

# Verification experiment of the "electromagnetic wave" theory based on a half-wave dipole dual-antenna pair

**[Abstract]** Maxwell's equations of electromagnetics theoretically introduce the hypothesis of "displacement current", stating that in a vacuum, a changing electric field can induce a changing magnetic field. Based on this, Maxwell predicted the existence of "electromagnetic waves" in a vacuum. The latest research indicates that the theory of "electromagnetic waves" has never been experimentally verified. The experiment conducted by German physicist Hertz in 1887 did not prove the existence of "electromagnetic waves" but rather demonstrated that wireless communication could be achieved by independent "electric field waves". Further research reveals that the hypothesis of "displacement current" is theoretically inconsistent. The simplest and most convincing way to verify the correctness of Maxwell's "electromagnetic wave" theory is to independently measure the electric field intensity and magnetic field intensity of electromagnetic radiation in wireless communication, and then determine through experiments whether the electric field energy density is equal to the magnetic field energy density. This verification experiment is based on the 3-meter method of EMC electromagnetic compatibility standards. A half-wave dipole dual-antenna configuration with reverse attenuation is used to cancel out the magnetic fields generated by the conduction currents of the two antennas, and the electric field intensity and magnetic induction intensity in the far-field of electromagnetic radiation are independently measured. The verification experiment shows that the electric field energy density is 137.6 times that of the magnetic field energy density, and the experimental result is 137.6 times the theoretical value of the "electromagnetic wave" theory. In this verification experiment, the relative error of the electric field intensity measurement is +/- 5%, and that of the magnetic field intensity measurement is +/- 40%. The experimental results are real and valid. This experiment fully proves that, whether in the near-field or far-field, the electromagnetic fields originate from the conduction current of the antenna. In a vacuum, without the participation of charges, a changing electric field cannot generate a changing magnetic field, and a changing magnetic field cannot generate a changing electric field. "Electromagnetic waves" do not exist in the objective physical world.

**[Keywords]** Ampere's circuital law, Maxwell's equations, displacement current, electromagnetic wave, magnetic field probe, electric field energy density, magnetic field energy density, wave impedance, half-wave dipole antenna.

## 1. Introduction

According to Ampere's circuital law, the conduction current in a metal wire generates a magnetic field around the wire, and the magnitude of the magnetic field is proportional to the conduction current.

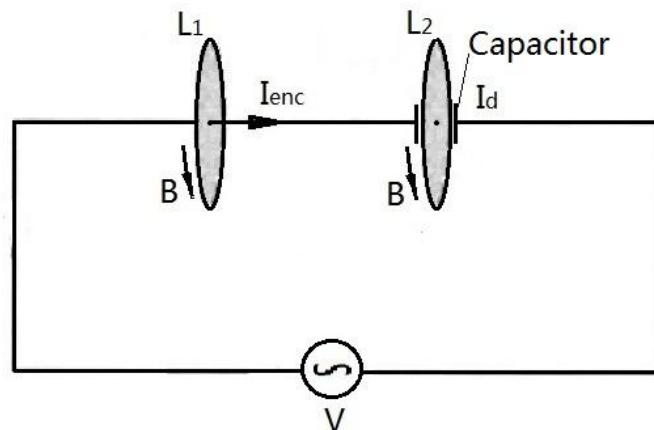


Figure 1.1 A simple circuit containing a capacitor

Figure 1.1 shows a simple circuit containing a capacitor. A conducting current  $I_{enc}$  flows through the cross-section of the closed curve  $L_1$ ; hence,

$$\oint_{L_1} B \cdot d\ell = \mu_0 I_{enc} \quad (1-1)$$

The cross-section of the closed curve  $L_2$  is between two plates of the capacitor, and there is no conducting current  $I_{enc}$  passing through, but there are an electric field and an electric flux between the two plates. Therefore, Maxwell introduced the “displacement current” hypothesis in 1865 and defined the “displacement current”  $I_d$  as

$$I_d = \epsilon_0 \frac{d\Phi_E}{dt} \quad (1-2)$$

Maxwell introduced the “displacement current” hypothesis and extended Ampere’s circuital law to the full current law, that is, the Ampere-Maxwell law.

$$\oint_L B \cdot d\ell = \mu_0 I_{enc} + \mu_0 \epsilon_0 \frac{d\Phi_E}{dt} \quad (1-4)$$

The Ampere-Maxwell law reveals that a magnetic field can be excited by the conduction current  $I_{enc}$ , and also by a changing electric field.

According to the Ampere-Maxwell law, a changing electric field induces a magnetic field. According to Faraday’s law, a changing magnetic field induces an electric field. The electric field and the magnetic field are closely linked and induce each other to form electromagnetic waves, as shown in Figure 1.2.

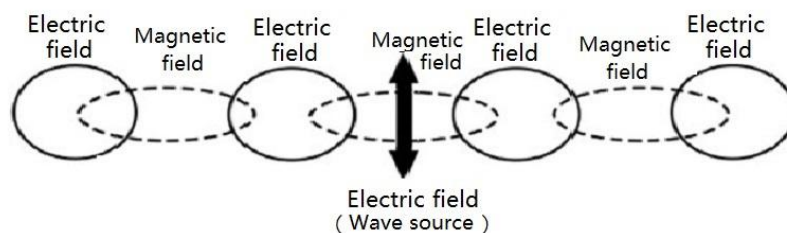


Figure 1.2 One of the propagation modes of “electromagnetic waves”

Maxwell introduced the “displacement current” hypothesis in 1865, which theoretically predicted the existence of electromagnetic waves and inferred from Maxwell’s equations that light was an electromagnetic wave. The experimental conditions at that time could not prove that a changing electric field induced a magnetic field and a changing magnetic field induced an electric field. The electromagnetic wave theory was not accepted by most scientists.

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In 1887, more than 20 years after Maxwell proposed the theory of electromagnetic waves, based on experiments that the high-voltage discharge sparks generated between two small balls at the transmitting point could excite high-voltage discharge sparks between the two small balls at the receiving point, Hertz experimentally proved the existence of electromagnetic waves.

Recent research points out that the "displacement current" hypothesis is not theoretically self-consistent, contradicts Coulomb's law, and violates energy conservation. Hertz's verification experiment in 1887,

based on high-voltage discharge sparks, did not prove the existence of "electromagnetic waves"; but rather proved that wireless communication was achieved by independent electric field waves [2].

