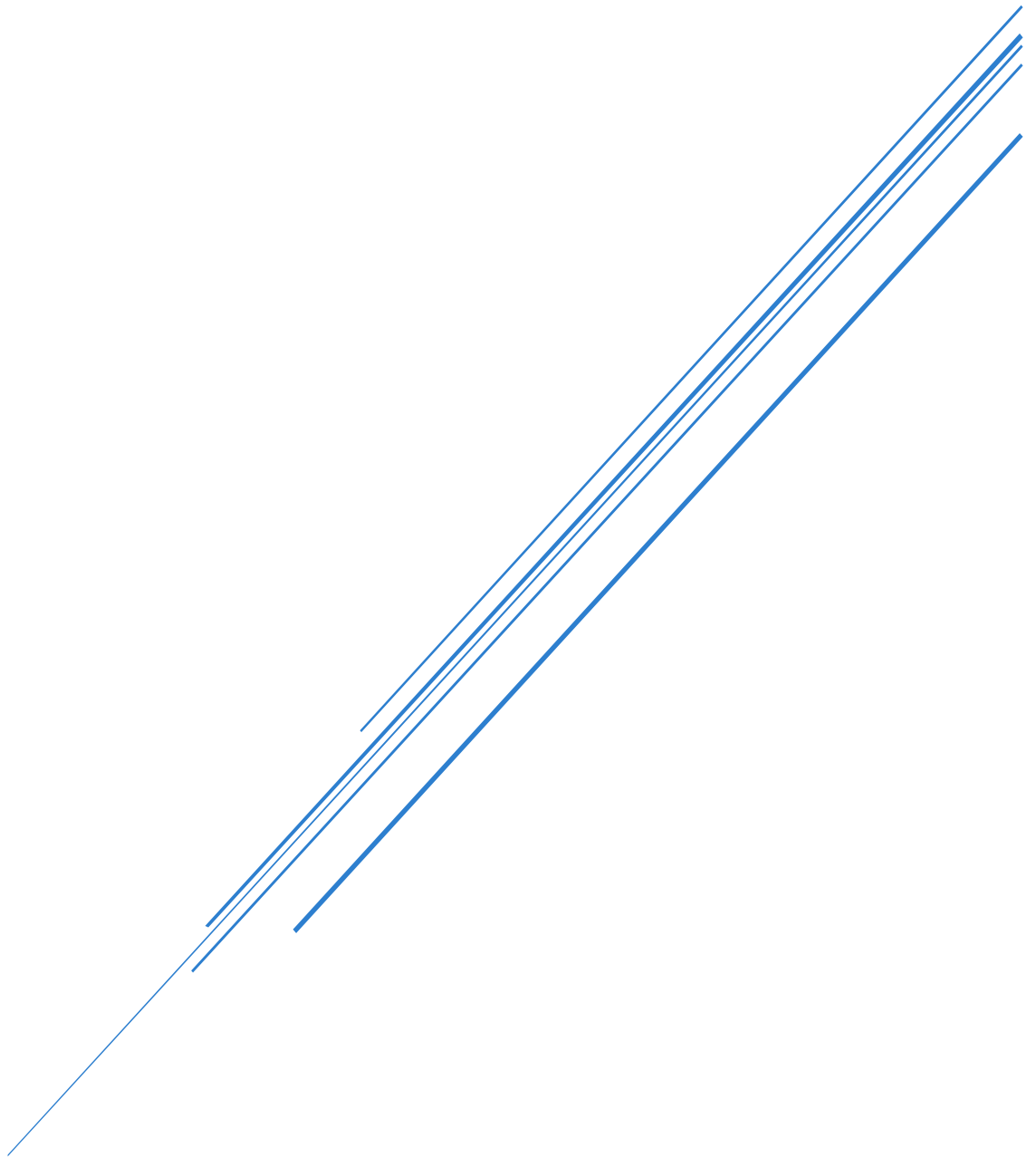


ELECTRICAL & ELECTRONIC PRINCIPALS

Resonance within Electronic Components



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Abstract

The following report details and outlines the processes behind the planning, simulation, and practical testing of an LC circuit. Results show that in the simulated circuit, a narrow bandwidth is found, showing a low negative gain, providing a tight but clean operating frequency range. However, the physical circuit shows a wider range with a larger negative gain, producing a wide operating range with losses within the input signal against the output, potentially due to the variance in the physical components versus the perfect conditions shown within the simulation.

Introduction

The proposed circuit was an LC circuit with a series resistor and consists of a capacitor and an inductor in parallel, with a resistor in series, powered by a signal generator, and measured by an oscilloscope.

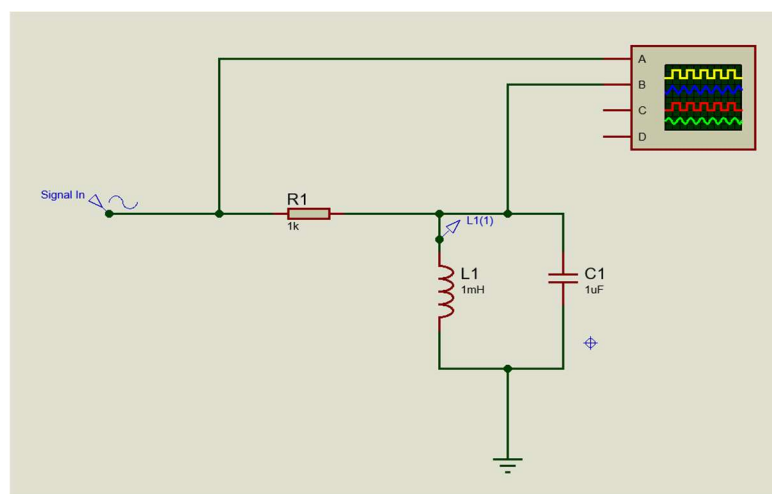


Figure 1: The circuit used for this experiment, consisting of an inductor, a resistor, and a capacitor.

The intent of the circuit was to test and measure the point of resonance between L1, the inductor, and C1, the capacitor, which will then stabilize the current at a specific frequency, achieving resonance.

One of the main uses for this type of circuit is in the use of signal processing, specifically LC filters [1], which are built using a capacitor and an inductor in parallel with a resistor in series, as shown in Figure 1.

These filters pass either low/high frequency signals and cut the opposing signal depending on the configuration of the circuit, for example, a low-pass filter will allow for low frequency signals but cuts any high frequency signals.

LC Circuits can also be tuned and configured to only allow a set range of frequencies, cutting any frequencies outside of this range, this is known as a band-pass filter [2]

Theory of an LC Circuit

An LC circuit typically consists of 3 main components, a resistor, a capacitor and an inductor, with an AC input source. The purpose of the resistor is to dampen oscillation rate to preventing current from flowing to infinity [3], potentially damaging components. And by utilising the properties of capacitors and inductors, wherein energy is stored in two different states to achieve a state of ‘resonance’, where

the charge and discharge cycles of the inductor and capacitor are perfectly in sync with one another. Resonance occurs when the magnitude of reactance between the inductor and the capacitor are equal. At resonance, there is a change between cycles where the energy is stored, where in one cycle the energy is stored within the capacitor, and then stored within the inductor in the next. The peak frequency of the changes in cycles is known as the resonant frequency and can be found using the formula below [1], where L is the value of the inductor and C is the value of the capacitor, and f is the frequency between the oscillations. This frequency is where resonance is achieved, also known as the centre frequency.

$$f = \frac{1}{2\pi\sqrt{LC}} \quad \{1.0\}$$

Following this it is also necessary to calculate the “Quality Factor” or “Q Factor”, which provides a value for the voltage magnification factor across the inductor coil and the capacitor and can be worked out using the following formula, where X_L is the reactance of the inductor, X_C is the reactance of the capacitor, f is the signal input frequency, and R is the total resistance within the circuit.

$$Q = \frac{X_L}{R} = \frac{2\pi fL}{R} \quad \{2.0\}$$

Or

$$Q = \frac{X_C}{R} = \frac{1}{2\pi fCR} \quad \{2.1\}$$

Q Factor may also be found in terms of the passive components within the circuit [4], the formula is as follows.

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} \quad \{3.2\}$$

From the Q factor it is possible to work out the overall bandwidth of the circuit, which determines the functional frequency range of the circuit. The bandwidth, shown as Δf , is worked out using the following formula, where f_h is the high band edge, f_l is the low band edge, f_c is the centre frequency, and Q is the Q Factor.

$$BW = \Delta f = f_h - f_l = \frac{f_c}{Q} \quad \{3.0\}$$

The high and low band edge are measured at the 70.7% amplitude points either side of the centre frequency captured on the frequency curve shown on a graph.

For the proposed circuit the factors will be as follows.

Centre frequency:

$$f = \frac{1}{2\pi\sqrt{LC}} = \frac{1}{2\pi\sqrt{0.001(1*10^{-6})}} = 5032.921$$

Q Factor:

$$Q = \frac{1}{R} \sqrt{\frac{L}{C}} = \frac{1}{1000} \sqrt{\frac{0.001}{1 \times 10^{-6}}} = 0.0316$$

LC Circuit Simulation

The following section details the steps followed in the setup, and simulation of the circuit detailed in Figure 1 within the proteus design software, the results drawn from the simulation, and the conclusions that can be drawn from these results.

Simulation Setup

When setting up the simulation the first aspect to be considered was the components required for the simulation. As shown in Figure 1, it was necessary to use an inductor, a capacitor and a resistor as the key components, the capacitor and the inductor were placed in parallel to one another, with the resistor placed in series to the input. A signal generator was then placed on the input, shown as 'SignalIn' in Figure 1, and a voltage probe was placed on the inductor, to display the frequency response on a graph as shown below. Finally, a simulated oscilloscope will be placed at both the signal input and across the capacitor and the inductor, to allow for the results of the simulation to be measured in a visual space.

The point on the graph where the curve reaches zero, is regarded as the centre frequency, and from this point the f_l and f_h points can be found, allowing for the bandwidth to be calculated.

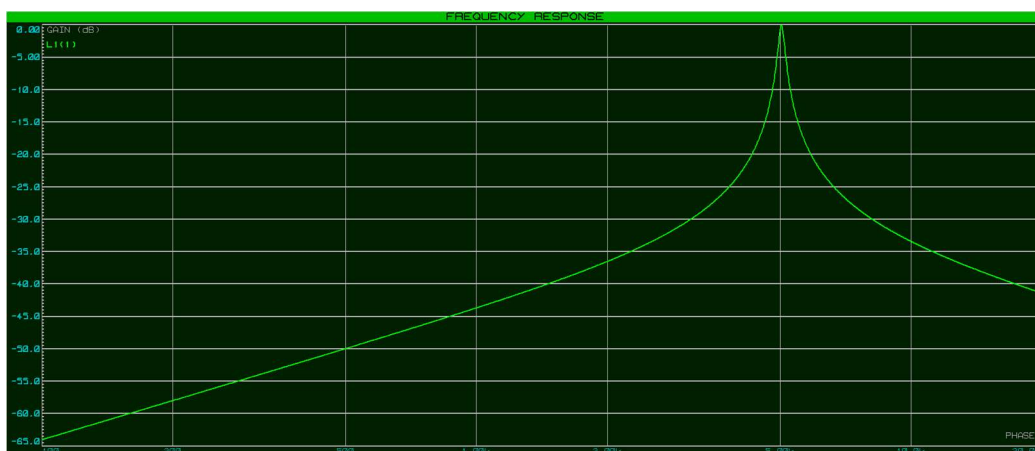


Figure 2: The simulated frequency response of the circuit, showing the frequency on the bottom axis and the gain on the vertical axis. Obtained using the voltage probe on the inductor within proteus.

Simulation Results

When the circuit shown in figure 1 was simulated, the following table of results was obtained, showing the frequency response of the circuit at different input frequencies. The results, shown in Table 1, also show an approximate location for the centre frequency, where resonance was achieved.

