ELE2EMI 2007
Laboratory 3: AC Measurements

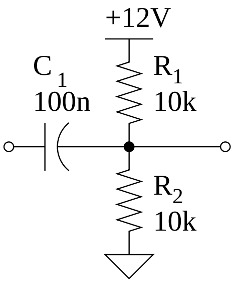
Components and Equipment

1. Stationery
2. Breadboard
3. Op Amp
4. 1×100 nF capacitor
5. 3×10 kΩ resistors
6. 5V dc supply capable of 12 V dc
7. Signal generator
8. Oscilloscope
9. Cables for oscilloscope
10. Multimeter
11. Leads
12. Single strand hookup wire

Experiment

1 Measurement of AC Signals

Build the capacitor-resistor network shown in the figure below.



Set the signal generator to **sine** output and its frequency to **4 kHz**. Connect the oscilloscope's channel 1 lead to the output of the generator and its channel 2 lead to the junction of R_1 and R_2.

Question 3.1.1: Calculate the period T (in μs) of the sine wave.

The phase difference will be small; to measure it, first ensure that both oscilloscope channels' traces are present and positioned on the centre of the graticule when the channels are switched to GND.

Switch the channels to AC and be sure *not* to touch the vertical position control from now on.

Phase change between input and output is determined by measuring the time difference between two points with equivalent phase on the two waveforms: to obtain a more accurate measurement, it's recommended that you choose these points to be where they cross the centre (origin) of the graticule.

Question 3.1.2: Why would it be less accurate to choose the peaks or troughs of the sinewave as the reference points?

So that the time difference can be accurately measured, increase the sweep speed (that is, decrease the time base) on the oscilloscope. It may be necessary to re-adjust the triggering so that the two waveforms' corresponding points are both clearly visible.

3.1.3: Now measure the time difference $\Delta t = t_{output} - t_{input}$ and convert it to a phase difference $\Delta\phi$ expressed in degrees.

Δt (divisions)	Time scale (μs/div)	Δt (μs)	Period T (μs)	$\Delta\phi$ (degrees)

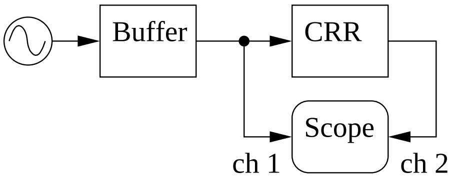
2 Bandwidth Measurement

One measurement commonly required is the 3 dB bandwidth of a circuit.

Question 3.2.1: Prove that the -3 dB power points correspond to 71% of the maximum voltage gain.

Write your proof here:

Turn *off* the signal generator. Connect it to the **buffer** circuit you built in earlier lab work. Now connect the buffer so that it is driving the capacitor-resistor network of the previous section.



We will now find the lower -3 dB breakpoint of the network. Quickly sweep through a range of frequencies and observe the variations in output amplitude to get a rough idea of the shape of the frequency response. Adjust the frequency of the input signal until it is in the passband of the network.

With the output of the network displayed on the oscilloscope, adjust the Volts/div knob and the input signal level to get the output at 5 divisions peak-to-peak on the oscilloscope screen. We are looking for the lower breakpoint, so decrease the input frequency until the output falls to 71% of its passband value, i.e. 71% of 5 divisions, or 3.55 divisions peak-to-peak. The frequency at which this occurs is the lower breakpoint and can be determined from the *oscilloscope display* - never trust the scale on the signal generator!

The upper breakpoint can be found in a similar fashion by increasing the input frequency until the output falls to 3.55 divisions.

3.2.2: Record your results here:

Peak Amplitude (V)	-3dB amplitude (V)	Lower Breakpoint (Hz)	Upper Breakpoint (Hz)

The procedure assumed that the input amplitude remains constant with frequency, which requires that the input impedance of the circuit is frequency independent. However this is rarely true. To minimise this problem a buffer was used. The buffer presents a nearly constant impedance load to the signal generator, and hence keeps the input amplitude nearly constant.

Question 3.2.3: What limitations might the buffer have?

3 Measurement of Rise Time

Although the peak-to-peak amplitude of a signal is measured from the minimum to the maximum voltage, the **rise time** is defined as the time taken for the signal to increase from 10% to 90% of the peak-to-peak amplitude.

Disconnect the previous circuit from the signal generator and the oscilloscope. Place one channel of the oscilloscope across the output of the signal generator. Switch the generator to a **square** wave with a frequency of **1 kHz**.

In a similar fashion to the procedure described in the previous section, make adjustments such that the generator's signal takes up 5 divisions vertically. Position the minimum value of the trace onto the 0% graticule line so that the maximum line will be on the 100% graticule line.

Increase the sweep speed (i.e. decrease the time base setting) of the oscilloscope so that the rising edge is clearly visible on the screen. You may need to adjust the triggering and use the **times-10 X-magnification** switch on the oscilloscope to see this clearly. Measure the time difference Δt between the points where the trace crosses the 10% and 90% markings: this value is the rise time. If you have the X-magnification switched on, remember to take this into consideration when determining the rise time.

3.3.1: Record the Rise Time results here:

Δt (div)	Time base (μs/div)	X-mag (1 or 10)	Rise Time (μs)

4 Measurement of AC and DC Signals

Quite often there are both an AC and a DC voltage present across a component. Such a situation frequently occurs when biasing transistors. The AC signal is generally the signal to be amplified and the DC is the bias used to place the transistor in a suitable linear region. It is important to be able to measure both the AC and the DC voltages separately.

3.4.1: Use the CRR network of section 1 with the oscilloscope leads still across the signal generator and R_2. Switch both oscilloscope channels to the DC position. Adjust the level of the signal generator and the output of the power supply, and **observe** the effects they have on the two waveforms.