According to the "electromagnetic wave" theory and the principle of energy conservation, the electric field energy density and magnetic field energy density at any point in space must be equal. The Electromagnetic Compatibility (EMC) laboratory is a professional institution for measuring electromagnetic radiation. In EMC testing applications, the electromagnetic fields are divided into the near-fields and the far-fields. When the distance  $r$  from the detection point to the radiation source is  $r < \lambda/2\pi$ , the electromagnetic field is the near-field. When the distance  $r$  from the detection point to the radiation source is  $r \gg \lambda/2\pi$ , the electromagnetic field is considered to be the far-field, namely the radiation field. A changing electric field generates a changing magnetic field, and a changing magnetic field generates a changing electric field. Figure 1.3 shows the relationship diagram of the near-field, far-field in the EMC electromagnetic field.

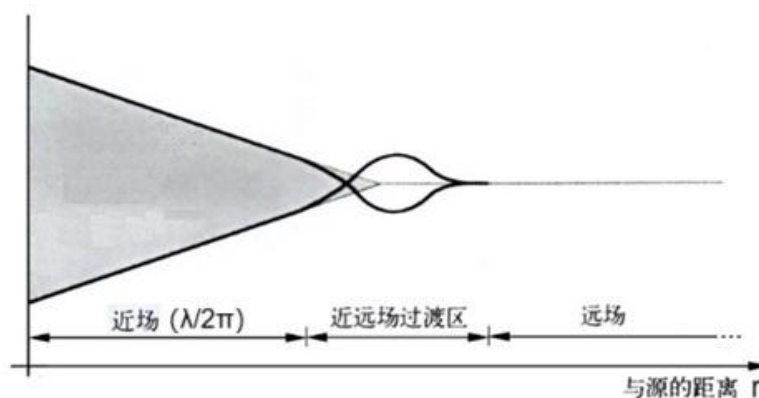


Figure 1.3 Near-field and far-field

In the far field, the electromagnetic field is a radiation field, that is, a changing electric field generates a changing magnetic field, and a changing magnetic field generates a changing electric field. In EMC engineering measurements, for far-field signals, only the electric field intensity of the radiation signal is directly measured, and then the magnetic field intensity is obtained through theoretical calculation using the relationship  $E = 377 H$ . Here,  $377 \Omega$  is defined as the wave impedance. The wave impedance of  $377 \Omega$  is derived from Maxwell's "electromagnetic wave" theory. Surprisingly, the wave impedance of  $377 \Omega$  has never been verified by experiments.

In summary, the simplest way to verify the correctness of Maxwell's "electromagnetic wave" theory is to independently measure the electric-field intensity and magnetic-field intensity contained in electromagnetic radiation fields in wireless communication. Determine through experiments and compare whether the electric field energy density and magnetic field energy density at a point in space are equal.

## 2. Development of measurement instruments for radio frequency magnetic induction intensity

In radio frequency (RF) electromagnetic radiation measurement, generally only the electric field intensity is measured, and the magnetic induction intensity is calculated from the measured electric field intensity value using theoretical formulas. There is no off-the-shelf measuring equipment for the direct measurement of RF magnetic fields. In this verification experiment, an RF magnetic induction intensity

measuring instrument is first developed, and this dedicated measuring instrument is applied to the measurement of 98 MHz sinusoidal magnetic field waves.

## 2.1 Composition of Measuring Instruments

A dedicated measuring instrument for RF magnetic induction intensity consists of a 200MHz high-precision oscilloscope, a BNC/SMA high-frequency connecting line, and an electric-field shielded magnetic field probe, as shown in Figure 2.1.

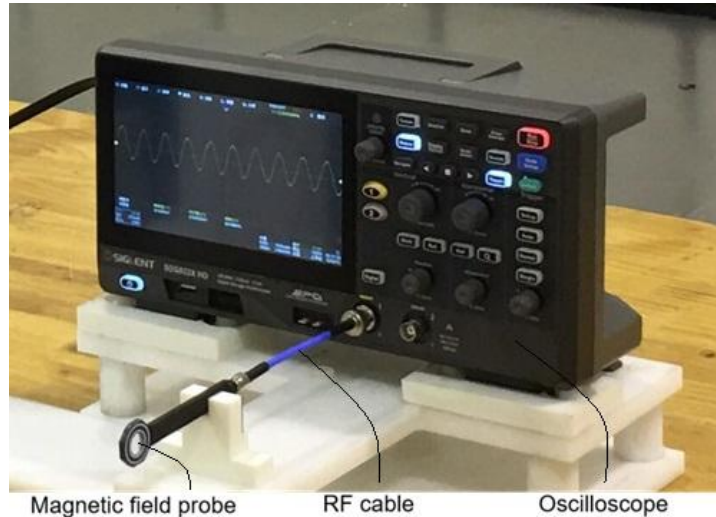


Figure 2.1 Composition of the dedicated measurement instrument system for radio frequency magnetic induction intensity

The oscilloscope used is the Siglent SDS822X HD high-definition digital oscilloscope, which has an operating bandwidth of 200 MHz, a sampling rate of 2G, a resolution of 12-bit, and a background noise of 70  $\mu\text{V}$  rms.

The BNC/SMA high-frequency connecting cable uses Dongfang Xupu RM141-BNC-J/SMA-JG, with a length of 100 mm. This connecting cable adopts a five-layer structure, with a characteristic impedance of 50 $\Omega$  and a frequency range of DC - 6GHz.

The magnetic field probe is of the electric-field shielding type, which has excellent shielding characteristics against the electric fields. That is to say, the influence of the electric field wave on the magnetic field probe is very small.

## 2.2 Detection of the electric field shielding performance of magnetic field probes

The working principle of the magnetic field probe is based on Faraday's law of electromagnetic induction. A changing magnetic field induces an electromotive force in the sensor's induction coil, and this induced voltage is proportional to the magnetic flux density and frequency of the radiated magnetic field. To reduce the influence of the electric field on the magnetic field probe, an electric field shielded magnetic field probe is used in the experiment, as shown in Figure 2.2.



