ISSN: 2993-8643

Research Article

Engineering: Open Access

The Radiation of Infinite Current Sheets Considering a Half Retarded and Half Advanced Field Rather than Potential

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Submitted: 2024, Jul 27; **Accepted:** 2024, Aug 30; **Published:** 2024, Sept 02

Citation: Zhao, S. (2024). The Radiation of Infinite Current Sheets Considering a Half Retarded and Half Advanced Field Rather than Potential. *Eng OA, 2*(3), 01-15.

Abstract

Consider that any current will generate half retarded waves and half advanced waves. The retarded wave is responsible for radiation, while the advanced wave is responsible for absorption. The radiation and absorption of the current sheet were calculated. The radiation and absorption of electromagnetic waves by the double plate current sheets were calculated. The energy flow between them was calculated. The author found that this energy flow is a mutual energy flow rather than a self energy flow. Revised the magnetic field of Maxwell's classical electromagnetic theory. Further clarified the definition and measurement of magnetic fields. After correction, a theory of retarded field is obtained, instead of retarded potential theory like Maxwell's classical electromagnetic theory. The calculation results indicate that the mutual energy flow is generated at the source and annihilated at the sink. Therefore, the mutual energy flow is determined by the properties of particles. The author believes that mutual energy flow is the photon. This theory supports Cramer's quantum mechanical transactional interpretation and is a concrete implementation of the transactional interpretation.

Keyword: Maxwell's Equation, Electromagnetic Wave, Poynting's Theorem, Retarded Wave, Advanced Wave, Retarded Potential, Advanced Potential, Electric Field, Magnetic Field, Electromagnetic Field, Transformer, Receiving Antenna, Receive Power, Retarded Field

1. Introduction

1.1 Half Retarded and Half Advanced Electromagnetic Waves

Wheeler Feynman proposed the concept of half retarded and half advanced in 1945 [1,2]. In 1980, Stephenson conducted research on advanced waves [3]. Cramer extended this concept to the transactional interpretation of quantum mechanics in 1986 [4,5]. On the other hand, in the field of electromagnetic field research, Welch proposed the time-domain reciprocity theorem in 1960, and Rumsey proposed a new reciprocity theorem in 1963 [6,3]. The author proposed the mutual energy theorem in 1987 [7-9]. De Hoop proposed the reciprocity theorem for cross correlation at the end of 1987 [10]. These reciprocity theorems and mutual energy theorems also involve advanced waves, but reciprocity theorems are mathematical theorems. If advanced waves occur, they can be considered virtual. The mutual energy theorem as an energy theorem, it is believed that the advanced waves that appear are of course real quantities in physics.

In 2017, the author proposed the mutual energy flow theorem based on the mutual energy theorem, which was developed into the law of conservation of energy. He believed that the mutual energy flow was a photon and used it to interpret quantum mechanics [11]. Afterwards, the author gradually applied this theory to specific examples, such as calculating the energy flow from the primary coil to secondary coil of a transformer. The energy flow from the transmitting antenna to the receiving antenna. The author also discusses the energy flow between current sheets [12-14, 15-19]. During this process, the author added a correction factor ($-j$) to the far-field retarded magnetic field calculated of Maxwell's electromagnetic theory [20-24].

1.2 Feynman's Calculation of the Electromagnetic Field of Infinite Current Sheet

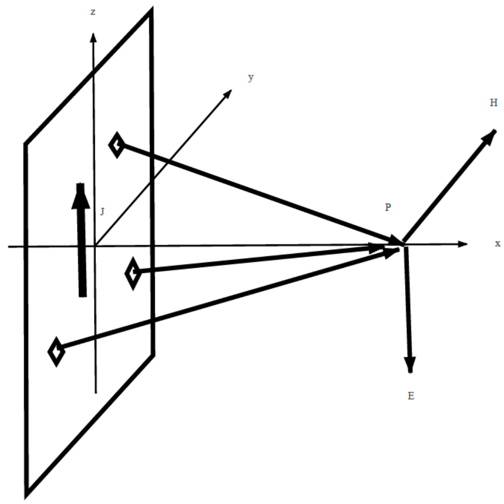

Figure 1: The Electromagnetic Field Generated by a Plane Current Sheet. Assuming That This Field is Generated by Three Small Current Elements Along the Way, the Electric and Magnetic Fields Near Each Small Current Element Should Maintain A 90 Degree Phase Difference, and Their Combined Electric and Magnetic Fields At Point *P* Should also Maintain a 90 Degree Phase Difference

Feynman specifically talked about the radiation of an infinite plane current sheet in his physics lecture [6], and Feynman considered that the electromagnetic field generated by the plane current sheet is a plane electromagnetic wave. Refer to Figure 1. Consider the current as

$$\boldsymbol{J} = J\hat{z} \tag{1}$$

Consider the starting value of the magnetic field being in phase with the current. Therefore, on the right side of the current, the magnetic field is

$$\boldsymbol{H} = \frac{J}{2}\hat{y}\exp(-jkx) \tag{2}$$

Because according to Maxwell's electromagnetic theory, the electric and magnetic fields of plane electromagnetic waves are in phase. Therefore, the electric field also has the same phase as the current at its inception. The electric field is,

$$\boldsymbol{E} = \frac{J}{2}\eta_0\exp(-jkx)(-\hat{z})$$

Among them, $\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}$ is the vacuum impedance. We know that for a very small current element $I\hat{z}\Delta l$, the surface electric and magnetic fields are

$$\boldsymbol{E} = -j\omega\boldsymbol{A} \sim -j\boldsymbol{A} \sim -jI\hat{z} \tag{3}$$

$$\boldsymbol{H} \sim I\hat{y} \tag{4}$$

$\sim$ means in proportion to, it does only care the phase and the direction of the vector. The electric and magnetic fields of small current elements maintain a 90 degree phase difference near the current elements. Our intuition tells us that if these current elements form an infinite current sheet, the electric field and magnetic field must consider the contribution of infinitely many small current elements in Figure 1. If the Huygens principle is used for both electric and magnetic fields, this electric field and magnetic field cannot become the same phase! Furthermore, Feynman did not calculate the electric field according to the true retarded potential method. This article will use the retarded potential method to calculate the electric field. The electric field calculated in this way will make people believe it.

1.3 The Author's Electromagnetic Field Theory

The author believes that Maxwell's electromagnetic theory is completely equivalent to the retarded potential theory proposed by Lorenz in 1867. Therefore,

$$\boldsymbol{E} = -\frac{\partial}{\partial t}\boldsymbol{A}^{(r)} - \nabla\Phi^{(r)}, \quad \boldsymbol{B} = \nabla \times \boldsymbol{A}^{(r)} \tag{5}$$

$$\boldsymbol{A}^{(r)} = \frac{\mu_0}{4\pi}\int_V \frac{\boldsymbol{J}(\boldsymbol{x}\prime, t - r/c)}{r} dV \tag{6}$$

$$\Phi^{(r)} = \frac{1}{4\pi\epsilon_0}\int_V \frac{\rho(\boldsymbol{x}\prime, t - r/c)}{r} dV \tag{7}$$

Supperscript (r) means retarded. c is speed of light. $\boldsymbol{E},\boldsymbol{H}$ are electric field and magnetic field. $\boldsymbol{J}$ is the current. ρ is the charge intensity. V is the region of current and charge.

However, the author believes that the theory of retarded potential is not entirely correct. The author supports the theory of retarded fields. That is to say, it should not be the retardation of vector potential and scalar potential, but rather the retardation of electric and magnetic fields. The retardation of electric and magnetic fields is based on the following principles:,

1.There is an advanced wave. Although advanced waves violate causality, the author believes that they are indeed objective physical phenomena. The source emits a retarded wave, while the sink emits a advanced wave. The source of radiation can be a primary source of light, a transmitting antenna, or a primary coil of the transformer. A sink can be a light sink, a receiving antenna or the secondary of the transformer.

2.Any current can simultaneously emit half retarded wave and half advanced wave. Near the current, the electric and magnetic fields of the retarded wave and the advanced wave generated by the current should be superimposed, and no one should cancel each other out.

3. Radiation does not overflow the universe.

$$\int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} \boldsymbol{E} \times \boldsymbol{H} \cdot \hat{n} d\Gamma = 0 \tag{8}$$

This means that self energy flow does not overflow the universe

$$\int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} \boldsymbol{E}_i \times \boldsymbol{H}_i \cdot \hat{n} d\Gamma = 0 \tag{9}$$

Or infrequncy domain,

$$\oiint_{\Gamma} \boldsymbol{E}_i \times \boldsymbol{H}_i^* \cdot \hat{n} d\Gamma = 0 \tag{10}$$

This law requires electromagnetic waves to be of reactive power. This law requires the radiated electric and magnetic fields to maintain a phase difference of 90 degrees. Moreover, the mutual energy flow does not overflow the universe,

$$\int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} (\boldsymbol{E}_i \times \boldsymbol{H}_j + \boldsymbol{E}_j \times \boldsymbol{H}_i) \cdot \hat{n} d\Gamma = 0 \tag{11}$$

Where Γ is a sphere with an infinite radius.

4. Satisfying the law of conservation of energy flow

$$\sum_{j=1}^{N} \sum_{j=1, j\neq i}^{N} \int_{t=-\infty}^{\infty} dt \int_V \boldsymbol{E}_i \cdot \boldsymbol{J}_j = 0 \tag{12}$$

According to the quasi-static conditions, the above formula is the law of conservation of energy. According to Maxwell's equation, the formula above is no longer the law of conservation of energy, but can only take a step back to become the energy theorem. The author called it the mutual energy theorem. The author believes that the above equation is a law of conservation of energy. The above equation cannot be derived from the Maxwell equation as the law of conservation of energy, which is the loophole in the Maxwell equation. The author's requirement that radiation does not overflow the universe is actually to ensure that the law of energy conservation holds even in the case of radiated electromagnetic fields.

5.The law of conservation of energy flow[11],

$$-\int_{t=-\infty}^{\infty} dt \int_{V_j} \boldsymbol{E}_i \cdot \boldsymbol{J}_j = (\xi_i, \xi_j) = \int_{t=-\infty}^{\infty} dt \int_{V_i} \boldsymbol{E}_j \cdot \boldsymbol{J}_i dV \tag{13}$$

Among them,

$$(\xi_i, \xi_j) = \int_{t=-\infty}^{\infty} dt \oiint_\Gamma (\boldsymbol{E}_i \times \boldsymbol{H}_j + \boldsymbol{E}_j \times \boldsymbol{H}_i) \cdot \hat{n} d\Gamma$$

Γ is any closed surface or infinite open surface that separates two current elements $\boldsymbol{J}_i$ and $\boldsymbol{J}_j$.

The retarded field theory proposed by the author requires the above conditions to be applied. We first study the electromagnetic waves of infinite current sheets, using the method proposed by the author as an example.

1.4 The Contents of this Article

This article further discusses the energy flow between two flat plates. In the discussion of this article, the author specifically considered the concepts of half retarded and half advanced. After adding this concept, the annoying factor of 1/2 that appeared in the original author's theory automatically disappeared. The theory is more self consistent. In addition, the author emphasizes that any current generates half retarded and half advanced waves. Therefore, retarded waves and advanced waves should be superimposed on each other near the surface of the current, rather than offset. This condition can also be seen as a new boundary condition in electromagnetic field theory. The author's correction of the magnetic field precisely supports this viewpoint.

This article further explains the definition and measurement of magnetic fields. A practical and feasible solution has been proposed, which is different from the definition of magnetic field in Maxwell's electromagnetic theory using the curl of vector potential.

Plane electromagnetic waves can be generated by infinite plane currents. Calculating the electromagnetic field generated by an infinite current sheet is the simplest example in electromagnetic theory. This example can test whether there are inconsistencies in classical electromagnetic theory.

