DATE	**COURSE/YEAR/GROUP**	**NAME**

UNIVERSITY OF PLYMOUTH

Department of Communication and Electronic Engineering

COMPUTER SIMULATION USING “ELECTRONICS WORKBENCH”

TONE CONTROLS

Introduction

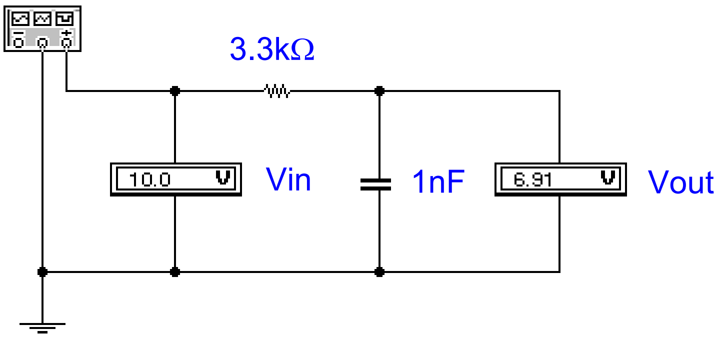
Signal Processing is a substantial field in Communication Engineering. A popular application occurs in the form of tone controls for audio systems – bass boost, bass cut, reduction in mains hum, hiss, scratch filters etc. Also, equaliser circuits covering the whole audio spectrum are now an essential feature on any mixer desk.

In this simulated experiment, you will

Try out a number of tone control circuits.
Learn to plot a Frequency Response Graph.
Meet another Electronics Workbench instrument, the **Bode Plotter.**
Use logarithmic scales including the decibel scale.
See how changing resistor and capacitor values will alter significant frequencies on the response curves.

1) The Low-Pass Filter

The humble combination of a resistor and capacitor in series can be used to suppress high frequencies (low-pass) or low frequencies (high pass). In a low-pass



filter circuit, the output is taken across the capacitor. The frequency at which the filter begins to operate is called the corner or cut-off frequency.
This occurs when the reactance of the capacitor, $1/2\pi fC$, equals the resistor value.

At this point $$V_{out}/V_{in} = 1/\sqrt{2} = -3\text{dB}$$

At lower frequencies, the reactance of the capacitor dominates, and nearly all the input voltage appears across it. At higher frequencies the reactance of the capacitor gets progressively less, and so does the voltage across it. You can think of it roughly as a frequency-dependant voltage divider.

Set up the above circuit on Electronics workbench, changing the default resistor and capacitor values to those shown. Switch the two voltmeters to AC. Do this by double-clicking on each meter and choosing 'AC'.

Set the function generator to an amplitude of 14.2V. (This conveniently has a r.m.s. value of 10V). Check that the waveform is a sine wave. Take readings of V_{out} and V_{in} for the frequencies shown, and plot the performance on the graph below.

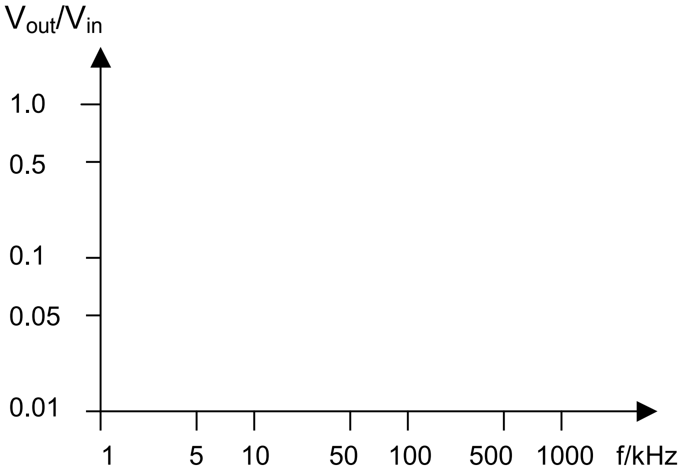
You should find that, at low frequencies $V_{out} = V_{in}$. So, the circuit is "passing" low frequency notes – hence its name.

The funny scales are logarithmic, rather than linear. There are two reasons for doing this:-

i) A large range of frequencies can be accommodated on the scale.
ii) The shape of the graph is simpler – two straight lines joined by a "bend".