Figure 2.2 Working principle of the magnetic field probe and the structure of the electric field shielded magnetic field probe

To test the shielding performance of the magnetic field probe against the electric field, as shown in Figure 2.3. A signal generator produces a sine wave with a frequency of 98 MHz and a peak-to-peak voltage of 1.5 V. This sine wave is applied to a two-plate capacitor composed of two circular copper plates. The diameter of each plate is 400 mm, and the distance between the two plates is 100 mm. A non-inductive resistor of  $200 \Omega$  is connected in series with the two plates. Then, an alternating sinusoidal electric field with a peak-to-peak electric field intensity of 15.0 V/m and an effective value of 5.30 V/m is formed between the two plates.

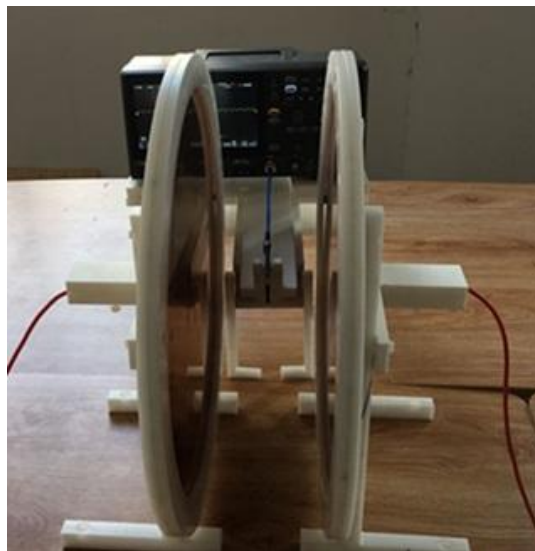


Figure 2.3 Test of the electric field shielding performance of the magnetic field probe

The shielded magnetic field probe was placed in the 98 MHz sinusoidal electric field wave formed by the two plates, and the magnetic field probe was located in the central area of the two plates. The normal direction of the magnetic field probe was set horizontally, consistent with the direction of the electric field. The peak - to - peak induced voltage of the magnetic field probe was read as 4.87 mV on the oscilloscope display. This induced voltage is a random signal. Considering it as one-third, the peak-to-peak induced voltage of the electric field on the magnetic field probe is 1.62 mV. Therefore, the magnetic field probe selected in this verification experiment has excellent shielding performance against the electric field, and the influence of the electric field on the magnetic field probe is very small.

### 2.3 Calibration of measuring instruments

The calibration of the measuring instrument uses an alternating magnetic field generated by a current-carrying ring, as shown in Figure 2.4. The signal generator produces a 98 MHz sine wave. This sine signal is connected in series with a 100 Ω non-inductive resistor and loaded onto the current-carrying ring to generate a 98 MHz high-frequency sine magnetic field. The above-selected shielded magnetic field probe is placed in this high-frequency sine magnetic field. The magnetic field probe is parallel to the current-carrying ring, and their central axes coincide.

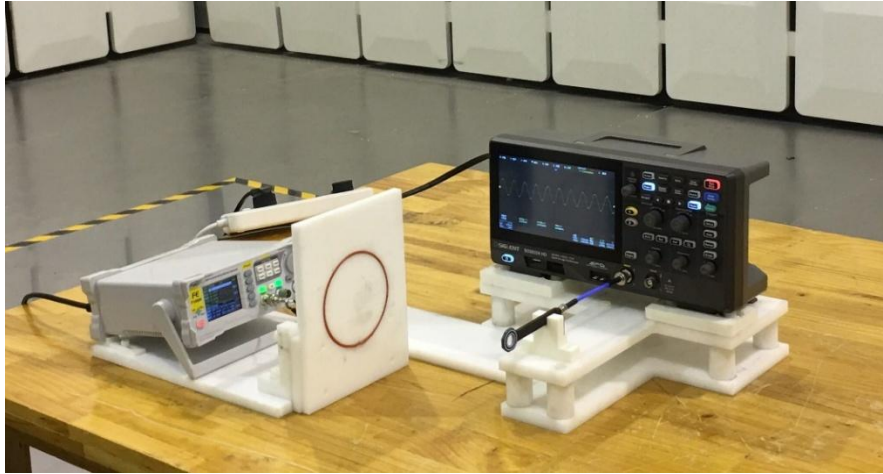


Figure 2.4 Calibration of Measuring Instruments

Let the radius of the current-carrying circular loop be  $R$ , and the current be  $I$ . Then the magnetic induction intensity at a point  $(x)$  on the central axis is:

$$B = \mu_0 I R^2 / (2(R^2+x^2)^{3/2}) \quad (2-1)$$

In the above formula (2-1), where  $I$  represents a constant current. For medium-and low-frequency sinusoidal alternating currents, the effective value can be used for the current  $I$ , and the corresponding magnetic induction intensity  $B$  is also the effective value.

In this experiment, the current is a sinusoidal wave with a frequency of 98 MHz and a wavelength of 3 meters. Let the peak value of the current be  $I_{PMax}$ , and the radius of the current - carrying ring be  $R = 0.05$  m. Then the length of the current-carrying ring is 0.314 meters, and the maximum phase difference of the current on the ring is approximately  $36^\circ$ . The magnetic field generated by the ring should be calculated by integrating current elements. To simplify and approximately calculate the peak current of the current - carrying ring, the ring is evenly divided into 9 small segments:  $S_1, S_2, S_3, S_4, S_5, S_6, S_7, S_8$  and  $S_9$ , where  $S_1$  is the starting segment of the ring,  $S_5$  is the middle segment, and  $S_9$  is the terminal segment, as shown in Figure 2.5.

