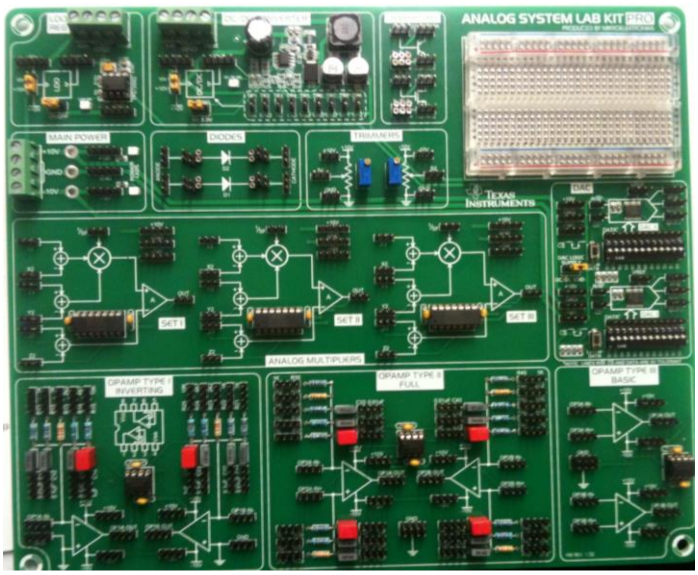
T7

Amplifier Input and Output Impedances and Loading Effects

In this lab you will learn the importance of input and output impedances on the performance of circuits such as amplifiers. Using the Texas Instruments ASLK PRO kit, you will build a transistor amplifier and measure its impedances, both unloaded and under load. This will illustrate the importance of some of the circuit theory that you have learned. Ways of improving the performance will then be tested, using buffer op-amp circuits. At the end of this you will have established the ideal requirements for impedance for active circuits, and what happens if you do not allow for this.



This lab uses the ASLK PRO kits, which have been kindly donated to ECS by Texas Instruments.

Schedule

Preparation time	:	3 hours
Lab time	:	3 hours

Items provided

Tools	:	n/a
Components	:	2N3904 transistor
Equipment	:	Oscilloscope, Signal Generator, Bench PSU, Multimeter, Texas Instruments ASLK Pro kit.
Software	:	A circuit simulator eg MultiSim, LTSpice, PSpice etc

Items to bring

Essentials. A full list is available on the Laboratory website at https://secure.ecs.soton.ac.uk/notes/ellabs/databook/essentials/

Before you come to the lab, it is essential that you read through this document and complete ***all*** of the preparation work in section 2. If possible, prepare for the lab with your usual lab partner. Only preparation which is recorded in your laboratory logbook will contribute towards your mark for this exercise. There is no objection to several students working together on preparation, as long as all understand the results of that work. Before starting your preparation, read through all sections of these notes so that you are fully aware of what you will have to do in the lab.

Academic Integrity – *If you undertake the preparation jointly with other students, it is important that you acknowledge this fact in your logbook. Similarly, you may want to use sources from the internet or books to help answer some of the questions. Again, record any sources in your logbook.*

Revision History

July 02, 2013	Nick Harris (nrh)	Minor revisions
September 12, 2012	Nick Harris (nrh)	First version of this lab created

1 Aims, Learning Outcomes and Outline

This laboratory exercise aims to:

- Allow you to experience the importance of loading effects
- Introduce transistors and op-amps

Having successfully completed the lab, you will be able to:

- Demonstrate understanding of key network theory concepts for resistive circuits
- Demonstrate knowledge and understanding of the operation of bipolar transistors, and op-amps

In this lab you will learn the importance of input and output impedances on the performance of circuits such as amplifiers. Using the Texas Instruments ASLK PRO kit you will build a transistor amplifier and measure its impedances, both unloaded and under load. This will illustrate the importance of some of the circuit theory that you have learned. Ways of improving the performance will then be tested, using buffer op-amp circuits. At the end of this you will have established the ideal requirements for impedance for active circuits, and what happens if you do not allow for this.

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2 Preparation

Read through the course handbook statement on safety and safe working practices, and your copy of the risk assessment form. Make sure that you understand how to work safely. Read through this document so you are aware of what you will be expected to do in the lab.

