Introduction to Analog Electronics Lab.

This analog electronics laboratory manual is based on the course textbook and you will have to refer to the text for further details. The aim is to give you practical experience of the subject matter of the course. Not all of the course material is covered in this lab manual so you should feel free to construct any of the circuits discussed in the text and examine their working in more detail. Essentially this is a guide to a minimum laboratory program.

The text of the book "Fundamental Analog Electronics" is available from the website www.physics.dcu.ie/∼bl. Some of the Units have a facility called "Compute" where you will find a Java module which will carry out some of the computations for that Unit. You should use this facility to check your results and also to design circuits which you can try out in the Lab.

With regard to write ups for this analog electronics lab course, I do not want any formal write ups. What is required is that you keep a desk manual or notebook of the work which you do in the lab which should contain circuit diagrams and the values of the components. The notebook should also contain any numerical measurement and the calculations you make together with the graphs which you plot. Any important points about the performance or non performance of the circuit should be written into the book. Each days work should be dated and initialed by you. Your aim in keeping the lab or bench notebook should be to record all of the information which you might need if you were ever required to complete a formal write up of the experiment. It may occasionally happen that you will complete the calculations after the laboratory session is over but normal practice is that no writing will be required outside lab hours. This lab book will be handed up for marking by me at the end of the six (approximately) week session.

Try to develop a waffle free style of report writing. Also try to present your data and calculations in a well laid out tabular form. Always include a sample calculation of any tabular data and calculations.

If you do not understand something, ask me or a demonstrator. You will never be penalized for asking a question. You are supposed to ask questions!

Two final points:— You should always enter the name of your partner(s) into the book at the end of each working session and you should do the calculations independently. Your partner(s) may be wrong!

Resistor Networks

Connect a series resistor network of five different resistors between a +9 V and a -9 V as shown in figure 1.

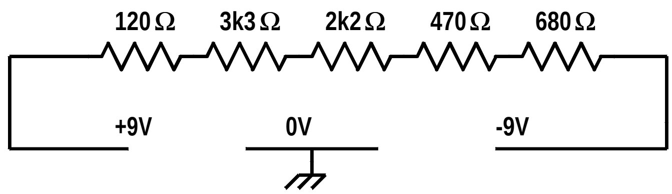

Figure 1:

Calculate the voltages which you should obtain at the nodes and measure the voltages with respect to the power supply ground.

Construct the R-2R resistor ladder and verify that the voltage drops by a factor of 2 between successive nodes.

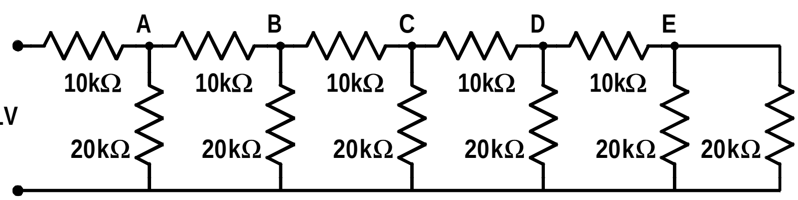

Figure 2:

Construct the circuit shown in Figure 3 and verify that removal of the horizontal cross resistors does not affect the resistance measured between A and B. Use the same value for all of the resistors. A suitable value would be 1 kΩ.

Construct the circuit shown in Figure 4 and measure the resistance between the corner points A and B. Apply a voltage between A and B and measure the voltage at each of the cube corners. What conclusions can you draw from these measurements?

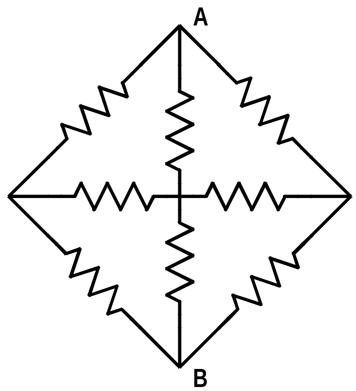

Figure 3:

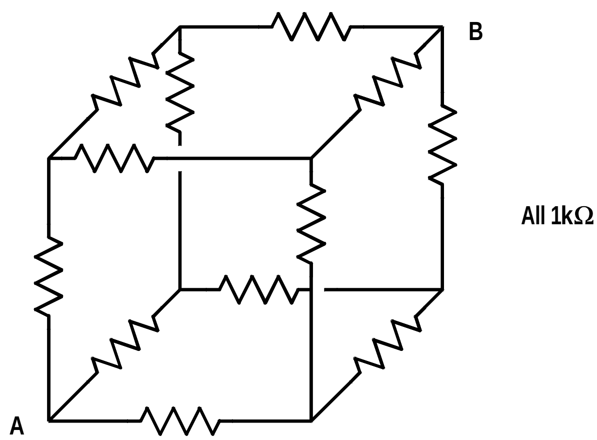

Figure 4:

Currents in a capacitor

Apply a sinusoidal voltage across a capacitor and sense the current by measuring the voltage across a small value resistor using the circuit shown in Figure 5. A Typical value of a current sensing resistor would be about 100 Ω.

