

Calculate the Energy Flow of Transformers, Antenna Systems, and Photons Through a New Interpretation of the Classical Electromagnetic Fields

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Abstract Poynting energy flow is considered to be the energy flow of electromagnetic waves, but the author found that such conclusions are not accurate enough. The author once proposed the mutual energy theorem. After careful study, the mutual energy theorem is actually the law of energy conservation, including all energy exchange. If the mutual energy represents all the energy, the self energy flow, that is, the energy flow corresponding to the Poynting vector, should not transfer energy to space. However, the calculation of the antenna radiates active power. In this way, the self energy flow also radiates energy, so the mutual energy flow + self energy flow is more than the total energy flow should be. When studying the transformer, the author notes that a current element can be calculated according to both inductance and antenna. If it is calculated according to the inductance, it produces reactive work, and if it is calculated according to the antenna, it produces active work, which is contradictory. It is found that the problem lies in the definition of magnetic field. At present, the definition of magnetic field in classical electromagnetic theory only takes into account the retarded effect of magnetic vector potential, but does not take into account the retarded effect of magnetic field itself. In other words, the current electromagnetic theory is the retarded potential theory, while Poynting's theorem and mutual energy flow theorem all need a retarded field theory. The authors propose a retarded magnetic field. This magnetic field and electric field maintain a phase difference of 90 degrees. Unlike the classical electromagnetic theory, the magnetic field and electric field in the distance of the antenna maintain the same phase. According to the definition of the new magnetic field and the electromagnetic mutual energy theory proposed by the author, the author finds that the two components of the mutual energy flow between the primary coil and the secondary coil of the transformer and the two components of the mutual energy flow between the transmitting antenna and the receiving antenna are very close to the description of the wave of particles in John Cramer's interpretation of quantum mechanics. Therefore, the author believes that electromagnetic mutual energy flow is photon, and other particles are also composed of mutual energy flow. The theory of electromagnetic mutual energy can be regarded as the concrete realization of the transactional interpretation of quantum mechanics.

Keywords: maxwell equation, reciprocity theorem, conservation of energy, poynting theorem, energy flow, transformer, primary coil, secondary coil, transmitting antenna, receiving antenna, retarded wave, retarded potential, advanced wave, advanced potential, absorber, radiator, emitter, photons, quantum, electromagnetic wave, electromagnetic field, transactional interpretation

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1. Introduction

1.1. Physical Theory Including Advanced Wave

As we all know, there are some flaw in today's electromagnetic field theory. It can not describe photons, and there is no solution to the collapse of waves and the duality of waves and particles. Wheeler Feynman put forward the absorber theory [1,2] in 1945. This theory

advocates that any current source radiates not only retarded waves, but also advanced waves. Wheeler Feynman's absorber theory is based on the principle of action at a distance [3,4,5]. Before 1980, Stephenson also put forward his own advanced wave theory [6]. Based on the absorber theory, Cramer put forward the transactional interpretation of quantum mechanics around 1980 [7,8], arguing that the handshake process between the retarded wave emitted by the light source and the advanced wave emitted by the light sink really determines the electromagnetic radiation. Cramer built a model in which the emitter sends a retarded wave to the absorber. The

absorber sends an advanced wave to the emitter. These two waves produce a handshake process, which is the synchronization process mentioned by the author. On the back of the absorber, the absorber sends a retarded wave. This retarded wave and the retarded wave sent by the emitter have a phase difference of exactly 180, so it is offset. On the back of the emitter, the emitter sends an advanced wave, which has a phase difference of 180 with the advanced wave of the absorber, so it is also offset, as shown in Fig. 0. In this way, the energy flow is established only between the emitter and the absorber.

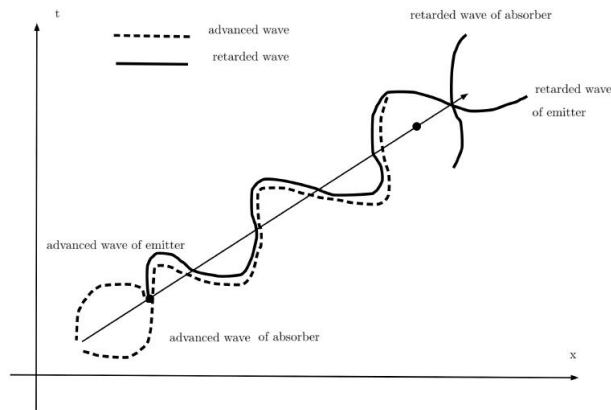


Figure 0: Cramer's quantum transactional interpretation model

1.2. Electromagnetic Theory Including Advanced Wave

Lorentz reciprocity theorem was proposed in about 1900. Later, this theory was further developed [9-11]. On the other hand, Welch proposed a time domain reciprocity theorem in 1960 [12]. In 1963, Rumsey proposed a new reciprocity theorem [13]. The author proposed the mutual energy theorem in 1987 and applied it to spherical and plane wave expansion [14-16]. At the end of 1987, de Hoop put forward the cross-correlation reciprocity theorem [17]. The author found that the form of mutual energy theorem is the same as that of Rumsey's reciprocity theorem. The author also found that Rumsey's new reciprocity theorem or mutual energy theorem can be obtained by Fourier transform of de Hoop cross-correlation reciprocity theorem. Welch's reciprocity theorem is a special example of de Hoop cross-correlation reciprocity theorem. Therefore, these three reciprocity theorems and the mutual energy theorem should belong to one theorem, which is both reciprocity theorem and mutual energy theorem. However, the Lorentz reciprocity theorem is indeed a reciprocity theorem rather than an energy theorem. In the mutual energy theorem, there are two fields, one is the retarded wave of the source and the other is the advanced wave of the sink.

1.3. Development of Mutual Energy Theory

About 2015, the author found that only the author believed that the theorem of mutual energy was the theorem of energy, and other authors (Welch, Rumsey, de Hoop) only mentioned that it was the reciprocity theorem. Therefore, the primary problem facing the author is

whether the mutual energy theorem is really an energy theorem. In fact, the author asked this question when he first (around 1985) proposed the mutual energy theorem. At that time, the author tried to prove the mutual energy theorem from the complex Poynting theorem, but failed. When the author entered this field for the second time, he already knew Welch reciprocity theorem, and knew that Welch reciprocity theorem and the mutual energy theorem proposed by the author could be connected by Fourier transform. Therefore, as long as we prove that Welch reciprocity theorem is actually an energy theorem. Starting from the Poynting theorem (not the complex Poynting theorem), the author easily proves the Welch reciprocity theorem. That proved the mutual energy theorem is a sub-theorem of the Poynting theorem. The Poynting theorem is an energy theorem and hence the mutual energy theorem too. Later, the author learned that complex Poynting's theorem is not the Fourier transform of Poynting's theorem, but a different Poynting's theorem. The mutual energy theorem cannot be proved from the complex Poynting theorem.

On the basis of the mutual energy theorem, the author puts forward the electromagnetic theory of mutual energy, including the principle of mutual energy, the law of energy conservation, the law that electromagnetic radiation does not overflow the universe, and the theorem of mutual energy flow. Constitute a complete electromagnetic field theory, referred to as mutual energy theory. The author applies the theory of mutual energy to quantum mechanics, puts forward the interpretation of mutual energy flow, holds that photons are mutual energy flow, and all particles are mutual energy flow, and tries to solve the problem of wave particle duality [18-21].

In order to complete the discussion of this paper, the author plans to make several preparations in advance. The first preparation is to study the energy conservation law of the primary coil and secondary coil of the transformer. It is considered that the transmitting antenna and receiving antenna should meet the same law of energy conservation as the transformer system, so it is concluded that the radiation of the receiving antenna is an advanced wave [22].

The second preparation is the theory of advanced waves. Because the wave inside the photon is more like a plane wave, that is, the wave in the waveguide. Therefore, the author comes out to discuss not only the advanced wave in vacuum, but also the retarded and advanced wave in waveguide [23].