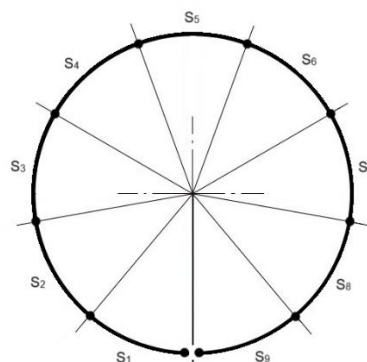


Figure 2.6 Current distribution of a current-carrying circular loop

Let the mid-point of  $S_5$  be the maximum peak  $I_{PMax}$ . Then, starting from the initial segment  $S_1$ , the currents at the mid-points of the 9 small segments are respectively:  $I_{PMax} \cos 16.75^\circ$ ,  $I_{PMax} \cos 12.56^\circ$ ,  $I_{PMax} \cos 8.38^\circ$ ,  $I_{PMax} \cos 4.19^\circ$ ,  $I_{PMax}$ ,  $I_{PMax} \cos 4.19^\circ$ ,  $I_{PMax} \cos 8.38^\circ$ ,  $I_{PMax} \cos 12.56^\circ$  and  $I_{PMax} \cos 16.75^\circ$ . The average value of the currents in these 9 small segments is the peak current of the current-carrying ring, that is,  $I_p = 0.98 I_{PMax}$ . The difference between this peak current and the one without considering the current phase difference is only 2%. The corresponding effective value is  $I = 0.693 I_{PMax}$ . The magnetic induction intensity is directly proportional to the current. Taking the current as 0.001 A, according to Equation (2-1), the magnetic induction intensity:

$$\begin{aligned} B_k &= \mu_0 I R^2 / (2 (R^2 + x^2)^{3/2}) \\ &= (4 \times 3.14 \times 10^{-7} \times 0.001 \times 0.05^2 / 2) / ((R^2 + x^2)^{3/2}) \\ &= (1.57 \times 10^{-12}) / ((0.05^2 + x^2)^{3/2}) \end{aligned}$$

At a current of 1 mA, the magnetic induction intensities were calculated at x values of 40 mm, 50 mm, 60 mm, 80 mm, 100 mm, 125 mm, 150 mm, and 175 mm respectively. The calculated values are shown in Table 2-1.

Let the signal generator produce a sine wave with a frequency of 98 MHz and an output peak-to-peak voltage of 3V. The peak-to-peak voltage measured across the series-connected 100  $\Omega$  non-inductive resistor is  $V_{PP} = 2.10V$ , and the maximum peak current is  $I_{PMax} = 10.5$  mA. Then its effective value is  $I = 0.693 I_{PMax} = 7.28$  mA.

In Figure 2.4, set the distances between the center of the magnetic field probe and the center of the current-carrying ring to 40 mm, 50 mm, 60 mm, 80 mm, 100 mm, 125 mm, 150 mm, and 175 mm respectively, and read the peak-to-peak induced voltage values of the magnetic field probe. The experimental measurement results are shown in Table 2-1.

Table 2-1 Relationship between magnetic induction intensity (effective value) and peak-to-peak induced voltage of the magnetic field probe (sine wave at 98 MHz)

|        | Magnetic Induction Intensity $B_k$ (1mA) | Magnetic Induction Intensity B (7.28 mA) | Peak-to-peak Induced Voltage $V_{PP}$ (mV) |
|--------|--|--|--|
| 40 mm  | 0.00598 $\mu T$                          | 0.0435 $\mu T$                           | 751  |
| 50 mm  | 0.00444 $\mu T$                          | 0.0323 $\mu T$                           | 541  |
| 60 mm  | 0.00330 $\mu T$                          | 0.0240 $\mu T$                           | 415  |
| 80 mm  | 0.00187 $\mu T$                          | 0.0136 $\mu T$                           | 233  |
| 100 mm | 0.00112 $\mu T$                          | 0.0082 $\mu T$                           | 142  |
| 125 mm | 0.000643 $\mu T$                         | 0.0047 $\mu T$                           | 83.5                                       |
| 150 mm | 0.000397 $\mu T$                         | 0.0029 $\mu T$                           | 52.7                                       |
| 175 mm | 0.000260 $\mu T$                         | 0.0019 $\mu T$                           | 34.2                                       |
|        | 0.0                                      | 0.0                                      | 0.0  |

From the data in Table 2-1 above, the calibration curve of the magnetic field probe can be obtained, as shown in Figure 2.6.

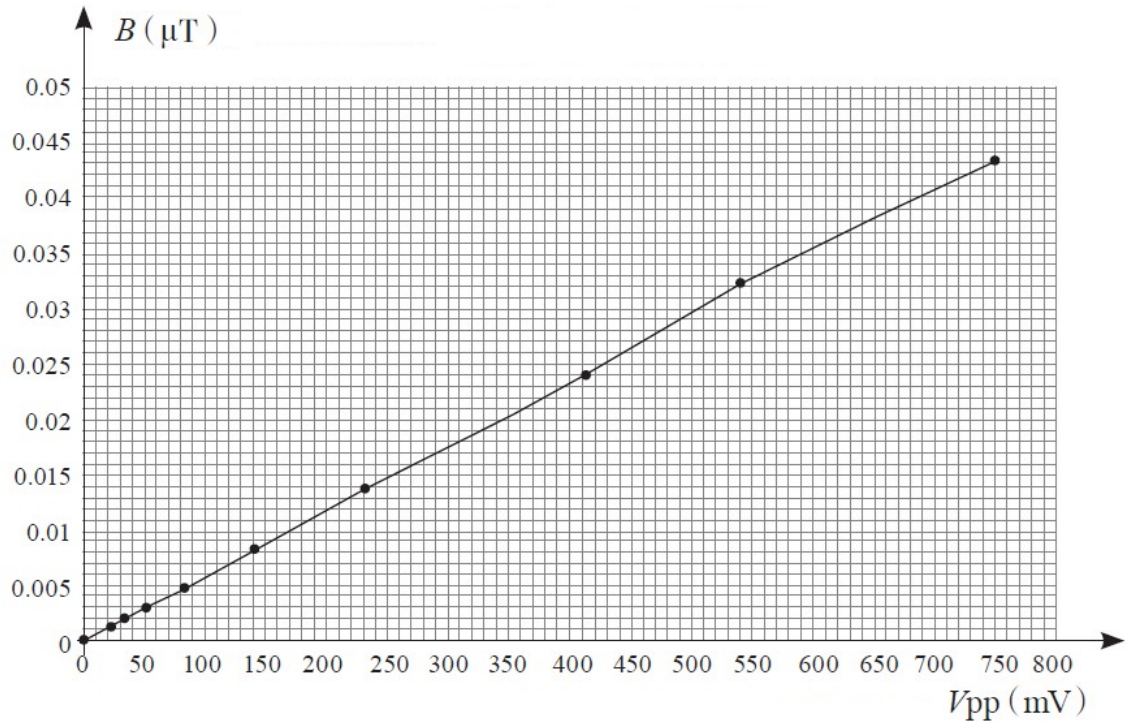


Figure 2.6 Calibration curve of the magnetic induction intensity

The above calibration curve is approximately a straight line, showing excellent linearity. By performing least - squares linear fitting on the experimental data, the relationship between the magnetic induction intensity and the peak - to - peak induced voltage of the magnetic field probe is obtained:

$$B = 0.000058 V_{PP} \quad (2-2)$$

The above regression line passes through the origin. Here,  $B$  represents the effective value of the magnetic induction intensity, with the unit of  $\mu\text{T}$ ;  $V_{PP}$  is the peak-to-peak induced voltage of the magnetic field probe, with the unit of  $\text{mV}$ . Let  $K_{VB} = 0.000058$ , where  $K_{VB}$  is the magnetic field calibration coefficient.

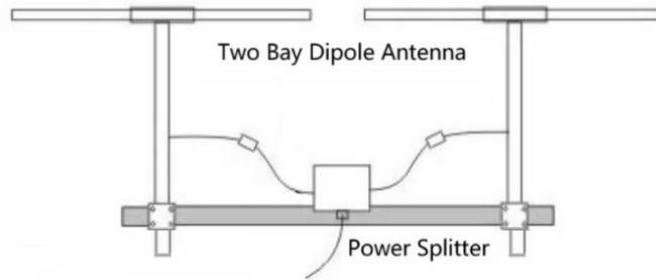
### 3. Verification experiments on the theory of "electromagnetic waves"

The simplest and most convincing way to verify the correctness of Maxwell's "electromagnetic wave" theory is to independently measure the electric field intensity and magnetic field intensity contained in electromagnetic radiation in wireless communication, and verify whether the electric field energy density and magnetic field energy density at any point in space are equal.

The verification experiment uses the FMUSER FU-200 FM transmitter, as shown in Figure 3.1A. The transmission frequency range of this transmitter is from 88 MHz to 108 MHz, and the maximum RF power is 200 W. It is widely used in wireless broadcasting systems such as campuses, villages, and shopping malls. The transmitting antenna is the FMUSER double-layer DP100 half-wave dipole antenna, which includes a power divider, as shown in Figure 3.1B.



Figure 3.1A FU-200 FM Frequency Modulation Transmitter Figure



3.1B Dual DP100 Half-wave Dipole Antenna

The principle of the half-wave dipole antenna is shown in Figure 3.2. It consists of two single arms of wires with the same length and thickness. The length of each single arm is  $\frac{1}{4}$  of the wavelength  $\lambda$ , and the total length is half of the wavelength. The two arms of the dipole antenna have positive and negative polarities. The currents  $I$  on the two arms of the dipole antenna have the same amplitude and direction at symmetric positions.

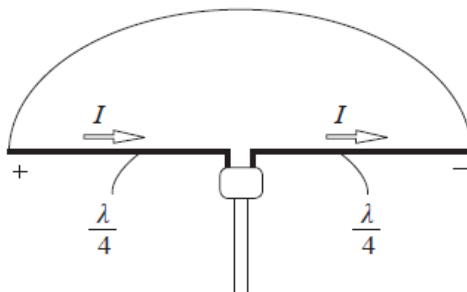


Figure 3.2 Half-wave dipole antenna

In order to improve the transmission power of the antenna, a dual-antenna structure is often adopted in applications, as shown in Figure 3.3. The co-directional enhancement configuration of the half-wave dipole dual-antenna can double the transmission power of the antenna.

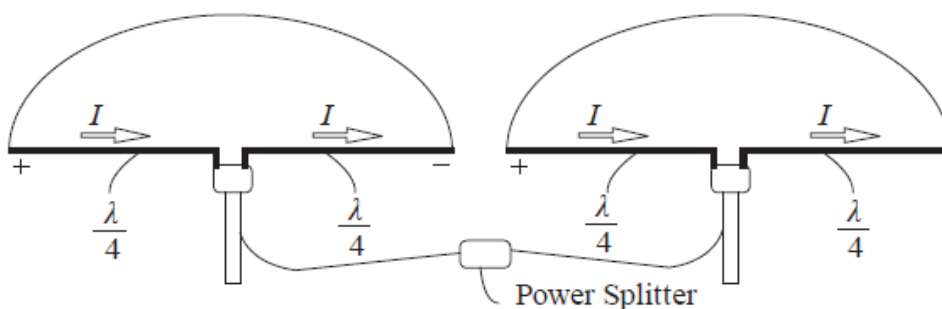


Figure 3.3 Co-directional enhancement configuration of a half-wave dipole dual-antenna

In the configuration of two half-wave dipole antennas with reverse attenuation, the magnetic fields generated by the currents on the two arms are equal in magnitude and opposite in direction. That is, the magnetic fields generated by the conduction currents of the two antennas cancel each other out, and in theory, the total magnetic field is zero, as shown in Figure 3.4.