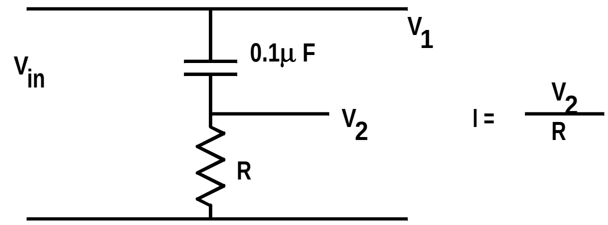

Figure 5:

What is the largest value of the sense resistor which causes no apparent effect on the performance of the circuit. Verify that the waveforms are similar to those shown in Figure 6 and scale the figure. Calculate values for the current as a function of the voltage and capacitor. Write down a numerical equation which describes the current waveform in the capacitor as you have observed it on the oscilloscope.

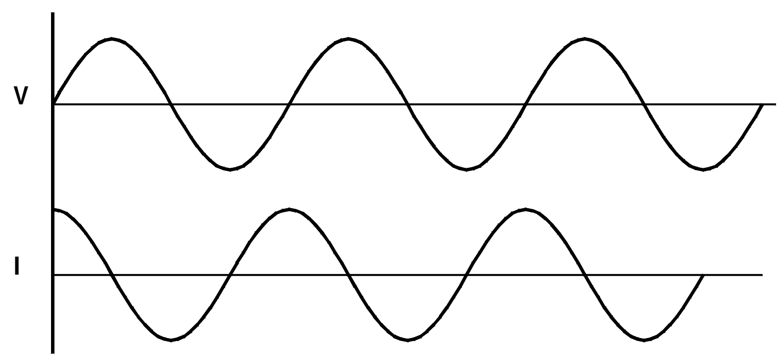

Figure 6: Current and voltage waveform in a capacitor

Measure the amplitude of the current in the capacitor using $I_{Meas} = \frac{V_2}{R}$
Calculate the amplitude of the current using $I_{Calc} = CV_{In}2\pi f$
Compare these two values for a range of R, f and C and show that the best agreement is obtained when R is as small as possible consistent with obtaining a measurable signal.

Currents in an Inductor

Apply a sinusoidal voltage across an inductor using the circuit shown in Figure 7. Measure the current by measuring the voltage across the small value sensing resistor R.

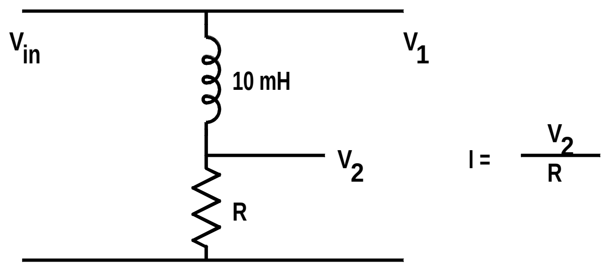

Figure 7:

Show that the current and Voltage waveforms are as shown in Figure 8. Change the component values and measure the new waveforms. Calculate numerical values for the expression which describes the waveforms.

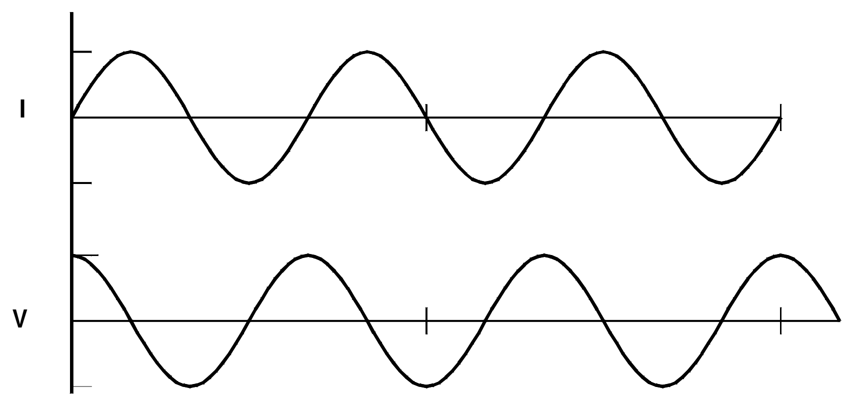

Figure 8: Current and voltage waveform in an inductor

Measure the amplitude of the current in the inductor using $I_{Meas} = \frac{V_2}{R}$
Calculate the amplitude of the voltage across the inductor using
$V_{Calc} = LI_{Meas}2\pi f$
Compare this calculated voltage with the measured V_{In} value for a range of R, f and C and show that the best agreement is obtained when R is as small as possible consistent with obtaining a measurable signal.

Generalized potential divider

The general form of a potential divider is shown in Figure 9. Use the frequencies and the component values shown in the table and obtain the attenuation and phase shifts by displaying the input and output waveforms and measuring the amplitudes of the signals and the time displacement of the signals.

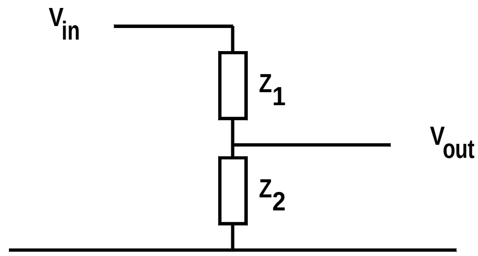

Figure 9: General form of a potential divider

f	Z_1	Z_2	attenuation	Phase shift
1 kHz	1.5 kΩ	0.1 μF		
500 Hz	10 kΩ	22 nF		
1.5 kHz	0.1 μF	1.2 kΩ		
7 kHz	10 mH	680 Ω		
60 kHz	470 Ω	1 mH		

Simple Bridge

Use the Simple bridge circuit shown in Problem 15.8 of the textbook to measure the resistance and capacitance in one of the sealed boxes which you will obtain from your demonstrator, Each of the boxes contain different values of R_x and C_x so you should present your measured values of R_x and C_x together the number of the box for verificationof the measured values by the supervisor.

