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BLACK BOX LAB | REPORT

Introduction:

Background:

⇒ The black box experiment involved analysing an unknown circuit inside a sealed box, of which could be constructed of resistors, capacitors or inductors. The box contained an input and output terminal allowing signals to be passed through the circuit inside and analysed at its output.

⇒ This experiment is useful to gain experience of how to reverse engineer and to better understand strategic testing in order to interpret a circuits function.

Aims:

⇒ Using various bench testing equipment, the aim of the experiment was to identify the structure of the circuit in terms of its components, and to calculate their values.

⇒ To understand how the output of different electronic components react or behave to different input signals.

⇒ To gain more experience operating the bench equipment and to learn how to use different pieces of the equipment in conjunction to analyse the circuit.

⇒ To record data accurately in a suitable range and interpret it correctly to calculate component values and the primary operation of the circuit.

Theory:

Resistors:

Resistors are passive devices which limit the flow of current depending on the voltage across it, and for an ohmic resistor, they follow ohms' law, $V = IR$. [1]

$$Therefore\ \ R = \frac{V}{I}$$

R = Resistance in Ohms, Ω

V = Potential Difference in Volts, V

I = Current in Amperes, A

They have the same characteristics whether the current flowing through them is AC or DC, for a constant resistance, the current flowing through the resistor is directly proportionate to the potential difference (voltage) across it (*figure 1)*. However, for an AC current, the relationship between current and voltage, electrical resistance, is defined as impedance, Z.

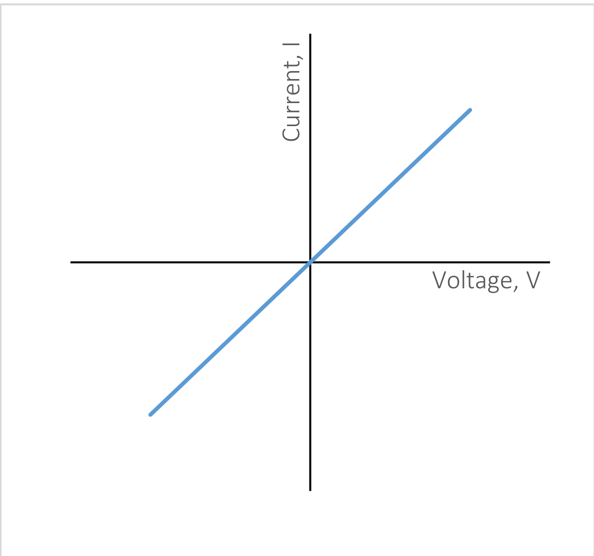

Figure 1: An ohmic resistor IV characteristics for both AC and DC.

⇒ The line passes through the origin of the graph, which signifies that unless there is a potential difference, no current can flow.

⇒ Constant gradient for a fixed resistance.

⇒ $Gradient = \frac{I}{V} = \frac{1}{R}$

Capacitors:

Capacitors are electronic devices that store charge on two plates surrounding an insulator. When a potential difference is applied, charge accumulates on the capacitors plates, and as the density of charge on the plates increases, so does the potential difference across the plates.

Capacitance is defined as the amount of charge a capacitor can store per unit of potential difference across its plates, and is measured in $Farads, F.$

For a capacitor of fixed capacitance, the charge stored on the plates is directly proportionate to the potential difference across them [2].

The equation that links the potential difference across the plates and the charge stored is:

$$C = \frac{Q}{V}$$

C = Capacitance, Farads, F

Q = Charge, Colombes, C

V = Potential Difference, Volts, V

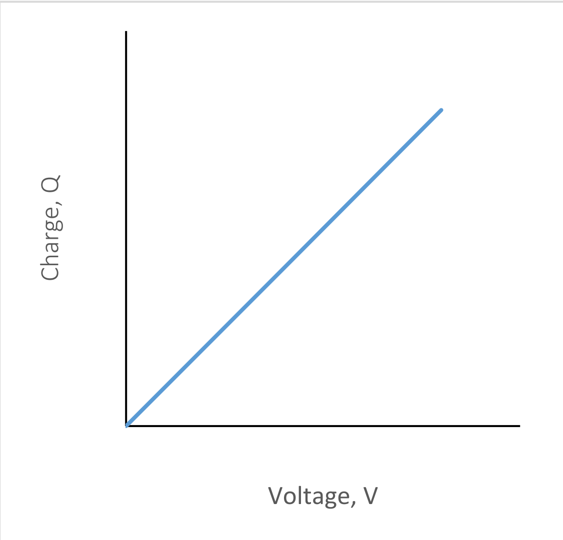

Figure 2: A Capacitors QV characteristics for DC.

