Black Box Experiment - Report

1. Introduction

Black Boxes are electronic circuits defined by the transformation they perform from input signal to output signal. This experiment aims to characterise the components within a network of black boxes by measuring the Alternating Current (AC) Root Mean Square (RMS) Voltage across each of the boxes at a range of frequencies. This allows us to further practise the use of lab equipment such as the Digital Multimeter (DMM) and Waveform Generator, and introduces the concept of recording and interpreting data.

2. Theory

AC signals have a current that reverses direction (changes from positive to negative and vice versa) compared to a fixed reference. Usually this occurs at a constant rate known as the frequency and measured in Hertz (Hz – times per second).

RMS Voltage refers to an average voltage produced by an AC signal that can be used to calculate power dissipation from components within the circuit. This is measured directly by the DMM.

This experiment deals exclusively with three passive components: resistors, capacitors and inductors. Each of these components has a specific response DC signals and AC signal frequency which can be used to characterise the components within each black box.

Once in a steady state, capacitors have an effective infinite resistance to DC signals. As inductors are coils of wire, once in a steady state, they have an effective short circuit resistance to DC signals.

Resistors are frequency independent, they have the same level of impedance (in this case solely resistance) across all frequencies. Capacitors have an impedance that is inversely proportional to frequency; the higher the AC frequency the lower the impedance. Inductors have an impedance that is proportional to frequency; the higher the AC frequency the higher the impedance.

Gain is a measure of the level of attenuation or amplification occurring within an electronic circuit. To calculate gain, the following equation was used in this experiment:

$$Gain\ (dB) = 20log_{10}\left(\frac{V_{out}}{V_{in}}\right) \qquad (1)$$

3. Method

Black Boxes 000000478 (X) and 202000000 (Y) were used for this experiment. These serial numbers allow the boxes to be traced.

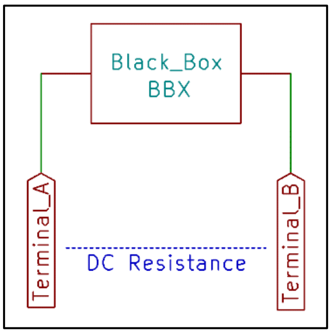

Figure 1: DC Resistance Circuit

The 2 Wire DC Resistance of each box was measured using the DMM according to **Figure 1**. The DMM can be connected to the Black Box Terminals using 4mm Banana Plugs.

The Black Boxes were then connected in a Potential Divider formation as per **Figure 2**. The AC source was provided by the Waveform Generator which was set up to produce a sinusoidal AC output signal of 1V Peak to Peak. The Waveform Generator can then be used to vary the frequency of the input AC signal.

Initially a wide frequency range of 100 Hz to 800K Hz in steps of approximately 100K Hz was applied to the circuit to roughly determine its behaviour. At each frequency the Voltage In (RMS Voltage between Vin and REF) and Voltage Out (RMS Voltage between Vout and REF) was measured using the DMM.

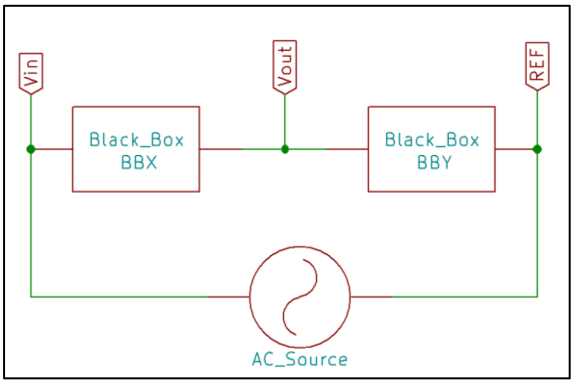

Figure 2: AC Potential Divider Circuit

Once the approximate frequency range having the greatest change in gain was found, more frequency points within this range were tested to better characterise the operation of the circuit.

At each frequency tested, the Frequency, Voltage In and Voltage Out were recorded. The gain was then calculated for each frequency using equation 1. The same testing was then completed with the position of the black boxes within the circuit swapped.

Bode plots with frequency in the $\log_{10}$ scale on the x axis and gain on the y axis where then created with the data for each potential divider circuit configuration.

4. Results

The DC Resistance measurements for each Black Box were as follows:

Box Y: 1.988K Ω

Box X: 67.4 Ω

The following graphs show the results from the AC frequency sweep tests. **Figure 3** shows the gain calculated from the Voltage across Box Y; **Figure 4** shows the gain calculated from the Voltage across Box X. In effect these graphs show the level of attenuation produced by each circuit configuration.

