An Experiment to Measure the Speed of Alternating Electricity

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Abstract: Our experiment to measure the speed of alternating electricity is briefly reported here. It is found that the speed of alternating electricity within the metal wire is not constant, which is depended on the circuit parameters. In most cases, the speed of alternating electricity is less than the speed of light. However, our recent experimental results show that at less than 3 MHz frequency region and under our circuit parameters, the speed of alternating electric field can be 20 times more than the speed of light.

Key words: AC circuit, alternating electricity, time delay, superluminal speed

1. Introduction

In our daily life, 50-60 Hz alternating electricity is employed. The genius inventor，Nikola Tesla，conceived that AC speed might be faster than light. However, in his era, he had no way to measure it. Many textbooks assume that the speed of alternating electricity must be less than (or equal to) the speed of light [1-3]. However, in recent years, many researches suggest that in the case of low-frequency and near-field, there is superluminal phenomenon [4-7].

In AC circuits, the direction of longitudinal electric field coincides with the direction of energy flow. This electric field in wires has certain similarities with the electrostatic field in free space. They are longitudinal electric field; both of them are related to electric source; an electric field ***E*** is the gradient of electric potential.

Although there are some similarities between a longitudinal electric field in a circuit and an electrostatic electric field in vacuum, in fact, they have certain differences. In the circuit theory, the electromotive force plays a leading role. The resistance and self-inductance in the circuit play an important role as well. Experiment and theory show that Ohm's law is valid for alternating electricity at frequencies below 10 GHz. In our experiment, we study the alternating electric field of 1-9 MHz, which belongs to the low-frequency region.

For the quasi-static electric field, the Kirchhoff's second law is valid in the circuit theory. The Kirchhoff's second law requires the sum of voltages is zero for all branch circuit, namely the loop voltage equation.

A simple circuit has a power source and a resistance, which are connected by wires with self-inductance. The Ohm’s law can be written as:

$$U(t) = I(t)\mathrm{R} + \mathrm{L}\,\mathrm{d}I(t)/\mathrm{d}t \qquad (1)$$

In Eq. (1), U(t) represents the alternating electromotive force; I(t) is the current; R is the resistance, L is the inductance [8]. From Eq. (1), it can be seen that the circuit theory has an implicit assumption: the electromotive force applies to the resistance and inductance almost simultaneously. In another word, the longitudinal electric field is almost instantaneous. The speed of longitudinal electric field represents the speed of electricity.

Due to the small self-inductance along metal wires, the longitudinal electric field has certain time delay in the circuit. For a straight wire, self-inductance is calculated by the following formula [9]:

$$L = 2\, l\, [Ln\, (2l/r) - 0.75] \times 10^{-7} \qquad (2)$$

In Eq. (2), l is the wire's length, and r is the radius of the wire. The unit of length is in meter. The unit of the calculated value of the distributed inductance is in H (Henry). By calculation, we obtain 530 nH for a copper wire with the diameter of 1.0 mm and the length of 0.4 m; also we obtain 11.2 μH for the wire with the length of 6.4 m.

Our experimental results show that, in the less than 3 MHz frequency region and under our circuit parameters, by comparing the time delay of two metal wires with different lengths, the speed of alternating electricity in wires is 20 times greater than the speed of light.

2. The experimental setup

For measuring the time delay of the alternating electric field, a schematic description is shown in the figure below. The frequency of 1-9 MHz sinusoidal alternating electric signal is generated by a signal source. At the output of a signal generator, there is a T-type "two-way" BNC element, which connects to a short copper wire and a long copper wire. The length of the short wire is 0.4 m; the length of the long wire is 6.4 m. The other ends of the two wires are connected to the oscilloscope with two channels as inputs. The input impedance of the oscilloscope is 1MΩ. In fact, this is a circuit of two loops with different length of wires. The self-inductance is caused by the length of each wire.
From the display of the oscilloscope, the red line represents the signal passing through the 0.4 m wire, and the blue line represents the signal passing through the 6.4 m wire.