2. Review of the Electromagnetic Field Theory Revised by the Author

2.1 Retarded Potential vs Retarded Field

This article adopts the viewpoint proposed by Wheeler Feynman that half retarded and half advanced the wave. Therefore, in the frequency domain,

$$\boldsymbol{A}^{(r)} = \frac{\mu_0}{4\pi} \int_V \frac{\boldsymbol{J}}{r} \exp(-jkr) dV \tag{14}$$

$$\boldsymbol{A}^{(a)} = \frac{\mu_0}{4\pi} \int_V \frac{\boldsymbol{J}}{r} \exp(-jkr) dV \tag{15}$$

For retarded potential and advanced potential. Where $J = J_0 \exp(\omega t)$.

$$\boldsymbol{E} = -\frac{1}{2}\left(\frac{\partial}{\partial t}\boldsymbol{A}^{(r)} + \frac{\partial}{\partial t}\boldsymbol{A}^{(a)}\right) = -\frac{1}{2} j\omega(\boldsymbol{A}^{(r)} + \boldsymbol{A}^{(a)}) \tag{16}$$

For current sheets, due to symmetry, the effect of scalar potential ϕ is 0 and hence can be ignored. $\boldsymbol{E}$ is the induced electric field. For magnetic fields, consider

$$\frac{1}{\mu_0} \nabla \times \boldsymbol{A}^{(r)} = \frac{1}{4\pi} \int_V \nabla \frac{1}{r} \exp(-jkr) \times \boldsymbol{J} dV$$

$$= \frac{1}{4\pi} \int_V \boldsymbol{J} \times \left(\frac{\boldsymbol{r}}{r^3} + jk\frac{\boldsymbol{r}}{r}\right) \exp(-jkr) dV \tag{17}$$

Considering,

$$\lim_{kr \to 0} \frac{1}{\mu_0} \nabla \times \boldsymbol{A}^{(r)} = \frac{1}{4\pi} \int_V \boldsymbol{J} \times \left(\frac{\boldsymbol{r}}{r^3}\right) dV + jk \frac{1}{4\pi} \int_V \boldsymbol{J} \times \left(\frac{\boldsymbol{r}}{r}\right) dV$$

$$= \boldsymbol{H} + jk \frac{1}{4\pi} \int_V \boldsymbol{J} \times \left(\frac{\boldsymbol{r}}{r}\right) dV \tag{18}$$

$kr \to 0$ means $\frac{2\pi}{\lambda} r \to 0$, or $r \ll \lambda$. This indicates that the range we are considering is much smaller than the wavelength. Consider $k = \omega\sqrt{\mu_0 \epsilon_0}$, if the frequency is relatively low, the second term in the above equation can be ignored. At this point,

$$\lim_{kr\to 0}\frac{1}{\mu_0}\nabla\times\boldsymbol{A}^{(r)}=\boldsymbol{H} \tag{19}$$

The $\boldsymbol{H}$ in the above equation is a static magnetic field, which is generated by a constant current $\boldsymbol{J}$. If the frequency is not very low, the second term cannot be ignored, as this term represents the far-field radiation. However, the author believes that the imaginary number j appearing in the equation (18) is very suspicious, as it gives the far-field of the magnetic field a phase factor j in the indication of the current. The author believes that if we follow the principle of magnetic field retardation instead of vector potential retardation, the far field of the magnetic field should not have this phase factor. So the definition of magnetic field has been modified,

$$\boldsymbol{h}_n^{(r)}=\frac{1}{4\pi}\int_V \boldsymbol{J}\times(\frac{\boldsymbol{r}}{r^3})\exp(-jkr)dV \tag{20}$$

$$\boldsymbol{h}_f^{(r)}=jk\frac{\mu_0}{4\pi}\int_V \boldsymbol{J}\times\frac{\boldsymbol{r}}{r}\exp(-jkr)dV \tag{21}$$

$$\boldsymbol{H}=\frac{1}{2}(\boldsymbol{h}_n^{(r)}+(-j)\boldsymbol{h}_f^{(r)})+(\boldsymbol{h}_n^{(a)}+(j)\boldsymbol{h}_f^{(a)}) \tag{22}$$

In the above equation, $\boldsymbol{h}_n^{(r)}$ is the near field of the magnetic field calculated according to the retarded potential theory, $\boldsymbol{h}_f^{(r)}$ is the far-field calculated by the retarded potential theory. The superscript (a) represents advanced, while the superscript (r) represents retarded. $\boldsymbol{h}_n^{(a)}$ is the near field obtained from the advanced potential calculation, $\boldsymbol{h}_f^{(a)}$ calculate the far field based on the advanced potential. $\boldsymbol{H}$ is a redefined magnetic field by the author. This magnetic field is obtained based on the retardation or advance of the magnetic field, rather than the retardation or advance of the potential.

Note that after modification, the electric and magnetic fields in the far field are no longer in phase, but maintain a 90 degree phase difference. This makes the Poynting vector,

$$\boldsymbol{S}^{(r)}=\boldsymbol{E}^{(r)}\times(\boldsymbol{B}^{(r)})^*\sim j \tag{23}$$

$$\boldsymbol{S}^{(a)}=\boldsymbol{E}^{(a)}\times(\boldsymbol{B}^{(a)})^*\sim j \tag{24}$$

Is a pure imaginary number. This indicates that both the retarded wave and the advanced wave are waves of reactive power, and the time average of these waves does not transfer energy.

Due to the fact that the retarded and advanced waves are reactive power, the author believes that energy transmission does not rely on the retarded and advanced waves themselves, but rather on the mutual energy flow composed of retarded and advanced waves.