Write your observations here:

3.4.2: Next adjust the power supply until the voltage divider's DC output voltage is 9 V. Adjust the signal generator until the peak-to-peak AC voltage is 100 mV. Now measure the DC and AC voltages across R_2. You will have to change the oscilloscope settings to be able to measure each of these accurately.

R_2 DC Voltage (V)	R_2 AC Voltage (mV)

5 AC Measurement using the Multimeter

You may have noticed that your multimeter also has an AC setting. Let's use the oscilloscope and the multimeter to take some AC measurements and compare the two sets of results.

3.5.1: Disconnect the previous circuit from the signal generator. Place one oscilloscope lead across the output of the signal generator. Set the generator to output a **1 kHz sine** wave. Measure the peak-to-peak voltage using the oscilloscope, and then measure the AC voltage using the multimeter. The two instruments are using different units so they will not give the same numerical reading.

V_{p-p} (sine, oscilloscope)	V_{AC} (sine, multimeter)

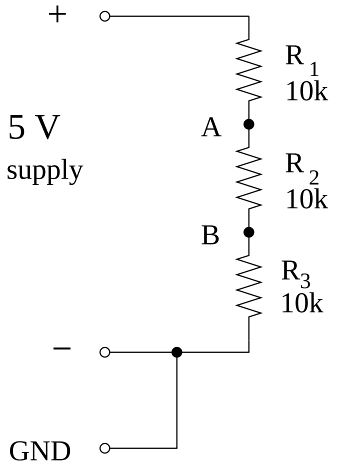
3.5.2: Now switch the signal generator over to a square wave. Adjust the level control on the generator until the peak-to-peak voltage on the oscilloscope is the same as for the sine wave measurement. Now measure the AC voltage using the multimeter.

V_{p-p} (square, oscilloscope)	V_{AC} (square, multimeter)

Notice that although the peak-to-peak voltages for the two waveforms were the same, the multimeter produced two different results. Multimeters on AC settings often display the RMS (root mean square) voltage, V_{rms}. For the meter to be able to do this, it assumes that the waveforms it is measuring is a sine wave. Unfortunately there is no way to tell by a multimeter whether this asumption is correct. Unless you can be certain that you are measuring a sine wave, it is best to use the oscilloscope. If required, the RMS voltage of a sine, square or triangular wave can be obtained from the peak-to-peak reading on an oscilloscope using an appropriate formula.

6 Measurement Reference Points

To perform a voltage measurement with a multimeter, you simply placed the two leads across whatever part of the circuit you desired. Using the oscilloscope to take voltage measurements requires a little more care. The ground clip on the oscilloscope probe is physically connected through the cable and the earth lead of the oscilloscope's power cord to ground potential. The two leads on the multimeter are not fixed at any potential since the meter is battery powered. Whereas connecting the ground clip of an oscilloscope to a circuit connects that point in the circuit to ground potential. Build the following circuit (configuration 1) to help see this effect.



This circuit is a voltage divider comprised of three series resistors. Connect the **green ground terminal** of the power supply to the point marked as GND in the circuit diagram above.

Calculate the voltage *across* the middle resistor R_2. **Check** this result experimentally using the multimeter.

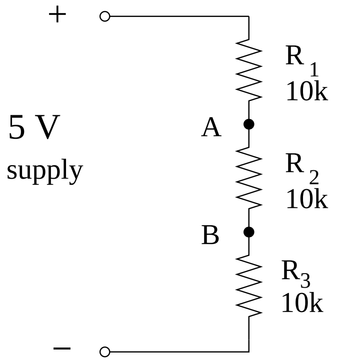
Now **measure** the same voltage with the **oscilloscope**, placing the **ground clip** at node B and the **probe tip** at node A.

3.6.1: Record the results in this table:

Calculated V(R_2)	DMM measured V(R_2)	Oscilloscope measured V(R_2)

Question 3.6.2: Do the DMM and oscilloscope measurements agree?

Remove the ground connection of the power supply from the circuit so that the circuit is now modelled by the next figure (configuration 2).



3.6.3: Repeat the measurements using both the multimeter and the oscilloscope as before, but with the circuit of configuration 2.

Calculated V(R_2)	DMM measured V(R_2)	Oscilloscope measured V(R_2)

Question 3.6.4: Do the multimeter and oscilloscope measurements agree now?

Explanation: Since the ground clip on the oscilloscope is at ground potential, it will tie node B to ground potential. In configuration 1 the other side of resistor R_3 was also at ground potential, which effectively short circuited R_3.

3.6.5: Work out in theory what the voltage should be across R_2 when R_3 is shorted.

Do this calculation here. Draw a box round the answer.

3.6.6: Question: Does this value agree with what you measured in configuration 1 with your oscilloscope?

In configuration 2 the potential at node B will be grounded by the oscilloscope ground clip, but since no other connections are made to the ground potential, there are no components shorted out.

3.6.7: Work out what the voltages are, **relative to ground potential**, for all nodes, including the power supply outputs, for **configuration 2**.

V(PS - node)	V (node A)	V (node B)	V (PS + node)

Neither lead on the multimeter is connected to earth, so they can be placed at any point in a circuit without affecting it in the manner just described.

The ground potential on the oscilloscope ground clip can cause other problems.

Question 3.6.8: In *each* of the *two* configurations, explain what would happen if the ground clip touched the +5 V terminal of the supply.

Describe the effects in the 2 cases here:

Question 3.6.9: Think of (2) possibly expensive reasons why you shouldn't do this when using the circuit shown of *configuration 1*.

Write the 2 possibly expensive reasons here: