Resonance and Q in Electric Circuits

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# Summary

# Introduction

Electrical resonance occurs in electrical circuits at a specific input frequency at which the impedance is minimum. At this frequency, the impedance of the capacitive and inductive components of the circuit are equal in magnitude but are 180 degrees out of phase with each other. Resonating circuits can generate higher peak voltages than the input and reach higher peak currents. Resonant RLC circuits are used commonly in wireless communications, as they are effective at selectively “blocking” frequencies other than the resonant frequency.

This report and experiments will be investigating RLC series circuits and their behaviour at different frequencies. Our aim is to estimate the resonant frequency using known measured values as well as finding it experimentally.

# Theory

# AC circuits and impedance

Figure 1: Simple RLC Circuit

A diagram of a circuit

Description automatically generatedComponents in an AC circuit will have a corresponding impedance Z, which is a measure of opposition to an alternating current. For a resistor, the impedance is simply the value of R and is constant regardless of the frequency of AC signal passing through it.

For inductors and capacitors, their impedance changes as the frequency ω changes. These are represented as imaginary quantities on the complex plane. The imaginary portion implies a phase shift, a capacitor contributes negative phase shift while an inductor contributes positive phase shift.

Resonance occurs in RLC circuits when the imaginary terms of the circuit’s total impedance cancel out. The total impedance Z() of the circuit shown in Figure 1 can be found.

At the point where , resonance occurs. The impedance of the circuit is purely real and independent of frequency. The resonant frequency can be calculated by solving for angular frequency .

Eq (1)

Our maximum current at resonance can also be calculated as Z() = R.

Eq (2)

# Q Factor, Magnification, and resonance bandwidth

A graph of a red line

Description automatically generated

(Hz)

Figure 2: Frequency-Voltage response of an RLC circuit

Q factor, or “quality” factor, is a measure of the bandwidth of the resonant frequency and the magnification of the input voltage at resonance.

is the ratio between the input voltage and the peak voltage across the inductor at resonance.

Eq(3)

Magnification factor is important in determining the maximum voltage generated in an RLC circuit, as this can exceed the input voltage and potentially damage hardware. Voltages generated can become dangerous depending on the input voltage and circuit design.

A graph of a red line

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(Hz)

Figure 3: Graphical representation of resonance bandwidth

refers to the “width” of the resonant peak. More specifically, it is a measure of the range of frequencies between which the circuit is above 50% power compared to the resonant peak. This corresponds to a frequency range of where is the frequency at which the circuit is at 50% power. can be found by determining the point at which the voltage across the inductor reaches , this corresponds a 50% power level as described by the equation for electrical power.

Eq(4)

Eq(5)

# Experimental Methods

# Frequency response of an RLC circuit

The capacitance of the 3.3uF capacitor and resistance of 33 ohm resistor are recorded with a Digital Multimeter (DMM) and are recorded for use in calculations. The resistor, capacitor, and a 0.1 ± 0.01 H are connected in a circuit as shown in Figure 2.

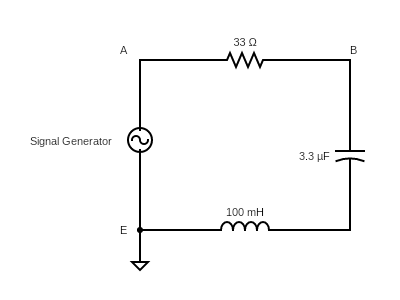


Figure 4: Circuit diagram for frequency response experiment.

The signal generator peak voltage was set to 0.57V. A digital multimeter was connected across the terminals temporarily to verify an RMS of 0.4V. Channels 1 and 2 are connected to points A and B respectively, the oscilloscope was grounded at point E. To verify the setup, the frequency was quickly swept on the signal generator. Channel A was observed to be constant while Channel B was observed to change with frequency. Two DMMs are connected to the circuit shown in Figure 1; one between point A and point B to measure VR ; and one between A and E to measure V0. Measurements are taken at a range of frequencies from 100Hz to 500Hz, including at the expected resonant frequency. Results are recorded in Figure 6 and 7.