It is worth noting that due to retarded waves and advanced waves being reactive power, these waves can be ineffective. If the retarded wave emitted by a current cannot be synchronized with the advanced wave emitted by another current (in Cramer's parlance, it is a handshake between two waves), this retarded wave is invalid [4,5]. Therefore, when we consider a pair of antennas with a transmitting antenna and a receiving antenna, the advanced wave of the transmitting antenna is ineffective, and only the retarded wave is effective. We often do not need to discuss the reflection caused by the retarded wave of the receiving antenna. Therefore, the receiving antenna only works with advanced waves. Therefore, there are often,

$$\boldsymbol{E}=-\frac{1}{2}j\omega\boldsymbol{A}^{(r)}\quad or\quad \boldsymbol{E}=-\frac{1}{2}j\omega\boldsymbol{A}^{(a)} \tag{25}$$

$$\boldsymbol{H}=\frac{1}{2}(\boldsymbol{h}_n^{(r)}+(-j)\boldsymbol{h}_f^{(r)})\quad or\quad \boldsymbol{H}=\frac{1}{2}(\boldsymbol{h}_n^{(a)}+(j)\boldsymbol{h}_f^{(a)}) \tag{26}$$

2.2 Mutual Energy Flow and Law of Conservation of Energy

Although the author has already defined the wave with half retarded and half advanced generated by the current, due to historical reasons, the author did not initially consider the factor 1/2 in (16,22). In this case, the author obtains the law of conservation of energy as [11]

$$\sum_{i=1}^{N}\sum_{j=1,j=i}^{N}\int_V(\boldsymbol{E}_i\cdot\boldsymbol{J}_j^*)dV=0 \tag{27}$$

The law of mutual energy flow,

$$-\int_V (\boldsymbol{E}_i \cdot \boldsymbol{J}_j^*)dV = (\xi_i, \xi_j) = \int_V (\boldsymbol{E}_j^* \cdot \boldsymbol{J}_i)dV \tag{28}$$

The mutual energy flow is defined as,

$$(\xi_i, \xi_j) \equiv \oiint_\Gamma (\boldsymbol{E}_i \times \boldsymbol{H}_j^* + \boldsymbol{E}_j^* \times \boldsymbol{H}_i) \cdot \hat{n} d\Gamma \tag{29}$$

We know that the solution obtained by Maxwell's equation is equivalent to the solution obtained by the Lorenz retarded potential method [25]. According to this method of retarded potential, the law of conservation of energy (27) above does not hold and can only be used as an energy theorem.

This energy flow law (29) cannot be established within the theoretical framework of retarded potential (Maxwell's electromagnetic field theory). But they can hold true under the electric and magnetic field conditions defined by the author earlier (25,26).

Note that the author has found some issues with the above formula through practical examples. The correct formula should be,

$$-\int_V (\boldsymbol{E}_i \cdot \boldsymbol{J}_j^*)dV = \frac{1}{2}(\xi_i, \xi_j) = \int_V (\boldsymbol{E}_j^* \cdot \boldsymbol{J}_i)dV \tag{30}$$

Note that the calculated value of the mutual energy flow is twice as large. The above formula (28) has not yet considered the factors of half retardation and half advance. If we consider half retardation and half advance, we need to substitute the above equation (28) as follows,

$$\boldsymbol{E}, \boldsymbol{H} \leftarrow \frac{1}{2}\boldsymbol{E}, \frac{1}{2}\boldsymbol{H} \tag{31}$$

After doing so, the formula (28) is,

$$-\int_V (\frac{1}{2}\boldsymbol{E}_i \cdot \boldsymbol{J}_j^*)dV = (\frac{1}{2}\xi_i, \frac{1}{2}\xi_j) = \int_V (\frac{1}{2}\boldsymbol{E}_j^* \cdot \boldsymbol{J}_i)dV \tag{32}$$

In the above equation, $\boldsymbol{E}_i$ The electric field with half retarded and half advanced is not considered. This is just Eq.(30). If we record the electric field with half retardation and half advance as,

$$\boldsymbol{E}_i{}' = \frac{\boldsymbol{E}_i}{2}, \quad \boldsymbol{H}' = \frac{\boldsymbol{H}}{2} \tag{33}$$

Or,

$$-\int_V (\boldsymbol{E}'_i \cdot \boldsymbol{J}_j^*)dV = (\xi'_i, \xi'_j) = \int_V ((\boldsymbol{E}'_j)^* \cdot \boldsymbol{J}_i)dV \tag{34}$$

From this, it can be seen that if we consider half retardation and half advance, the problem with the formula (28,29), i.e. the fact of 1/2 can be solved. This is also why we need to consider half retarded and half advanced waves.

2.3 New Definition and Measurement of Magnetic Field of Electromagnetic Waves

The author discussed the definition of a magnetic field in the reference [19]. It is rephrased here, hoping to express the author's thoughts more clearly. Assuming a uniform AC magnetic field,

$$\boldsymbol{H} = H_0 \exp(j\omega t)\hat{y} \tag{35}$$

We need to measure this magnetic field, and the traditional method is to make a small coil, *C*, with the normal of coil *C* pointing towards $\hat{y}$. The induced electromotive force of the coil is

$$\mathcal{E} = \oint_C \boldsymbol{E} \cdot d\boldsymbol{l} = -\frac{\partial}{\partial t}\iint_\sigma \boldsymbol{B} \cdot \hat{y} d\sigma \tag{36}$$

$$= -j\omega\mu_0 H_y \sigma$$

Where $\sigma = \iint_\sigma d\sigma = L^2$ is the area, assume the coil is square, and the circumference is 4L. So,

$$H_y = \frac{\mathcal{E}}{-j\omega\mu_0\sigma} = \frac{4LE}{-j\omega\mu_0 L^2} = \frac{4E}{-j\omega\mu_0 L} = \frac{4E\sqrt{\mu_0\epsilon_0}}{-j\omega\sqrt{\mu_0\epsilon_0}\mu_0 L}$$

$$= \frac{4E}{-jkL}\sqrt{\frac{\epsilon_0}{\mu_0}} = \frac{4}{-jkL}\frac{E}{\eta_0} \quad (37)$$

Where E is the measured induced electromotive potential, $\boldsymbol{H}_y$ It is a magnetic field, so if we already know the induced electromotive potential, we can use this method to measure the size of the magnetic field, i.e

$$H_y = \frac{4}{-jkL}\frac{E}{\eta_0} \quad (38)$$

E only needs to be measured on one side of the square, without the need for a whole coil. Now if we have an electromagnetic wave,

$$\boldsymbol{E} = E_0 \exp(-jkx)(-\hat{z}) \quad (39)$$

$$E = \boldsymbol{E}(x) \cdot \hat{z} = -E_0 \exp(-jkx) \quad (40)$$

The magnetic field of the newly defined electromagnetic wave is,

$$H_y = \frac{4E}{-jkL\eta_0} = j\frac{4}{kL}\frac{E}{\eta_0} = j\frac{E}{\eta_0} \quad (41)$$