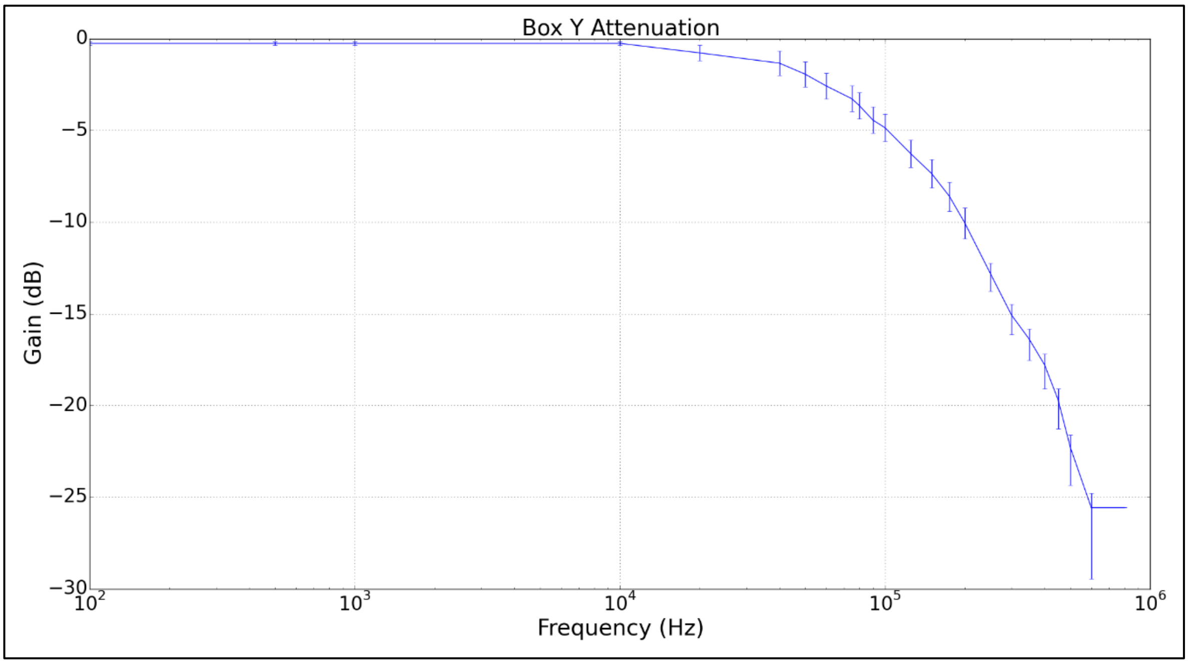

Figure 3: Gain calculated from Voltage across Box Y

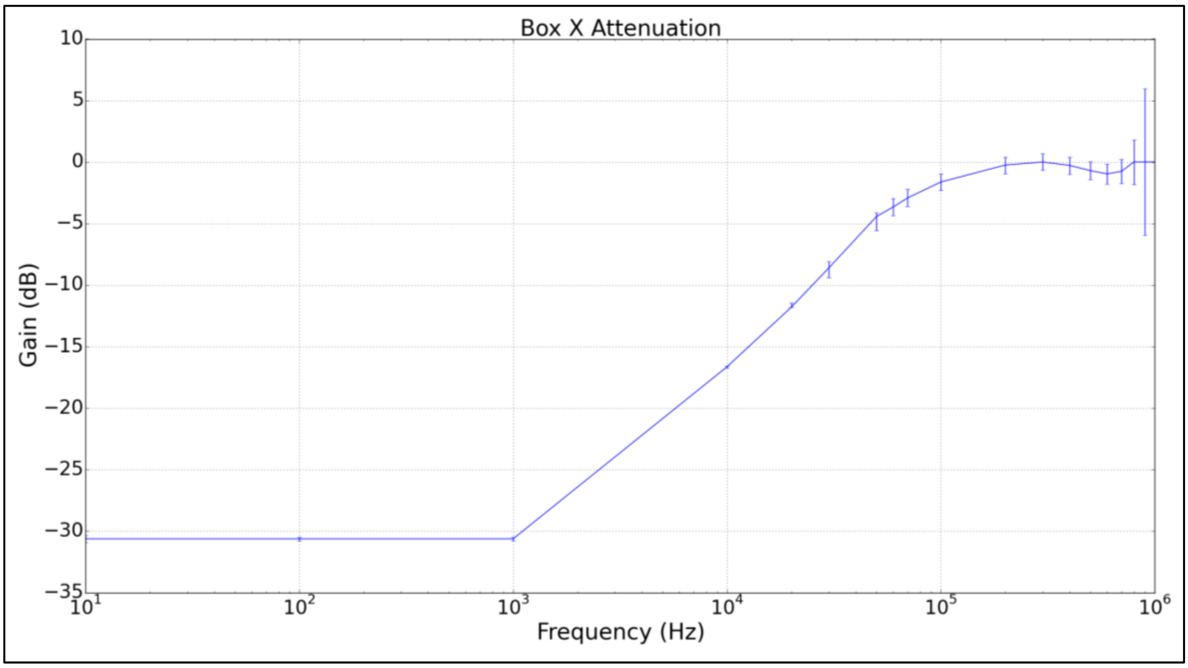

Figure 4: Gain calculated from Voltage across Box X

5. Discussion of Results

Figures 3 and **4** clearly show that Box X has a high impedance at high frequency. We can therefore state that Box X must contain an inductor according to the previously discussed theory. As the gain plateaus at approximately 0 in both graphs, Box Y must contain a frequency independent impedance. Therefore, Box Y must contain a resistor.