The third preparatory work is to discuss the electromagnetic field inside a waveguide [24].

The fourth preparatory work is to discuss the bug of Poynting's theorem. The solution of classical electric field theory does not meet Poynting's theorem. The main work of this paper is to discuss the bugs of Poynting's theorem and establish it in order to make up for this bug. We redefine the magnetic field in order to establish Poynting's theorem. This bug is not easy to see. Otherwise, how could it be hidden for more than 100 years [25].

The fifth preparation is related to displacement current. Many people question the displacement current proposed by Maxwell in Maxwell's theory. The establishment of Maxwell equation and classical electromagnetic field theory are studied. [26].

The sixth preparation is to establish a new electromagnetic field theory based on the method introduced by Kirchhoff and Lorenz [27].

This paper attempts to solve the bug of the Poynting theorem. In fact, this bug also appears in the mutual energy flow theorem. The author believes that Poynting's theorem and mutual energy flow theorem are energy conservation laws, so the solution of classical electromagnetic field equations should first consider satisfying these energy conservation laws, and then satisfy Maxwell's equations. If you choose between Maxwell's equation and the law of conservation of energy (including Poynting's theorem, mutual energy principle and mutual energy flow theorem), the law of conservation of energy should first satisfy rather than Maxwell's equations.

This article was written around mid-2022 and was originally published in other journals. However, due to various reasons, it was not published and has been delayed until now. The viewpoint is somewhat outdated compared to the author's papers published in the second half of last year and this year [30-37]. But in order to supplement an important stage of the author's viewpoint growth. The author still made no modifications to the content of the original paper and directly published it.

2. Review of Electromagnetic Field Theory

2.1. Quasi Steady Electromagnetic Field

Quasi static electromagnetic field is the electromagnetic field defined by displacement current, which is not included in Maxwell's equation. For convenience, we use Maxwell's equation defined by Maxwell himself,

Gauss law,

$$\nabla \cdot \mathbf{D} = \rho \quad (1)$$

Definition of magnetic field

$$\mathbf{B} = \nabla \times \mathbf{A} \quad (2)$$

Faraday's law and definition of electric field

$$\mathbf{E} = -\nabla\phi - \frac{\partial}{\partial t}\mathbf{A} \quad (3)$$

Ampere circular law

$$\nabla \times \mathbf{H} = \mathbf{J} \quad (4)$$

Where $\mathbf{D} = \epsilon_0 \mathbf{E}$, $\mathbf{B} = \mu_0 \mathbf{H}$. The corresponding current continuity equation is,

$$\nabla \cdot \mathbf{J} = 0 \quad (5)$$

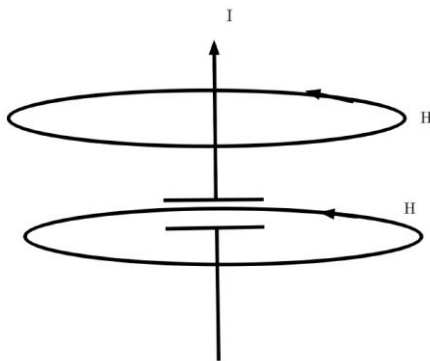


Figure 1. Calculate the magnetic field including capacitive current.

2.2. Electromagnetic Field of Circuit With Capacitor

Suppose there is an current in a infinite long wire, see figure 1, on which there is a capacitor. The current in the circuit is known and contains time variation. If we calculate the magnetic field, we will calculate the magnetic field with ampere circular current,

$$\oint_C \mathbf{H} \cdot d\mathbf{l} = I \quad (6)$$

If the curved surface is inside the capacitor, we use the displacement current inside the capacitor to calculate the magnetic field,

$$\oint_C \mathbf{H} \cdot d\mathbf{l} = \iint_S \frac{\partial}{\partial t} \mathbf{D} \cdot \hat{n} dS \quad (7)$$

The magnetic field calculated by the above two methods is the same, and the magnetic field and current have the same phase,

$$H \sim I \quad (8)$$

The symbol " $\sim$ " means proportional to what. H is the magnetic field close to the current. However, if we use the magnetic vector $\mathbf{A}$ and consider that the magnetic vector $\mathbf{A}$ has a retardation factor to calculate the magnetic field,

$$\mathbf{A} \sim \iiint_V \frac{1}{r} \exp(-j\mathbf{k} \cdot \mathbf{r}) dV \quad (9)$$

Because the electric field current is infinitely long, the radial electric field component $\nabla\phi$ should be negligible, so it has,

$$\begin{aligned} \mathbf{E} &\sim \frac{\partial}{\partial t} \mathbf{A} \sim j\omega \mathbf{A} \\ \mathbf{H} &\sim \nabla \times \mathbf{A} \sim \iiint_V \nabla \frac{\exp(-j\mathbf{k} \cdot \mathbf{r})}{r} \times \mathbf{J} dV \end{aligned} \quad (10)$$

or

$$\begin{aligned} \mathbf{H} &\sim \iiint_V (\nabla \left(\frac{1}{r}\right) \exp(-j\mathbf{k} \cdot \mathbf{r}) + \frac{1}{r} \nabla \exp(-j\mathbf{k} \cdot \mathbf{r})) \times \mathbf{J} dV \\ &= -\iiint_V \left(\frac{\mathbf{r}}{r^3} + \frac{j\mathbf{k}}{r}\right) \times \mathbf{J} \exp(-j\mathbf{k} \cdot \mathbf{r}) dV \end{aligned} \quad (11)$$

We will find that $\mathbf{H}$ there is an additional far-field component of the magnetic field in phase with the electric field,

$$H_f \sim j \iiint_V \mathbf{J} \times \left(\frac{\mathbf{k}}{r}\right) \exp(-j\mathbf{k} \cdot \mathbf{r}) dV \quad (12)$$

The problem is that the far-field component appears in the near-field range. We will find that this far-field component exists even without capacitors. This is unreasonable. The two methods (8) and (12) get different results. The correct magnetic field should be

$$H_f \sim \iiint_V \mathbf{J} \times \left(\frac{\mathbf{k}}{r}\right) \exp(-j\mathbf{k} \cdot \mathbf{r}) dV$$

2.3. The Magnetic Field Close to the Current on a Long Conductor

Considering,

$$\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial}{\partial t} \mathbf{D} \quad (13)$$

There is

$$\oint_C \mathbf{H} \cdot d\mathbf{l} = \iint_S \mathbf{J} \cdot \hat{n} dS + \iint_S \frac{\partial}{\partial t} \mathbf{D} \cdot \hat{n} dS \quad (14)$$

Consider that the radius of the wire is R , and C is the ring around the wire. Considering that D should be roughly uniform, there is

$$2\pi R H = I + \pi R^2 \frac{\partial}{\partial t} D \quad (15)$$

$$H = \frac{I}{2\pi R} + \frac{1}{2} R \frac{\partial}{\partial t} D \quad (16)$$

Considering that the electric field E will not change greatly due to the thinning of the conductor, when $R \rightarrow 0$, $H \sim I$ (17)

That is to say, there should be a magnetic field with the same phase as the current. This result is different from the formula (12). This shows that the formula (10) does not meet the boundary conditions of the differential equation, and such a solution should also be marked with a question mark.

