Experiment FT2: Measurement of Inductance and Mutual Inductance

Name: ___________________________ ID: _________________

1. Objectives:

- To study the effect of magnetic inductance of the given circuit.
- To measure self inductance and mutual inductance.

2. Apparatus/Components:

- Dual Trace Oscilloscope
- Function Generator
- Digital Multimeter
- +/- 12V power supply
- Transformer (ratio 1:1+1, part no.: RS196-375)
- Resistor 1 kΩ (2 units)
- Operational amplifier IC LM741
- Breadboard

3. Theory:

When electric current flows through a conductor, a magnetic field is immediately brought into existence in the space surrounding the conductor. The magnetic field is produced essentially by the electrons moving in the conductor. The opposite is also true, i.e., when a magnetic field embracing a conductor moves relative to the conductor, it produces a flow of electrons. This phenomenon, whereby an electromotive force (e.m.f), and hence current (i.e. flow of electrons), is induced in any conductor that cut across or is cut by a magnetic flux, is known as **electromagnetic induction**.

Figure 1: Electromagnetic induction set up.
Imagine a coil of wire, similar to the one shown in Figure 1, connected to an ac supply. It is found that whenever an effort is made to increase current through it, it is always opposed by the instantaneous production of counter e.m.f of self-induction. Energy required to overcome this opposition is supplied by the ac supply. This energy is stored in the form of additional flux produced. If, now, an effort is made to decrease the current then again it is delayed due to the production of self-induced e.m.f, this time in the opposite direction. This property of the coil which opposes any increase or decrease of current through it is known as self-inductance.

In Figure 1, any change of current in the primary coil is always accompanied by the production of mutually induced e.m.f in the secondary coil. A mutual inductance $M$ may be defined to quantify the ability of one coil to produce an e.m.f in a nearby coil by induction when the current in the first coil changes. This action is reciprocal, i.e., the second coil can also induce an e.m.f. in the first one when the current in the second coil changes.

The device in Figure 1 is known as a transformer. It can transfer electrical energy from one circuit to another at the same frequency. The two coils or windings are electrically isolated from each other (infinite resistance between them), but magnetically linked through the iron core.

According to Faraday’s law, when current $I_1$ flows in the primary winding, the induced e.m.f. in the secondary winding is

$$emf = M \frac{dI_1}{dt}$$

If the secondary circuit is closed, for example, by connecting a resistor to the terminals, a current $I_2$ will start to flow. By this electromagnetic induction, the electrical energy is transferred from the primary winding to the secondary winding by means of magnetic field coupling.

Assuming that there is no loss of power and no flux leakage, the apparent output power in the secondary circuit will be equal to the apparent input power in the primary circuit. The output voltage can be higher or lower than the primary circuit voltage according to a fixed ratio. This ratio is equal to the ratio of the number of turns of the secondary winding to that of primary winding, i.e. $N_2 / N_1$. This ratio is known as the Voltage Transformation Ratio, $K$.

One method to measure self and mutual inductance is by using the auto-balancing bridge as shown in Figure 2. In this experiment, the self and mutual inductance of transformer windings are measured. For each winding, the self inductance can be modeled as a pure inductor in series with a resistance. The impedance is therefore

$$Z = R + j\omega L_s$$

or

$$|Z|^2 = R^2 + (\omega L_s)^2$$

(1)
Figure 2: Auto-balancing bridge for inductance measurement.

The resistance $R$ can be measured using a multimeter. Impedance $Z$ can be measured using the procedure as described below. The inductance can be calculated using equation (1).

The voltage drop across the primary winding of the transformer is $V_1$ and the output voltage of the amplifier is $V_F$. The voltages $V_1$ and $V_F$ can be measured by using an oscilloscope. A phase difference between the waveforms will be observed. The impedance can be measured for various frequencies from 2 kHz to 20 kHz.

$$V_F = -I_F R_F$$

$$Z = V_1 / I_1 = -V_1 R_F / V_F$$

$$|Z|^2 = \frac{R_F |V_1|}{|V_F|}^2 = R^2 + (\omega L_s)^2$$

$R_F = 1 \text{k}\Omega$ is selected in this experiment.
4. Procedure:

![Transformer diagram]

Figure 3: Transformer winding connections.

Part A: Understanding the Operation of Transformer

1. By using a multimeter, measure the resistance of the primary winding (between terminal 1 and 6), the secondary winding (3 and 4), and between the primary and the secondary windings (1 and 3). Is there any electrical connection between the primary winding and the secondary winding?

2. Set both CH1 and CH2 of the oscilloscope to AC coupling (i.e. the AC/GND/DC switch in the AC position). Make sure the vertical sensitivity knob is in the “Cal” position.

3. Set “VERT MODE” to “DUAL”, “SOURCE” to “CH1”, “COUPLING” to “AC”, and “TRIGGER MODE” to “AUTO”.

4. Set the Function Generator for a 2 kHz sine wave and connect the output to terminals 1 and 6 of the transformer.

5. Connect a probe from CH1 of the oscilloscope to terminals 1 and 6.

6. Adjust the Function Generator sine wave amplitude to 0.4 V.

7. Connect the second probe from CH2 of the oscilloscope to terminals 3 and 4.

8. Sketch the waveforms displayed on the oscilloscope and label the traces (CH1 and CH2). What is the ratio of the secondary voltage to the primary voltage?
Part B: Measurement of Self Inductance

Figure 4: Measurement setup for inductance measurement.