2.1 Transistor Amplifiers

Figure 1 shows a Common Emitter (CE) amplifier, with a bypassed emitter resistor. Details of how this amplifier works are available from the ELEC1207 course notes. It is a very common and useful amplifier configuration. Before you arrive in the lab, you must establish certain predicted parameters for the performance of this circuit. Simulation provides a good starting point, and you should enter the circuit of Figure 1 into a circuit simulator such as MultiSim, LTSpice or PSpice.

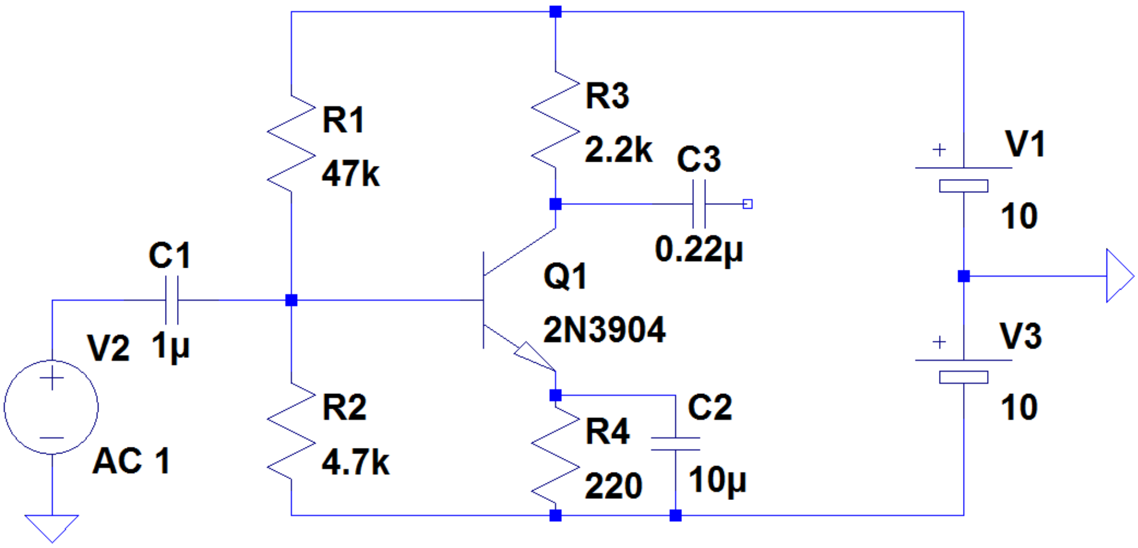

FIGURE 1: Common emitter amplifier.

Notice the following features and points:

1) V1 and V3 are DC supplies set to 10V each. This is the power supply for powering the circuit, and gives a +/-10V supply.
2) V2 is the input signal generator. This is the place where the input signal to be amplified will come from.
3) There is a ground connection (the triangle between V1 and V3). Without this the circuit will not simulate.
4) One end of C3 is floating. This is the output of the amplifier, and is not currently connected to anything.
5) Make sure everything else is connected. In Figure 1, a blue blob shows where nodes connect.

You should now establish the DC collector current (I_C). In LTSpice this is most easily done using an Operating Point (OP) simulation.

- *What is the predicted collector current?*
- *Is this a sensible value?*

Change your simulation to measure the gain for an input frequency of 10kHz. To do this you will need to run an AC analysis with a frequency sweep running from 0.1Hz to 1GHz. In the diagram above, V2 is the input source and should have its AC parameter set to 1 to allow easy calculation of the gain. The output of the amplifier is the floating connection of C3. Plot the resulting frequency sweep diagram in your logbook (print it out and stick it in).

- *What is the mid band gain of the circuit, both in dB and in linear values?*
- *What is the 3dB bandwidth? i.e. at what frequency does the gain fall below 3dBs of the mid band gain. Mark these points on the frequency sweep diagram in your logbook.*

Change the value of C1 to 10uF, and the value of C2 to 100uF and rerun your simulation to show that the midband gain seen at 10kHz can be extended to 1kHz.

Print out and stick in the new response.

Here is the equivalent small (AC) signal model of the circuit.