2.4. The Problem of Displacement of Current

There are two definitions of D in displacement current, which may be ambiguous

$$D^{(1)} = \epsilon_0 E = \epsilon_0 (-\nabla\phi) \quad (18)$$

$$D^{(2)} = \epsilon_0 E = \epsilon_0 (-\nabla\phi - \frac{\partial}{\partial t} A) \quad (19)$$

$D^{(1)}$ is defined according to the electrostatic field. $D^{(2)}$ is defined according to the radiated electromagnetic field. The Maxwell-Ampere circuital law according to the first method is,

$$\nabla \times H = J + \frac{\partial}{\partial t} D^{(1)} = J + \frac{\partial}{\partial t} (\epsilon_0 (-\nabla\phi)) \quad (20)$$

and then,

$$\begin{aligned} \nabla \cdot \nabla \times H &= \nabla \cdot J + \frac{\partial}{\partial t} \nabla \cdot D^{(1)} \\ &= \nabla \cdot J + \frac{\partial}{\partial t} (\epsilon_0 (-\nabla \cdot \nabla\phi)) = \nabla \cdot J + \frac{\partial}{\partial t} \rho = 0 \end{aligned} \quad (21)$$

The scale ϕ potential is considered,

$$\nabla \cdot \nabla\phi = -\frac{1}{\epsilon_0} \rho \quad (22)$$

For the second method

$$\nabla \times H = J + \frac{\partial}{\partial t} D^{(2)} = J + \frac{\partial}{\partial t} (\epsilon_0 (-\nabla\phi - \frac{\partial}{\partial t} A)) \quad (23)$$

$$\begin{aligned} \nabla \cdot \nabla \times H &= \nabla \cdot J + \frac{\partial}{\partial t} \nabla \cdot D^{(2)} \\ &= \nabla \cdot J + \frac{\partial}{\partial t} (\epsilon_0 (-\nabla \cdot \nabla\phi - \frac{\partial}{\partial t} \nabla \cdot A)) = \nabla \cdot J + \frac{\partial}{\partial t} \rho = 0 \end{aligned} \quad (24)$$

The wave equation is considered

$$\begin{aligned} \nabla \cdot \nabla\phi + \frac{\partial}{\partial t} \nabla \cdot A \\ = \nabla \cdot \nabla\phi + \mu_0 \epsilon_0 \frac{\partial^2}{\partial t^2} \phi = -\frac{1}{\epsilon_0} \rho \end{aligned} \quad (25)$$

The Lorenz gauge condition is considered,

$$\nabla \cdot A = -\epsilon_0 \mu_0 \frac{\partial}{\partial t} \phi \quad (26)$$

and ϕ satisfy the wave equation

$$\nabla \cdot \nabla\phi + \mu_0 \epsilon_0 \frac{\partial^2}{\partial t^2} \phi = -\frac{1}{\epsilon_0} \rho \quad (27)$$

2.5. Near Field of Electromagnetic Field

It is worth mentioning that we also use Maxwell's equation,

$$\nabla \cdot D = \rho \quad (28)$$

$$B = \nabla \times A \quad (29)$$

$$E = -\nabla\phi - \frac{\partial}{\partial t} A \quad (30)$$

$$\nabla \times H = J + \frac{\partial}{\partial t} D \quad (31)$$

The solution of defines the electromagnetic field. The corresponding current continuity equation is,

$$\nabla \cdot J = -\frac{\partial \rho}{\partial t} \quad (32)$$

However, our field is near field, so all items caused by time retardation are ignored. The near-field displacement current still works, but because it is relatively close, the

phase of the electric field and magnetic field is determined by Faraday's theorem,

$$\nabla \times E = -\frac{\partial}{\partial t} B = -j\omega B \quad (33)$$

The above formula considers that the electromagnetic field has a time factor $\exp(-j\omega t)$. The curl of the electric field $\nabla \times E$ and the electric field itself have the same phase of E . Note that there will be a time retardation factor $\exp(-jk \cdot r)$ when considering the far field of the electric field, so

$$\nabla \times \sim -jk \times \quad (34)$$

The symbol " $\sim$ " indicates what is proportional to. Therefore, taking the curl $\nabla \times$ of the electric field E will change the phase of the electric field E . If this retarded phase factor is ignored, $\nabla \times$ will not change the phase of the electric field. At this time, the phase difference between the electric field and the magnetic field will always maintain 90 degrees. In this way, the electromagnetic field is close to the quasi static electromagnetic field.

This situation can also be regarded as the same as quasi static electromagnetic field. The near-field of electromagnetic field is slightly more relaxed than that of quasi static electromagnetic field. Displacement current is allowed. It just ignores all the retardation radiation effects.

2.6. New Definition of Magnetic Field

Generally, when the time retardation is not considered, the magnetic vector is,

$$A = \frac{\mu_0}{4\pi} \iiint_V \frac{J(x',t)}{r} dV \quad (35)$$

the current is AC, $J(x',t) = J_0(x') \exp(j\omega t)$. The magnetic field is defined as,

$$\begin{aligned} B &\triangleq \nabla \times A = \frac{\mu_0}{4\pi} \iiint_V \nabla \left(\frac{1}{r} \right) \times J(x',t) dV \\ &= \frac{\mu_0}{4\pi} \iiint_V J(x',t) \times \frac{r}{r^3} dV \end{aligned} \quad (36)$$

$r = x - x'$, at this time, the phase of magnetic field and vector A is the same.

$$\begin{aligned} A^{(+)} &= \frac{\mu_0}{4\pi} \iiint_V \frac{J(x',t-r/c)}{r} dV \\ &= \frac{\mu_0}{4\pi} \iiint_V \frac{J_0(x') \exp(j\omega(t-r/c))}{r} dV \\ &= \frac{\mu_0}{4\pi} \iiint_V \frac{J_0(x') \exp(j\omega t) \exp(-j\omega r/c)}{r} dV \\ &= \frac{\mu_0}{4\pi} \iiint_V \frac{J(x',t) \exp(-jk \cdot r)}{r} dV \end{aligned} \quad (37)$$

$k = \frac{\omega}{c}$. $k = k \frac{r}{r}$. Therefore, the corresponding retarded potential can be directly obtained by increasing the retardation factor $\exp(-jk \cdot r)$ from the non retarded potential. The magnetic field is calculated from the retarded potential below, but we quote two other symbols: magnetic field h and magnetic induction intensity b . This magnetic induction intensity is the magnetic induction intensity defined in the original classical electromagnetic field theory. The author believes that this definition is inconsistent with the magnetic field defined in the quasi static case, so it needs to be distinguished. So instead of writing $B \triangleq \nabla \times A^{(+)}$, we write

$$b \triangleq \nabla \times A^{(+)} \quad (38)$$

$$h \triangleq \frac{1}{\mu_0} b \quad (39)$$

We reserve the magnetic field symbols $\mathbf{H}$ and $\mathbf{B}$ for the new magnetic field defined by the author in the following. The purpose of this is to remind readers that the magnetic field of classical electromagnetic theory is not completely consistent with the magnetic field defined by quasi static state from here. Magnetic field,

$$\mathbf{b} = \frac{\mu_0}{4\pi} \iiint_V \nabla \frac{\exp(-jkr)}{r} \times \mathbf{J}(\mathbf{x}', t) dV$$

$$= \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \times \left(\frac{\mathbf{r}}{r^3} + \frac{j\mathbf{k}}{r} \right) \exp(-j\mathbf{k} \cdot \mathbf{r}) dV \quad (40)$$

Which takes into account

$$\nabla \frac{\exp(-jkr)}{r} = \nabla \left(\frac{1}{r} \right) \exp(-jkr) + \frac{1}{r} \nabla \exp(-jkr)$$

$$= -\frac{\mathbf{r}}{r^3} \exp(-jkr) + \frac{1}{r} \nabla \exp(-j\mathbf{k} \cdot \mathbf{r})$$

$$= -\frac{\mathbf{r}}{r^3} \exp(-jkr) + \frac{1}{r} (-j\mathbf{k}) \exp(-j\mathbf{k} \cdot \mathbf{r})$$

$$= -\left(\frac{\mathbf{r}}{r^3} + \frac{j\mathbf{k}}{r} \right) \exp(-j\mathbf{k} \cdot \mathbf{r}) \quad (41)$$

$k = \frac{\omega}{c}$. According to this definition, when the magnetic field is far-field,

$$\mathbf{b}_f = -j\mathbf{k} \times \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \frac{\exp(-j\mathbf{k} \cdot \mathbf{r})}{r} dV$$

$$= -j\mathbf{k} \times \mathbf{A}_f^{(+)} \quad (42)$$

Use the foot mark f to indicate the far away. The phase of far field of magnetic field $\mathbf{b}_f$ and magnetic vector potential $\mathbf{A}_f^{(+)}$ are different. The problem is that this far-field component also appears near the antenna. That is to say, if it appears close to the current and is calculated according to the retarded potential, the magnetic field will have a component different from the phase of the magnetic vector $\mathbf{A}$. This is inconsistent with the formula (36).