However, it is difficult to plot the points accurately on these roughly marked logarithmic scales. Do your best.

Freq. kHz	**V_{out} Volts**	**V_{in} Volts**	**V_{out}/V_{in}**



Measure the corner frequency (cut-off frequency) in three different ways:-

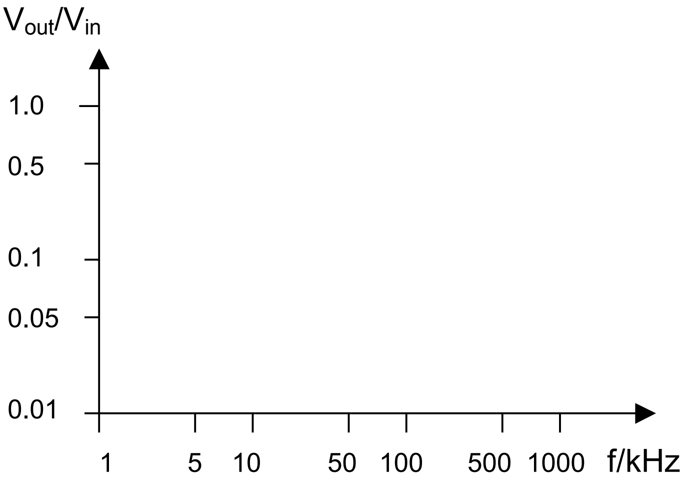
i) Extend the two straight line portions until they meet
………………………

ii) Calculate the frequency from $f_c = 1/(2\pi RC) =$
………………………

iii) Estimate the frequency from the graph when $V_{out} = V_{in}/1.414 =$
………………

2) The High-Pass Filter

Swap the positions of the resistor and capacitor and repeat the experiment, taking the output across the resistor.



Freq. kHz	**V_{out} Volts**	**V_{in} Volts**	**V_{out}/V_{in}**

This time, the output voltage is highest for high frequencies, and it drops progressively below the corner frequency.

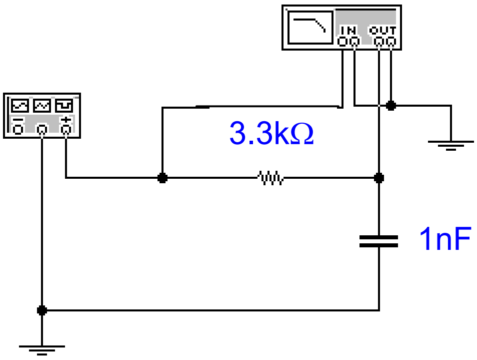
Measure the corner frequency in several ways:-

3) The Bode Plotter

Electronics Workbench contains a rather natty gadget called a Bode Plotter.

What we have been doing is measuring the frequency response of the circuits by a series of manual readings at different frequencies. The Bode Plotter does this for us automatically!

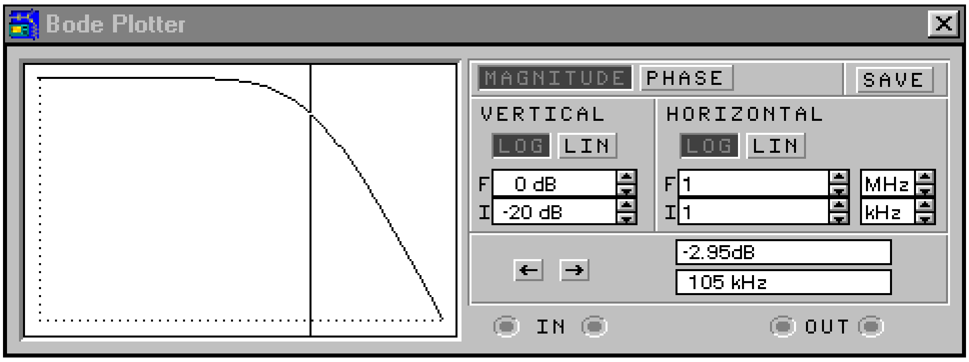
Replace the meters in the low-pass filter circuit by the Bode Plotter. The voltages V_{in} and V_{out} are connected to the IN and OUT terminals as shown.