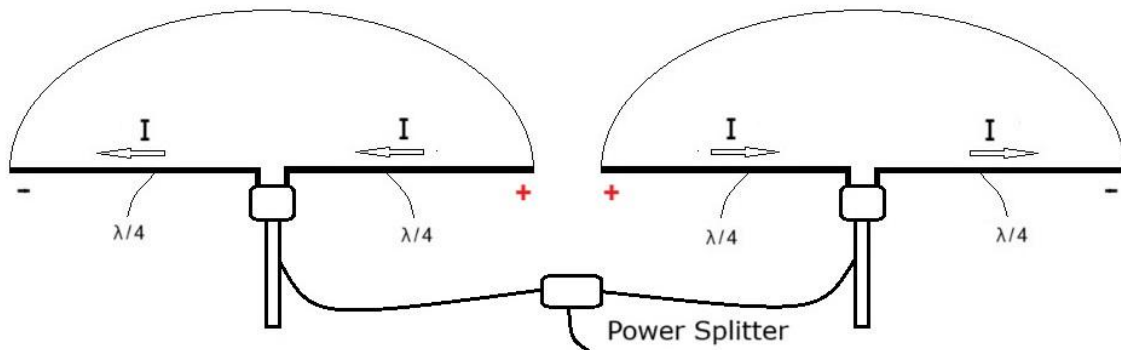


Figure 3.4 Reverse weakening configuration of a half-wave dipole dual-antenna

Based on the above analysis, the verification experiment is based on the 3-meter method of the EMC standard, and the experimental site is the EMC laboratory of the National Robot Testing Center of the Chinese Academy of Sciences. The experiment uses an FMUSER FU - 200 FM frequency - modulated transmitter, and the transmission frequency is set to 98 MHz (wavelength  $\lambda = 2.94$  m). The electric field intensity is measured using the standard field-intensity probe configured in the EMC laboratory. This probe is the FL7006 three-dimensional probe produced by AR Company in the United States, with a resolution of 0.01 V/m. The magnetic induction intensity is measured using the self-developed 98 MHz dedicated radio-frequency magnetic induction intensity measuring instrument mentioned above, and its magnetic field probe has excellent shielding performance against the electric field. The FMUSER double DP100 half-wave dipole antennas are configured with horizontal reverse attenuation. The antennas and the measuring probes are on the same horizontal plane, 1.5 m above the ground. The transmitting antenna is 3 m away from the measuring probe, and a 3 m x 3 m standard absorbing material is laid on the ground between the transmitting antenna and the measuring probe. The distance (3 m) between the transmitting antenna and the detection point is much greater than  $\lambda/2\pi$  (0.468 m), so the electromagnetic field at the detection point is the far - field, i.e., the radiation field, as shown in Figure 3.5. The three-dimensional coordinate system is established with the horizontal connection line from the antenna to the measuring probe as the y-axis and the vertical axis as the z-axis. If the normal direction of the magnetic field probe is parallel to the x-axis, it is the x-direction of the magnetic field probe, and so on, the y-direction and z-direction of the magnetic field probe.

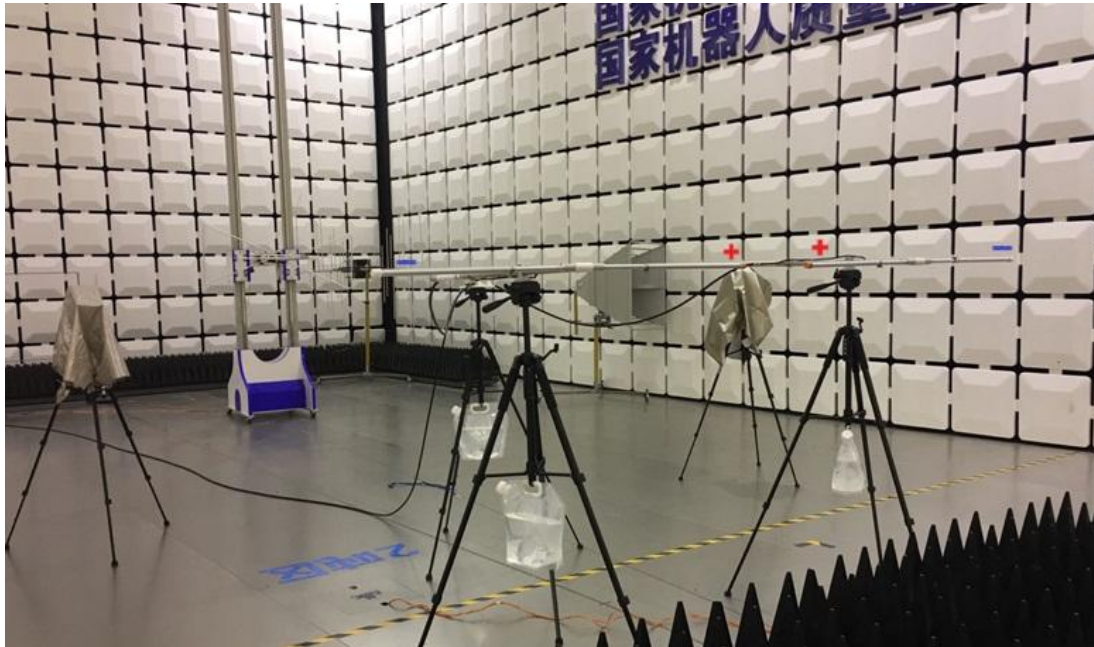


Figure 3.5 Reverse weakening configuration of a half-wave dipole dual-antenna

**Measurement of zero-point error in the laboratory environment:**

Set the measurement frequency range of the electric field intensity to 98 MHz. In an environment where the FM transmitter is not started and the electromagnetic radiation is zero, read the electric field intensity  $E_0$  and the peak-to-peak induced voltage  $V_{PP0A}$  of the magnetic field probe. The experimental measurement values are shown in Table 3 - 1.

Table 3-1: Experimental values of the environmental zero-point electric field intensity and the induced voltage of the magnetic field probe

| Electric Field Intensity $E_0$ (V/m) |      |      |         | Peak-to-peak Induced Voltage $V_{PP0A}$ (mV) |      |      |         |
|--------------------------------------|------|------|---------|--|------|------|---------|
| 1                                    | 2    | 3    | average | 1  | 2    | 3    | average |
| 0.16                                 | 0.15 | 0.17 | 0.16    | 2.28   | 2.30 | 2.50 | 2.36    |

In the above table, the peak-to-peak induced voltage of the magnetic field probe is 2.36 mV. However, this induced voltage is a random signal. Considering it as one-third, the peak-to-peak induced voltage at zero point of the magnetic field probe in a radiation-free environment is 0.79 mV. Compared with the measurement signals ranging from tens to hundreds of mV, this environmental zero-point error is very small.

**Measurement of the zero-point error of the magnetic induction intensity measurement system:**

Remove the magnetic field probe from the magnetic induction intensity detector and keep the radio frequency connecting cable. Set the transmission frequency to 98 MHz and the transmission power to 160 W. Start the frequency modulation transmitter and read the peak-to-peak induced voltage  $V_{PP0B}$  of the magnetic field probe. The experimental measurement values are shown in Table 3-2.