⇒ Gradient of the line is the capacitance of the capacitor.

⇒ A charged capacitor will have a very high or infinite resistance.

For an AC current flowing through the capacitor, the reactance is its resistance depending on the frequency of the AC current. [3]

The equation for the reactance of a capacitor is:

$$X_C = \frac{1}{2\pi f C}$$

X_C = Reactance, Ohms, Ω

f = Frequency, Hertz, Hz

C = Capacitance, Farads, F

When the frequency of the AC current is high, the reactance of the capacitor is low, so the resistance is low. Similarly, when the frequency of the AC current is low, the reactance of the capacitor is high, so the resistance is high.

RC Circuits:

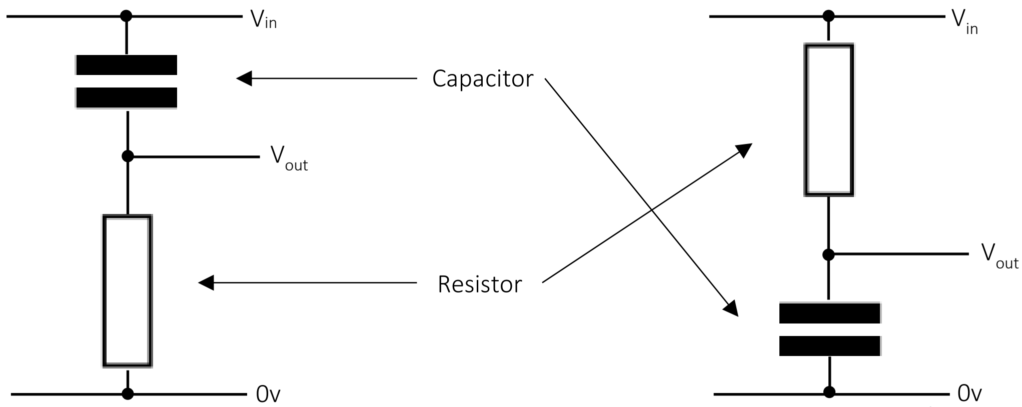

Figure 3: High Pass Filter

Figure 4: Low Pass Filter

Figure 3 and *4* represent 2 passive RC filters, which allow or block signals of certain frequencies to pass.

The cut off frequency of an RC circuit is the frequency at which the reactance of the capacitor is equal to the resistance, $X_C = R$. At this frequency, the gain of the output signal is $20\log\left(\frac{Vout}{Vin}\right) = -3dB$ or 70.7% of the input signal. [4]

The equation to find the "cut off" frequency of an RC circuit is:

$$f_{CO} = \frac{1}{2\pi RC}$$

f_{co} = Cut off Frequency, Hertz, Hz

R = Resistance of resistor, Ohms, Ω

C = Capacitance, Farads, F

For a high pass filter, like in *figure 3,* frequencies above the cut off frequency are unaffected, whereas frequencies below are attenuated.

For a low pass filter, like in *figure 4*, frequencies below the cut off frequency are unaffected, whereas frequencies above are attenuated.

Inductors:

Inductors are coils of wire wrapped around an air or iron core that store energy when a voltage is applied in the form of an electromagnetic field, they also have a small but significant resistance.

For a DC current flowing through an inductor, an Electromotive Force (EMF) is induced in the coil, which opposes the change of the current, creating a voltage across the inductor. The current will continue to rise until the induced EMF has fallen to zero, where there is now a steady current flowing through the inductor. Since there is no more back EMF induced to oppose the current flow, the inductor acts like a short circuit and maximum current is allowed to flow through it. [5]

For an AC current flowing through an inductor, the frequency of the current varies the inductors opposition to the current, known as the inductors Reactance.

The equation for an Inductors Reactance for a given frequency is:

$$X_L = 2\pi fL$$

X_L = Reactance, Ohms, Ω

f = Frequency, Hertz, Hz

L = Inductance, Henries, H

This means that an inductor behaves like a frequency dependant resistor, but opposite to a capacitor.