In the above we have chosen,

$$\frac{4}{kL} = 1$$

that means,

$$L = \frac{4}{k} = \frac{4}{2\pi}\lambda = \frac{2}{\pi}\lambda \quad (42)$$

for electric field measurement needle. For example, if the electric field of an electromagnetic wave is,

$$\boldsymbol{E} = j\frac{J_0}{2}\eta_0 \exp(-jkx)(-\hat{z}) \quad (43)$$

hence,

$$E(x) = -j\frac{J_0}{2}\eta_0 \exp(-jkx) \quad (44)$$

$$H_y = j\frac{E}{\eta_0} = j\frac{1}{\eta_0}\left(-j\frac{J_0}{2}\eta_0 \exp(-jkx)\right) = \frac{J_0}{2}\exp(-jkx) \quad (45)$$

So the above equation is our newly defined magnetic field, which should also be used as the definition for calculating the magnetic field. In this way, the magnetic field of the electromagnetic wave is not in phase with the electric field, but has a phase difference of 90 degrees.

3 Electromagnetic Waves of Infinite Current Sheets

The author first calculates the electromagnetic and magnetic fields according to Maxwell's electromagnetic theory, which is the theory of retarded potential, and then makes appropriate corrections to the magnetic field. Note that although the author has pointed out that the electric and magnetic fields should be calculated based on half retardation and half advance. This calculation should have a factor of 1/2. However, in the following calculations, the author still ignores the factor of 1/2. This calculation can enable readers to clearly see where the calculation will go wrong and understand why we need this factor of 1/2.

3.1 Calculating Electromagnetic Fields Based on Maxwell's Retarded Potential Theory

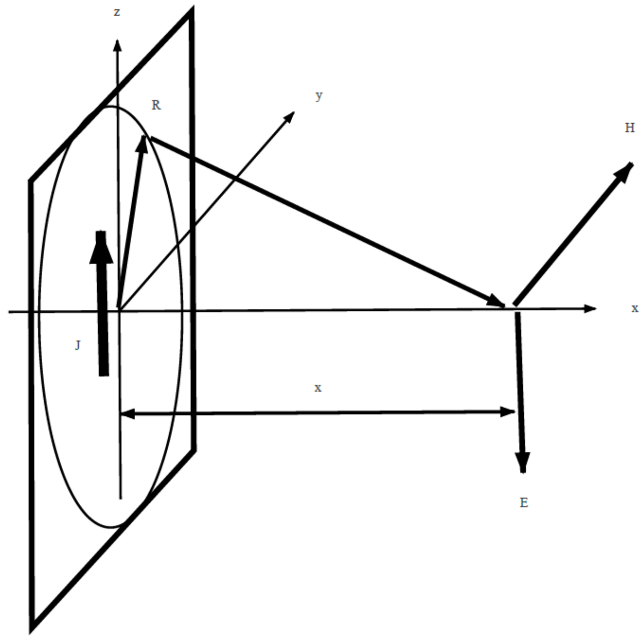

Figure 2: Assuming that the Flat Plate is a Circular Disc with a Radius of *R*, there is a Uniform Current Density on this Circular Disc Pointing Towards the z-axis. find the Vector Potential Function it Generates

Consider the normal of the current sheet in the $\hat{x}$ direction. The current is $\boldsymbol{J}_1$ in the $\hat{z}$ -axis direction, as shown in Figure 2. The vector potential of retardation can be written as,

$$\boldsymbol{A}^{(r)} = \frac{\mu_0}{4\pi}\int_0^{2\pi}\int_0^R \frac{J_1\hat{z}}{\sqrt{x^2+\rho^2}}\exp(-jk\sqrt{x^2+\rho^2})\rho d\rho d\theta$$

$$= \frac{\mu_0}{4\pi}2\pi\int_0^R \frac{J_1\hat{z}}{\sqrt{x^2+\rho^2}}\exp(-jk\sqrt{x^2+\rho^2})\rho d\rho$$

$$= \frac{\mu_0}{2}\int_0^R \frac{J_1\hat{z}}{\sqrt{x^2+\rho^2}}\exp(-jk\sqrt{x^2+\rho^2})\frac{1}{2}d\rho^2$$

$$= \frac{\mu_0}{2}\int_0^R J_1\hat{z}\exp(-jk\sqrt{x^2+\rho^2})d\sqrt{x^2+\rho^2}$$

$$= \frac{1}{-jk}\frac{\mu_0}{2}J_1\hat{z}\int_0^R d\exp(-jk\sqrt{x^2+\rho^2})$$

$$= \frac{1}{-jk}\frac{\mu_0}{2}J_1\hat{z}(\exp(-jk\sqrt{x^2+R^2}) - \exp(-jkx)) \quad (46)$$

The induced electric field of a circular plane with a radius of *R* is,

$$\boldsymbol{E}_1^{(r)}(R) = -j\omega\boldsymbol{A}^{(r)} = \frac{\omega}{k}\frac{\mu_0}{2}J_1\hat{z}(\exp(-jk\sqrt{x^2+R^2}) - \exp(-jkx))$$

$$= \frac{J\eta_0}{2}\hat{z}(\exp(-jk\sqrt{x^2+R^2}) - \exp(-jkx)) \quad (47)$$

The first term in the above equation diverges at $R \to \infty$, but its average value is 0 and hence, can be ignored.

$$\boldsymbol{E}_1^{(r)} = \lim_{R\to\infty} \boldsymbol{E}_1^{(r)}(R) = \frac{J_1\eta_0}{2}\exp(-jkx)(-\hat{z}) \tag{48}$$