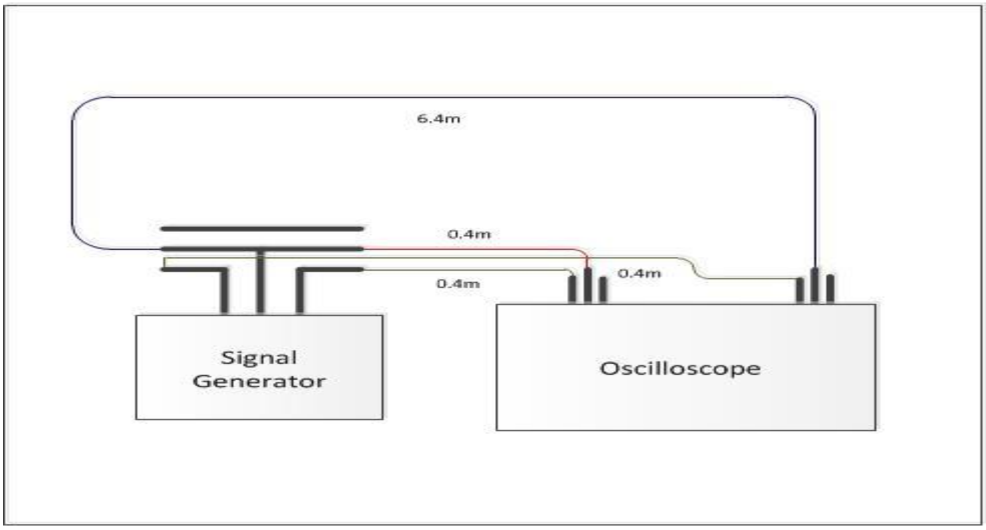

Figure 1， Schematic diagram of the experiment

The experimental instruments are a signal generator and an oscilloscope. The specifications of the signal generator are: RIGOL (manufacturers), DG4162 (model), 160 MHz, 500 MSa/s. The peak voltage about 5 volts is selected as the output in our experiment. The specifications of the oscilloscope are: Agilent Technologies (manufacturers), DSO-X-3034A (model), 350 MHz, 4 GSa/s. The input impedance of the oscilloscope is chosen 1MΩ (another choice is 50Ω, but it is too small to meet our design requirement).

The diameter of copper wires is 1mm. The distance between the midpoint of the 0.4 m wire and the midpoint of the 6.4 m wire is approximately 1.5 m.

3. Experimental data and analysis

In the experiment, we first exchange the signals inputting into two channels of the oscilloscope. It shows no change of the display for exchanging the channels. This indicates that the two channels have consistent performance.

In our experimental study, alternating electric signals at 1-9 MHz are studied. In this frequency region, we have selected more than 30 different frequencies for testing. Listed below are two figures given as examples:

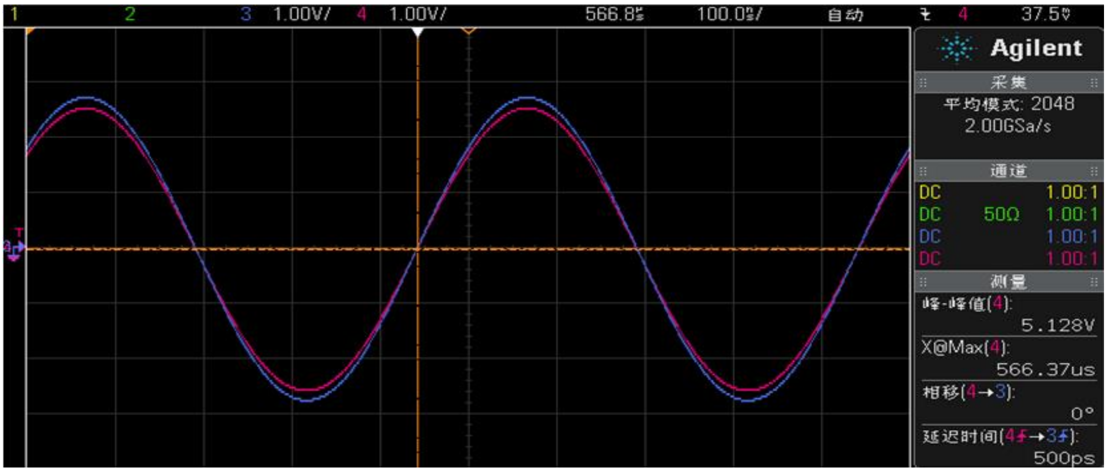

Figure 2, Display of time delay, 6.4 m versus 0.4 m, at 2.0 MHz

In Fig. 2, the red line represents the signal of the 0.4 m wire; the blue line represents the signal of the 6.4 m wire. In the lower right corner of Fig. 2, it displays “Time Delay”, which is 0.5 ns in this case. This value comes from the time difference between the two yellow vertical lines in the figure， which is 500 ps in this case.

In order to ensure the reliability of the measurement, we take a 9.4 m wire to replace the 6.4 m wire. Then we repeat the measurements. The distance between the midpoint of the 0.4 m wire and the midpoint of the 9.4 m wire is approximately 2.5 m.

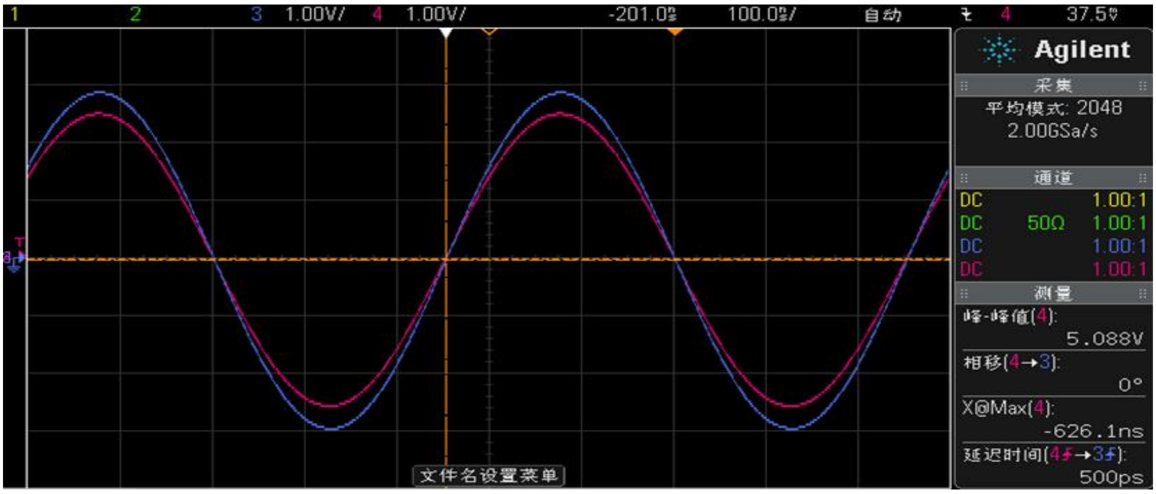

Figure 3, Display of time delay, 9.4 m versus 0.4 m, at 2.0 MHz

In Figure 3, the time delay is 0.5 ns.

In the experiment, we have obtained two curves of “the time delay Vs. frequency” for the two different lengths of the wire. The experimental results are shown below:

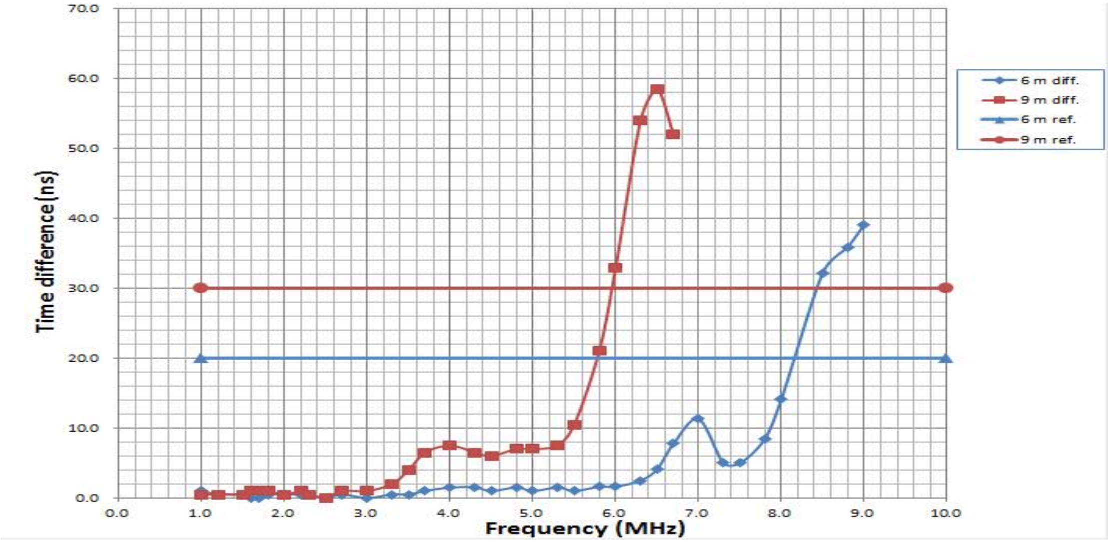

Figure 4, Time delay Vs. Frequency

In Fig. 4, the red curve represents that the length difference of the two wires is 9 m, the blue curve represents the length difference of two wires is 6 m. In Fig. 4, the two horizontal lines represent the reference of the speed of light. Suppose that the speed of alternating electric field in metal wires is the speed of light. It would be 30 ns for the 9 m case, and is shown in the red line in the horizontal direction. It would be 20 ns for the 6 m case, and is shown in the blue line in the horizontal direction.

With the distributed inductance of the 0.4 m copper wire being about 530 nH, the calculated impedance for the 5 MHz signal is 17 Ω. Additionally, with the inductance of 9.4 m copper wire being about 11.2 μH, the calculated impedance for 5 MHz signal is 350 Ω. Meanwhile, the input impedance of the oscilloscope is 1MΩ. Therefore, either 17 Ω or 350 Ω are negligible with respect to the input impedance of 1 MΩ. For the 9.4 m wire, its impedance is also negligible.

Our experimental data show that when the frequency of signal is greater than 3 MHz, the magnitude of the signal from the 6.4 m wire (the blue line) would be decreased. This phenomenon also appears at higher frequencies for the 0.4 m wire (the red line). At the same time, the phase shift from the oscilloscope display becomes apparent. This phenomenon is most likely caused by the interaction between the two wires and the inside capacitance and the inductance of the oscilloscope. It has a similar phenomenon for the 9.4 m wire.

For the 6.4 m wire, we estimate the actual total inductance of the wire is 10-20 μH; and at the input terminal of the oscilloscope, it has a capacitance of about 25 pF. Therefore, a resonant peak appears at 7 MHz. For the 9.4 m wire, due to the fact that the total inductance is greater than the 6.4 m wire, the resonant peak appears at 6.5 MHz.

In order to avoid the capacitance influence from the oscilloscope, we set the 1-3 MHz frequency as the most optimal frequency to test the time delay in our experiment.

In the experiment, we obtain the data from the internal procedures of the oscilloscope. There is a "zero-position" to get access to the data inside the oscilloscope. Since the slope is the largest at the "zero-position" for the sinusoidal signal, it is the most sensitive point to measure the time delay. In this experiment, the accuracy of the time-delay measurement does not exceed 0.5 ns.

For measuring the speed of alternating electric field in metal wires, we suggest a "working definition" in this paper. We define the speed of an alternating electric field is equal to the length difference between the two wires divided by the time difference, which is called as the “working speed”.

From the data displayed in Fig. 4, it is easy to see that when the signal frequency is less than 3.0 MHz, It does not matter when the metal wire length is 6.0 m or 9.0 m, the difference of time delay is less than 1ns, and the working speed of electric field is more than 15 times of the speed of light. In particular, from Fig.2, when the signal frequency is 2.0 MHz, the wire length difference is 6.0 m, the time delay is 0.5 ± 0.5 ns. Therefore the calculated working speed of the electric field is 20 times more than the speed of light.

On the other hand, when the signal frequency is greater than 3.0 MHz, there are significant differences of time delay for two different lengths. It is shown in the curve of “Time delay Vs Frequency” in Fig. 4. For the same frequency, the time delay for the difference of the 6.0 m wire is significantly less than the time delay of the 9.0 m wire. If it is converted into the working speed, the working speed of the 6.0 m wire is significantly greater than the working speed of the 9.0 m wire.

In Fig. 4, it also shows that when the signal frequency is greater than 6.0 MHz, the working speed of the 6.0 m wire is still superluminal, but the working speed of the 9.0 m wire is less than the speed of light. Let us discuss the definition of working speed a bit more here. We consider such a case: the wire length D1 = 0.4 m, and D2 = 6.4 m. In the experiment, it is found that the speed of alternating electric field is length-related. The speed in the short wires may be greater than the speed in the long wire, i.e. $v1 > v2$. The time difference in the experiment becomes $t = (D2/v2) - (D1/v1)$. Since $v1 > v2$, and $D1 \ll D2$, The 2nd term at the right hand of the above equation, $(D1/v1)$, can be ignored approximately. Then $t \approx (D2/v2)$; thus $v2 = (D2/t)$ is a good estimation. For the sake of convenience and also for increasing the reliability of the results, we take a conservative working definition: the working speed is defined as $v = (D2 - D1) / t$. Thus, we have $v \approx v2$.