These values are backed up by the DC Resistance measurements of each box. Box Y has a much lower DC resistance that is typical of a coil of conductive wire, thus it is likely it is an inductor. Box X has a higher DC resistance, but a resistance that is well below open circuit, thus it is likely that it is a resistor.

The main source of error within the experiment was the DMM. At AC signal frequencies of greater than 30K Hz, the AC RMS Voltage measurement has an error of 3% of Reading plus 0.3% of Range [1, p.101]. This explains the large error bars shown at high frequencies on the graphs from section 4. However, as we are looking at the general trend of the attenuation of the circuits, this has little effect on the conclusions we can draw about the components the Black Boxes contain.

6. Conclusion

Having measured the DC Resistance and the AC Frequency response of the Black Boxes, it can be concluded that Box X contains an inductor and Box Y contains a resistor. The AC circuit was acting as a Low Pass Filter when measuring the Voltage across Box Y and as a High Pass Filter when measuring the Voltage across Box X. Potentially it may be beneficial to perform further experiments on a capacitor and inductor in series to characterise that circuit's response to AC frequency.

7. References

[1] Agilent Technologies, "Agilent 34450A $5^1/_2$ Digit Multimeter User's Guide," Santa Clara, CA, USA, Tech. Manual 34450-9000, July 2014.

8. Appendices

Appendix 1: Tabulated Data for AC Measurements of Box X.

Frequency (Hz)	Voltage In (V)	Voltage Out (V)	Gain (dB)	Minimum Error (dB)	Maximum Error (dB)
10	0.34	0.01	-30.63	-30.91674134	-30.34443561
100	0.34	0.01	-30.63	-30.77725228	-30.48294319
1000	0.34	0.01	-30.63	-30.77725228	-30.48294319
10000	0.34	0.05	-16.65	-16.72780431	-16.5724791
20000	0.35	0.09	-11.8	-11.8410746	-11.43152108
30000	0.35	0.13	-8.6	-9.404927245	-8.070712687
50000	0.35	0.2	-4.44	-5.589420959	-4.136775649
60000	0.35	0.23	-3.65	-4.357687453	-2.939096412
70000	0.35	0.25	-2.92	-3.623977949	-2.223546818
100000	0.35	0.29	-1.63	-2.319824177	-0.948195168
200000	0.35	0.34	-0.25	-0.924447347	0.420712527
300000	0.34	0.34	0	-0.674772941	0.674772941
400000	0.31	0.3	-0.28	-0.977356355	0.407515187
500000	0.26	0.24	-0.7	-1.425972713	0.034785347
600000	0.19	0.17	-0.97	-1.779020367	-0.154677693
700000	0.12	0.11	-0.76	-1.733098986	0.219333203
800000	0.04	0.04	0	-1.830784854	1.830784854
900000	0.01	0.01	0	-5.955536765	5.955536765
1000000	0	0	0	0	0

Appendix 2: Tabulated Data for AC Measurements of Box Y.

Frequency (Hz)	Voltage In (V)	Voltage Out (V)	Gain (dB)	Minimum Error (dB)	Maximum Error (dB)
100	0.34	0.33	-0.26	-0.345915291	-0.172691515
500	0.34	0.33	-0.26	-0.345915291	-0.172691515
1000	0.34	0.33	-0.26	-0.345915291	-0.172691515
10000	0.34	0.33	-0.26	-0.345915291	-0.172691515
20000	0.35	0.32	-0.78	-1.195066007	-0.36199148
40000	0.35	0.3	-1.34	-2.022238549	-0.656609491
50000	0.35	0.28	-1.94	-2.627968137	-1.249910423
60000	0.35	0.26	-2.58	-3.279127544	-1.886728171
75000	0.35	0.24	-3.28	-3.983087817	-2.573955264
80000	0.35	0.23	-3.65	-4.357687453	-2.939096412
90000	0.35	0.21	-4.44	-5.159140854	-3.718928738
100000	0.35	0.2	-4.86	-5.589420959	-4.136775649
125000	0.35	0.17	-6.27	-7.025151329	-5.526422982
150000	0.35	0.15	-7.36	-8.133791017	-6.594090209
175000	0.35	0.13	-8.6	-9.404927245	-7.811632409
200000	0.35	0.11	-10.05	-10.89451318	-9.228107077
250000	0.35	0.08	-12.82	-13.75531175	-12.25900668
300000	0.34	0.06	-15.07	-16.12163234	-14.49527638
350000	0.33	0.05	-16.39	-17.54312177	-15.81097399
400000	0.31	0.04	-17.79	-19.08754558	-17.19303663
450000	0.29	0.03	-19.7	-21.25869606	-19.09103452
500000	0.26	0.02	-22.28	-24.35609624	-21.62163763
600000	0.19	0.01	-25.58	-29.44246129	-24.79023915
700000	0.09	0	-25.58	0	0
800000	0.04	0	-25.58	0	0