input source v_S be 400mV Vp-p at $f_S = 1$ kHz.

B-4. The non-inverting configuration is expected to have large R_{in} . The 'probe resistance' R_X should be consistent with R_{in} so $R_X = 1M\Omega$ is a suggested starting value (or $R_X = 10M\Omega$ if the effect of equation (1-1a) is not distinct). This resistance should also have a jumper wire, as shown by figure 1-B3. The output should be in a no-load state (i.e. $R_L = \text{infinity}$).

Connect CH1 to the input node and verify that you see a Vp-p (= peak-peak voltage) of 400mV when R_X is shunted by the jumper wire.

Connect the output to CH2, (see figure 1B-2). Output amplitude should be approximately 7.5V pk-pk.

Measure and record the Vp-p values of v_O and v_S in an Excel data table. Identify the approximate accuracy of your measurements as an additional data entry. The Vp-p values are your data and the computation of transfer gain is accomplished later in life. As a snake check you might informally check the transfer gain to confirm that your circuit is OK

B-5. For evaluation of R_{in} , measure output voltage v_O with the jumper alternately ON and OFF. The output v_O is just a multiplication factor of v_I the algebra is the same, except v_{O1} (= jumper ON) and v_{O2} (= jumper OFF) replace v_S and v_I , respectively. Apply the algebra later (Excel spreadsheet) to determine R_{in} .

B-6: Now repeat parts B-4 and B-5 for $f_S = 10$ kHz and 100kHz.

At these higher frequencies the value of R_{in} will decrease by approximately an order of magnitude per decade. If a adjustment of amplitude or probe resistance R_X improves the measurement accuracy you have license to make changes. Be sure to indicate whatever modifications you have made in your data table. Also identify the accuracy of your measurements as part of the data record. Transfer characteristics may not be as consistent at the higher frequencies because you may begin to encounter a limiting constraint of the opamp called the slew rate, for which $dV_o/dt = \text{finite}$, typically 0.5V/ μ s.

B-7. Repeat parts B-4 through B-6 for $R_2 (= R_F) = 330k\Omega$. Adjust source amplitudes as needed for best results.

C-1. Reset the measurement topology to reflect that represented by figure 1C-1. Since R_{out} for an opamp is expected to be small then resistance R_L (as 'probe' resistance) needs to be consistent (50Ω) in order to realize a reasonable effect.

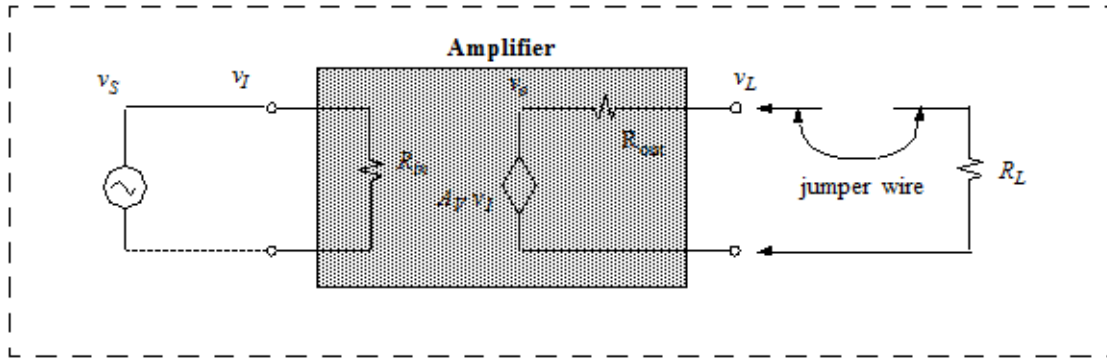


Figure 1C-1. Measurement of output resistance.

Measure v_o with jumper wire alternately ON (connected) and OFF (disconnected). Enter these values into your data table as v_{O1} and v_{O2} , for which the voltage divider will be of the form:

$$\frac{v_L}{v_o} = \frac{v_{O1}}{v_{O2}} = \frac{R_L}{R_L + R_{out}}$$

Undertake a set of measurements using the two values of feedback resistance R_2 and the values of frequency that were used in parts B-4 thru B-7.

D-1. Setup the multiple T network shown by figure D-1, for which an R-2R ladder is used as a feedback network instead of a resistance pair. Evaluate this network in the same manner as was accomplished in **part B** of the measurement procedures, but with $R = 0.5\text{k}\Omega$ and $50\text{k}\Omega$, respectively rather than $R_1 = 10\text{k}\Omega$ and R_2 with two different values. Take note that it is bad form to string resistances end to end on a prototyping board. And also take note that $1\text{k}\Omega \parallel 1\text{k}\Omega = 0.5\text{k}\Omega$, and that $100\text{k}\Omega \parallel 100\text{k}\Omega = 50\text{k}\Omega$. Set up a new data table for this configuration.