The formula (36) is the result when the time retardation is ignored. The formula (42) is to consider the magnetic field in the place with time retardation but close to the current. The magnetic field should be the same for these two cases, but the magnetic field in the above two cases is indeed different. This constitutes the inconsistency of the definition of magnetic field in classical electromagnetic theory. This inconsistency is not inappropriate for the establishment of Maxwell's equations, but it leads to the invalidation of Poynting's theorem [28],

$$-\iiint_V \mathbf{e} \cdot \mathbf{J}^* dV \neq \oint_{\Gamma} (\mathbf{e} \times \mathbf{h}^*) \cdot \hat{n} d\Gamma \quad (43)$$

Of course, this problem will also infect the mutual energy principle and mutual energy flow theorem [18] proposed by the author, so that,

$$-\iiint_V \mathbf{e}_2^* \cdot \mathbf{J}_1 dV \neq (\xi_1, \xi_2) \neq \iiint_V \mathbf{e}_1 \cdot \mathbf{J}_2^* dV \quad (44)$$

where

$$(\xi_1, \xi_2) = \oint_{\Gamma} (\mathbf{e}_1 \times \mathbf{h}_2^* + \mathbf{e}_2^* \times \mathbf{h}_1) \cdot \hat{n} d\Gamma \quad (45)$$

But it is not transmitted to the mutual energy theorem (the mutual energy theorem does not involve magnetic field). That is, there are still,

$$-\iiint_V \mathbf{e}_2^* \cdot \mathbf{J}_1 dV = \iiint_V \mathbf{e}_1 \cdot \mathbf{J}_2^* dV \quad (46)$$

Therefore, the author needs to redefine a magnetic field, which requires its far-field and near-field properties to be consistent. This new magnetic field is represented by $\mathbf{B}$. Indicates that this is a magnetic field defined by magnetic field retardation. And use the foot mark f to indicate the distance. definition,

$$\mathbf{B}_f \triangleq -j(\nabla \times \mathbf{A}^{(+)})_f$$

$$= -j\mathbf{b}_f = -j(-j\mathbf{k} \times \mathbf{A}^{(+)})$$

$$= -\mathbf{k} \times \mathbf{A}^{(+)} \quad (47)$$

We know that the directions and phases of $\mathbf{A}^{(+)}$ and current $\mathbf{J}$ are consistent. The magnetic field direction and phase defined above is consistent with that determined by the right-hand helix

$$\mathbf{B}_n = \nabla \times \mathbf{A} = \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \times \frac{\mathbf{r}}{r^3} dV \quad (48)$$

$\mathbf{A}$ given by formula (35). The magnetic field defined above does not consider the retardation effect at all. In fact, this retardation factor should also be added.

$$\mathbf{B}_n = \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \times \frac{\mathbf{r}}{r^3} \exp(-j\mathbf{k} \cdot \mathbf{r}) dV$$

$\mathbf{B}_n$ It is the near-field part of the newly defined magnetic field. Therefore, the magnetic field defined by the author is,

$$\mathbf{B} \triangleq \mathbf{B}_n + \mathbf{B}_f$$

$$= \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \times \frac{\mathbf{r}}{r^3} \exp(-j\mathbf{k} \cdot \mathbf{r}) dV$$

$$+ \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \times \frac{\mathbf{k}}{r} \exp(-j\mathbf{k} \cdot \mathbf{r}) dV$$

$$= \frac{\mu_0}{4\pi} \iiint_V \mathbf{J}(\mathbf{x}', t) \times \left(\frac{\mathbf{r}}{r^3} + \frac{\mathbf{k}}{r} \right) \exp(-j\mathbf{k} \cdot \mathbf{r}) dV \quad (49)$$

$$\text{where, } \mathbf{r} = \mathbf{x} - \mathbf{x}', \quad r = |\mathbf{r}|, \quad \mathbf{k} = k \frac{\mathbf{r}}{r}, \quad k = \frac{\omega}{c} \quad (50)$$

$\mathbf{b}$ is the magnetic field calculated according to the vector potential retardation (38), and $\mathbf{B}$ (49) is the magnetic field calculated according to the retardation of the magnetic field itself. foot mark f represents the far field and foot mark n represents the near field. $\mathbf{B}$ is equivalent to our changing the definition of curl. The limiting curl is taken in the coordinate system of light speed. We know that in the case of quasi static electromagnetic field, the electric field and magnetic field maintain a phase difference of 90 degrees. In the coordinate system with the same speed of light, the magnetic field and electric field become quasi static electromagnetic field. At this time, the electric field and magnetic field always maintain a phase difference of 90 degrees. Therefore, the new magnetic field we defined maintains the properties of quasi static electromagnetic field. However, the traditional magnetic field defined by retarded potential can not maintain the properties of quasi static magnetic field. This makes the traditional magnetic field $\mathbf{b}$ have errors or bug in Poynting's theorem and mutual energy flow theorem. This point will be discussed in more detail in the next chapter.

2.7. Application of Circuital Ampere Law

Suppose there is a long straight antenna standing upright, and the current is along the z axis. $I = I_0 \exp(-j\omega t)$. We can apply the circuital ampere law in the $x - y$ plane. Here we should consider the retardation effect of the magnetic field, there is

$$\oint_C \mathbf{H} \cdot d\mathbf{l} \sim I \exp(-jkR) \quad (51)$$

C is a large ring with radius R on the $x - y$ plane. $k = 2\pi/\lambda = \omega\sqrt{\mu_0\epsilon_0}$. Since the radius $R \gg \lambda$, λ is the wavelength, the length of the antenna cannot be regarded as infinite, and the circuital theorem of classical electromagnetic theory is not tenable. However, the above circuital ampere law is still true. The direction of the

magnetic field can be determined by the right-hand rule. We can use the above circuital theorem to determine the phase of the magnetic field. The author believes that the magnetic field should be,

$$H \sim I \exp(-jkR) \quad (52)$$

The formula (49) conforms to the above Ampere circuital theorem. This is different from the magnetic field calculated in the classical magnetic field theory. The far field of the classical magnetic field is,

$$\begin{aligned} \mathbf{h}_f &= (\nabla \times \mathbf{A})_f \\ &= (-jk\hat{R}) \times I \exp(-jkR)\hat{z} \\ &\sim Ij \exp(-jkR)\hat{\phi} \end{aligned} \quad (53)$$

where

$$\hat{R} \times \hat{z} = -\hat{\phi}$$

is considered.

2.8. Definition of Electric Field

We need to define the retarded magnetic field, so do we need to define the retarded electric field? At present, the author has not found it necessary to do so, so the electric field can also be calculated according to the retarded vector potential and scalar potential,

$$\mathbf{E} = -\nabla\phi - \frac{\partial}{\partial t}\mathbf{A} \quad (54)$$

If the retarded potential is considered,

$$\mathbf{e} = -\nabla\phi^{(\pm)} - \frac{\partial}{\partial t}\mathbf{A}^{(\pm)} \quad (55)$$

Superscript (+) indicates retarded and (-) indicates advanced. $\mathbf{e}$ is a classical electromagnetic field. We use lowercase letters instead of uppercase letters. It means that this electric field is possible different from the definition of quasi static electric field. Capitalized electric field $\mathbf{E}$ is left to the electric field defined by the author. First let us to analyze the contribution of $-\frac{\partial}{\partial t}\mathbf{A}$ in the electric field.