Expand the Bode Plotter and set the controls as shown below. Note that

We are viewing the magnitude of the voltage, not the phase.
The vertical scale runs upwards from –20dB (Initial value I) to 0dB (Final value F)
The horizontal scale runs from 1kHz (Initial value I) to 1MHz (Final value F)
Both scales are set to be logarithmic, rather than linear.

Hopefully, the graph is the same as the one you plotted in the first part.



F 0 dB
I -20 dB
F 1 MHz
I 1 kHz
-2.95dB
105 kHz

The vertical line is a cursor which can be moved by clicking on the left and right arrows, or by dragging the line with the mouse.

Measure the frequency for which V_{out}/V_{in} is – 3dB
……………………

Switch to a linear vertical scale, and repeat for a figure of 0.707
……………………

Also, try extending the two straight line portions of the graph in the above picture of the Bode Plotter.

What is the corner frequency? …………………

What was the calculated value in part 1 ? …………………

Move the cursor to both ends of the horizontal scale, and label the axes as in a conventional graph.

4) Decibels

You probably associate decibels with loud sounds, to be found in discos or near airport runways.

In fact, decibels are commonly used in Communication Engineering for measuring signal levels of all sorts.

A decibel figure is also a ratio, and is actually the logarithmic version of the one we have been measuring.

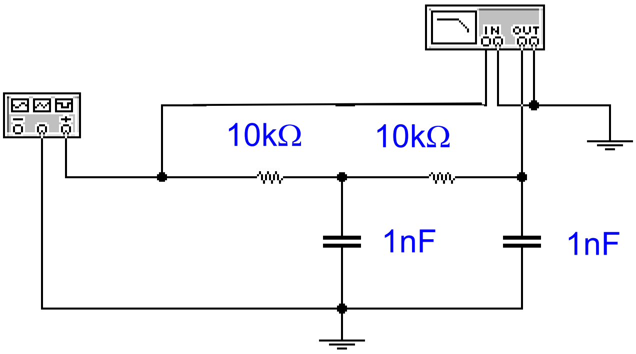
V_{out}/V_{in}	dB
1	0
0.707	- 3
0.5	- 6
0.31	- 10
0.1	- 20
0.01	- 40

Positive decibel values are found in amplifiers where V_{out} is bigger than V_{in}.

Note that we may use the expression “Voltage Gain” for the ratio V_{out}/V_{in} , whether this is greater than 1, as in an amplifier, or less than 1, as in these circuits.

5) Two-Stage Low-Pass Filter

The single stage filter is a bit tame. We can strengthen its action by cascading two RC circuits with the same corner frequency. Note that the resistor values here are 10kΩ.



The 'strength' of the filter is commonly measured in decibels per octave. Theoretically:-

A single stage circuit produces	-6dB per octave
A two-stage circuit produces	-12dB per octave

An octave is a doubling of frequency, e.g. eight notes on the piano keyboard from middle C (256Hz) to the next C up (512Hz).

Set the Bode Plotter as follows:-

Frequency range	1kHz to 1MHz as before
Voltage gain	-60dB to 0dB

Measure the slope of the graphs by taking dB readings at 100kHz and 200kHz. These frequencies are 1 octave apart. So, subtract the dB readings to get the slope.

Do this in the circuit above. Then disconnect the second stage, and take readings for the single stage circuit.

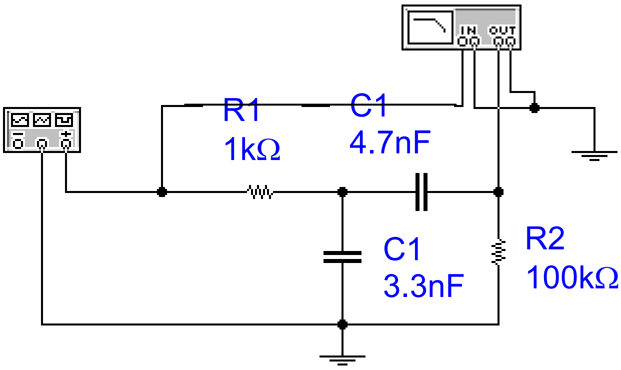
	V_{out}/V_{in} at 100kHz	V_{out}/V_{in} at 200kHz	Slope (dB/octave)
Single Stage			
Double Stage			

Does the double-stage filter cut off more rapidly? …………………

Do the figures agree with the theoretical values? …………………

6) Band-Pass Filter

A band-pass filter lets through a centre range of frequencies, cutting off both ends. A simple example is made by cascading a low-pass filter (R_1 and C_1) and high-pass filter (R_2 and C_2).