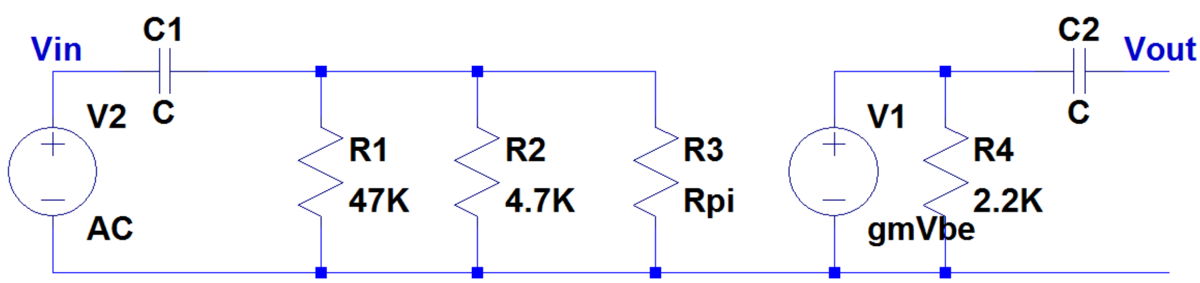

Figure 2 Small signal Equivalent of Figure 1

It is useful for you to understand how this circuit is developed. If you don’t understand this circuit, then please refer to the ELEC1207 notes.

Notice that the transistor has been replaced by the hybrid Pi model. Also notice that the input impedance of this circuit is the parallel combination of R1, R2 and Rpi. We don't know what Rpi is yet, as that is related to the transistor, but we will find out soon!

Recall from the ELEC1207 notes that g_m is defined by the static value of I_C as $g_m = \frac{qI_C}{kT} \approx 40I_C$

And consequently, $r_\pi = \frac{\beta}{g_m}$

Using the value of I_C you obtained earlier, calculate the value of g_m.

Now, assuming a value of 300 for beta, calculate the value of r_π.

- *From inspecting the small signal model, and knowing the value of g_m, what is the expected small signal gain of the amplifier?*
- *Compare it with the predicted value from the simulator. Is it the same? Can you think of any reasons why they are different?*

Again, from inspecting the small signal model, predict the expected AC input impedance. Write it down in your logbook.

3 Laboratory Work

First, you should build the circuit shown in the Figure 3 on the ASLK PRO board. Plug the transistor provided into the section labelled "transistor". Make sure it is the right way round! Use the prototyping area for the other components. Connect the bench power supply to the "Main Power" terminals on the left to give a +10V, 0 and -10V supply to the prototyping board. Check these voltages with a multimeter.

