Magnetic Resonance in Coupled Thomson Oscillators

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***Abstract*—This report presents a comprehensive analysis of magnetic resonance in coupled Thomson oscillators. It provides a detailed theoretical overview, experimental procedures, data analysis, and discussion of key findings. The analysis is supported by calculations and graphical visualizations. Key conclusions are highlighted, particularly on the resonance frequency shift under varying capacitor settings.**

***Index Terms*—Magnetic Resonance, Thomson Oscillator, Electromagnetic Coupling, Frequency Analysis**

I. Introduction

This section introduces the concept of magnetic resonance in coupled Thomson oscillators. The primary aim is to investigate the conditions under which two electromagnetically coupled circuits achieve resonance. This phenomenon is critical in understanding electromagnetic transmission and energy transfer in coupled oscillatory systems.

II. Theoretical Background

Theoretical background was taken mostly from [1].

1. Vibrational Motion: Vibrational motion occurs when a system oscillates around its equilibrium due to an external force. The time for one complete oscillation is called the period τ, while the number of oscillations per second is the frequency f. The two are related by:

$$f \cdot \tau = 1 \tag{1}$$

The maximum displacement during oscillation is the amplitude. If oscillations lose energy over time, the vibration is damped; if not, it is undamped.

2. Resonance: When a system is subjected to a periodic force with a frequency matching its natural frequency, its amplitude reaches a maximum—a condition called resonance. This occurs at the resonance frequency f_r. The period τ and frequency f have the units:

$$[\tau] = s, \quad [f] = s^{-1} = Hertz(Hz) \tag{2}$$

3. Thomson Vibration Circuit: A Thomson circuit consists of a capacitor C and an inductor L connected together. When the charged capacitor discharges, current flows through the inductor, creating a magnetic field. As the capacitor discharges, its charge decreases, while the current in the inductor increases. This process repeats, resulting in oscillations. The period of oscillation τ is:

$$\tau = 2\pi\sqrt{LC} \tag{3}$$

where L and C are the inductance (measured in Henrys) and capacitance (measured in Farads), respectively.

4. Magnetic Coupling: When two Thomson circuits are placed close to each other, magnetic coupling occurs. The magnetic field of one circuit induces an electromotive force (emf) in the other. If the oscillation frequencies of the two circuits match, resonance occurs, maximizing the energy transfer between the circuits.

The self-vibration frequencies of the two coupled circuits are:

$$f_1 = \frac{1}{2\pi\sqrt{L_1C_1}}, \quad f_2 = \frac{1}{2\pi\sqrt{L_2C_2}} \tag{4}$$

When $f_1 = f_2$, maximum current flows in the second circuit. This resonance condition is mathematically represented as:

$$L_1C_1 = L_2C_2 \tag{5}$$

In this scenario, the first circuit acts as a transmitter, and the second as a receiver. By adjusting the capacitance or inductance, the frequencies can be matched to achieve resonance.

III. Experimental Setup

The experimental setup Figs. 2 and 1 includes a Hartley oscillator circuit using a TIP 15A transistor as the transmitter and a coupled receiver circuit. The setup also incorporates variable capacitors and a microammeter to measure resonance response. The primary components are:

- Transmitter: Hartley oscillator with adjustable capacitance.
- Receiver: Coupled Thomson oscillator with a microammeter for current measurement.
- Variable capacitors C_1 and C_2 for tuning the resonance condition.

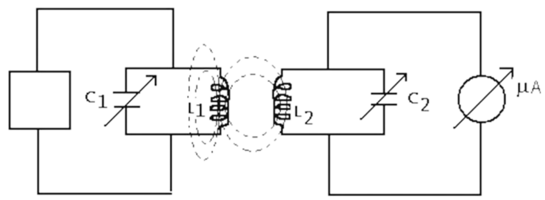

Fig. 1: Diagrammatic Representation of Experimental Setup

Fig. 2: Physical Experimental Setup with Transmitter and Receiver

IV. Methodology

The experiment begins by activating the transmitter and aligning the receiver to achieve magnetic coupling. The capacitance C_1 of the transmitter is varied, and the corresponding receiver current is measured. This process is repeated for different capacitance values to observe changes in current as the system approaches resonance.

Next, the capacitance C_2 of the receiver is adjusted to match the self-vibration frequencies of both circuits. As the frequencies align, the current in the receiver peaks at resonance. Measurements of capacitance and current are recorded for further analysis.

