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**Report Sheet for Experiment 12: Propagation of electromagnetic waves**

Abstract

In this experiment, the propagation of electromagnetic wave in terms of its components waves of voltage and current waves, which occurs from the induction of magnetic and electric field, and the speed of the electromagnetic wave is investigated. Lecher line of two parallel lines is used to generate different types of standing wave occurring. The results are going well with what the theory suggests, that, in a short circuit when a 0 Ohm resistor(supposedly metal) is connected the lecher line, the voltage antinode is the same position as the current node. On the other hand, open circuit shows that the position at the end of the lecher line is voltage antinode and current node at the same place. Furthermore, when the impedance of the circuit is matched with the external one used to connect the lecher lines, no change in current/voltage wave will be observed, indicated by the constant brightness of the measuring light bulb (either probe lamp or induction loop) across the lecher line. Furthermore, the speed of wave calculated by multiplying the wavelength and used frequency of the UHF generator are 2.83x108m/s and 2.92x108m/s, for the open circuit and short circuit, respectively. The error could possibly come from the measurement process as a slight change in distance, when multiplied with frequency of large scale, the resulting speed could be affected quite dramatically.

Introduction and Theoretical Background

Oscillation of charged particles can generate electromagnetic wave by induction due to the time-dependent magnetic and electric filed. This can be easiest applied with an alternating current which therefore will create time-dependent magnetic flux. According to Faraday’s law of induction, this will further induce time-dependent electric field. The process of inducting back and forth of electric and magnetic field will eventually result in a propagation of electromagnetic wave.

However, with the use of alternating current, only high frequency wave will be achieved because problems like interference. Lecher line is then utilized because of it two parallel lines set-up. Figure 1 demonstrates how the movement of charges corresponding to the generated magnetic and electric field is measured. The electric field can be expressed as:

Figure 1 depicts the induction of electric and magnetic fields in the lecher line

The voltage and current will act as waves and reflect at the end of lecher line like the formation of standing waves and there will be 3 types of measurement done in this experiment.

1. Short circuit

The end of the lecher line is closed, resistance will be considered as 0 (nothing is added). The phase of the current wave will stay unaffected while that of the voltage wave will be shifted by 180. So, their time-dependent values can be described as follow:

…eq.(1)

…eq.(2)

From equation (1) and (2), it can be seen that the antinodes of current wave will be the nodes of the voltage wave and vice versa, therefore, the measured positions between the nodes will be with a distance of .

1. Open circuit

The end of the lecher line is opened, there is no resistance added at the end. The phase of the voltage wave will stay unaffected while that of the current wave will be shifted by 180. So, their time-dependent values can be described as follow:

…eq.(3)

…eq.(4)

1. Impedance matching circuit

Standing waves will not be created at both ends of the lecher line connected to the ohmic resistance, the incoming voltage and current waves are not reflected.

Furthermore, the process of measuring such nodes and antinodes of voltage/current waves can be elaborated as follows. The light up will be turned on wherever the voltage antinodes are, indicating a difference in potential of the circuit. On the other hand, induction loop is used to detect that of current wave. It will be turned on when there’s a maximum(antinode) of the current wave. This implies high magnetic fluxing passing through that area. During the measurement, both loops should not directly tough the lecher line to avoid transmission.

Methods

1. Set up the apparatus as shown in the Figure 2 which the length of the lecher line is 0.88 m.
2. Generate the frequency at 433.92 MHz to the Lecher line
3. Start observing open-circuited Lecher line
4. Put the light bulb on the right end of Lecher line
5. Slowly move the light bulb from the right to the left and record the position on the Lecher line that enlighten the light bulb.
6. Align the loop of coil above the Lecher line at the right end. Make sure that the loop does not touch the line
7. Slowly move the loop from the right to the left and record the position on the Lecher line that enlighten the light bulb.
8. Repeat step 4 to 7 again but change to short-ended circuited(connect with 200 Ohm resistor) and Impedance matching circuited respectively.

