Verification experiment of Faraday's law of electromagnetic induction based on a RF alternating magnetic field

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[Abstract] As one of the three fundamental universal laws of electromagnetism, Faraday's law of electromagnetic induction reveals that the induced voltage generated in a metal coil is proportional to the number of turns of the coil and the rate of change of the magnetic flux passing through a single turn of the coil. New research indicates that Faraday's law of electromagnetic induction is only an engineering approximation formula, and Lorentz's magnetic field force theorem is the microscopic physical essence of the electromagnetic induction. This verification experiment utilizes two induction coils C_A and C_B with identical structure and dimensions. C_A is wound uniformly with 15 turns in a single layer, and C_B is wound densely with 30 turns in a single layer. The ratio of the number of turns between C_B and C_A is 2. The two coils C_A and C_B are sequentially placed in sinusoidal alternating magnetic fields with frequencies of 200Hz, 50MHz and 100MHz, respectively. The experiment demonstrates that at a low frequency of 200Hz, the ratio of the induced voltages of C_B and C_A is approximately 2, which is proportional to the number of turns of two coils. Under low-frequency conditions, Faraday's law of electromagnetic induction and the experimental results are well approximated and consistent. At a radio frequency of 50MHz, the ratio of the induced voltages of coil C_B and coil C_A is 1.52, which significantly deviates from the ratio of the number of turns of coil C_B and coil C_A, which is 2. Faraday's law of electromagnetic induction and the experimental results are clearly inconsistent. At a radio frequency of 100MHz, the ratio of the induced voltages of coil C_B and coil C_A is 0.83, with the induced voltage of the 30-turn induction coil C_B being smaller than that of the 15-turn coil C_A. Faraday's law of electromagnetic induction and the experimental results are completely opposite. The reason is that Faraday's law of electromagnetic induction does not take into account the electromagnetic radiation of the induction coil, and assumes that the propagation speed of the electromagnetic field is infinite. Faraday's law of electromagnetic induction is one of the two necessary conditions of the "electromagnetic wave" theory. Faraday's law of electromagnetic induction does not hold true in the RF "electromagnetic wave", which further proves that the "electromagnetic wave" theory is incorrect. There is no an "electromagnetic wave" in the objective physical world, and it is an independent electric field wave that realizes wireless communication.

[Keywords] Faraday's law of electromagnetic induction, Lorentz's magnetic field force theorem, Helmholtz coil, Radio frequency signal, Electromagnetic radiation, Antenna effect, Electronic field wave.

As one of the three fundamental universal laws of electromagnetism, Faraday's law of electromagnetic induction reveals that the induced voltage generated in a metal coil is proportional to the number of turns of the coil and the rate of change of magnetic flux passing through a single turn of the coil. It is expressed in the formula:

$$\varepsilon = - n \frac{d\Phi_B}{dt} \qquad (1\text{-}1)$$

New research indicates that Faraday's law of electromagnetic induction is only an engineering approximation formula, and Lorentz's magnetic field force theorem is the microscopic physical essence of electromagnetic induction. Below, we present an experimental verification of

Faraday's law of electromagnetic induction based on radio frequency alternating magnetic fields.

The verification experiment utilized two induction coils, CA and CB, which have identical structures and dimensions, as shown in Figure 1.

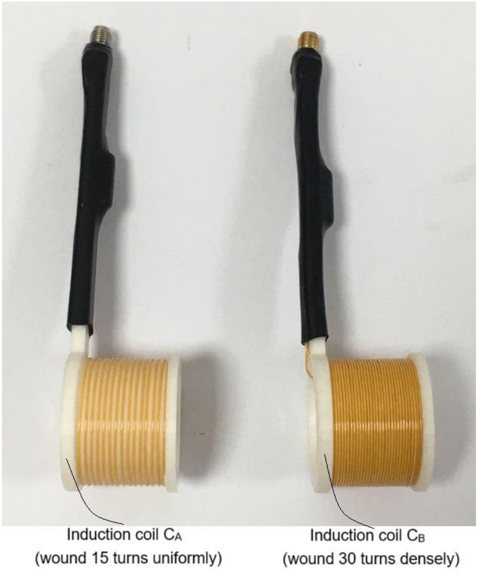

Figure 1 Induction coil structure

The coils are wound with 0.72 mm enameled wire, with a mid-diameter of 31.8 mm and a height of 22 mm. Induction coil C_A is wound uniformly for 15 turns in a single layer, with a length of 1.5 m of enameled wire used for winding. Induction coil C_B is wound densely for 30 turns in a single layer, with a length of 3 m of enameled wire used for winding. The number of turns of induction coil C_B is twice that of induction coil C_A.

At first, the experiment utilizes a Helmholtz coil, which can generate a uniform alternating magnetic field of equal intensity in its central region. A sinusoidal AC power supply is used to power the Helmholtz coil, with a frequency set at 200Hz and the input effective voltages set at 60V and 120V. The experimental photo is shown in Figure 2.

Figure 2 Induction coils under a low-frequency alternating magnetic field

The induction coil C_A with 15-turns and coil C_B with 30-turns are placed in the central area of the Helmholtz coil in sequence. The peak-to-peak induced voltages detected by the oscilloscope is shown in the table below:

Induction Coli /Voltage（rms）	**Peak-to-peak induced voltage (V_{PP})**
C_A / 60V	103mV
C_B/ 60V	202mV
C_A/ 120V	203mV
C_B/ 120V	405mV

From the table above, it can be seen that the ratio of the peak-to-peak induced voltage of coil C_B and coil C_A is approximately 2, which is proportional to their number of turns. Therefore, under the low-frequency experimental condition of 200Hz, Faraday's law of electromagnetic induction can be well approximated by the experimental results.

Furthermore, the following verification experiment of Faraday's law of electromagnetic induction is based on RF alternating magnetic fields. A signal generator generates sine waves of 50MHz and 100MHz, which are connected in series with a 100Ω non-inductive resistor and loaded onto a current-carrying ring, generating high-frequency sine magnetic fields of 50MHz and 100MHz respectively. Induction coils C_A and C_B are placed in sequence on positioning bases located in the magnetic field area to ensure that the alternating magnetic field environments of induction coils C_A and C_B are the same. The experimental photo is shown in Figure 3.

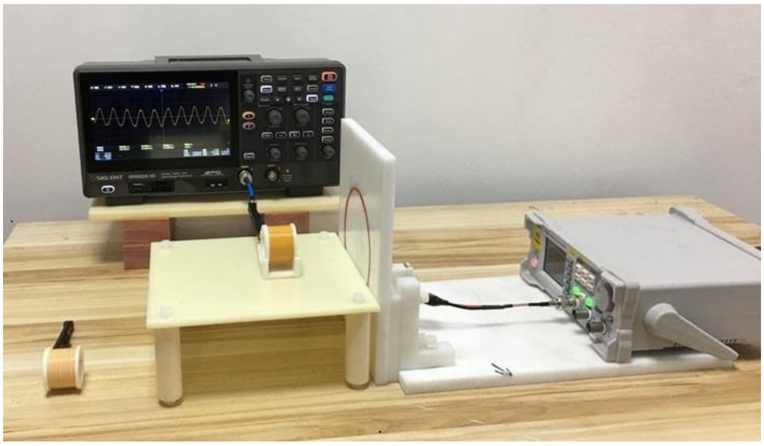

Figure 3: Induction coils under an RF alternating magnetic field

The peak-to-peak induced voltages V_{PP} under an RF alternating magnetic field are shown in the following table:

Induction coil /Frequency /Peak-to Peak signal voltage	Peak-to Peak induced voltage (V_{PP})
C_A /50MHz /5V	326mV
C_B /50MHz /5V	473mV
C_A /100MHz /3V	286mV
C_B /100MHz /3V	236mV

From the table above, we can see that: Under a 50MHz /5V RF signal, the ratio of the peak-to-peak induced voltage of coils C_B and C_A is 1.45, which is significantly different from the turn's ratio of 2 between coils C_B and C_A. The reason is that under a high-frequency alternating electromagnetic field, the induction coil has an obvious antenna effect. There is electromagnetic radiation that cannot be ignored, and a considerable part of the energy of the electromagnetic field is emitted through the surrounding air. Not only the current and potential in the coil wire exhibit a phase difference, but also the peak-to-peak voltage values (or effective values) vary at different positions. In Faraday's era, electromagnetic radiation had not yet been proposed, and Faraday's law of electromagnetic induction did not take into account the influence of electromagnetic radiation on induced electromotive force.

Under a 100MHz/3V RF signal, the peak-to-peak induced voltage of the 30-turn induction coil CB is 236mV, which is smaller than the peak-to-peak induced voltage of the 15-turn CA coil, which is 286mV. This experimental result is completely contrary to Faraday's law of electromagnetic induction. The reason is that the coil's mid-diameter is 31.8mm, and the length of the 30-turn enameled wire is 3m, which is exactly the wavelength of 100MHz. If there is no electromagnetic radiation, the peak-to-peak values (or effective values) of current and potential in the coil wire remain the same at different positions, as shown in Figure 4. The distance between point A and point B in the coil wire is equal to the wavelength $\lambda = 3m$, the potential difference between these two points is 0.

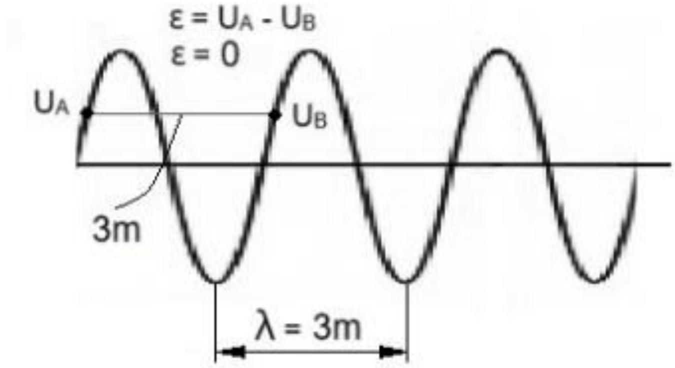

Figure 4: The voltage ε between point A and point B is equal to 0

In fact, the peak-to-peak induced voltage of the induction coil C_B is 236mV, which is not equal to zero. This is because in the above experiment, there is non-negligible electromagnetic radiation in the induction coil CB. As the current flows through the coil wire, the peak-to-peak value (or effective value) of current and potential continuously attenuates. As shown in Figure 5, the distance between point A and point B in the coil is equal to the wavelength λ = 3m. The potential difference between these two points cancels each other out, but it cannot be completely cancelled out, so the potential difference ε between the two points is not equal to 0.

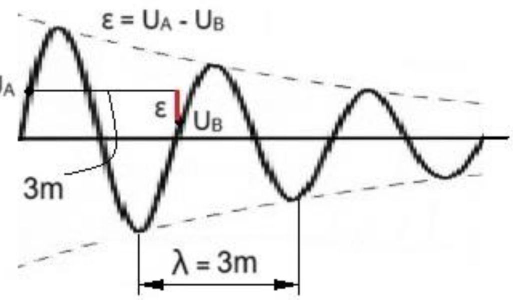

Figure 5 The voltage ε between point A and point B is not equal 0

At the time when Faraday discovered the phenomenon of electromagnetic induction, it was believed that the interaction between electromagnetic fields was instantaneous, and Faraday's law of electromagnetic induction implied that the propagation speed of electromagnetic fields was infinite.

In summary, under the low-frequency alternating electromagnetic field, the electromagnetic radiation and the wavelength of the electromagnetic field have little influence on the electromagnetic induction, and Faraday's law of electromagnetic induction can be well approximated with the experimental results. Under the RF high-frequency alternating electromagnetic field, the electromagnetic radiation and the wavelength of the electromagnetic field have a great influence on electromagnetic induction, and Faraday's law of electromagnetic induction is very different from the experimental results, or even completely opposite. Faraday's law of electromagnetic induction does not take into account the electromagnetic radiation of the induction coil, and assumes the propagation speed of the electromagnetic field to be infinite. Faraday's law of electromagnetic induction does not hold true under the RF high-frequency electromagnetic field.

Faraday's law of electromagnetic induction is one of the two necessary conditions of the "electromagnetic wave" theory. Faraday's law of electromagnetic induction does not hold true in the RF "electromagnetic wave", which further proves that the "electromagnetic wave" theory is incorrect. There is no an "electromagnetic wave" in the objective physical world, and it is an independent electric field wave that realizes wireless communication.