Table 3-2: Zero error of the magnetic induction intensity detector system

| Peak-to-peak Induced Voltage $V_{PP0B}$ (mV) |      |      |         |
|--|------|------|---------|
| 1  | 2    | 3    | average |
| 3.92   | 3.73 | 3.36 | 3.67    |

In the above table, the peak-to-peak induced voltage of the magnetic field probe is 3.67 mV. Compared with the measurement signals ranging from tens to hundreds of millivolts, the zero-point error of this measuring instrument system is very small.

**Experimental measurement:**

Set the transmission frequency to 98 MHz and the transmission power to 160 W. Install the magnetic field probe and repeatedly adjust the antenna locally to minimize the peak-to-peak induced voltage of the magnetic field probe in the x, y, and z axis directions. Read the peak-to-peak induced voltage of the magnetic field probe. The experimental measurement values are shown in Table 3-3.

Table 3-3: Peak-to-peak induced voltages in three directions of the magnetic field probe (98 MHz, 160 W)

|      | Peak-to-peak Induced Voltage (mV) |      |      |         |
|------|-----------------------------------|------|------|---------|
|      | 1                                 | 2    | 3    | average |
| X 方向 | 7.24                              | 8.06 | 7.06 | 7.45    |
| Y 方向 | 33.1                              | 32.5 | 32.8 | 32.8    |
| Z 方向 | 36.5                              | 34.6 | 35.3 | 35.5    |

Based on the measured values of the x, y, and z axes in the above table, the total peak-to-peak induced voltage  $V_{PP}$  of the magnetic field probe in three dimensions is calculated to be 49.0 mV according to vector calculation. The ratio of the total three-dimensional peak-to-peak induced voltage to the peak-to-peak induced voltage of the z-axis is 1.38.

The measurement frequency of the electric field intensity was set to 98 MHz. The magnetic field probe was set in the z-direction, with an emission frequency of 98 MHz and emission powers of 160 W, 80 W, and 40 W respectively. The effective value of the electric field intensity and the peak-to-peak induced voltage of the magnetic field probe on the z-axis were read. The experimental measurement values are shown in Table 3 - 4.

Table 3-4: Experimental values of peak-to-peak induced voltage of electric field intensity and magnetic field probes (98 MHz)

| Emission Power | Z-Peak-to-peak Induced Voltage $V_{PPZ}$ (mV) |      |      |         | Electric Field Intensity E(V/m) |      |      |         |
|----------------|---|------|------|---------|---------------------------------|------|------|---------|
|                | 1   | 2    | 3    | average | 1                               | 2    | 3    | average |
| 160W           | 36.5  | 34.6 | 35.3 | 35.5    | 9.82                            | 9.77 | 9.81 | 9.80    |
| 80W            | 25.7  | 26.2 | 24.3 | 25.4    | 7.14                            | 7.21 | 7.01 | 7.12    |
| 40W            | 19.1  | 18.3 | 19.8 | 19.1    | 5.09                            | 5.11 | 5.21 | 5.14    |

From the above table, the total peak-to-peak induced voltage  $V_{pp}$  of the magnetic field probe in three dimensions can be calculated. According to the relationship (2-2) between the magnetic induction intensity and the peak-to-peak induced voltage of the magnetic field probe, the corresponding effective value of the magnetic induction intensity can be obtained.

Then the magnetic field energy density:

$$P_B = B^2 / (2\mu_0) \quad (3-1)$$

Among them, the vacuum magnetic permeability  $\mu_0 = 1.257 \times 10^{-6}$  H/m.

Electric field energy density:

$$P_E = \epsilon_0 E^2 / 2 \quad (3-2)$$

Among them, the vacuum permittivity  $\epsilon_0 = 8.854 \times 10^{-12}$  F/m.

Substitute the magnetic induction intensity and electric field intensity obtained from the experiment into Eqs. (3-1) and (3-2) to calculate the ratio of the electric field energy density to the magnetic field energy density. See Table 3-5.

Table 3-5: Ratio of electric field to magnetic field energy density (experimental results)

| Emission Power | Peak-to-peak Induced Voltage $V_{PP}(mV)$ | Magnetic Field Intensity $B(\mu T)$ | Magnetic Field Energy Density $P_B(J/m^3)$ | Electric Field Intensity $E(V/m)$ | Electric Field Energy Density $P_E(J/m^3)$ | Ratio of electric field to magnetic field energy density $P_E/P_B$ |
|----------------|---|-------------------------------------|--|-----------------------------------|--|--|
| 160W           | 49.0                                      | 0.0028                              | $3.09 \times 10^{-12}$                     | 9.80                              | $425.2 \times 10^{-12}$                    | <b>137.6</b>   |
| 80W            | 35.1                                      | 0.0020                              | $1.58 \times 10^{-12}$                     | 7.12                              | $224.5 \times 10^{-12}$                    | <b>141.1</b>   |
| 40W            | 26.4                                      | 0.0015                              | $0.89 \times 10^{-12}$                     | 5.14                              | $117.0 \times 10^{-12}$                    | <b>131.5</b>   |

According to Maxwell's "electromagnetic wave" theory, in the electromagnetic radiation field, the electric field energy density at any point in space is equal to the magnetic field energy density, that is, the ratio of the electric field energy density to the magnetic field energy density is equal to 1. The above verification experiment shows that the electric field energy density is 137.6 times that of the magnetic field energy density, that is, the result of the verification experiment is 137.6 times the theoretical value.

#### Analysis of experimental accuracy and error:

In the above verification experiment, the FM transmission frequency is 98 MHz. The electric field intensity is measured using a standard field intensity probe configured in the EMC laboratory. This probe is the FL7006 three-dimensional probe produced by AR Company in the United States, with a resolution of 0.01 V/m and a relative measurement error of the electric field intensity of +/- 5%. When the FM transmission power is 160 W, the measured effective value of the electric field intensity is 9.80 V/m. Considering the measurement error of the field intensity probe, the minimum effective value of the electric field intensity  $E_{min} = 9.31$  V/m, and the corresponding minimum electric field energy density is  $P_{Emin} = 383.7 \times 10^{-12}$  J/m<sup>3</sup>; the maximum effective value of the electric field intensity  $E_{max} = 10.29$  V/m, and the corresponding maximum electric field energy density is  $P_{Emax} = 468.7 \times 10^{-12}$  J/m<sup>3</sup>.