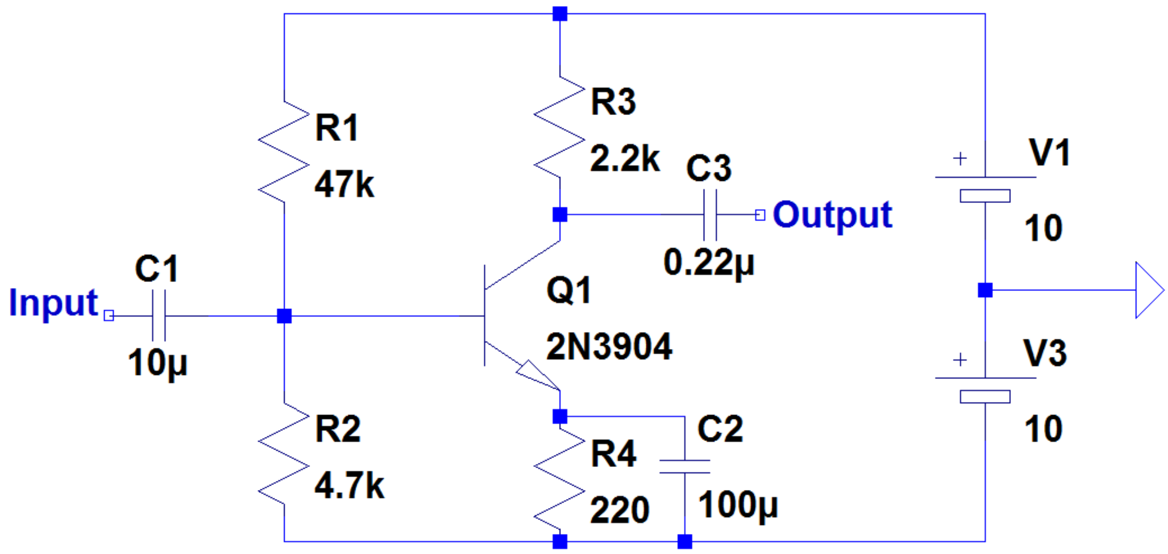

FIGURE 3: Circuit to build in the lab.

3.1 Checking your Predicted Values

Measure the value of I_C in your circuit. To do this, measure the voltage drop across R3 with the circuit powered up, using either a meter or an oscilloscope. Using Ohms law calculate the current through the resistor, and make a note of it in your logbook.

How does it compare to your predicted value.

Measure the voltage at the collector of Q1. Is it suitable for use as an amplifier? Hint: it should be a few volts away from the supply rail.

Now measure the midband gain of the amplifier by connecting a signal generator to the input of the circuit. Set it to 10kHz, and an input size of about 10mV. Measure the amplitude of the output signal at the unconnected end of C3. Divide the output amplitude by the input amplitude to obtain the gain.

How does this compare to the simulated gain obtained earlier?

3.2 Measuring Input Impedance

Now you are going to measure the input impedance of your amplifier. The input of the amplifier can be viewed as a Thevenin equivalent circuit, and this can be seen if you look at your small signal equivalent circuit. Unfortunately we cannot use the standard approach of measuring the open circuit voltage and short circuit current as the amplifier is AC coupled through a capacitor and hence does not allow DC signals through. Thus, intuitively, we can see that the open circuit voltage would be zero and the short circuit current would be zero, which is unlikely to be the true answer. Therefore we need an alternative approach.

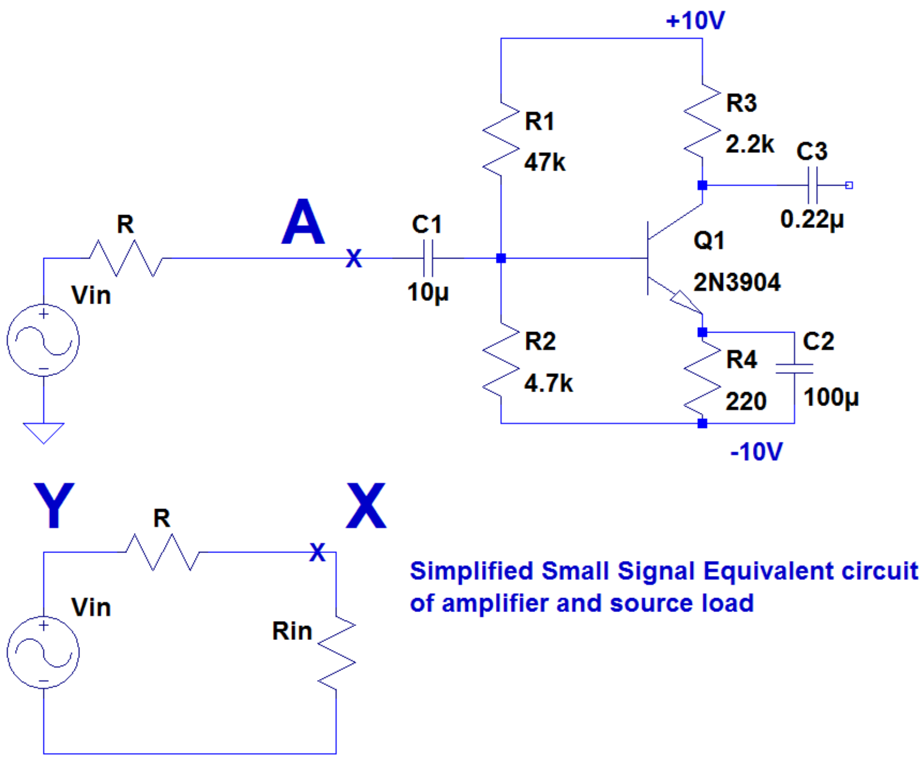

FIGURE 4: Measuring input impedance (Thevenin equivalent).