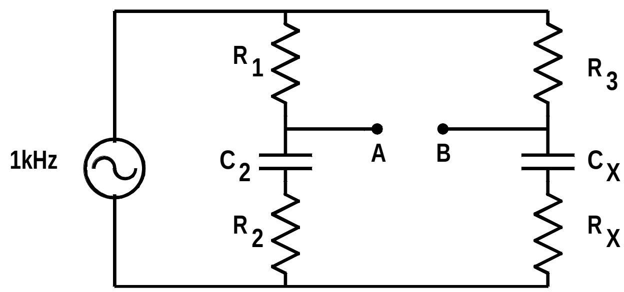

Figure 10: Simple bridge

The method used for balancing the bridge is to aim to have the two sides of the bridge contianing roughly equal (factor of 10) component values. So we give you the information that the unknown resistors are in the $1\,\mathrm{k}\Omega$ range and the unknown capacitors are in the $1\,\mu\mathrm{F}$ range.
Use variable resistors (pots) for R_1 and R_2.
Set an oscilloscope with the same sensitivity on each channel.
Set scope to ADD mode.
Invert channel B.
This displays $V_A - V_B$.
Adjust R_1 and R_2 for a minimum wave on scope.
Measure R_1 and R_2 out of circuit with a multimeter.

$$R_X = \frac{R_2 R_3}{R_1}$$

$$C_X = \frac{R_1}{R_3} \times C_2$$

Filter circuits.

The four main types of filter circuits are shown in Figure 11.

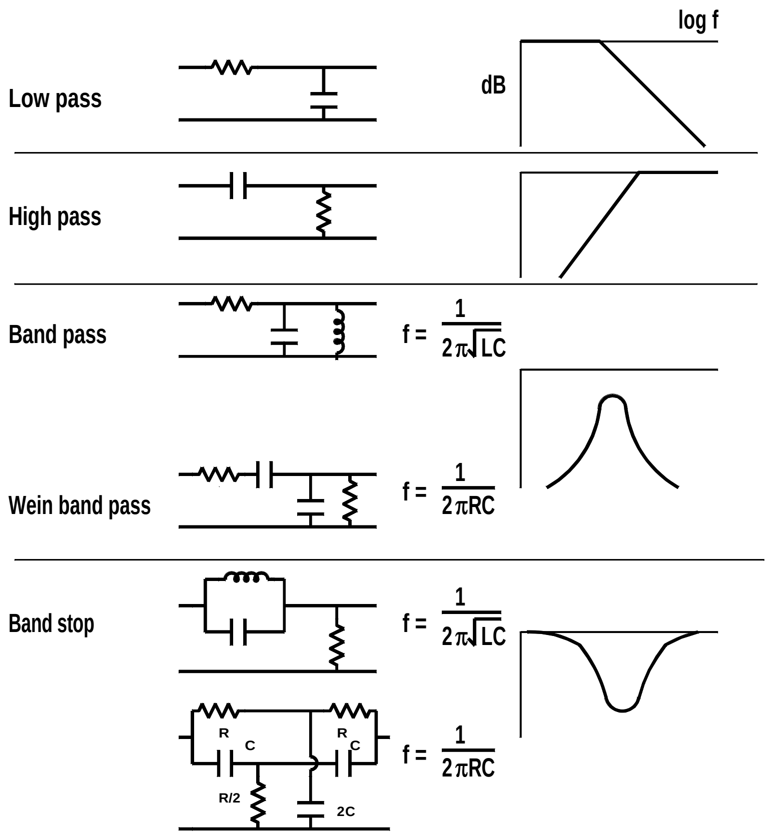

Figure 11:

You should construct one example of each of these filter types and measure the response as a function of frequency for the filter. Since you will be plotting the response as a function of the log of the frequency, you should make measurements at frequencies which are spaced so as to give a uniform sample point density on a log scale. Suitable frequencies would then be 100, 200, 500, 1k, 2k, 5k, 10k Hz etc. Always make sure to take measurements over many decades of frequency. You may of course take more detailed or closely spaced measurements near critical points such as the peaks of responses.

You will have to plot the Bode response for the filter circuits. An example of this is shown in Figure 12.

A typical circuit which is used for these measurements is shown in Figure 13.

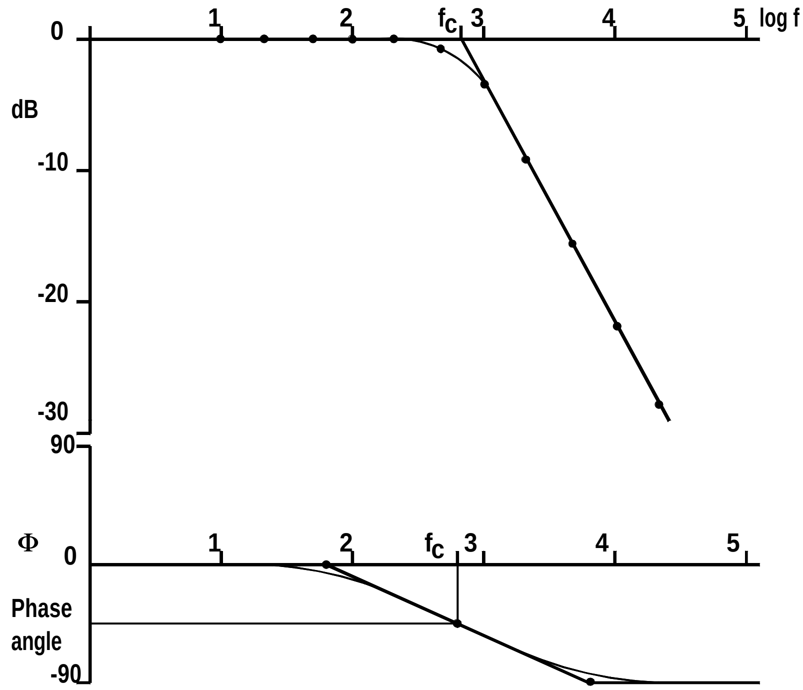

Figure 12: Bode plot.