# Determining resonance using an oscilloscope

The experimental setup remains unchanged from the previous experiment. Channel A was adjusted such that the waveform crosses zero on the centre line of the display, and the volts/division was turned down such that the lines appear nearly vertical. Channel B was shifted until the peaks of the waveform are close to the centre line. The frequency on the signal generator was adjusted until peaks of channel B line up with the points channel A crosses zero. This indicates a phase difference of between the voltage at the input and the voltage over the inductor. The frequency on the signal generator was recorded and contributes to the previous exercise.

# Measuring Quality Factor

The 33 ohm resistor was removed from the circuit, the new circuit setup is shown below.

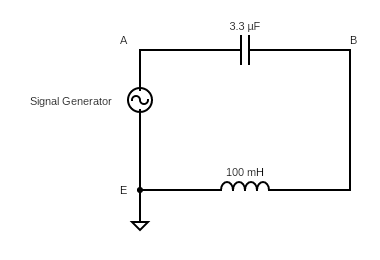


Figure 5: Circuit diagram for Quality Factor experiment.

Using the oscilloscope method described above, the resonant frequency of the circuit was measured and recorded. Voltage measurements were taken using a DMM across the capacitor, inductor, and signal generator at the resonant frequency and recorded. The frequency on the signal generator was lowered until . This frequency was recorded as . The frequency was raised above the resonant frequency until the same relationship was true, this frequency was recorded as . The difference between and was recorded as . All frequency measurements were taken using the reading on the signal generator.

# Measurement of Equivalent Resistance

Using the same experimental setup as in Figure 3, a DMM was used to measure the DC resistance across the inductor. The value of each denomination of capacitor was measured using the DMM and recorded. Using the signal generator and oscilloscope method described previously, the resonant frequency was predicted then measured for each denomination of capacitor. At the resonant frequency for each capacitor denomination, voltage measurements were taken across the signal generator, inductor, and capacitor using a DMM. These values were recorded for later analysis.

# Results and Uncertainty

# Frequency response of an RLC circuit

Table 1: Measured values of circuit components

|  |  |  |
| --- | --- | --- |
| Value | Expected Value | Measured Value |
| Capacitance |  |  |
| Resistance |  |  |
| Inductor |  | Value is given |

Using Eq(1):

A graph with blue dots

Description automatically generated

Figure 6: vs results

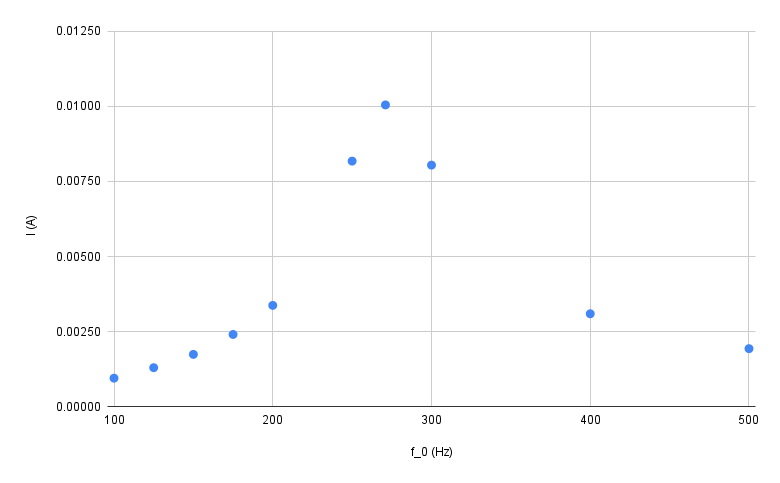
Resonant frequency determined using oscilloscope method: .

Figure 7: vs results

Table 2: DMM Measurement results at measured resonant frequency

|  |  |
| --- | --- |
| Value | Measured Value |
| (V) |  |
| (V) |  |
| (A) |  |

# Measuring Quality Factor

Resonant frequency determined using oscilloscope method:

Table 3: Voltage measurements across RC components at resonance

|  |  |
| --- | --- |
| Value | Measured Value (V) |
|  |  |
|  |  |
|  |  |

Using Eq(3):

|  |  |
| --- | --- |
| Frequency (Hz) | Measured Value (Hz) |
|  |  |
|  |  |

Using Eq(4):

Using Eq(5):

# Measurement of Equivalent Resistance

# Analysis of Results

# Conclusion

# Acknowledgements

# Appendices