Sketch the frequency response, marking the scales. Suitable ranges are:-

Frequency from	20Hz to 1MHz
Gain from	-20dB to 0 dB

Calculate the two corner frequencies, and compare with the simulation

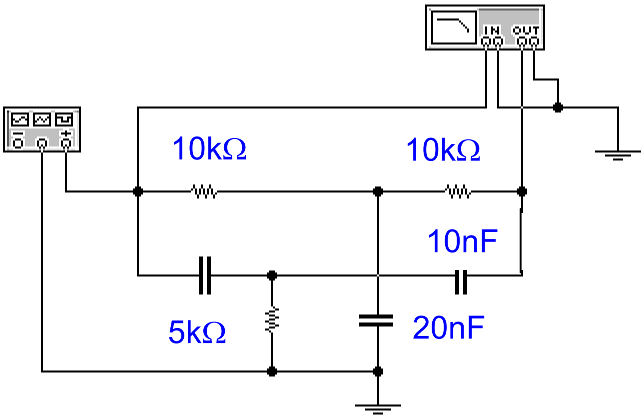
		Calculated	Measured
Low-pass	$1/(2\pi R_1C_1)$ =		
High-pass	$1/(2\pi R_2C_2)$ =		

This is a simple design. More efficient jobs can be done using op-amp circuits.

7) Notch Filter

This is included for its dramatic effect.

Sometimes it is required to suppress a particular frequency, e.g. mains “hum” at 50Hz.
The notch filter does this rather well.



Have a play with this circuit. The notch depth is 50 dB, which is a lot.
Try shifting the notch frequency to 50Hz.

Hint Change the R values, but preserve the ratio R, R, R/2.
If you double each R value, what effect does it have on the notch frequency?
Try doubling again.

If you double the C values, preserving the ratio C, C, 2C, what happens?

Record your final R and C values when you are close to 50Hz.

R =

C =

Obtain a printout of the bode plot and stick it in the space below.

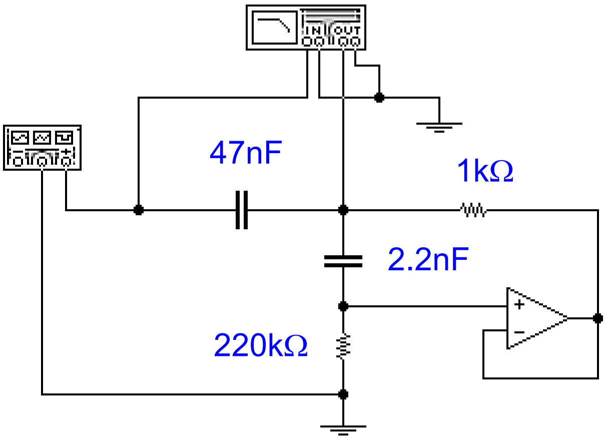
8) Graphic Equaliser Circuits

This circuit contains an active device, an operational amplifier. Hence it can produce a gain greater than one. What it does is to provide a powerful boost at a particular frequency, determined by the component values in the circuit. ("Equaliser" is not a very obvious name for the circuit.)

A full Graphic Equaliser would have ten of these circuits connected in parallel, and designed to operate on frequencies of say:-

32Hz 64Hz 125Hz 250Hz 500Hz 1kHz 2kHz 4kHz 8kHz 16kHz

These values cover the whole audio spectrum on a logarithmic scale.



Try the Bode Plotter with the vertical scale set to linear, from 0 to 5. Sketch the graph in the space below.

To change the centre frequency, alter the 47nF capacitor. Doubling this to 100nF should halve the frequency. Try it.