The X input is the Channel 1 input on the oscilloscope and is the filter input signal. The Y input on this diagram is the oscilloscope Channel 2 input and is the filter output. At a particular frequency you can switch between the time base setting and the XY mode on the oscilloscope and rapidly collect the data for the attenuation and phase shift measurements.

$$\text{Attenuation in dB} = 20\log(\frac{V_{out}}{V_{in}})$$

$$\text{Phase shift} \quad \phi = \sin^{-1}(\frac{A}{B})$$

You should then prepare a table similar to that shown below which contains the measurements and the measured and theoretical attenuation and phase shift.

f Hz	V_{in}	V_{out}	A	B	Att. dB (meas)	ϕ(meas)	Att. dB (th)	ϕ (th)
500	1.3	.54	3.6	6.8	-7.6	32°	-6.5	29°
1000								

You will have to take care in assigning the sign of the phase shift as it is not possible to observe the direction in which the ellipse is traced out.

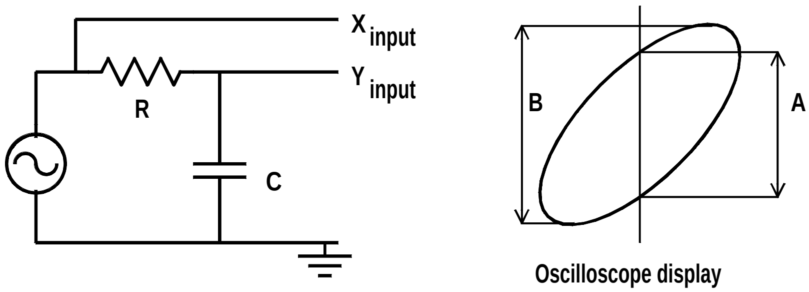

Figure 13: Filter amplitude and phase measuring circuit.

The response of the filter circuits shown in Figures 14 to 19 should be measured and the Bode plots prepared.

Figure 14:

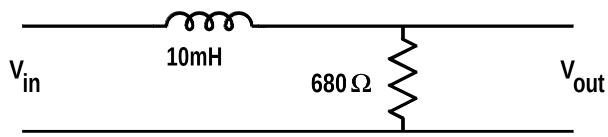

Figure 15:

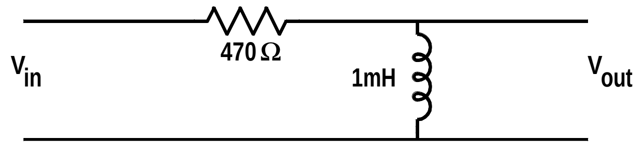

Figure 16:

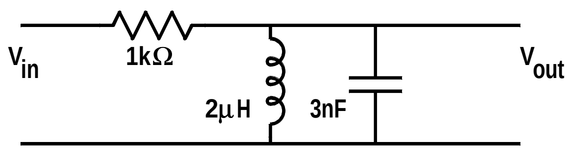

Figure 17:

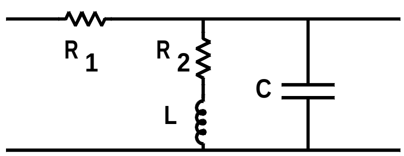

Figure 18:

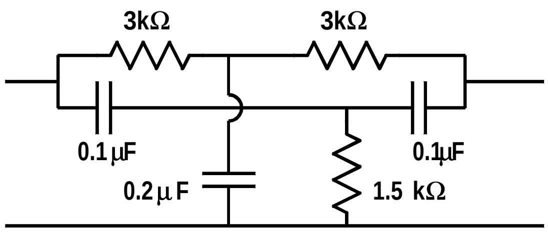

Figure 19:

Thévenin's Theorem

Identify the output of the function generator which you are using. There should be an output impedance value printed on the panel beside the output socket. Connect an oscilloscope to the output and set the output amplitude to about 5 V. Now connect various values of resistor across the function generator output and measure the output voltage. Plot the measured output voltage as a function of the calculated output current. From the slope of this curve you should be able to calculate a value for the function generator output impedance. Do all of the laboratory function generators have the same output impedances?

Principle of Superposition

Construct the circuit shown in Figure 20 and measure the voltages at the various nodes in the circuit. Verify that the voltages and the currents which you obtain using Ohm's law and the voltage differences between the nodes agree with the calculated values of the currents.

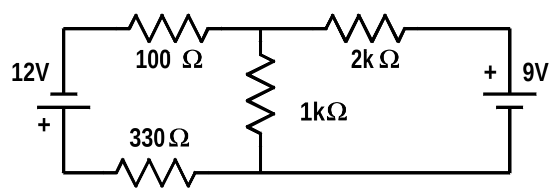

Figure 20:

Diode Characteristics

You can measure the current through a diode as a function of the voltage across the diode by using a circuit such as that in Figure 21. When the current and voltage values are plotted you will obtain a diode characteristic curve. You should measure and plot the characteristic for a diode such as a 1N4004 diode.