Consider the circuit in Figure 4. If we "look" into the circuit at position A under AC conditions we would see an equivalent Thevenin circuit, which we can get from the small signal model. We can see that the Thevenin voltage is zero as there are no sources in the input circuit. Therefore the Thevenin circuit is just a resistor, and this is the input impedance of the circuit. By considering the second diagram, the equivalent circuit becomes that shown where Rin is the input impedance of the amplifier, and R is the source impedance. This is a potential divider and it is now easy to see how to work out what Rin is.

The voltage at X is given by:

$$V(X) = \frac{R_{in}}{R_{in} + R} V(Y)$$

Therefore when:

$$R_{in} = R$$

$$V(X) = \frac{V(Y)}{2}$$

Thus all we need to do is adjust R until the voltage at X is half that of Y and the value of R is then the value of Rin. So fit a variable resistor of value 10k in place of R and adjust until the voltage at X is half that of Y.(Note: The variable resistor has three legs. Use the centre one and one of the end ones. Do not use the third leg – leave it out of any circuit). The variable resistor can then be removed from the circuit and measured, and this will be the value of the input impedance.

You can now calculate the value of Rπ, as you have previously established that the amplifier input impedance is the parallel combination of R1, R2 and Rπ. Write this in your logbook.

How does it compare to the theoretical value you calculated in the preparation?

3.3 Measuring Output Impedance

A similar technique can be used to measure the output impedance. Connect the signal generator to the input of the amplifier (no resistor this time).

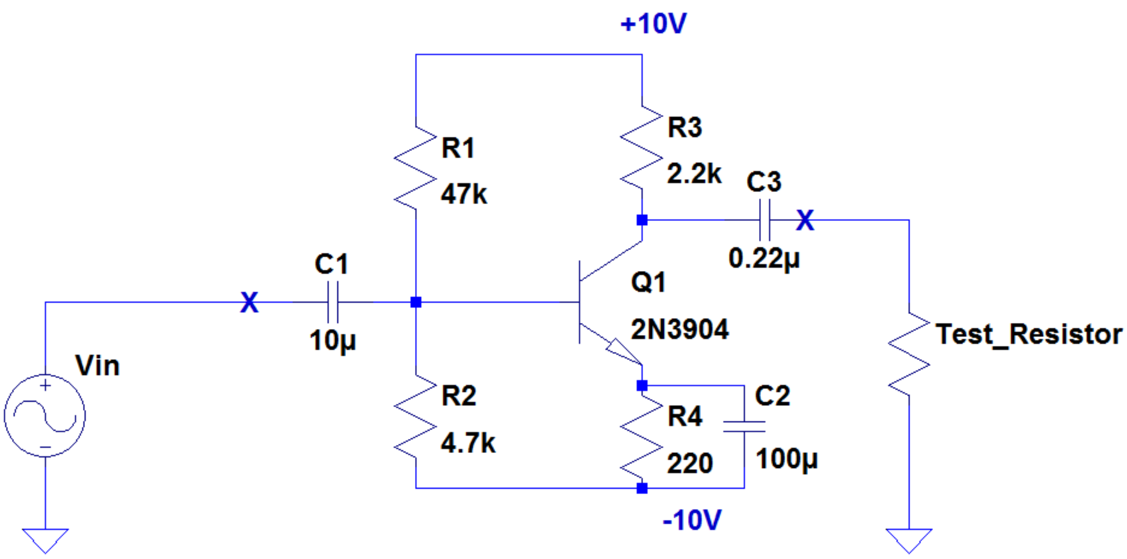

FIGURE 5: Measuring output impedance.

Using an oscilloscope, measure the output voltage amplitude of the amplifier. Adjust the input voltage so that you get an undistorted signal. Make a note of the amplitude you have set.

Connect a 10k variable resistor from the amplifier output to ground. Adjust the resistor until the voltage across it is half the value you noted without a resistor. Disconnect this resistor and measure its value. This is the output impedance of the amplifier. Make a note of it in your logbook.