From these results, it is evident that as the input frequency increases the cycle rate between the inductor and the capacitor increases, reaching its peak around 4950Hz, giving an approximate reference point for the point of resonance, where V_{in} and V_{out} will be equal and the gain would be 0dB. From the graph below it is possible to calculate the approximate low and high bands for the frequency response. Shown in Table 2 the approximate f_l and f_h points are drawn from marking the

70.7% on the curve and drawing the frequencies from the marked points where they are then subtracted from one another to show the overall bandwidth of the of the circuit.

Frequency(Hz)	V-In	V-Out	Gain(dB)	Frequency(Hz)	V-In	V-Out	Gain(dB)
100	2	0.0013	-63.74	5050	2	1.2500	-4.08
200	2	0.0025	-58.06	5500	2	0.3000	-16.48
500	2	0.0063	-50.03	6000	2	0.1650	-21.67
1000	2	0.0132	-43.61	6500	2	0.1150	-24.81
2500	2	0.0425	-33.45	7000	2	0.0900	-26.94
3000	2	0.0600	-30.46	7500	2	0.0750	-28.52
3500	2	0.0885	-27.08	10000	2	0.0415	-33.66
4000	2	0.1446	-22.82	15000	2	0.0235	-38.60
4500	2	0.3175	-15.99	20000	2	0.0165	-41.67
4950	2	1.7240	-1.29	50000	2	0.0063	-50.03
5000	2	1.6000	-1.94	100000	2	0.0031	-56.19

Table 1: The results of the simulated circuit at various frequencies from 100Hz to 1MHz.

It should also be noted that the frequency response curve of the simulated circuit does not reach zero, this could potentially be due to proteus simulating the impedance of the oscilloscope, thus affecting the data due to additional elements being added to the circuit. The results shown in Table 1 were the closest to zero gain that could be achieved within the proteus design software. This simulated impedance could have potentially also affected the output data, as the equation, $f = \frac{1}{2\pi\sqrt{LC}}$, states that the peak frequency should have been 5032.921Hz, however the results showed a peak frequency where 4950Hz is the closest to 0 achievable.

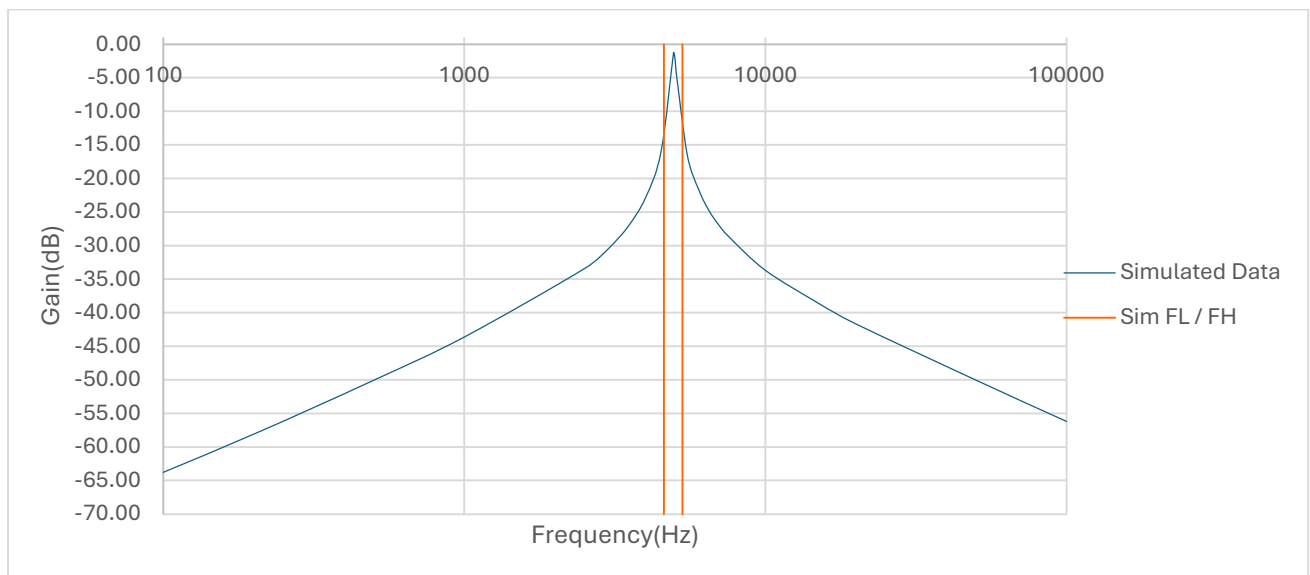


Figure 3: The frequency response curve of the simulated circuit using the data from Table 1.