The effect of resistance in the receiver circuit is also investigated. Higher resistance lowers the peak current and broadens the resonance curve, indicating the damping effect of resistance on the system. The collected data is used to analyze the relationship between capacitance, resistance, and resonance behavior in coupled Thomson oscillators.

V. Results

The results of the experiment are tabulated as follows:

C (F-divisions)	I (microampere)
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	1
80	4
90	39
100	4
110	2
120	1
130	0

TABLE I: Current Intensity as a Function of Capacitance C_2 ($R = 0$)

C (F-divisions)	I (microampere)
0	0
10	0
20	0
30	0
40	0
50	0
60	0
70	0
80	1
90	15
100	1
110	1
120	0
130	0

TABLE II: Current Intensity as a Function of Capacitance C_2 ($R = 2.2k\Omega$)

The analysis reveals the conditions under which resonance is achieved. The maximum current flow occurs when the self-vibration frequencies of the two coupled circuits match, as indicated by the peak in the $I = f(C_2)$ curve. The effects of varying resistance R are also discussed. When $R = 2.2k\Omega$, the resonance peak shifts, highlighting the influence of resistance on resonance behavior.

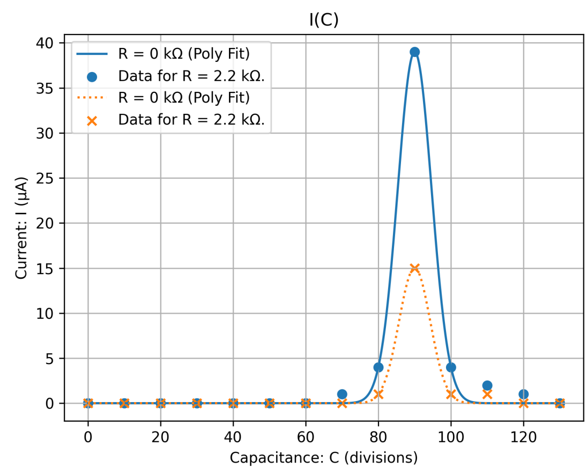

Fig. 3: Current vs. Capacitance for Different Resistances

VI. Discussion

The results from the experiment demonstrate the effect of capacitance and resistance on resonance in coupled Thomson oscillators. As observed in the graph, the resonance condition occurs when the capacitance values are adjusted such that the self-vibration frequencies of the transmitter and receiver circuits align. At this point, the current in the receiver circuit reaches its maximum value, indicating efficient energy transfer between the two circuits.

When the resistance R is set to $0\,\mathrm{k\Omega}$, the resonance curve is sharp and the peak current is significantly higher. This behavior aligns with theoretical predictions, as minimal resistance reduces energy losses in the system, allowing for stronger resonance. On the other hand, when $R = 2.2\,\mathrm{k\Omega}$, the peak current is notably lower, and the resonance curve is broader. This indicates increased damping due to higher resistance, which causes energy losses and reduces the efficiency of energy transfer. The broadening of the curve also suggests that the system is less sensitive to changes in capacitance near the resonance condition.

The symmetry of the resonance curves confirms that the oscillations behave predictably around the resonance point. The results illustrate how resistance influences the sharpness and amplitude of resonance in coupled oscillatory systems.

VII. Conclusion

This experiment highlights the principles of resonance in coupled Thomson oscillators and demonstrates the effect of resistance on resonance behavior. The resonance condition, where maximum current occurs in the receiver circuit, is achieved by aligning the self-vibration frequencies of the transmitter and receiver circuits through capacitance adjustment. Lower resistance results in sharper and higher resonance peaks, while higher resistance reduces the peak current and broadens the resonance curve due to damping effects.

The experimental results confirm the theoretical relationships between capacitance, resistance, and resonance in oscillatory systems. Future studies could explore additional factors influencing resonance, such as variations in the inductance or the spatial alignment of the circuits to further understand the energy transfer mechanisms in coupled oscillators.

VIII. Additional Resources

For detailed information, including the Lab Manual, source code, and related experiments, visit the GitHub repository provided below or scan the QR code in Fig. 4.

Fig. 4: Access the GitHub repository for the lab manual, source code, and related experiments: https://github.com/ibeuler/LAB-Reports.

References

[1] ISTANBUL UNIVERSITY, *Physics Laboratory II Experiment Book: Electricity and Magnetism*, Department of Physics, 2024.

[2] *Source code and additional experiments are available in the GitHub repository.* https://github.com/ibeuler/LAB-Reports