1. With the Function Generator set to 2 kHz sine wave, with 0.4 V amplitude, construct the circuit (with resistor $R_F = 1 \, k\Omega$) shown in Figure 4.

2. Connect a probe from CH1 of the oscilloscope to terminal 1 of the transformer. The grounding wire of the probe should be connected to ground conductor of the circuit. Measure the voltage $V_1$ from the oscilloscope.

3. Connect a probe from CH2 of the oscilloscope to the op-amp output. The grounding wire of the probe should be connected to ground conductor of the circuit. Measure the voltage $V_F$ from the oscilloscope.

4. Repeat the experiment for different frequencies from 2 kHz to 20 kHz. Measure the voltage $V_1$ and $V_F$ and record the results in Table 1.

5. Plot the graphs of impedance ($Z$) vs. frequency ($f$) and self-inductance ($L$) vs. frequency ($f$).

6. At the frequency of 20 kHz, sketch the waveforms displayed on the oscilloscope and label the traces (CH1 and CH2). What is the phase relationship of the two waveforms?

Note: Resistance of the winding has been measured in Part A.
Part C: Measurement of Mutual Inductance

Figure 5: Measurement setup for mutual inductance measurement.

1. With the same experiment setup as in Part B, connect a probe from CH1 of the oscilloscope to terminal 3 of the transformer. Connect terminal 4 to the ground conductor of the circuit.

2. Measure the voltage $V_F$ and $V_2$ for different frequencies from 2 kHz to 20 kHz, and record the results in Table 2.

3. Compute the mutual/transfer impedance using $|Z| = \frac{|V_2|}{I_1} = \frac{-V_2 * R_F}{V_F}$

4. Compute the mutual inductance using $M_{21} = \frac{|Z|}{\omega}$

5. Plot the graph of mutual inductance ($M_{21}$) vs. frequency ($f$)
5. MEASUREMENT RESULTS

Part A

Resistance of the primary winding = ________ Ω

Resistance of the secondary winding = ________ Ω

Resistance between the primary and the secondary windings = ________ Ω

Time base: ______ s/div, CH1 ($V_1$): ______ V/div, CH2 ($V_2$): ______ V/div

Ratio of the secondary voltage to the primary voltage, $V_2 / V_1 = $ ______

Discussions:

1. How do we make sure the resistance is measured as accurately as possible?
2. Is there any electrical connection between the primary winding and the secondary winding?
3. If a battery is connected between terminals 1 and 3, will there be any current flow?
4. What is the phase relationship between the primary and the secondary voltage waveforms?
5. What is the turn ratio of the secondary and primary windings?
### Part B

#### Table 1:

<table>
<thead>
<tr>
<th>Frequency, $f$ (kHz)</th>
<th>$\omega = 2\pi f$</th>
<th>$V_1$, peak (V)</th>
<th>$V_F$, peak (V)</th>
<th>Impedance, $Z$ (Ω)</th>
<th>Self Inductance, $L$ (µH)</th>
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Time base: ______ s/div, CH1 ($V_1$): ______ V/div, CH2 ($V_2$): ______ V/div

#### Discussions:

6. How do we reduce the error in measuring the voltages using the oscilloscope?
7. What is the phase relationship of the two waveforms?
8. Is the graph of $Z$ versus $f$ a perfect straight line? If not, what causes the deviation?
9. Is the graph of $L$ versus $f$ a perfect straight line? If not, what causes the deviation?
10. Can we consider the measurement results are satisfactory? Why?
Part C

Table 2:

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<th>Frequency, $f$ (kHz)</th>
<th>$\omega = 2\pi f$</th>
<th>$V_2$, peak (V)</th>
<th>$V_F$, peak (V)</th>
<th>Impedance, $Z$ (Ω)</th>
<th>Mutual Inductance, $M_{21}$ (µH)</th>
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Discussions:

11. Is the graph of $M_{12}$ versus $f$ a perfect straight line? If not, what causes the deviation?

12. Can we consider the measurement results are satisfactory? Why?

6. LABORATORY REPORT

The report should contain the following:

(1) This lab sheet (covering the Objectives, List of instruments/components, Basic Theory, and Tabulation of observed and computed data).

(2) Graphs of the measurement results

(3) Discussions, and

(4) Conclusion.

Please obtain signature from the lecturer before you leave the lab:

Date:

IMPORTANT NOTES TO THE STUDENTS:

1. Read the lab sheet before attending the experiment session.

2. Bring along the necessary GRAPH PAPERS and calculator to the lab.

3. The completed laboratory report must be submitted to the laboratory technician AT THE END OF THE EXPERIMENT SESSION.

4. You are required to sign on submission of lab report (and of course you have to sign in and out before and after the experiment session).

5. Each student is required to submit an INDIVIDUAL REPORT.