Calculating the magnetic field of a circular plane using the classical Maxwell retarded potential method,

$$\boldsymbol{h}_1^{(r)}(R) = \frac{1}{\mu_0}\nabla \times \boldsymbol{A}^{(r)}(\rho = R)$$

$$= \frac{1}{\mu_0}\nabla \times \frac{1}{-jk}\frac{\mu_0}{2}J_1\hat{z}(\exp(-jk\sqrt{x^2+R^2}) - \exp(-jkx))$$

$$= \frac{1}{\mu_0}\frac{1}{-jk}\frac{\mu_0}{2}(\exp(-jk\sqrt{x^2+R^2})\frac{-jkx}{\sqrt{x^2+R^2)}}\hat{x}$$

$$-(-jk)\exp(-jkx)\hat{x}) \times J_1\hat{z}$$

$$= \frac{1}{2}(\exp(-jk\sqrt{x^2+R^2})\frac{x}{\sqrt{x^2+R^2)}} - \exp(-jkx))J_1(-\hat{y}) \tag{49}$$

Considering $R \to \infty$ to obtain the magnetic field of an infinite plane,

$$\boldsymbol{h}_1^{(r)} = \lim_{R\to\infty} \boldsymbol{h}_1(R) = \frac{J_1}{2}\exp(-jkx)\hat{y} \tag{50}$$

Of course, we can also use this magnetic field to calculate the electric field, according to Ampere's circuital law,

$$\nabla \times \boldsymbol{h}_1^{(r)} = \frac{\partial}{\partial t}\epsilon_0\boldsymbol{E}_1^{(r)} = j\omega\epsilon_0\boldsymbol{E}_1^{(r)} \tag{51}$$

$$\boldsymbol{E}_1^{(r)} = \frac{1}{j\omega\epsilon_0}\nabla \times \boldsymbol{h}_1^{(r)}$$

$$= \frac{1}{j\omega\epsilon_0}(-jk\hat{x}) \times \frac{J_1}{2}\exp(-jkx)\hat{y}$$

$$= \eta_0\frac{J_1}{2}\exp(-jkx)(-\hat{z}) \tag{52}$$

Calculating $\boldsymbol{E}_1^{(r)}$ in this way can avoid the divergence problem of the previous electric field. Compare to (47,48).

3.2 Correction of the Magnetic Field According Auther's Theory

The magnetic field has been revised according to the author's new definition as,

$$\boldsymbol{H}_1^{(r)} = -j\boldsymbol{h}_1 = -j\frac{J_1}{2}\exp(-jkx)\hat{y} \tag{53}$$

The electric field Eq.(48) can be written as,

$$\boldsymbol{E}_1^{(r)} = -jj\frac{J_1\eta_0}{2}\exp(-jkx)(-\hat{z})$$

$$= \exp(-j\frac{\pi}{2})j\frac{J\eta_0}{2}\exp(-jkx)(-\hat{z})$$

$$= j\frac{J_1\eta_0}{2}\exp(-j(kx+\frac{\pi}{2}))(-\hat{z}) \tag{54}$$

$$\boldsymbol{H}_1^{(r)} = -j\boldsymbol{h}_1^{(r)} = -j\frac{J_1}{2}\exp(-jkx)\hat{y}$$

$$= \exp(-j\frac{\pi}{2})\frac{J_1}{2}\exp(-jkx)\hat{y}$$

$$= \frac{J_1}{2}\exp(-j(kx+\frac{\pi}{2}))\hat{y} \tag{55}$$

Similarly, we can calculate the electric field and magnetic field of the advanced wave, but the specific calculation here is omitted because it is basically consistent with the retarded electric field and magnetic field method. Hence,

$$\boldsymbol{E}_1^{(a)} = \lim_{R\to\infty}\boldsymbol{E}_1(R) = -\frac{J_1\eta_0}{2}(\exp(+jkx))(-\hat{z})$$

$$= jj\frac{J_1\eta_0}{2}(\exp(+jkx))(-\hat{z})$$

$$= j\frac{J_1\eta_0}{2}(\exp(+j(kx+\frac{\pi}{2}))(-\hat{z}) \tag{56}$$

The magnetic field according the curl of advanced potential is,

$$\boldsymbol{h}_1^{(a)} = \frac{J_1}{2}\exp(+jkx)\hat{y} \tag{57}$$

Correct the magnetic field and note that the correction factor is j for the advanced wave,

$$\boldsymbol{H}_1^{(a)} = j\boldsymbol{h}_1^{(a)} = \frac{J_1}{2}\exp(+j(kx+\frac{\pi}{2}))\hat{y} \tag{58}$$

We have seen,

$$\boldsymbol{E}_1^{(r)}(x=-\frac{\lambda}{4}) = \boldsymbol{E}_1^{(a)}(x=-\frac{\lambda}{4}) = j\frac{J_1\eta_0}{2}(-\hat{z}) \tag{59}$$

$$\boldsymbol{H}_1^{(r)}(x=-\frac{\lambda}{4}) = \boldsymbol{H}_1^{(a)}(x=-\frac{\lambda}{4}) = \frac{J_1}{2}\hat{y} \tag{60}$$

This indicates that after adjusting the magnetic field according to the author's method, what we see above is that the retarded wave and the advanced wave are exactly the same at point $x=-\frac{\lambda}{4}$. This ensures that the electric and magnetic fields of the retarded wave and the advanced wave do not cancel each other out. Ensure that the current sheet can emit both retarded waves and advanced waves at the same time. This cannot be achieved without correcting the magnetic field.