For a low frequency, the reactance of the inductor is low, so its resistance is low. But for a high frequency, the reactance is high, so its resistance is high.

Therefore, for a constant inductance of an inductor, the frequency of the current flowing though it is directly proportional to the reactance and hence the resistance of the inductor, as shown in *figure 5.*

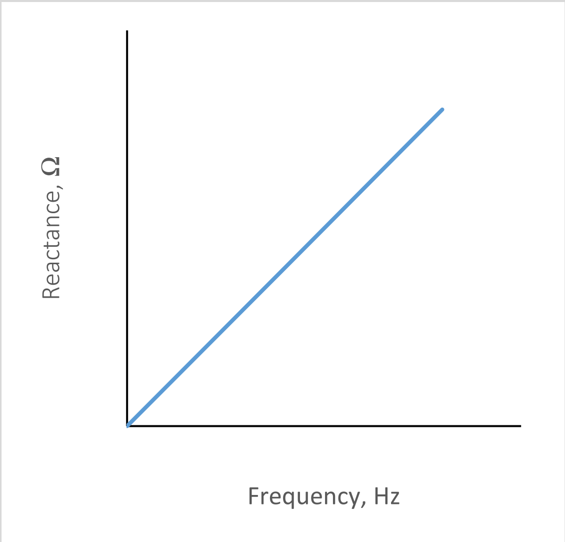

Figure 5: How reactance varies with frequency for an inductor.

Method:

Initially, both of the boxes were connected across a digital multimeter (DMM) as shown in *figure 6* to measure and record the resistance across their terminals. This was done first to enable me to approximate what type of components are in each box – a very high resistance could suggest that it is a capacitor, a low resistance could be an inductor and anywhere in-between could suggest it to be an ohmic resistor.

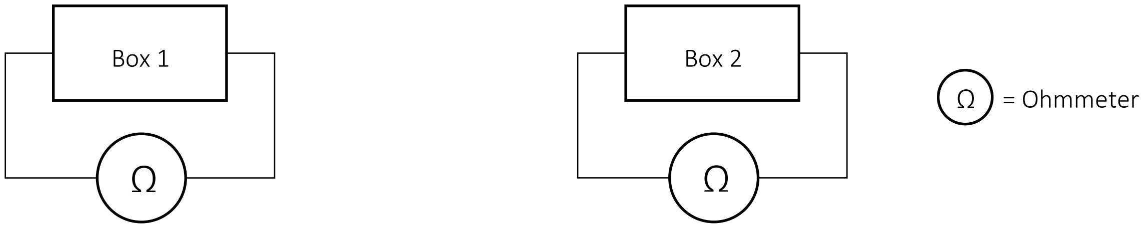

Figure 6: Schematic of ohmmeter connected to each box.

The two boxes were then connected in series, with the function generator being connected across them as shown in *figure 7*. Both probes of the digital oscilloscope were connected to the circuit, one on the output of the function generator, and the other on the output of the circuit between the 2 boxes. Then, both the probes on the oscilloscope were set to measure peak to peak voltage so the voltage at the input and output of the circuit could be measured.

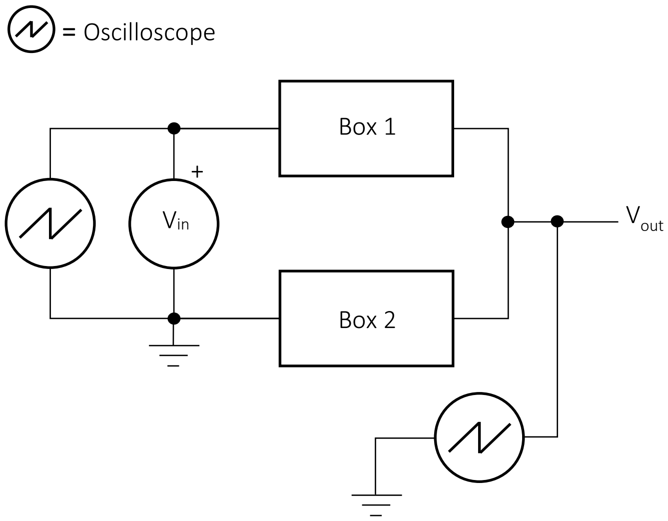

Figure 7: Schematic with oscilloscope probes connected.