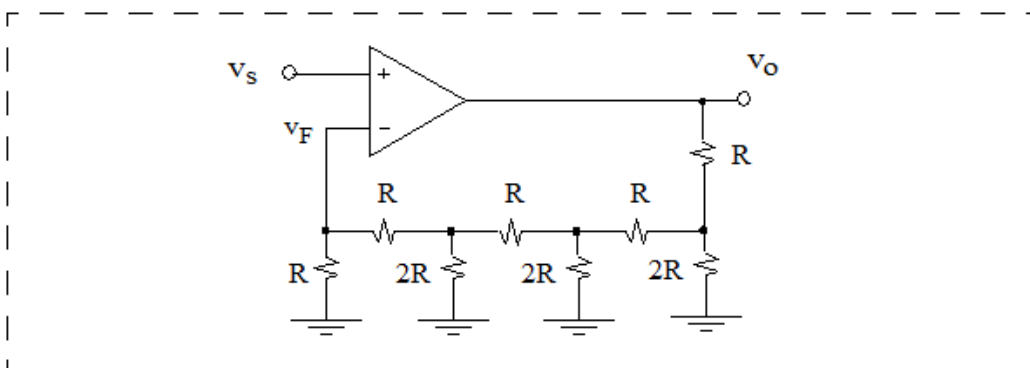


Figure D-1. Non-inverting T-network R-2R ladder

ANALYSIS and REPORT:

1. Transfer your data to an Excel spreadsheet environment if you did not already do so during the course of the experiment. Use the Excel calculator to determine the transfer characteristics R_{in} , R_{out} , and v_o/v_s for each of the tests.

Here is what you should expect for the results: Analysis of the effect of feedback will affect input resistance according to

$$= R_{in}(1 + \beta A_V) \quad (1-1)$$

and we usually call it R_{if} = 'input resistance with feedback.

The effect of feedback on the output resistance will be approximately of the form

$$= R_o / (1 + \beta A_V) \quad (1-2)$$

and we usually call it R_{of} = 'output resistance with feedback. In these equations β = feedback factor and A_V is the opamp gain.

You should also find out that R_{if} and R_{of} are frequency dependent, since the opamp gain A_V decreases with frequency at 20dB/decade rolloff. So at $f_s = 100\text{kHz}$, $A_V = 20$. And that should explain why you did not see values of R_{if} and R_{of} as extreme as represented by equations (1-1) and (1-2).

2. Execute each of the test configurations in pSPICE as if you were performing the measurements on the pSPICE workbench rather than on the laboratory workbench. Add these 'simulation values' to the Excel tables constructed under part 1.

You may also find it to be handy to use the pSPICE schematics as a means of drawing circuit schematics for your written report.

You should find that the behavior for R_{in} is not unlike the simulation of figure R-1a.

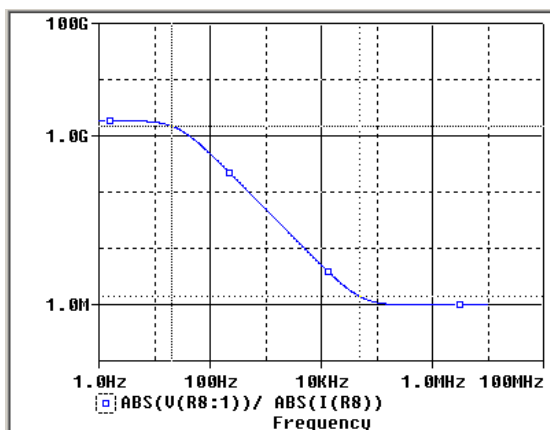


Figure R-1a: Data expectations, R_{in} vs f_s , (log-log plot).

3. Evaluate the error of your results for the workbench measurements and include these as a separate entry in your Excel data table.

Set all resistance components in your pSPICE to have a tolerance of 5% (double click on the component and you will see that a tolerance (in %) can be set. In each case, reset the display to show the tolerances).

Execute a 5-pass Monte-Carlo analysis (**Analysis>Setup>Monte Carlo**). Enter the variance of results in your data table. In your lab report show these circuit diagrams with tolerance values displayed.

4. Construct an MS Word document as the platform for which you will construct the report. Make use of the necessary cut and past utilities to make a good quality result, not unlike that for pspice homework. Write a short comment paragraph about what you have accomplished, citing difficulties, expectations, error analyses, and characteristics.

5. Convert your lab report to a .pdf document and submit electronically to the laboratory folder associated with your laboratory section.

Parts 4 and 5 are default instrux, and will not be repeated in later lab exercises.