3.3 On the Left Side of the Current Sheet

Consider the following transformation to (54,55),

$$z, x, y \to z, -x, -y \tag{61}$$

We obtain retarded electric and magnetic fields

$$\boldsymbol{E}_1^{(r)} = j\frac{\eta_0 J_1}{2}\exp(j(kx-\frac{\pi}{2}))(-\hat{z}) \tag{62}$$

$$\boldsymbol{H}_1^{(r)} = \frac{J_1}{2}\exp(j(kx-\frac{\pi}{2}))(-\hat{y}) \tag{63}$$

Advanced electromagnetic field, apply the transformation (61) to (56,58), there is,

$$\boldsymbol{E}_1^{(a)} = j\frac{J_1\eta_0}{2}(\exp(-j(kx-\frac{\pi}{2}))(-\hat{z}) \tag{64}$$

$$\boldsymbol{H}_1^{(a)} = j\boldsymbol{h}_1^{(a)} = \frac{J_1}{2}\exp(-j(kx-\frac{\pi}{2}))(-\hat{y}) \tag{65}$$

3.4 Right and Left Traveling Waves

We see that both retarded waves and advanced waves are reactive power, so they can be ineffective. Belong to invalid waves. Although the wave is established, due to an average energy flow of 0. Although such waves are emitted, they may not be effective. Therefore, it can be ignored. Below, the author will only consider one situation where the waves emitted by the current are in the $\hat{x}$ direction. Such a wave is a retarded wave on its right and an advanced wave on its left.

$$\boldsymbol{E}_1 = j\frac{J_1\eta_0}{2}(-\hat{z})\begin{cases}\exp(-j(kx+\frac{\pi}{2})) & x \geq 0\\ \exp(-j(kx-\frac{\pi}{2})) & x < 0\end{cases} \tag{66}$$

$$\boldsymbol{H}_1 = \frac{J_1}{2}\begin{cases}\exp(-j(kx+\frac{\pi}{2}))\hat{y} & x \geq 0\\ -\exp(-j(kx-\frac{\pi}{2}))\hat{y} & x < 0\end{cases} \tag{67}$$

For region $x > 0$, we can merge the phase factor exp $(-j\frac{\pi}{2})$ to the current J_1. Similarly, for $x < 0$, we can also assign the phase factor exp $(j\frac{\pi}{2})$ to J_1 In this way, the electromagnetic wave becomes,

$$\boldsymbol{E}_1 = j\frac{J_1\eta_0}{2}(-\hat{z})\begin{cases}\exp(-jkx) & x \geq 0\\ \exp(-jk) & x < 0\end{cases} \tag{68}$$

$$\boldsymbol{H}_1 = \frac{J_1}{2}\begin{cases}\exp(-jkx)\hat{y} & x \geq 0\\ -\exp(-jk)\hat{y} & x < 0\end{cases} \tag{69}$$

Consider $x > 0$,

$$\boldsymbol{S}_{11} = \boldsymbol{E}_1 \times \boldsymbol{H}_1^* = j\frac{J_1\eta_0}{2}(-\hat{z})(\frac{J_1}{2}\hat{y})^* = j\eta\frac{J_1J_1^*}{4}\hat{x} \tag{70}$$

$$\boldsymbol{S}_{11} = j\eta_0\frac{J_1J_1^*}{4}\hat{x}\begin{cases}1 & x \geq 0\\ -1 & x < 0\end{cases} \tag{71}$$

$$\boldsymbol{E}_1(x=0)\cdot J_1^*\hat{z} = j\frac{J_1\eta_0}{2}(-\hat{z})\cdot J_1^*\hat{z}$$

$$= -j\frac{J_1J_1^*\eta_0}{2} \tag{72}$$

We know that Poynting's theorem is

$$-\int_\sigma \boldsymbol{E}_1\cdot J_1^* d\sigma = \iint_\Gamma S_{11}\cdot\hat{n}d\Gamma \tag{73}$$

Equation (73) can be transformed into,

$$-\boldsymbol{E}_1\cdot J_1^* = S_{11}^{right}\cdot\hat{x} + S_{11}^{left}\cdot(-\hat{x}) \tag{74}$$

From (71,72), it can be seen that the above equation is satisfied (74), where the Poynting vector is a pure imaginary number, indicating that it does not transfer energy on average.

3.5 Double Infinite Current Sheets

In the author's electromagnetic theory, the energy flow between two current sheets is always calculated. One is the source and the other is the sink.

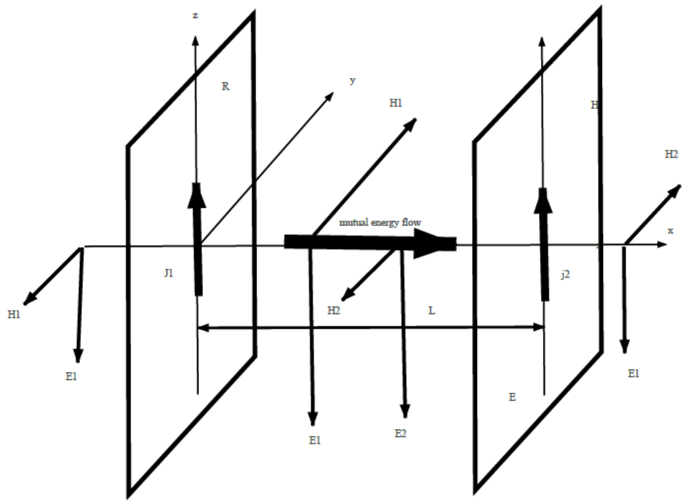

Figure 3: Double Current Sheets, with the Source Radiating Electromagnetic Waves on the Left and the Sink on the Right Responsible for Receiving Electromagnetic Waves. Both Plates Radiate Right-Handed Waves

In this section, the author considers the dual current sheets, one for the transmitting antenna and the other for the receiving antenna. Current $\boldsymbol{J}_1$ at $x = 0$, the current $\boldsymbol{J}_2$ at $x = L$. See Figure 3.

$$\boldsymbol{E}_2 = j\frac{J_2\eta_0}{2}(-\hat{z})\begin{cases}\exp(-jk(x-L)) & x \geq L \\ \exp(-jk(x-L)) & x < L\end{cases} \tag{75}$$

$$\boldsymbol{H}_2 = \frac{J_2}{2}\begin{cases}\exp(-jk(x-L))\hat{y} & x \geq L \\ -\exp(-jk(x-L))\hat{y} & x < L\end{cases} \tag{76}$$