The first method is to calculate the electric field from the retarded vector potential,

$$\begin{aligned} \mathbf{A}^{(+)} &\triangleq \frac{\mu_0}{4\pi} \iiint_V \frac{J(\mathbf{x}',t) \exp(-jk\cdot\mathbf{r})}{r} dV \quad (56) \\ \mathbf{e}^{(+)} &= -\frac{\partial}{\partial t}\mathbf{A}^{(+)} = -\frac{\partial}{\partial t} \frac{\mu_0}{4\pi} \iiint_V \frac{J(\mathbf{x}',t) \exp(-jk\cdot\mathbf{r})}{r} dV \\ &= -\frac{\mu_0}{4\pi} \iiint_V \frac{\frac{\partial}{\partial t} J(\mathbf{x}',t) \exp(-jk\cdot\mathbf{r})}{r} dV \end{aligned} \quad (57)$$

In the second method, the electric field is calculated according to the retarded electric field. First, the electric field is calculated according to the non retarded vector potential

$$\begin{aligned} \mathbf{E} &= -\frac{\partial}{\partial t}\mathbf{A} = -\frac{\partial}{\partial t} \frac{\mu_0}{4\pi} \iiint_V \frac{J(\mathbf{x}',t)}{r} dV \\ &= -\frac{\mu_0}{4\pi} \iiint_V \frac{\frac{\partial}{\partial t} J(\mathbf{x}',t)}{r} dV \end{aligned} \quad (58)$$

Then consider a retarded factor $\exp(-jk\cdot\mathbf{r})$,

$$\mathbf{E}^{(+)} = -\frac{\mu_0}{4\pi} \iiint_V \frac{\frac{\partial}{\partial t} J(\mathbf{x}',t)}{r} \exp(-jk\cdot\mathbf{r}) dV \quad (59)$$

There is,

$$\mathbf{E}^{(+)} = \mathbf{e}^{(+)} \quad (60)$$

We found that the electric field obtained by the two methods is consistent. The contribution of $-\nabla\phi$ in electric field is complex. It's difficult to analyze. We'll put it on hold. We only consider the electric field of $-\frac{\partial}{\partial t}\mathbf{A}$ for the time being.

Another reason is that we can see that the author's new definition of electric field is mainly to maintain the

establishment of Poynting's theorem, mutual energy flow theorem and the wave particle duality of quantum mechanics. It is not to do specific electromagnetic field calculation. For these, in fact, we only need to calculate in the plane perpendicular to the dipole antenna. At this time $\nabla\phi=0$, there is no contribution at all.

2.9. Energy Conservation Law

From the above discussion, we know that the electromagnetic field calculated according to the classical electromagnetic field theory does not meet Poynting's theorem, mutual energy principle and mutual energy theorem. Considering that the principle of mutual energy is very close to the theorem of mutual energy flow, we only retain the test of the theorem of mutual energy flow. i.e, it is possible,

$$-\oint_{\Gamma} (\mathbf{e} \times \mathbf{h}^*) \cdot \hat{n} d\Gamma \neq \iiint_V (\mathbf{e} \cdot \mathbf{J}^*) dV \quad (61)$$

$$-\iiint_{V_1} (\mathbf{e}_2^* \cdot \mathbf{J}_1) dV \neq (\xi_1, \xi_2) \neq \iiint_{V_2} (\mathbf{e}_1 \cdot \mathbf{J}_2^*) dV \quad (62)$$

But there should be,

$$-\oint_{\Gamma} (\mathbf{E} \times \mathbf{H}^*) \cdot \hat{n} d\Gamma = \iiint_V (\mathbf{E} \cdot \mathbf{J}^*) dV \quad (63)$$

$$-\iiint_{V_1} (\mathbf{E}_2^* \cdot \mathbf{J}_1) dV = (\xi_1, \xi_2) = \iiint_{V_2} (\mathbf{E}_1 \cdot \mathbf{J}_2^*) dV \quad (64)$$

The electromagnetic field defined by the author should satisfy Poynting's law and mutual energy flow theorem. Or we should solve it in the integral form of Poynting's theorem and mutual energy flow theorem, instead of calculating the retarded vector potential (56) and then calculating the magnetic field (40) according to the curl.

3. Transformer

We must simplify the shape of the transformer as much as possible in order to analyze it easily. Next, we consider a coplanar double ring transformer. The primary coil is in the inner ring. The secondary coil is in the outer ring.

3.1. Poynting Vector of Double Loop Transformer

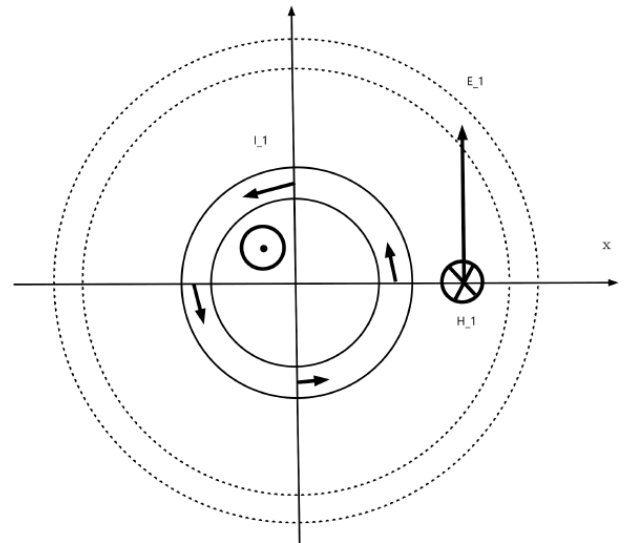


Figure 2. For a double ring transformer, we calculate the Poynting vector of the primary coil.

This transformer is composed of two concentric rings, as shown in figure 2. It is assumed that the small ring is the primary coil and the large ring is the secondary coil. Since we mainly calculate the Poynting vector generated by the small ring current, it is independent of the large ring. The large ring of the secondary coil is drawn as a dotted line. It is assumed that there is a constant current source in the primary coil of the small ring, so its current is,

$$I_1 = I_0 \exp(-j\omega t) \quad (65)$$

We calculate the electromagnetic field on the primary and secondary coils along the x-axis. Then calculate the Poynting vector here. We only calculate the direction and phase of the Poynting vector. We don't care about the value of the Poynting vector.

$$E_1 = -M_{2,1} \frac{\partial}{\partial t} I_1 = -M_{2,1} \frac{\partial}{\partial t} I_1 = -M_{2,1} j\omega I_1 \sim -jI_1 \quad (66)$$

among the above,

$$M_{2,1} = \frac{\mu_0}{4\pi} \oint_{C_2} \oint_{C_1} \frac{dl_1 \cdot dl_2}{r} \quad (67)$$

E_1 is the electric field in the direction of the current. Since this is a quasi static field, we do not need to consider the time retardation, so $M_{2,1}$ is a real number. Here h_1 It can be obtained from the ampere circuital law,

$$\oint H_1 \cdot dl = I_1 \quad (68)$$

$$H_1 \sim I_1 \quad (69)$$

$$S_{11} = E_1 \times H_1^* = E_1 H_1^* (-\hat{x}) \sim (-jI_1)(I_1)^* (-\hat{x}) \sim j\hat{x} \quad (70)$$

The Poynting vector is an imaginary number for this case, so it has,

$$\Re\{S_{11}\} = 0 \quad (71)$$

" $\Re$ " indicates the real part. The above formula shows that the Poynting energy flow from the primary coil to the secondary coil is zero! This is consistent with the calculation in the case of quasi steady electromagnetic field. This is consistent with the prediction of mutual energy theory. Mutual energy theory predict that the self energy flow S_{11} don't transfer energy, it should transfer reactive work. The energy flow that really transfers energy is mutual energy flow S_m , which will be described in the next sub-section below.