1) In a 98 MHz sinusoidal electric field wave, the peak-to-peak induced voltage of the magnetic field probe is 4.87 mV. However, this induced voltage is a random signal. Considering it as one-third, the peak-to-peak induced voltage of the electric field on the magnetic field probe is 1.62 mV. Relative to the measured value of 49.0 mV, the relative error generated by the electric field on the magnetic induction intensity measurement system can be controlled within 4% in this experiment.

2) In the radiation-free background environment of the laboratory, the peak-to-peak induced voltage of the magnetic field probe is 2.36 mV. However, this induced voltage is a random signal. Considering it as one-third, the zero-point peak-to-peak induced voltage of the magnetic field probe in the radiation-free environment is 0.79 mV. Compared with the measured value of 49.0 mV, the relative error of the

zero point in the radiation-free environment of the laboratory can be controlled within 2% in this experiment.

3) The peak-to-peak voltage of the zero-point error of the magnetic induction intensity measurement system is 3.67 mV. Relative to the measured value of 49.0 mV, the relative zero-point error of the magnetic induction intensity measurement system in this experiment is 8%.

4) The magnetic induction intensity measuring instrument is a one-dimensional measuring instrument. In this experiment, measurements are carried out in the x, y, and z directions respectively, and then the total experimental measurement value is obtained by three-dimensional vector synthesis. The relative error caused by vector synthesis is 5%.

5) In the experimental measurement, the oscilloscope, RF connection cables, and magnetic field probes used are the same as those during calibration. The installation method of the magnetic field probe is the same as that during calibration, and the parameter settings of the oscilloscope are also the same as those during calibration. The calibration error mainly comes from the error of the calibration magnetic field, and the calibration error is a systematic error. In this experiment, the systematic calibration error is within 15%.

6) Other uncertainty errors are 6%.

Based on the above analysis, the total relative error of the magnetic induction intensity measurement system is +/- 40%. When the FM transmission power is 160 W, the measured peak-to-peak induced voltage is 49.0 mV, and the corresponding effective value of the magnetic induction intensity is 0.0028  $\mu\text{T}$ . Considering the measurement error of the magnetic induction intensity, the minimum effective value of the magnetic induction intensity  $B_{\min} = 0.0017 \mu\text{T}$ , and the corresponding minimum magnetic field energy density is  $P_{B\min} = 1.150 \times 10^{-12} \text{ J/m}^3$ ; the maximum effective value of the magnetic induction intensity  $B_{\max} = 0.0039 \mu\text{T}$ , and the corresponding maximum magnetic field energy density is  $P_{B\max} = 6.05 \times 10^{-12} \text{ J/m}^3$ . The ratio of the minimum electric field energy density to the maximum magnetic field energy density:  $P_{E\min} / P_{B\max} = 63.4$ ; the ratio of the maximum electric field energy density to the minimum magnetic field energy density:  $P_{E\max} / P_{B\min} = 407.6$ . Therefore, considering the experimental measurement error, the ratio of the electric field energy density to the magnetic field energy density is between 63.4 and 407.6. Even under the maximum error condition, the verification experimental result is 63.4 times the theoretical value, which verifies that the experimental result is true and valid.

In summary, the above verification experiment is based on the 3-meter method of the EMC (Electromagnetic Compatibility) standard. A configuration of two half-wave dipole antennas with reverse attenuation is adopted, so that the magnetic fields generated by the conduction currents of the two antennas cancel each other out, and the electric field intensity and magnetic induction intensity contained in the far - field of electromagnetic radiation are independently detected. The verification experiment shows that: The electric field energy density is 137.6 times that of the magnetic field energy density, and the experimental verification result is 137.6 times the theoretical value of the "electromagnetic wave".

## 4. Conclusion

Maxwell's theory of "electromagnetic waves" posits that in a vacuum, without the involvement of charges, a changing electric field generates a changing magnetic field, and a changing magnetic field generates a changing electric field. The latest research indicates that the "electromagnetic wave" theory has never been experimentally verified. The experiment conducted by German physicist Hertz in 1887 did not prove the existence of "electromagnetic waves" but rather demonstrated that wireless communication can be achieved by independent "electric field waves".

The Electromagnetic Compatibility (EMC) laboratory is a professional institution for measuring electromagnetic radiation. In Electromagnetic Compatibility (EMC) testing, the electromagnetic field is divided into the near-field and the far-field. The electric and magnetic fields in the near - field originate from the conduction current of the antenna; the far - field is a radiation field, and its electromagnetic field has no relation with the conduction current of the antenna. In the far-field, the electric field comes from the changing magnetic field, and the magnetic field comes from the changing electric field. During the transformation process of the electric and magnetic fields, the law of energy conservation must be satisfied. Therefore, the electric field energy density at any point in space must be equal to the magnetic field energy density.

To verify the correctness of Maxwell's "electromagnetic wave" theory, the simplest and most convincing way is to independently measure the electric field intensity and magnetic field intensity contained in electromagnetic radiation in wireless communication, and verify whether the electric field energy density and magnetic field energy density at any point in space are equal.

New research indicates that in both the near-field and far-field, the electromagnetic fields originate from the conduction current of the antenna. This verification experiment is based on the 3-meter method of the EMC (Electromagnetic Compatibility) standard. A reverse attenuation configuration of two half - wave dipole antennas is adopted to make the magnetic fields generated by the conduction currents of the two antennas cancel each other out, and the electric field intensity and magnetic induction intensity contained in the far - field of electromagnetic radiation are independently detected. The verification experiment shows that the electric field energy density is 137.6 times that of the magnetic field energy density, and the result of the verification experiment is 137.6 times the theoretical value of the "electromagnetic wave". In this verification experiment, the relative error of the electric field intensity measurement is +/- 5%, and that of the magnetic field intensity measurement is +/- 40%. Even under the maximum error condition, the electric field energy density is 63.4 times that of the magnetic field energy density, and the experimental result is 63.4 times the theoretical value.

This verification experiment demonstrates that: regardless of whether it is the near field or the far-field, the electromagnetic fields originate from the conduction current of the antenna. In a vacuum, without the participation of charges, a changing electric field cannot generate a changing magnetic field, and a changing magnetic field cannot generate a changing electric field. There is no "electromagnetic wave" in the objective physical world.