In short, from many experimental data, when the signal frequency is 2.0 MHz, the calculated working speed of alternating electric field is more than 20 times of the speed of light.

4. Discussion and preliminary conclusions

In most circuit experiments, besides the effects of the speed of electricity, there are many factors that may affect the phase shifts. The advantages of our experiment are to minimize or cancel out the phase shifts caused by many other factors, such as: the distributed capacitance; the distributed inductance; leakage resistance etc.

Our experiment has the following features: small-scale, micro-current, single wire and low frequencies. In addition, the signals go into two-way wires with different lengths from the same signal source. The impedance of the two channels of the oscilloscope inputs is designed to be the same, which is 1MΩ. Therefore, the time difference is mainly derived from the difference between the lengths of two wires. The phase shifts caused by other factors are basically cancelled out.

Specifically, the scale of the whole circuit is no more than 5 m; the electric current in the wires is no more than 5 μA; the single wire can effectively reduce the distributed capacitance; the operating frequency is less than 3 MHz. Under these conditions, our experimental results show that the speed of modulated alternating electric signals in metal wires is 20 times more than the speed of light.

In our experiment, the trigger signal for the screen refresh is based on the same electric trigger level. It is tested that the differences of the time delay between two signals are not caused by the trigger by exchanging the two channel's input signals.

Furthermore, from Eq. (1), the Ohm's law, the meaning of the 2nd term on the right hand side of Eq. (1) is due to the impedance of the self-inductance. It can be explained as the induced electromotive force. This term reflects the reaction of the induced electric field. For this reason, it produces a time delay. As a result, the longitudinal electric field has a limited superluminal speed.

We need to emphasize that the speed of the longitudinal electric field in the metal wires should not be confused with the electromagnetic wave propagating in the metal conductors. The electromagnetic wave is a transverse wave. The speed of low-frequency electromagnetic wave propagating in metal conductor is very low. For an example, the speed of electromagnetic wave with 400 Hz frequency is only about 10 m/s when it propagates in metal conductors.

Alternating power source generates electromotive force, and it also generates longitudinal electric fields in a circuit almost instantaneously. This is a non-local effect. On the basis of the classical microscopic theory of electric current, the longitudinal electric fields act on the free electrons in its direction. These electrons drift along the direction of the electric field, and it results a current, in turn, the longitudinal electric field along the wire has a re-distribution. Since this re-distribution is related to the distributed inductance and the length of wires, as a result, the time delay of the longitudinal electric field is related to the length of the wires and frequencies as well.

In our experiment, it shows the combined effects of a lumped circuit with resistance and inductance. The speed of longitudinal electric field is calculated from the data of time delay. This speed of the alternating electric field in wires means the speed of signal, or the speed of power flow. More specifically, the speed of the alternating electric field in wires means the speed of alternating electricity.

Because the alternating electric field in wires is not the electromagnetic waves, there is no definition of a wavelength. This speed of longitudinal electric field is independent of the constant speed of light. Since the speed of longitudinal electric field in wires under our circuit parameters is much faster than the speed of electromagnetic wave in a vacuum, this experiment also demonstrates that the AC power is entirely transmitted in metal wires. In other words, almost all of electromagnetic energy flow transmits inside the wire. [10]

In our experiments, the direct measured quantity is the time delay of alternating electric signals through two wires with different lengths. Because the measurement accuracy of time difference is 0.5 ns from the oscilloscope, the accuracy of the time difference obtained in our experiments is 0.5 ns ± 0.5 ns, it causes a large uncertainty when the measured time difference is converted into the speed of alternating electric field.

Other superluminal research associated with this paper can be found in [11-14].

From the experimental data, our preliminary conclusion is as follows:

Based on the experimental data reported here, it is found that the speed of alternating electricity within the metal wire is not constant, which is depended on the circuit parameters. In most cases, the speed of alternating electricity is less than the speed of light. However, under our circuit design, the experimental results show that at less than 3 MHz frequency region, the speed of alternating electric field can be 20 times more than the speed of light.

Since this paper is an original research work, more detail investigations are needed.

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