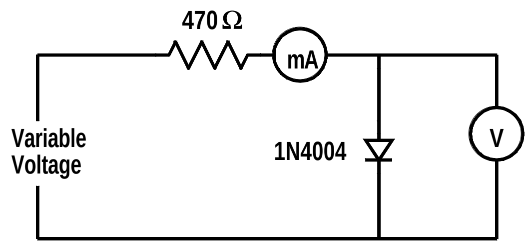

Figure 21:

A second way of obtaining a characteristic curve is to use a curve tracer. The Hung Chang oscilloscopes have a simplified version of a curve tracer called a component test facility which can be used to obtain characteristic curves displayed on the oscilloscope screen.

To use this component tracer facility on the Hung Chang you should use the following settings:

1. Turn on scope.
2. Set Sweep Time/Div to Ch B. (Fully clockwise).
3. Set both AC-GND-DC switches to GND.
4. Set Ch A V/Div to 2V/Div.
5. Set Ch B V/Div to 5 V/Div.
6. Press Component Test Button.
7. Connect component to be tested to the Component test terminals on left below oscilloscope screen.
8. You will then obtain a characteristic curve on the screen (Upside down).
9. The X axis display is the voltage across the component.
10. The Y axis display is the current through the component.

You should then sketch into your notebook the characteristic curves which you obtain for:

1. An open circuit.
2. A short circuit.
3. A resistor.
4. A Capacitor.
5. An inductor.
6. A diode.
7. A light emitting diode.
8. A Zener diode.

You should also examine the effects on the characteristic curve of a diode and a Zener diode caused by heating the component with a soldering iron or hot air blower.

Construct a number of the circuits discussed in the text and verify the operation of the circuits. In particular you should construct the circuit shown in Figure 22 and measure the voltages at points A, B, C and D. Verify that the measured values are in agreement with your calculations.

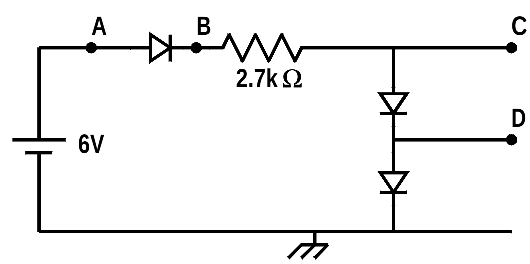

Figure 22:

Small signal diode circuits

You should construct the circuit shown in Figure 23 and measure the DC and AC voltages that appear across the diode. Verify that the oscilloscope measurements are in agreement with the calculations. Explain any discrepancies.

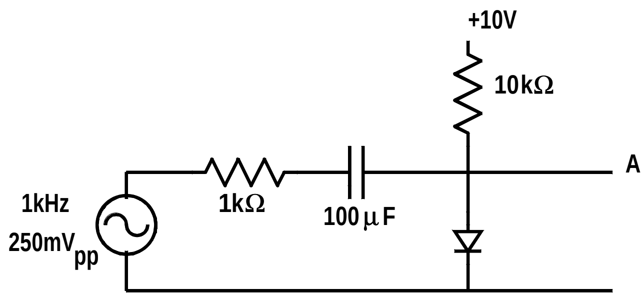

Figure 23:

Zener diodes

You have already obtained the characteristic curves for a Zener diode. You should examine the sharpness of the knee as a function of the Zener diode voltage. The higher voltage Zener diodes have sharper knees to the characteristics.

The main application of Zener diodes is as voltage regulators and in this application the generic circuit is as shown in Figure 24. The function of the resistor is to limit the maximum diode current to a value which is less than the maximum current for that particular type of Zener diode. You should plot the output voltage from this circuit as a function of the input voltage for input voltages from about -15 V to +15 V.

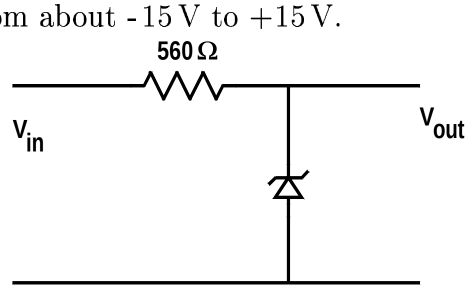

Figure 24:

Transistor characteristics

In measuring the characteristics of a transistor it will be necessary to make connections to the transistor. The BC109 is a typical small signal transistor and the connections to the transistor are identified by logging at the transistor bottom with the wires pointing towards you (bottom view). The connections are then as shown in the diagram in Figure 25.

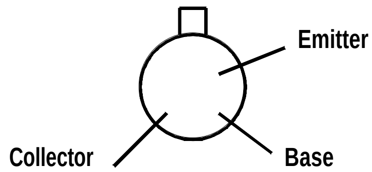

Figure 25:

The characteristics of a typical transistor such as the BC109 are measured using a circuit as shown in Figure 26.

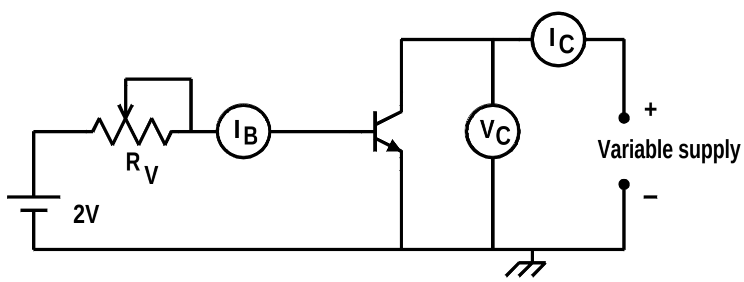

Figure 26:

You should then be able to plot the characteristics for the particular transistor which you have used and they will look something like Figure 27.

From the plotted characteristic you should then obtain an estimate of the value of the current gain, β, for the particular transistor. If you look up the current gain, β or h_{fe}, in the Radionics catalogue you will find that the value for the BC109 ranges from about 300 to 600.

You should also test the transistor by using a digital multimeter to check for diode action between the A and B and also between the B and C of the transistor, This means that you should carry out a total of six resistance measurements to verify that the transistor is still functioning. The chances are that you will meet many non functioning transistors in your working life so you should be able to check a transistor rapidly and easily using these six tests.

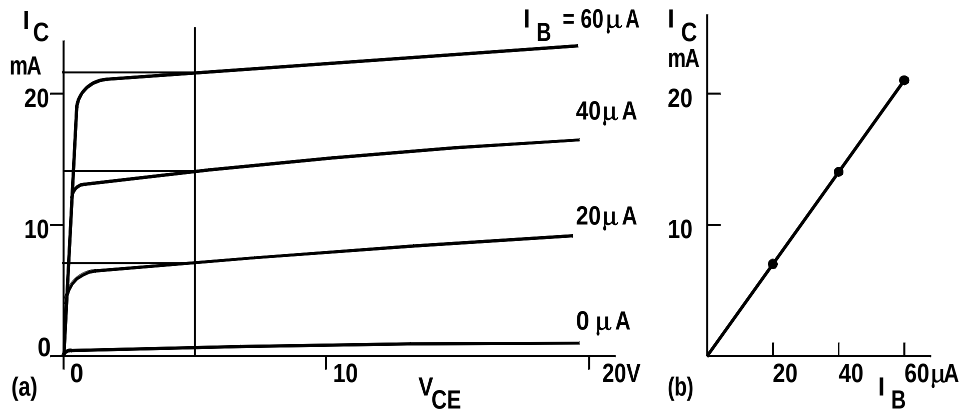

Figure 27:

Small signal amplification

Construct the transistor amplifier circuit shown in Figure 28. Measure the DC voltages at the Emitter, Base and Collector. You should now be able to calculate the Emitter, Base and Collector currents. You should also be able to calculate the β for the particular transistor used in the circuit.

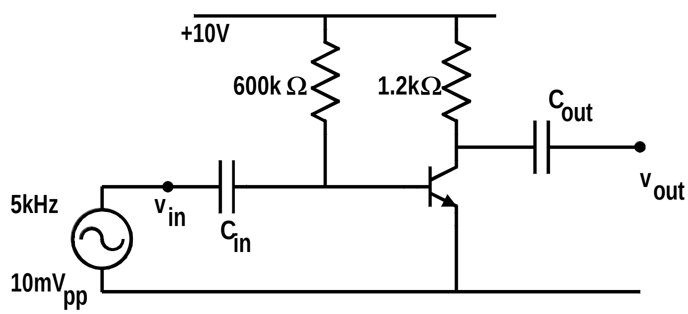

Figure 28:

Apply a small sinusoidal signal to the amplifier and measure the input signal and the output signal. You should then be able to give accurately scaled sketches of the waveforms shown in Figure 29.

From these waveforms you can now calculate the small signal gain of the amplifier. Verify that it is roughly as calculated. Measure the gain as a function of frequency using the 10, 20, 50, 100, etc spacing of frequency points. Plot the gain as a function of frequency.

if you have time you could construct some of the other circuits in Unit 33 and verify the performance.

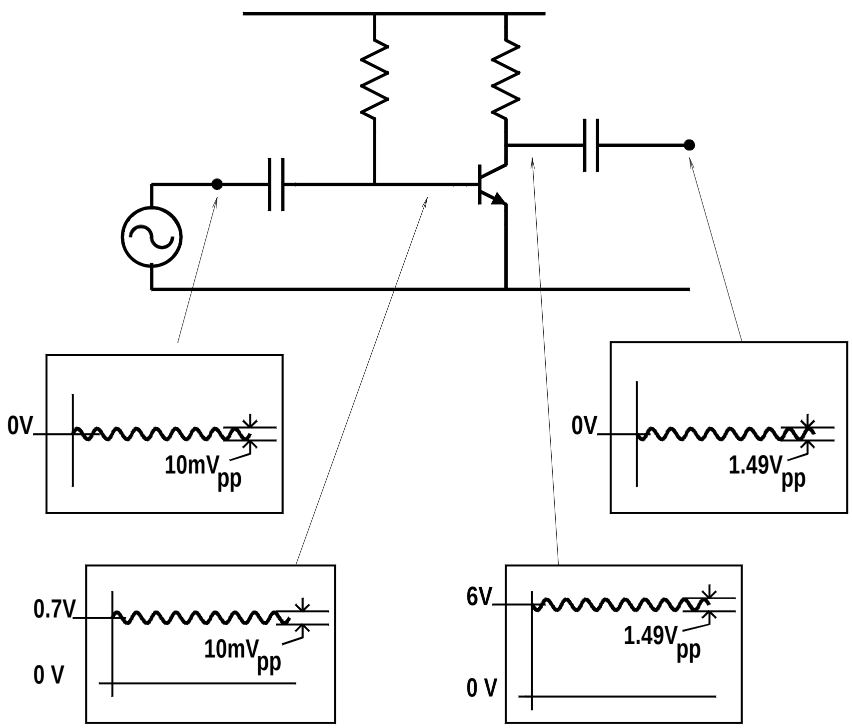

Figure 29:

Junction FETs

Look up the base diagram for a 2N3819 JFET in the Radionics catalogue and verify that it is the same as that shown in Figure 30. Measure and plot the characteristics using the circuit shown in Figure 30.