3.4 Loading Effects

You have now measured the input and output impedance of the amplifier, measured its gain, and seen how it compares with the theory. Now you will see why loading effects are important.

Re-measure the gain of your amplifier with nothing connected to the output capacitor of the amplifier. Reminder: this means compare the output voltage with the signal generator voltage.

Connect a 1MOhm resistor to the output (in the position of “Test_Resistor” in Figure 5).

- Measure the gain of your amplifier again. Make a note of it.
- Do the same again for resistors of value 100K, 10K, 1K, 100ohm and 10ohm in place of the 1MOhm resistor.
- Make a note of what happens to the gain.
- Put the 1Mohm resistor back.

Now do the same for the input. Connect a 1ohm test resistor in series with the signal generator as shown in Figure 6. Measure the gain again.

Now do the same for a 10ohm, 100ohm, 1k, 10k and 100k in place of the 1 ohm test resistor, and make a note of what happens to the gain.

Based on these experiments, what do you think the ideal amplifier would have as its input and output impedances?

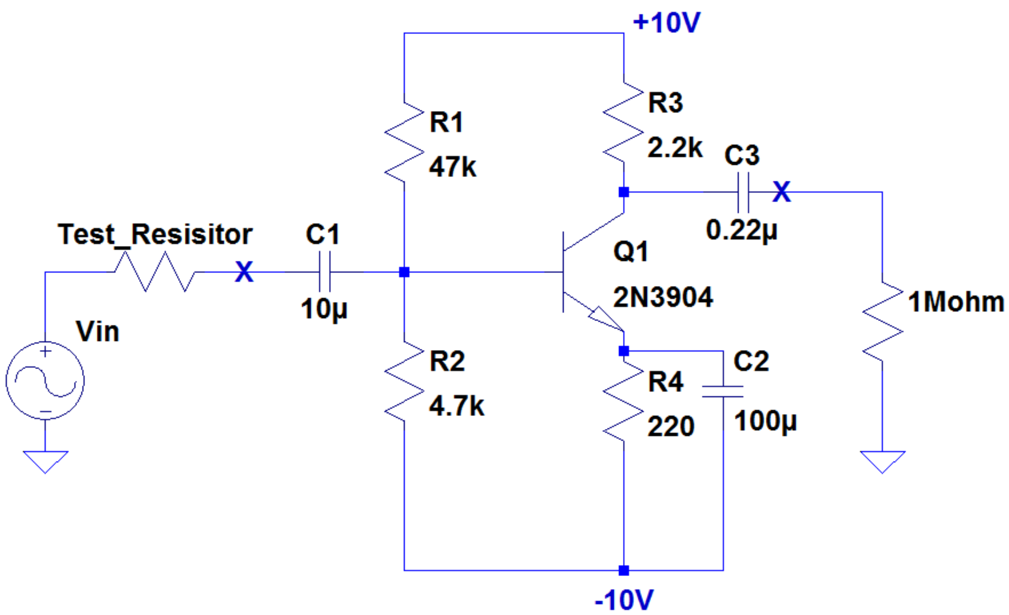

FIGURE 6: Measuring loading effects.

3.5 Improving Amplifier Performance

Using the Op-Amp type 3 basic amplifier block on the board, construct the following circuit:

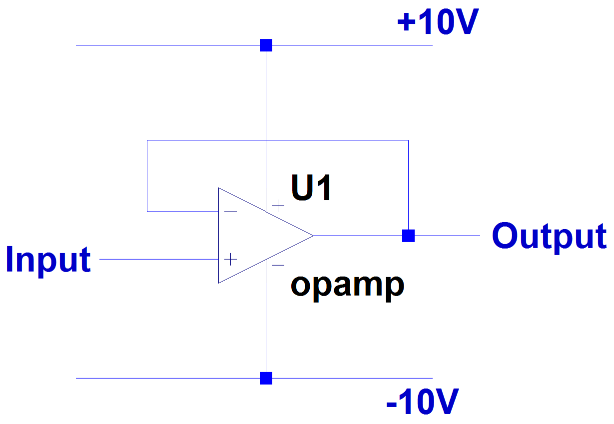

FIGURE 7: Unity gain buffer.

This is called a voltage follower, or a unity gain buffer.