In the above discussion we assume the electromagnetic field is quasi static field, but even considered the time retardation, the above result should be still correct. The Poynting vector still should not transfer the energy.

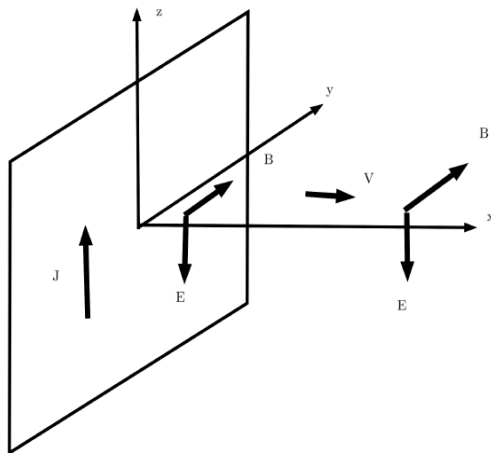


Figure 3. Electromagnetic field of single plate current

There is no concept of mutual energy flow in the classical electromagnetic field theory. The energy flow of Poynting vector is the only energy flow, so the energy flow of Poynting vector is needed to explain the energy transfer. However, for the author's mutual energy theory, energy can be transferred through mutual energy flow, so the energy flow of Poynting vector is not required to transfer energy.

3.2. Electromagnetic Field of Single Infinite Plate Current

In the figures 18-3 to 18-6 of the collection of Feynman lecture [29], describe an example of electromagnetism, where there is an infinite plane current, and then try to find its magnetic field and electric field, see Figure 3.

(1) Feynman believes that the initial phase of the magnetic field is consistent with the plate current. Then move according to the plane wave,

$$H = H_0 \exp(j(\omega t - kx)) \hat{y} \quad (72)$$

$$H_0 = H(z=0) \sim I \quad (73)$$

The electric field is also a plane wave, and the direction is $(-\hat{z})$,

$$E = E_0 \exp(j(\omega t - kx)) (-\hat{z}) \quad (74)$$

Consider Faraday's theorem

$$\nabla \times E = -\omega j\mu_0 H \quad (75)$$

or

$$-jk\hat{x} \times E_0 \exp(-jkx) (-\hat{z}) = -\omega j\mu_0 H_0 \hat{y} \exp(-jkx)$$

or

$$E_0 = \eta_0 H_0 \quad (76)$$

$$\eta_0 = \sqrt{\frac{\mu_0}{\epsilon_0}}. \text{ So } E_0 = E(x=0) \text{ and } H_0 = H(x=0) \text{ has}$$

the same phase.

$$E(x=0) \sim H(x=0) \sim I \quad (77)$$

(2) this author also see some people think that the electric field should be calculated according to the magnetic vector potential, so

$$E = -\frac{\partial}{\partial t} A = -j\omega A \sim -jA \sim jI(-\hat{z}) \quad (78)$$

$$E(x=0) \sim jI \quad (79)$$

Then it is obtained according to (76),

$$H(x=0) \sim jI \quad (80)$$

In this way, the electromagnetic field $H(x=0)$, $E(x=0)$ have phase j with the current. We all follow the classical electromagnetic theory. Why do we get two different results? The reason is that the classical electromagnetic theory is not always consistent. Both methods try to keep the Poynting vector real, so that at least the energy flow points out of the plate.

(3) Above, we get two different phases of the electromagnetic field. The author believes that neither is right. But in Feynman's method (1), the calculation of magnetic field is correct. The magnetic field and current have the same phase. Then propagate according to the plane wave. The author believes that the electric field method of others in algorithm (2) is correct. Therefore, there are,

$$E(x=0) \sim j \quad (81)$$

$$H(x=0) \sim 1 \quad (82)$$

So Poynting vector

$$E \times H^* \sim j\hat{x}$$

Therefore, the radiated power of the electromagnetic field of this current is reactive power. This is consistent

with the viewpoint of mutual energy theory put forward by the author. Poynting energy flow does not transfer energy.

3.3. Electromagnetic Field of Two Infinite Flat Transformers

The following figure 4 is the author's example. Here we need two plates to illustrate the problem. One plate is the primary coil of the transformer and the other is the secondary coil.

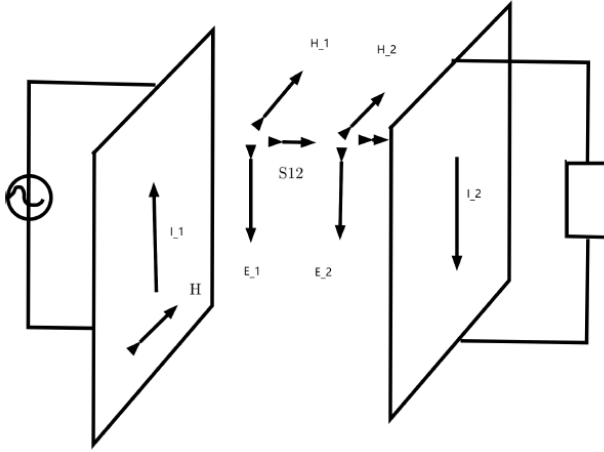


Figure 4. Double plate transformer.

We assume that the primary coil is an infinite conductor plate with current flowing to the z -axis. The secondary coil is a plate close to each other and then loaded, as shown in Fig. 4. H_1 It should be the same as the plane current J_1 in phase, assuming $J_1 \sim 1$. $H_1 \sim 1$, electric field $E_1 \sim j$. (note that the author and Feynman have different views).

Current J_2 and E_1 have the same phase $J_2 \sim j$, $E_2 \sim (-j)J_2 = (-j)j$, $H_2 \sim J_2 \sim j$, so there are still,

$$\begin{aligned} S_m &= \frac{1}{2}(\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1) \\ &= \frac{1}{2}(E_1 H_2^* + E_2^* H_1) \hat{x} \sim \frac{1}{2}((j)(j)^* + (-jj)^*(1)) \hat{x} = \hat{x} \end{aligned} \quad (83)$$

Therefore, we find that the mutual energy flow is indeed the energy flow from the primary coil to the secondary coil. We can imagine moving the secondary coil some distance away from the primary coil. Since the electromagnetic field generated by the infinite plate current must be a plane wave, the propagation of this plane wave will ensure the magnetic field H_1 and electric field E_1 Always maintain a 90 degree phase difference. E_2 and H_2 also always maintain a phase difference of 90 degrees. In this case, it is obvious that what we need is to calculate the distant magnetic field according to the magnetic field retardation.

$$H_1(x) = H_1(x=0)\exp(-jkx) \sim 1\exp(-jkx) \quad (84)$$

Instead of calculating the magnetic vector potential according to the retarded magnetic vector potential

$$\mathbf{A}_1^{(+)} \sim \exp(-jkx) \hat{z} \quad (85)$$

Then the magnetic field is calculated from the vector potential,

$$\begin{aligned} \mathbf{h}_1 &= \nabla \times \mathbf{A}_1^{(+)} = -jk \hat{x} \times \exp(-jkx) \hat{z} = \\ &jk \exp(-jkx) \hat{y} \end{aligned} \quad (86)$$

$$h_1 \sim j \exp(-jkx) \quad (87)$$

In this way, the magnetic field has a phase difference j from the current, which is wrong. Mutual energy flow is calculated,

$$\begin{aligned} S_m(x) &= \frac{1}{2}(\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1) \\ &= \frac{1}{2}(E_1 H_2^* + E_2^* H_1) \hat{x} \\ &\sim \frac{1}{2}((j \exp(-jkx))(j \exp(-jkx))^* \\ &\quad + (-jj \exp(-jkx))^*(1 \exp(-jkx))) \hat{x} \\ &= \hat{x} \end{aligned} \quad (88)$$

In the above formula, the mutual energy flow flows from the primary coil to the secondary coil.