When measured using the data from Figure 3, the FL and FH were found to be approximately 4600 and 5300 respectively, resulting in an overall GBP of 700Hz. This defines the cutoff frequencies of the simulated circuit [5].

LC Breadboard Circuit

The following details the steps taken in plotting of the proposed circuit in breadboard, and the steps involved in testing the circuit, as well as the results drawn and the conclusions that can be drawn from said results.

Breadboard setup

When assembling the breadboard, it is first important to gather the correct components. A 1k Resistor, a 1 μ f Capacitor, and a 1mH Inductor are all required for the circuit to function. Next is the plotting of the components onto breadboard, due to the simplicity of the circuit, all that is required is to run the capacitor and inductor in parallel to each other with the resistor in series. As shown in figure 4, the signal input would then need to be connected to the input of the resistor, shown as the red connection, a ground connection is to be put onto the output of the inductor-capacitor connection, and two oscilloscope probes are to be connected to the signal input and the input end of the inductor-capacitor connection.

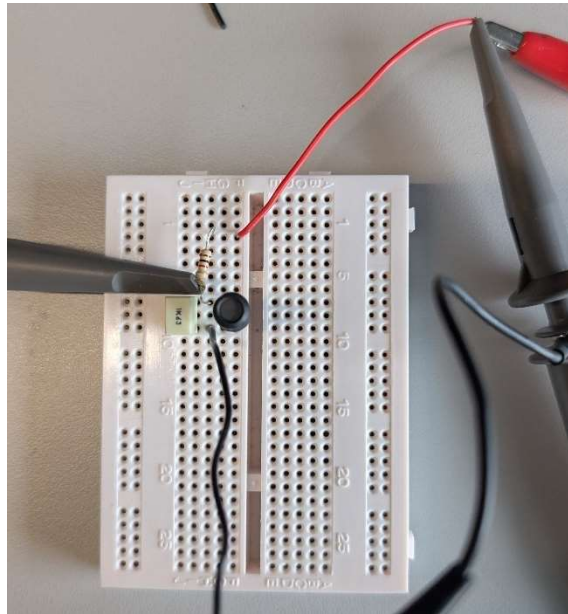


Figure 4: The Breadboard setup of the proposed circuit.

Using an LCR meter the components can be verified to be both functional and of the correct value.



Figure 5: The Resistor Included in the circuit.

The resistor shown in Figure 5 is shown to have a colour code of “Brown, Black, Red, Gold”, meaning it is a 1k Ohm Resistor with a 5% variance to the value. This is proven in Figure 6 with a shown value of 982 Ohm, well within the 5% variance from 1000 Ohms.



Figure 6: The values of the resistor, inductor and capacitor shown at 982 Ohms, .989 mH and 1.05uF respectively.

As shown in Figure 6, the values of the components are close to their intended value, so the test equipment can be connected and configured.

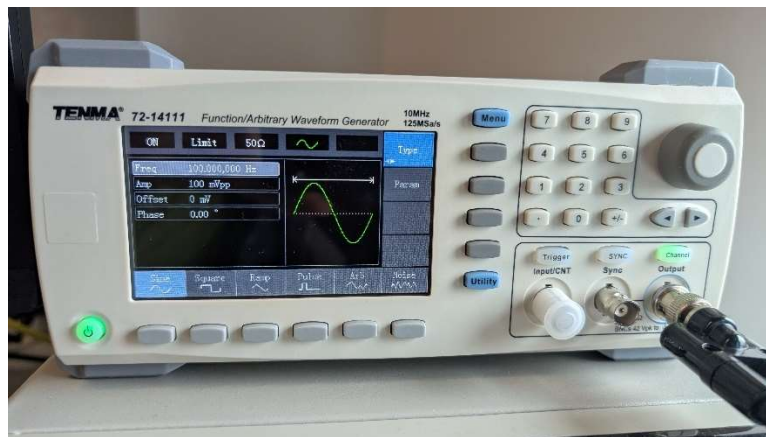


Figure 7: The connected Signal Generator.