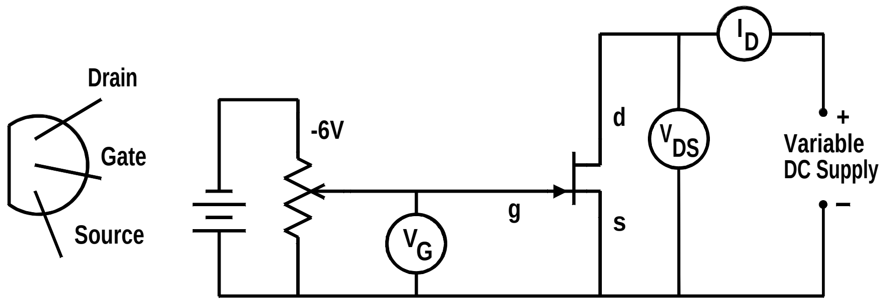

Figure 30:

JFET amplifier

Design and construct a JFET amplifier using the circuit shown in Figure 31. Your lab book should contain the details of the design calculations.

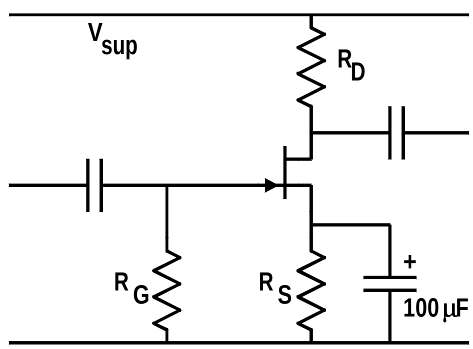

Figure 31:

Measure the DC values of the voltages in the circuit and use these values to confirm that the currents are in accordance with the design values. Measure the gain of the amplifier as a function of frequency and plot the frequency response.

Inverting amplifier using op-amps

The pin diagram for a type 741 op-amp is shown in Figure 32. Note that an integrated circuit is viewed from the top when identifying the pins.

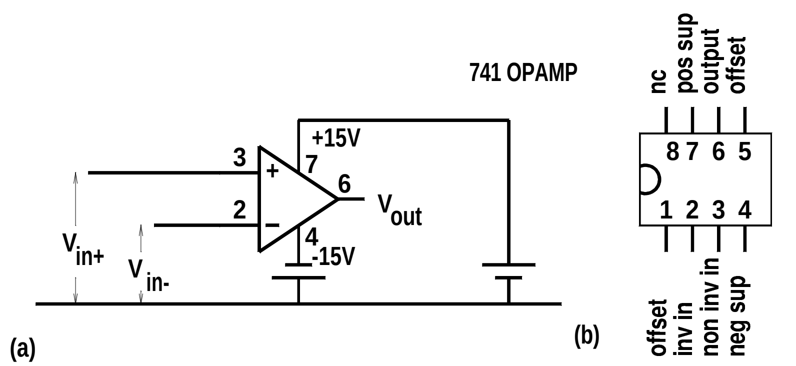

Figure 32:

You should design and construct an inverting amplifier having a gain of -15 using the circuit in Figure 33. Remember to add in the power supply connections and to switch on the power supply. The power supply connections are not shown for simplicity.

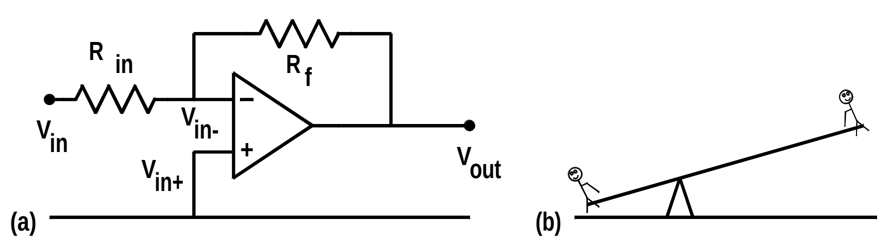

Figure 33:

Measure the DC gain of this amplifier for both positive and negative input signals. It is sometimes difficult to obtain small DC signals for testing DC amplifiers. It is very easy to use a potentiometer and a battery to generate small signals using the circuit shown in Figure 34. You can either make up this circuit yourself for your own use or you can use the units which are available in small boxes in the lab. Note that the made up units only make connection to the battery when the button is pressed. This conserves battery life as it is difficult to forget to take your finger off the button.

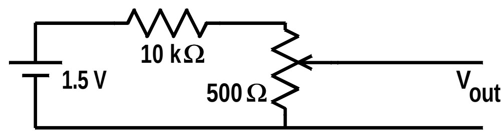

Figure 34:

You should also measure the output from the inverting amplifier as a function of the input voltage and investigate when the amplifier goes into saturation.