3.4. Near Field of Double Linear Transformer

The double ring transformer is not simple enough. We choose a simpler double linear transformer, see Figure 5. The primary coil and secondary coil are a long conductor. The two wires are close and parallel, and the time retardation effect can be ignored. We only consider these two straight wires with very small distance. It is assumed that other wires are far away and belong to the lead of transformer, so they can be ignored. We assume that the load resistance on the secondary coil is large, $R_2 > \omega L_2$. Therefore, for the current I_2 of the secondary coil and the induced electromotive force on it E_1 , the direction and phase are the same.

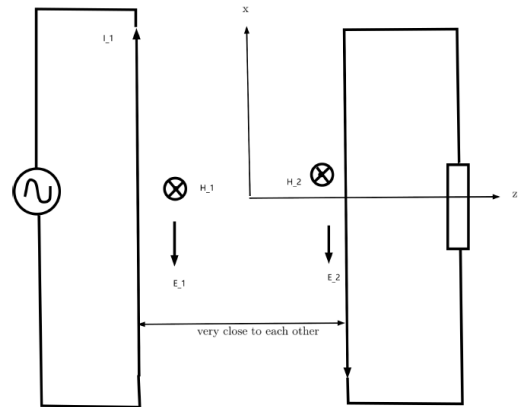


Figure 5. For a double wire transformer, we calculate the Poynting vector of the primary coil.

Magnetic vector potential,

$$\mathbf{A}_1 \sim I_1 \hat{x} \quad (89)$$

$$\mathbf{E}_1 = -\frac{\partial}{\partial t} \mathbf{A}_1 = -j\omega \mathbf{A}_1 \sim -j(I_1 \hat{x}) \quad (90)$$

Get $\mathbf{E}_1$ In the opposite direction of the current,

$$E_1 \sim jI_1 \quad (91)$$

Considering Ampere circuital law,

$$\oint \mathbf{H}_1 \cdot d\mathbf{l} \quad (92)$$

Determine the direction of magnetic according to the principle of right-hand spiral,

$$H_1 \sim I_1 \quad (93)$$

$$\mathbf{S}_{11} = \mathbf{E}_1 \times \mathbf{H}_1^* = E_1 H_1^* \hat{z} \sim (jI_1)(I_1)^* \hat{z} \sim j \quad (94)$$

$\mathbf{S}_{11}$ It is reactive power, which is consistent with the mutual energy theory and does not transfer energy.

$$I_2 \sim E_1 \sim jI_1 \quad (95)$$

$$\mathbf{E}_2 \sim -jI_2(-\hat{x}) \quad (96)$$

Consider $\mathbf{E}_2$ The direction of is also $-\hat{x}$,

$$E_2 \sim -jI_2 \sim -j(jI_1) \sim I_1 \quad (97)$$

$$H_2 \sim I_2 \sim jI_1 \quad (98)$$

$$\mathbf{S}_{22} = \mathbf{E}_2 \times \mathbf{H}_2^* = (-jI_2)I_1^* \hat{z} \sim -j\hat{z} \quad (99)$$

$\mathbf{S}_{22}$ is reactive power, which is consistent with the mutual energy theory and does not transfer energy.

$$\mathbf{S}_m = \mathbf{S}_{12} + \mathbf{S}_{21} = \frac{1}{2}(\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1)$$

$$= \frac{1}{2}(E_1 H_2^* + E_2^* H_1) \hat{z}$$

$$\sim \frac{1}{2}((j)(j)^* + (-jj)^*(1))I_1 I_1^* \hat{z} \sim \hat{z} \quad (100)$$

This is consistent with the estimation of mutual energy theory. Mutual energy flow is to transmit energy. On the left side of the primary coil and on the right side of the secondary coil, $\mathbf{S}_m$ is active power output. However, due to the magnetic field on the left side of primary coil 1, for $\mathbf{H}_1$ the direction has changed, hence $\mathbf{S}_m = 0$. Similarly, on the right side of the secondary coil, The direction of the magnetic field $\mathbf{H}_2$ has changed, and hence $\mathbf{S}_m = 0$. This indicates that the mutual energy flow is completely absorbed at the secondary coil. The mutual energy flow is from zero to something at the primary coil, indicating the generation of mutual energy flow. According to the mutual energy theory, the mutual energy flow represents photon. Here, photon are generated on the primary coil, and photon is completely absorbed on the secondary coil. The above description is very similar to the description of John Cramer's quantum mechanics transactional interpretation [7,8]. Cramer transactional interpretation is explained by the superposition of advanced wave and retarded wave. Here are the two components of mutual energy flow $\mathbf{S}_{12}$ and $\mathbf{S}_{21}$. The superposition is not the superposition of the field itself. In addition, in Cramer's theory, the advanced wave emitted at the light source has a phase of 180 degrees with the advanced wave emitted by the light sink, and the retarded wave emitted by the light sink has a phase of 180 degrees with the retarded wave emitted by the light source, so it is offset. This 180 degree phase difference cannot be explained more specifically in John Cramer's theory. This 180 degree phase angle is caused by the reversal of the magnetic field in the mutual energy theory proposed by the author in this paper, so it becomes very natural.

3.5. Phase of Far-Field Energy Flow of Linear Transformer System (Antenna System)

We assume that the secondary coil of the above transformer is moved far away from the primary coil, so that the primary coil becomes a transmitting antenna and the secondary coil becomes a receiving antenna. Calculate the mutual energy flow and self energy flow of the two antennas. We only check the calculation at the connecting line of the two antennas. First, we calculate the point $z = L$ close to the secondary coil. Then calculate the energy flow at any other point, self energy flow (Poynting vector) and mutual energy flow. Hypothesis $E_1(z = 0) \sim j$

The electric field at the receiving antenna,

$$E_1(z = L) \sim E_1(z = 0) \exp(-jkL) \sim j \exp(-jkL) \quad (101)$$

$$H_1(z = L) \sim \exp(-jkL) \quad (102)$$

Due to load resistance $R_2 \gg \omega L_2$ Therefore, the current I_2 Consistent with the direction of the induced electric field,

$$I_2 \sim E_1(z = L) \sim j \exp(-jkL) \quad (103)$$

$$H_2 \sim j \exp(-jkL) \quad (104)$$

$$\mathbf{E}_2 = -j\omega \mathbf{A}_2 \sim -j\mathbf{A}_2 \sim -jI_2 \sim -jj \exp(-jkL) \quad (105)$$

$$\mathbf{S}_m(z = L) = \frac{1}{2}(\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1)$$

$$= \frac{1}{2}(E_1 H_2^* + E_2^* H_1) \hat{z}$$

$$= \frac{1}{2}(j(\exp(-jkL))(j \exp(-jkL))^* + (-jj \exp(-jkL))^*(\exp(-jkL)) \hat{z} = \hat{z} \quad (106)$$

Mutual energy flow $\mathbf{S}_m(z = L)$ is the active power. We can easily prove that at any point $x = l$

$$\mathbf{S}_m(z = l) = \mathbf{S}_m(z = L - (L - l)) \quad (107)$$

Since a phase term is added to each term,

$$\exp(-jk(-(L - l))) \quad (108)$$

There is,

$$\mathbf{S}_m(z = l) \sim \mathbf{S}_m(z = L) = \hat{z} \quad (109)$$

Above, this author verified that on the connection of two current elements, the mutual energy flow is indeed from coil 1 to coil 2, and it is active power.

As in the previous section, for the right side of the receiving antenna, the current I_2 The radiation is a retarded wave due to the magnetic field H_2 Change sign, $\mathbf{S}_m = 0$. On the left side of the transmitting antenna current element, the current I_1 , the radiation is a advanced wave due to the magnetic field H_1 Change sign, offset occurs, so $\mathbf{S}_m = 0$. The above description is completely similar to the description of John Cramer's quantum mechanics transaction interpretation [7,8].