Verify the gain is 1.

You are now going to measure its input and output impedance.

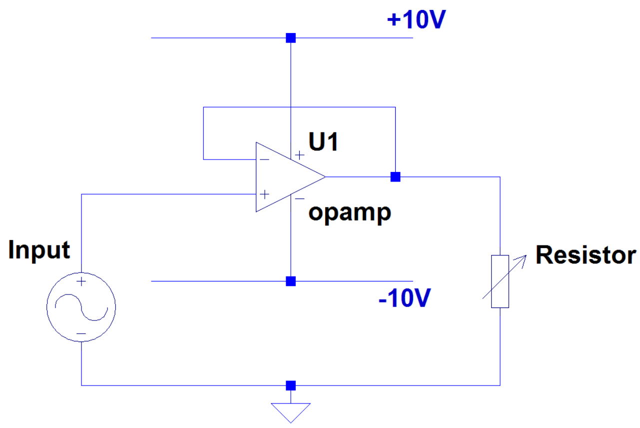

FIGURE 8: Measuring the output impedance.

Once again connect a signal generator to the input at about 10kHz, and connect the output to a variable resistor, and to ground as shown in fig.8.

Now adjust the value of the variable resistor until the voltage is half that of the input voltage. Remove the variable resistor from the circuit and measure its value. This is the output impedance of the op-amp. Compare this with the value that you got for the transistor amplifier.

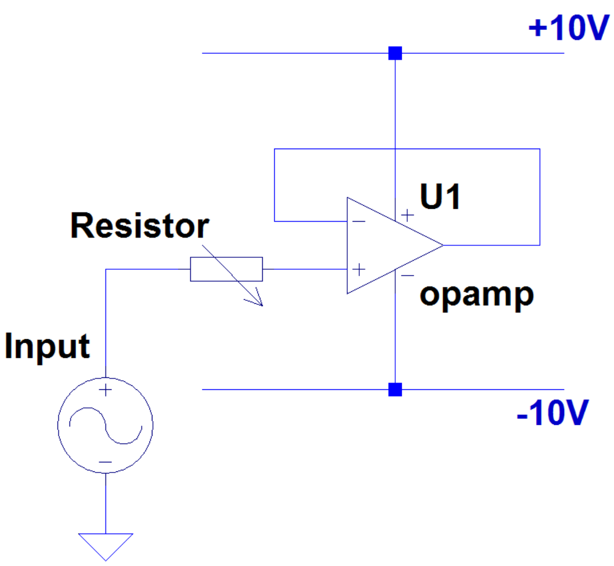

FIGURE 9: Measuring the input impedance.

Now measure the input impedance by using the same technique again, but this time use a test resistor in the input circuit as shown. Adjust the resistor until the output voltage is half the input voltage. Again, measure the value of the resistor.

Compare this value with the value obtained for the input impedance of the CE amplifier.

What are your measured input and output impedance values for the op-amp circuit?

How does this compare to the CE amplifier?

You will now see the advantage of having high input impedance and low output impedance.

Connect the output of the CE amplifier to the input of the buffer. Now construct another buffer amplifier using the other Op-amp type 3 that is available on the board. Connect the output of this new buffer to the input of the CE amplifier. Then connect the signal generator to the input of this buffer. You should have the CE amplifier connected between two buffers as shown in Figure 10.