The noninverting amplifier

The circuit for the noninverting amplifier is as shown in Figure 35.

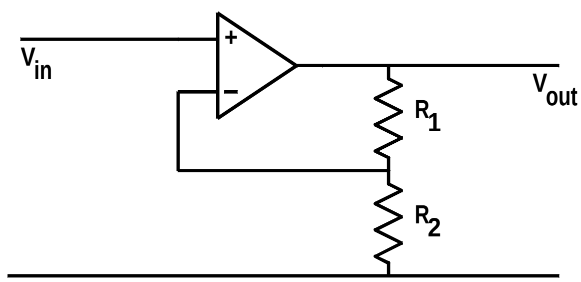

Figure 35:

Design a noninverting amplifier which has a gain of 17 and construct the amplifier. Measure the gain of the amplifier and also plot the output from the amplifier as a function of the input voltage.

Measure the gain of the amplifier for AC input signals. Increase the amplitude of the sinusoidal input signal and observe the shape of the output signal on an oscilloscope. At what amplitude of the output signal does the output start to become distorted? How is this related to the power supply voltage?

Adder circuits

The two types of adder circuits are shown in Figure 36 and Figure 37. You should design and construct and test both of these types of adder circuits. Target designs would be:

$$V_{out} = V_1 + V_2 \quad \text{and} \quad V_{out} = -2.1V_1 - 4.5V_2 - 3.9V_3$$

In testing these circuits you should pay particular attention to the design of appropriate test inputs for the circuits so as to fully exercise the circuits. A table showing the type of structure for the test matrix is shown on page 213 of the text. You should be able to explain what is tested in each line of this test matrix.

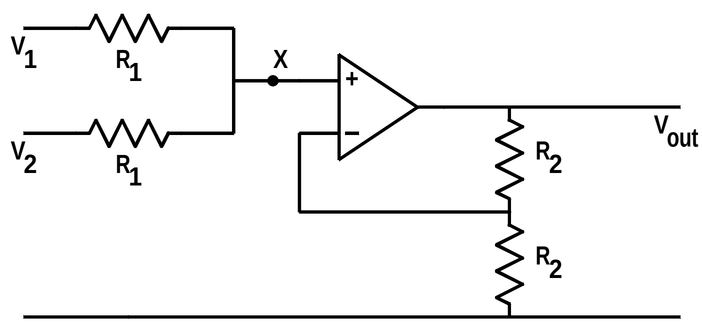

Figure 36: Noninverting adder

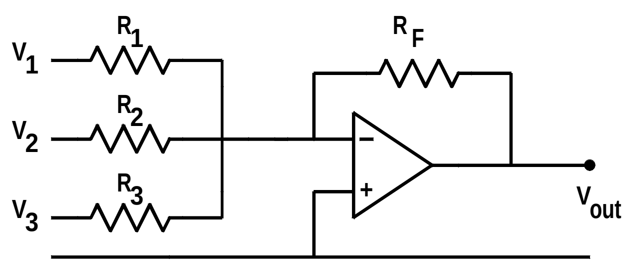

Figure 37: Inverting adder

Differentiator circuits

The basic differentiator circuit is shown in Figure 38. You should design and construct a differentiator circuit which has a time constant of .01 s. This circuit can then be tested by applying a sinusoidal input signal. You should be careful in applying higher frequency signals as the output increases in proportion to the frequency and you can easily drive the amplifier into saturation.

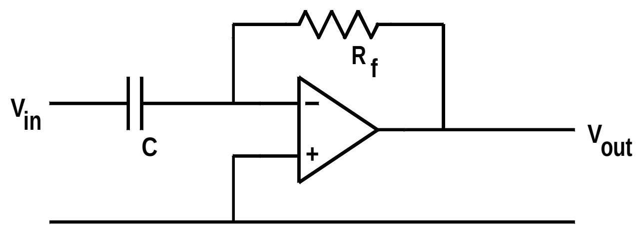

Figure 38:

You should display the input on one channel of an oscilloscope and the output on the other channel and your lab book should contain a sketch of the waveforms showing the relative phases of the input and output. You should also investigate the response of the circuit to a triangular waveform and again sketch the input and output waveforms.

Integrator circuits

The basic circuit for an integrator is shown in Figure 39. You should design and construct an integrator which has a time constant of .1 s. Write down the equation relating the input and output voltages.

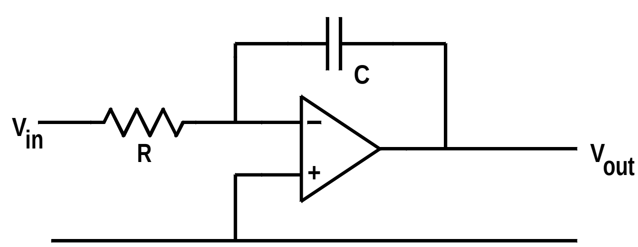

Figure 39:

This integrator is tested by applying a square waveform to the input and examining the output. You should test the circuit and sketch the waveforms.

You should also test the circuit with sinusoidal waveforms. Will the output of the circuit increase or decrease as the frequency of the input signal increases?

Active filters

Unit 48 in the text describes the operation of active filter circuits using opamps. if you have time you should attempt to design and construct at least one of the circuits. A design program is available in the website "www.physics.dcu.ie/∼bl" which will carry out the computations needed to design the Active Filters which are described in Unit 48. Click on Compute for Unit 48 in the Analog Electronics contents page to run the Java module.