Once connected the signal generator is configured to start at 100Hz, with a 100mVpp, meaning that the output waveform will fluctuate 100mV above and below 0V, or 1V above and below 0V. The offset is also set to 0mV to not affect the output measurements, and the phase is set to 0 degrees to show the true output of the circuit including any shift in phase.

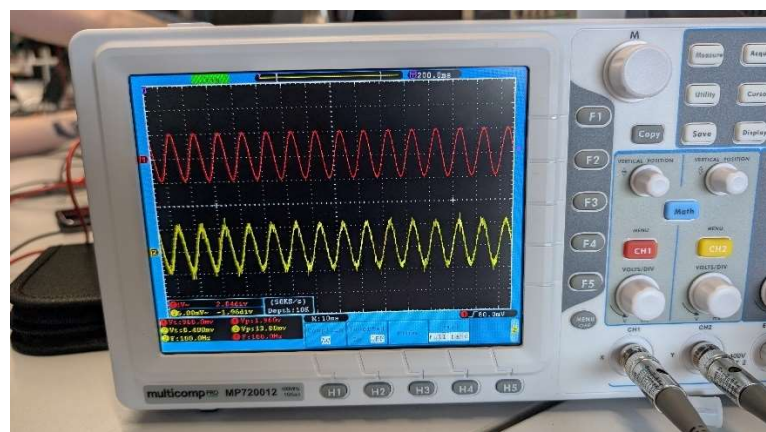


Figure 8: The connected oscilloscope with the signal input(red) and output(yellow) connected.

Finally, the oscilloscope is connected to the circuit to the inputs shown in Figure 4 to show the input and output product of the circuit with voltage measurements to show the gain of the circuit.

Breadboard Results

When the circuit has been built and configured correctly, the signal generator is used to input different frequencies to the circuit. From these changes in frequency the following results were gathered.

Frequency(Hz)	V-In	V-Out	Gain(dB)	Frequency(Hz)	V-In	V-Out	Gain(dB)
100	1.88	0.0103	-45.21	5050	1.92	0.2760	-16.85
200	1.88	0.0106	-45.01	5500	1.92	0.2080	-19.30
500	1.88	0.0122	-43.78	6000	1.88	0.1420	-22.44
1000	1.88	0.0167	-41.02	6500	1.88	0.1040	-25.14
2500	1.88	0.0424	-32.94	7000	1.88	0.0840	-27.00
3000	1.92	0.0568	-30.58	7500	1.88	0.0712	-28.43
3500	1.92	0.0808	-27.52	10000	1.88	0.0408	-33.27
4000	1.92	0.1224	-23.91	15000	1.88	0.0232	-38.17
4500	1.92	0.2000	-19.65	20000	1.88	0.0174	-40.67
4950	1.92	0.2740	-16.91	50000	1.92	0.0074	-48.28
5000	1.92	0.2760	-16.85	100000	1.96	0.0042	-53.46

Table 3: the results from the breadboarded circuit ranging from 100Hz to 1MHz.

From these results it is evident that, similarly to the simulated data, as the input frequency increases the cycle rate between the inductor and the capacitor also increases. This results at a peak frequency between 5000Hz and 5050Hz, however it can also be noted that the gain at this frequency is considerably less than the simulated data. This variance in the data could be due to the additional impedance introduced via the connections in the circuit, i.e. the signal input, or the breadboard connections. Alternatively, this variance could be due to the values of the components used within the circuit, as using the equation $f = \frac{1}{2\pi\sqrt{LC}}$, a peak frequency of 4938.867Hz can be found. As this figure differs so harshly from the produced data, it can be assumed that the difference in the results could be a product of the additional impedance introduced by the connections/breadboard, and the component values.