Let's calculate the mutual energy flow between two planes at $0 < x < L$, where the electric and magnetic fields can be written as

$$\boldsymbol{E}_1 = j\frac{J_1\eta_0}{2}(-\hat{z})\exp(-jkx) \tag{77}$$

$$\boldsymbol{H}_1 = \frac{J_1}{2}\exp(-jkx)\hat{y} \tag{78}$$

$$\boldsymbol{E}_1(x = L) = j\frac{J_1\eta_0}{2}(-\hat{z})\exp(-jkL) \tag{79}$$

Consider the size of J_2 is similar to that of J_1. Consider that the phase of J_2 is determined by $\boldsymbol{E}_1$, there are,

$$J_2 = -jJ_1\exp(-jkL) \tag{80}$$

$$\boldsymbol{E}_2 = j\frac{J_2\eta_0}{2}(-\hat{z})\exp(-jk(x-L))$$

$$= j\frac{\eta_0}{2}(-jJ_1\exp(-jkL))(-\hat{z})\exp(-jk(x-L))$$

$$= -jj\frac{\eta_0}{2}J_1\exp(-jkx)(-\hat{z}) \tag{81}$$

$$\boldsymbol{H}_2 = -\frac{J_2}{2}\exp(-jk(x-L))\hat{y}$$

$$= -\frac{1}{2}(-jJ_1\exp(-jkL)\exp(-jk(x-L))\hat{y}$$

$$= j\frac{J_1}{2}\exp(-jkx)\hat{y} \tag{82}$$

3.6 Calculation of Mutual Energy Flow

Now let us calculate the mutual energy flow,

$$\boldsymbol{S}_m = \boldsymbol{E}_1 \times \boldsymbol{H}_2^* + \boldsymbol{E}_2^* \times \boldsymbol{H}_1 = \boldsymbol{S}_{12} + \boldsymbol{S}_{21}$$

$$= (j\frac{J_1\eta_0}{2}(-\hat{z})\exp(-jkx)) \times (j\frac{J_1}{2}\exp(-jkx)\hat{y})^*$$

$$+(-jj\frac{\eta_0}{2}J_1\exp(-jkx)(-\hat{z}))^* \times (\frac{J_1}{2}\exp(-jkx)\hat{y})$$

$$= (j\frac{J_1\eta_0}{2}\exp(-jkx))(j\frac{J_1}{2}\exp(-jkx))^*$$

$$+(-jj\frac{\eta_0}{2}J_1\exp(-jkx))^*(\frac{J_1}{2}\exp(-jkx)))\hat{x}$$

$$= \frac{J_1J_1^*}{4}\eta_0(jj^* + (-jj)^*)\hat{x} = \frac{J_1J_1^*}{2}\eta_0\hat{x} \tag{83}$$

In the region of $0 \le x \le L$, $\boldsymbol{S}_{12}$ and $\boldsymbol{S}_{21}$ are superimposed, considering the magnetic field $\boldsymbol{H}_2$ at $x > L$ change the sign, $\boldsymbol{H}_1$ at $x < 0$ change the sign, therefore there are $\boldsymbol{S}_{12}$ and $\boldsymbol{S}_{21}$ offset, therefore there is,

$$\boldsymbol{S}_m = \begin{cases} 0 & x < 0 \\ \frac{J_1J_1^*}{2}\eta_0\hat{x} & 0 \le x \le L \\ 0 & x > L \end{cases} \tag{84}$$

This indicates that $\boldsymbol{S}_m$ generated at current $\boldsymbol{J}_1$ and annihilate at current $\boldsymbol{J}_2$. $\boldsymbol{S}_m$ having the properties of photons. This is why the author speculates that the mutual energy flows are the photons. The theorem of mutual energy flow is,

$$-\int_\sigma \boldsymbol{E}_2 \cdot \boldsymbol{J}_1^* d\sigma = \iint_\Gamma S_m \cdot \hat{n} d\Gamma = \int_\sigma \boldsymbol{E}_1 \cdot \boldsymbol{J}_2^* d\sigma \tag{85}$$

or

$$-\boldsymbol{E}_2(x=0) \cdot \boldsymbol{J}_1^*(x=0) = S_m \cdot \hat{x} = \boldsymbol{E}_1(x=L) \cdot \boldsymbol{J}_2^*(x=L) \tag{86}$$

considering,

$$\boldsymbol{E}_2(x=0) = -jj\frac{\eta_0}{2}J_1(-\hat{z}) \tag{87}$$

$$\boldsymbol{E}_2(x=0) \cdot \boldsymbol{J}_1^*(x=0) = -\frac{\eta_0}{2}J_1J_1^* \tag{88}$$

$$S_m \cdot \hat{x} = \frac{J_1J_1^*}{2}\eta_0 \tag{89}$$

We see that the formula (86) satisfies. However, there is still a problem here, in fact, the current $\boldsymbol{J}_1$, there is still radiation on the left side. Therefore, the radiation on the right should be twice as small. That means there should be,

$$S_m \cdot \hat{x} = \frac{1}{2}\frac{J_1 J_1^*}{2}\eta_0$$

When we consider half retarded and half advanced wave, the factor of 1/2 will automatically disappear. Please refer to the section 2.2. This is also why the author considers half retarded and half advanced waves.

4 Conclusion

The author calculated the radiation electromagnetic field of an infinite current sheet and the energy flow between two infinite plate currents. In this calculation, the author made revisions to the definition of magnetic field in classical electromagnetic field theory. After correction, the phase between the electric and magnetic fields is 90 degrees instead of being in phase. According to the author's revised magnetic field, energy conservation mutual law, and mutual energy flow law, they are all implemented in the example of the current sheet. If the magnetic field is not corrected, the calculation of mutual energy flow will appear as pure imaginary numbers, becoming reactive power. The author believes that mutual energy flow transfers energy flow. According to the author's revised magnetic field, the mutual energy flow will become a real number, and the mutual energy flow becomes active power. After correction, the self energy is converted into reactive power. The entire theory becomes self consistent. This example further demonstrates that the author's correction of the magnetic field is correct. Due to the fact that the mutual energy flow can be generated on the first current sheet (source) and annihilated on the second current sheet (sink), the mutual energy flow has the properties of photon. It can be seen that the author's guess that the mutual energy flow is photon is correct. This example in this article provides strong support for Cramer's quantum mechanic transactional interpretation [26,27].

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