A table was constructed to record down the input and output voltages at a range of frequencies, as well as the gain of the circuit being calculated for each frequency as seen in *figure 8*. The gain was calculated by dividing the output voltage by the input voltage, ($gain = \frac{Vout}{Vin}$).

Frequency (kHz)	V_{in} (mV)	V_{out} (mV)	Gain
1			
2			
3			

Figure 8: Example table to record measurements.

To measure all the data, the function generator was set to a peak to peak voltage of 2v, and initially was set to output a sine wave at a frequency of 100Hz. Using the oscilloscope, the voltage of the input and output was measured and was recorded in the table.

This process was repeated for every frequency in the range chosen, with the gain being calculated respectively.

The calculated gain was then plotted on a log-log graph against the range of frequencies, with frequency on the x-axis and gain on the y-axis.

Where the gradient of the line though the plotted data could be seen to change, a tighter range of frequencies were tested and recorded so that a more accurate trend line could be drawn where the gain begins to change.

The identify the cut off frequency of the circuit, a horizontal line was drawn from the y-axis at $gain = 0.707$ to meet the trend line, then a vertical line was drawn from the trend line to the x-axis. The frequency at which this line intersects the x-axis is the cut off frequency.

All the recorded data was then used to calculate the component values within the circuit.

Results:

Measured Data:

⇒ Resistance of first box = 99.8Ω
⇒ Resistance of second box = 11.8Ω

Frequency (kHz)	V_{in} (mV)	V_{out} (mV)	Gain
0.1	1280	150	0.12
0.2	1410	170	0.12
0.3	1400	170	0.12
0.4	1400	170	0.12
0.5	1400	170	0.12
0.6	1400	170	0.12
0.8	1400	180	0.13
1	1390	180	0.13
1.5	1380	200	0.14
2	1370	230	0.17
2.5	1370	270	0.2
3	1370	300	0.22
3.5	1360	330	0.24
4	1360	360	0.26
5	1370	430	0.31
6	1370	510	0.37
8	1390	640	0.46
10	1420	770	0.54
15	1500	1050	0.7
20	1570	1260	0.8
30	1730	1590	0.92
40	1810	1750	0.97
50	1850	1850	1
80	1930	1990	1.03
100	1930	2000	1.04

Graph:

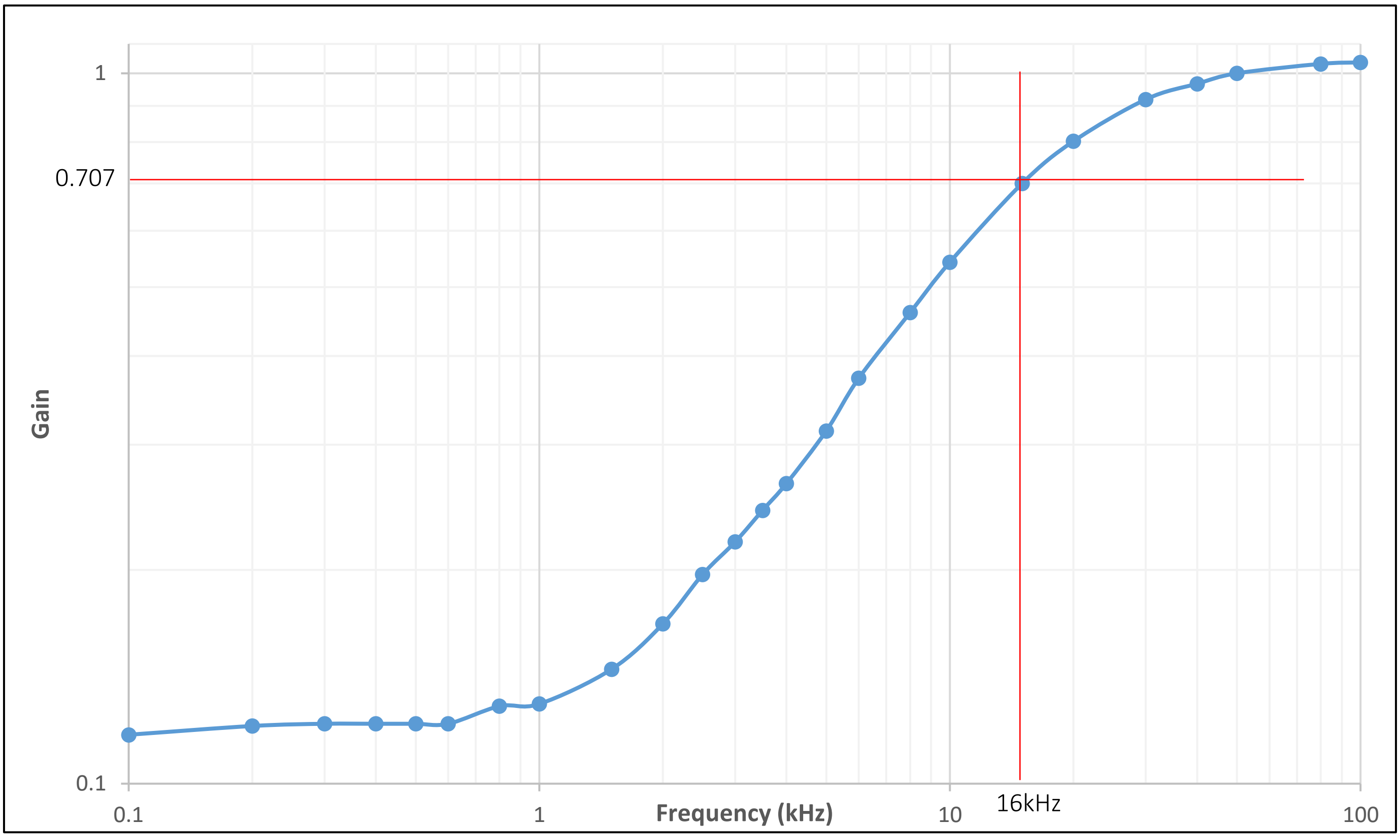

Figure 9: How gain varies with frequency for my circuit.

Calculations:

Indicated by the graph, the cut off frequency of the circuit is $16{,}000\ Hz\ (16kHz)$

Total resistance of both boxes $= 99.2\Omega + 11.8\Omega$

$R_T = 111\Omega$

The cut off frequency is given by [6]:

$$\boldsymbol{f_{co} = \frac{R_T}{2\pi L}}$$

Where f_{co} is the cut off frequency (Hz), L is the inductance of the inductor (H), and R_T is the total resistance of the circuit.

Rearrange to find the inductance L, in terms of R_T and f_{co}:

$$\boldsymbol{L = \frac{R_T}{2\pi f_{co}}}$$

Substitute in measured data:

$$\boldsymbol{L = \frac{111}{2\pi \times 16000}}$$

$$\boldsymbol{L = 1.10 \times 10^{-3}\ H = 1.10\ mH}$$

Discussion:

From the initial measurements of resistance from each box, the prediction for the arrangement of components in the circuit was a resistor followed by an inductor. This is because the first box had a resistance of 99.8Ω, which would be typically be too high for an inductor and too low for a capacitor. The second component was therefore assumed to be an inductor as it had a low resistance of 9.8Ω.

These predictions for the arrangement of the components are heavily supported in the results of the experiment and match the theory. For example, the graph in *figure 9* shows the gain to be attenuated at frequencies below 16kHz, making the circuit a high pass or a low cut filter. For an inductor, at high frequencies, the reactance is high and therefore the resistance is high, so in an RL circuit, the voltage dropped across the inductor will be high. This is exactly what is shown on the graph, as the frequency increases the voltage across the inductor increases, so gain increases up till unity (Gain of 1 for passive circuit).

In comparison, when the frequency falls, the reactance falls, resistance so the voltage across the inductor is lower than the voltage across the resistor, hence the gain of the output falls.

Conclusion:

In conclusion the experiment was successful in approximating the value of unknown components through using the characteristics and theory of how they operate with AC current.

The value calculated for the inductor was $1.1mH$, with the actual value being $1.0mH$. This calculation is very close to the actual value, with the slight fluctuation possibly being due to the tolerances of the inductor and resistor, as well as the impedance of the function generator and the oscilloscope probes.

References:

[1] http://www.s-cool.co.uk/a-level/physics/resistance/revise-it/resistance-ohms-law-and-conductance

[2] http://www.s-cool.co.uk/a-level/physics/capacitors/revise-it/how-capacitors-work

[3] http://www.sengpielaudio.com/calculator-RC.htm

[4] http://www.electronics-tutorials.ws/filter/filter_2.html

[5] http://www.electronics-tutorials.ws/accircuits/ac-inductance.html

[6] https://en.wikipedia.org/wiki/RL_circuit