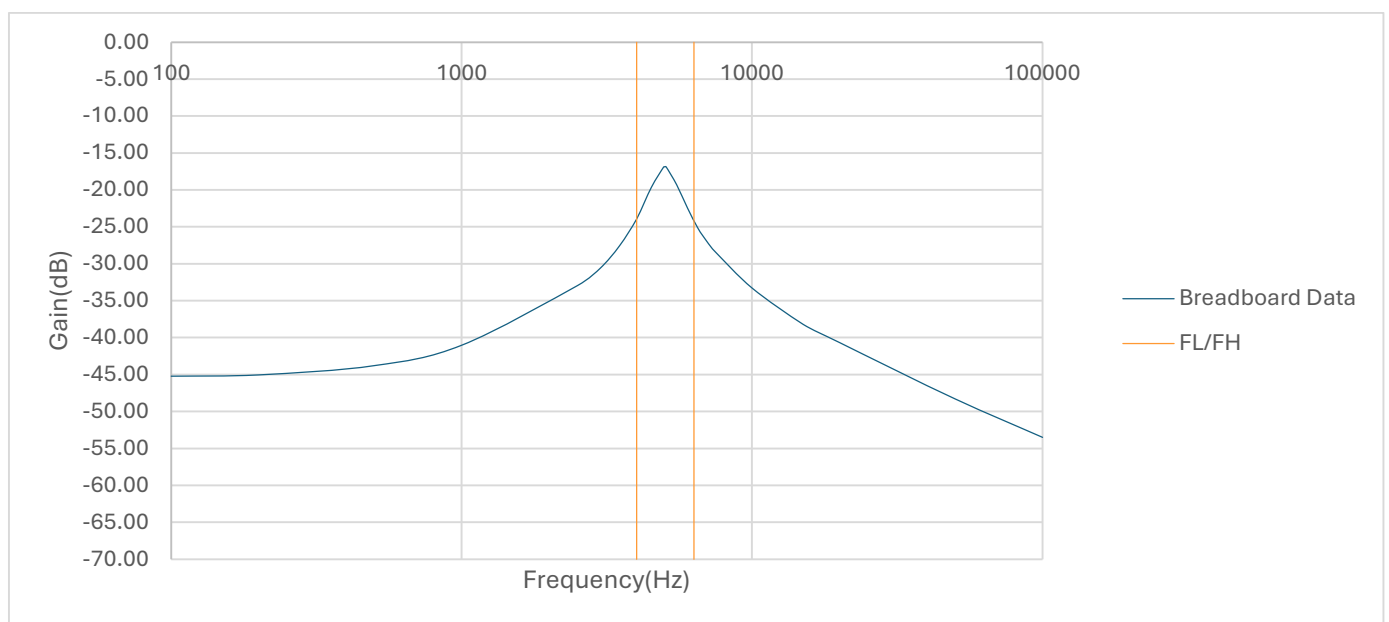


Figure 9: The Graph showing the frequency response of the breadboarded circuit.

The graph shown in figure 11 shows the frequency response of the breadboarded circuit, from this the FL and FH can be drawn, being 4000 and 6300 respectively, resulting in an overall GBP of 2300Hz, this defines the cutoff frequencies of the breadboarded circuit.

Due to the difference in results between the simulation and the breadboarded circuit, the overall bandwidth is much larger versus the simulated data. As previously mentioned, this could be due to a number of factors, including additional impedance introduced from the components and equipment used in the circuit.

Overall Results and Conclusion

Conditions for resonance were shown to be theoretically possible during simulations, however when built physically the results varied greatly from what was originally theorised. This was due to a number of variables encountered during the assembly and testing, a key problem being the variance in component values versus what was simulated in the initial brief. In future experiments the variables encountered will be addressed, including specially selecting components as close to the desired value as possible to avoid variance, as well as potentially directly connecting components to one another in an attempt to mitigate any parasitics or interference that could be introduced to the circuit via using excessive connections, which arise as unintentional resistance, capacitance or inductance within the circuit [6], potentially affecting the outcome of the circuit.

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