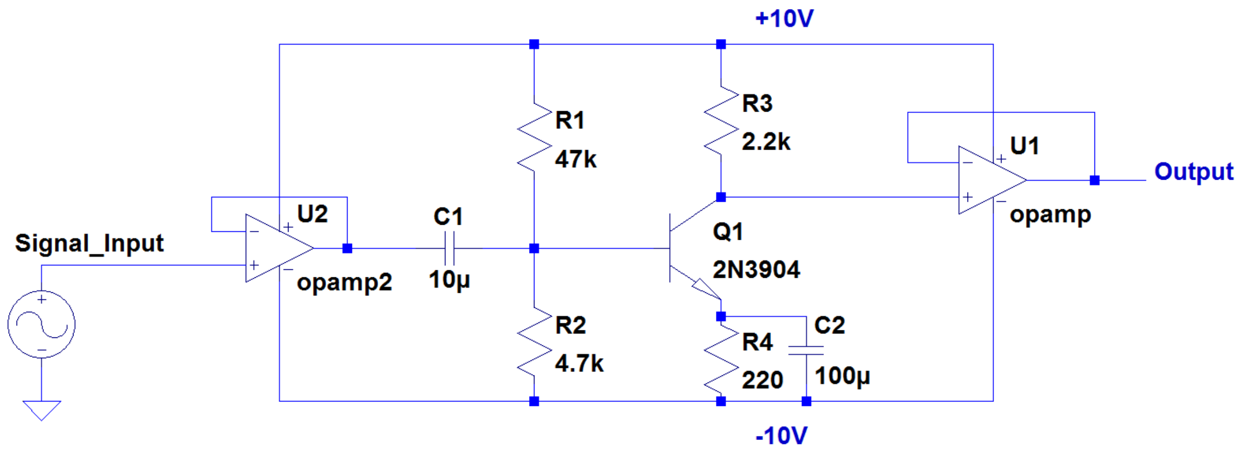

FIGURE 10: CE Amplifier with Op-Amp buffers

Measure the gain of this circuit, and compare it with the gain of the CE amplifier on its own.

Now, looking back at your results, choose values of input and output resistors that resulted in reduced gain before. Add these resistors to your circuit in appropriate places (see Figure 11).

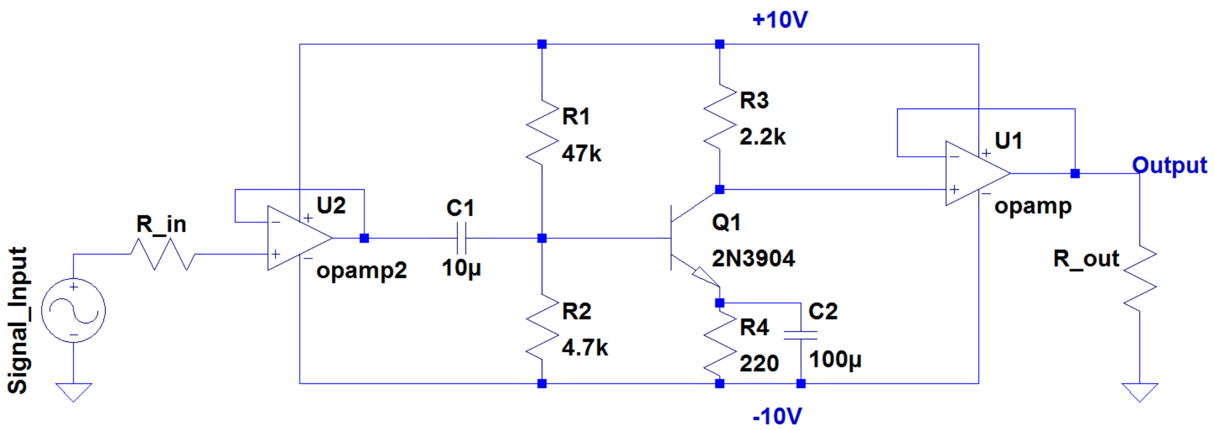

FIGURE 11: Test Circuit

Again measure the gain.

How does it compare to the CE amplifier with the same loads?

Write a paragraph in your logbook summarising your conclusions about input and output impdances, and the use of buffer amplifiers.

4 Optional Additional Work

Marks will only be awarded for this section if you have already completed all of Section 3 to an excellent standard and with excellent understanding.

Measure the bandwidth of the circuit above. To do this change the input frequency and measure the amplitude of the output frequency. The gain should be constant for a range above 10kHz. This is the “mid-band” of the amplifier and is the operational gain. Increase the frequency until the amplitude starts to fall. Make a note of the frequency at which the voltage has fallen to 0.707 of the mid band value. Now decrease the frequency until you once again reach an amplitude of 0.707 of the mid band value. The difference between these two is the 3dB bandwidth.

- *What is the bandwidth of the amplifier?*
- *What do you notice about the shape of the output waveform from the op-amp when the signal starts to reduce at high frequencies? Can you explain this.*