A picture containing text, indoor, device

Description automatically generated

Figure 1 depicts the experiment set-up

Results

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Short Circuit | | | Open Circuit | | | Impedance matching | |
| Probe lamp (minima positions, cm) | Induction loop (minima positions, cm) | Induction loop (maxima positions, cm) | Probe lamp (minima positions, cm) | Probe lamp (maxima positions, cm) | Induction loop (minima positions, cm) | Probe lamp (minima positions, cm) | Induction loop (minima positions, cm) |
| 23 | 7 | (7+38)/2 = 22.5 | 5 | (5+37)/2 = 21 | 20 | No light intensity changes | |
| 57 | 38 | (38+73)/2 = 55 | 37 | (37+73)/2 = 55 | 52 |
| 87.5 | 73 | - | 73 | - | 87.5 |

Table 1 summarizes the positions of minima and maxima of current and voltage waves in the experiments(short-circuited, open-circuited, and impedance-matched)

|  |  |  |
| --- | --- | --- |
|  | Short-circuited | Open-circuited |
| average wavelength (m) | 0.653 | 0.678 |
| frequency (Hz) | 4.34E+08 | 4.34E+08 |
| speed of wave (m/s) | 2.83E+08 | 2.94E+08 |
| %Error | -5.62% | -2.00% |

Table 2 summarizes the average wavelength calculated from Table 1, the frequency used, calculated speed of EM wave, nd their corresponding error compared to the speed of light.

The calculation in Table 2 can be demonstrated as follow.

* Average wavelength = [ (0.57-0.23)x2 + (0.875-0.57)x2 + (0.38-0.07)x2 + (0.73-0.38)x2 ] / 4 = 0.6525 m
* Speed of wave = frequency x average wavelength = 434x106 x 0.653 = 2.83x108 m/s
* %Error = = -5.62%

Discussion

From the experiment, Table 1 confirms that the position of the voltage maxima(measured with the probe lamp) is almost the same as the current maxima(calculate by average two adjacent minima positions which are measured by induction loop). To really compare the positions, the following are the pairs of numbers: (23,22.5) and (57,55) in centimeters. On the other hand, in open circuit, there is a voltage maximum at the end of the lecher line, therefore, the phase of the voltage wave does not change as the theory suggests. Furthermore, in the impedance matching experiment, no change in voltage/current wave detected by the change of light intensity – no maxima and minima. This is because of the equivalent amount of added impedance does not produce standing wave.

Wavelengths of each current and voltage wave is calculated by multiplying the distance between each minimum by two. The speed of such waves can be calculated from the known value of wave’s frequency of the generator (433.92 MHz) by the relationship . The results are 2.83x108m/s and 2.92x108m/s, for the open circuit and short circuit, respectively. This corresponds to the error of -5.62% and -2.00% compared to the vacuum speed of sound of 3x108m/s. The physical meaning of such speed can be explained as the back-and-forth induction between the voltage and current waves in the electromagnetic wave is happening at the speed of light. And the EM wave itself which has component of electric and magnetic fields from the current/voltage waves will too be moving at the speed of light. The error could potentially come from the position measurements with the probe lamp and induction loop. For example, the error of cm or m for such measuring tool could lead to an error in the speed of sound of 0.005 x 4.3392x108 = 0.0217x108 m/s which is considerably great with the expected intrinsic error from the particular technique, including, the resistances, and the inductances.

Conclusion

In conclusion, the concept of electromagnetic induction was applied to a circuit with alternating current source which will lead to an induction between the current and voltage waves as time dependent. Lecher line of two parallel lines is used to generate different types of standing wave occurring. The results are going well with what the theory suggests, that, in a short circuit when a 0 Ohm resistor(supposedly metal) is connected the lecher line, the voltage antinode is the same position as the current node. On the other hand, open circuit shows that the position at the end of the lecher line is voltage antinode and current node at the same place. Furthermore, when the impedance of the circuit is matched with the external one used to connect the lecher lines, no change in current/voltage wave will be observed, indicated by the constant brightness of the measuring light bulb (either probe lamp or induction loop) across the lecher line. Furthermore, the speed of wave calculated by multiplying the wavelength and used frequency of the UHF generator are 2.83x108m/s and 2.92x108m/s, for the open circuit and short circuit, respectively. The error could possibly come from the measurement process as a slight change in distance, when multiplied with frequency of large scale, the resulting speed could be affected quite dramatically.

Reference

1. Lab manual titled “**Ch10.** **Measuring the earths magnetic field”**from Department of Physics on KLMS