In the same way, we can prove

$$\Re\{\mathbf{S}_{11}(z = l)\} = \Re\{\mathbf{S}_{22}(z = l)\} = 0 \quad (110)$$

In this way, the self energy flow does not transfer energy. Energy is transferred by mutual energy flow.

4. Re-discussion of the Definition of Magnetic Field

4.1. Requirements of Mutual Energy Flow Theorem on Magnetic Field

Since the mutual energy theorem is the law of conservation of energy, it should be correct whether there is time retardation or not.

$$- \iiint_V \mathbf{E}_2^* \cdot \mathbf{J}_1 dV = \iiint_V \mathbf{E}_1 \cdot \mathbf{J}_2^* dV \quad (111)$$

Without considering the far-field retardation or in the case of quasi static electromagnetic field, the principle of mutual energy and the theorem of mutual energy flow can be deduced. The author has verified that the theorem of mutual energy flow and the principle of mutual energy are indeed successful.

$$- \iiint_V \mathbf{E}_2^* \cdot \mathbf{J}_1 dV = (\xi_1, \xi_2) = \iiint_V \mathbf{E}_1 \cdot \mathbf{J}_2^* dV \quad (112)$$

$$(\xi_1, \xi_2) = \iint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1) \cdot \hat{n} dV \quad (113)$$

$$\Gamma = \Gamma_1, \text{ or } \Gamma_2, \text{ or } \Gamma_3, \text{ or } \Gamma_4, \text{ or } \Gamma_5, \quad (114)$$

When time retardation needs to be considered, although Poynting's theorem, mutual energy principle and mutual energy flow theorem can still be proved theoretically, but these energy law cannot be verified with electric field and magnetic field $\mathbf{e}$, $\mathbf{h}$. It is for this reason that the author

redefined the electric field and magnetic field $\mathbf{E}, \mathbf{H}$. But for electric field and magnetic field $\mathbf{E}, \mathbf{H}$ the author can only calculate their values under special circumstances. For example, the electric field and magnetic field of infinite plane current. However, the author believes that the above formula is the energy conservation law. Even if the author does not know the expression formula of electromagnetic field $\mathbf{E}, \mathbf{H}$ the above energy conservation law (111) and mutual energy flow theorem (112) should be guaranteed. On the other hand, the above law of mutual energy flow can also be regarded as the definition of electric field. Electromagnetic field $\mathbf{E}, \mathbf{H}$ should satisfy the mutual energy flow formula.

This mutual energy flow should be along the x-axis, see figure 6. In order to make the mutual energy theorem hold, the magnetic field should maintain the corresponding retardation relationship with the electric field, and the phase difference should be 90 degrees. Even when it comes to the radiated electromagnetic field, the retardation effect of the field must be considered, and the above mutual energy flow theorem must still be satisfied. Instead of just ensuring that the magnetic vector $\mathbf{A}$ has the correct retardation relationship. Although the vector $\mathbf{A}$ has a correct retardation relationship, the magnetic field $\mathbf{h}$ defined by Maxwell can still be correct in Maxwell's equation, it cannot be guaranteed to be correct in the above mutual energy flow theorem. The author redefines the magnetic field $\mathbf{H}$ to ensure that the above formula (112-114) is valid.

In this way, we upgrade the mutual energy flow theorem to the law of conservation of energy, which is not only a theorem, but also an axiom of electromagnetic field theory. It will give a new definition of magnetic field.

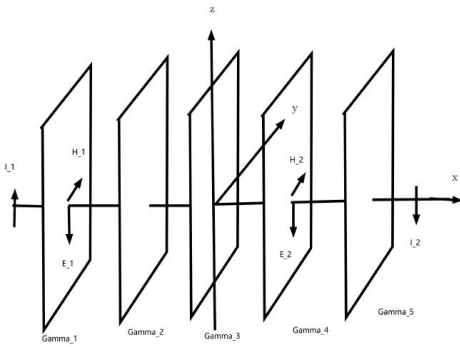


Figure 6. The mutual energy flow theorem require that the magnetic field H_1 keep a phase of 90 degree with the electric field E_1 . It is same to H_2 with E_2 .

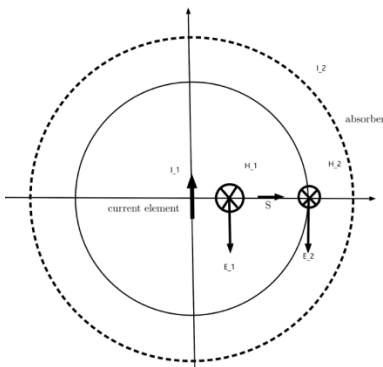


Figure 7. It is assumed that the sphere with infinite radius is covered with absorber material.

4.2. Poynting Energy Flow Under the Condition of Silver-Mueller Radiation

Assuming that we place a dipole antenna in real space, since the environment and distant cosmic dust can form the absorption of electromagnetic waves, we assume that the sphere with infinite radius is evenly covered with absorber materials, as shown in figure 7. Assuming that the absorber material can completely absorb electromagnetic waves, these absorber materials have an infinite number of small receiving antennas, which are followed by resistive loads. The far field is equivalent to satisfying the Silver-Mueller radiation condition. We prove that in this case, the energy flow provided by the mutual energy flow is the same as the Poynting vector energy flow. First, Poynting energy flow can be,

$$\mathbf{S}_{11}^{(c)} = \mathbf{e}_1 \times \mathbf{h}_1^* \quad (115)$$

Here $\mathbf{e}_1, \mathbf{h}_1$ It is a classical electromagnetic field (Note: the symbols of electric field and magnetic field $\mathbf{E}$ and $\mathbf{H}$ in this paper are left to the new electromagnetic field defined by the author). $\mathbf{S}_{11}^{(c)}$ represents the Poynting vector in the classical electromagnetic theory. We know that for the far-field component, there is

$$\mathbf{e}_1 = j\mathbf{E}_{10} \quad (116)$$

$$\mathbf{h}_1 = j\mathbf{H}_{10} \quad (117)$$

Here $\mathbf{E}_{10}$ And $\mathbf{H}_{10}$ Have the same phase angle, such as and current I_1 The phase is the same (here we are talking about the distant field).

$$\mathbf{S}_{11}^{(c)} = (j\mathbf{E}_{10}) \times (j\mathbf{H}_{10})^* = \mathbf{E}_{10} \times \mathbf{H}_{10}^* \quad (118)$$

We only calculate the Poynting vector along the x axis and the mixed Poynting vector of mutual energy flow. It is assumed that due to the action of the absorber, the electromagnetic field of the advanced wave generated by the spherical absorber with infinite radius is close to that of the retarded wave emitted by the radiation source (with due consideration of the phase).

$$E_1 \sim j\exp(-jkr) \quad (119)$$

$$H_1 \sim 1\exp(-jkr) \quad (120)$$

$$I_2 \sim E_1 \sim j\exp(-jkr) \quad (121)$$

where I_2 is the current of absorber which is stated at the sphere with infinite radius. And we have,

$$E_2 \sim -jI_2 \sim -jj\exp(-jkr) \quad (122)$$

$$H_2 \sim I_2 \sim j\exp(-jkr) \quad (123)$$

Because the absorber is covered with the whole infinite sphere, when the absorber is covered with the whole large sphere, the advanced wave generated by the absorber can be almost the same as the retarded wave generated by the radiation source current. It is almost necessary to consider the phase change caused by these absorbers. So we can assume

$$\mathbf{E}_1 \sim j\mathbf{E}_{10} \quad (124)$$

In the theory of mutual energy, there is a phase difference of 90 between magnetic field and electromagnetic field,

$$\mathbf{H}_1 \sim \mathbf{H}_{10} \quad (125)$$

Electric field $\mathbf{E}_2$ and current I_2 have the phase difference $-j$, current I_2 and electric field $\mathbf{E}_1$ have the same phase difference,

$$\mathbf{E}_2 = -j\mathbf{E}_1 = -j(j\mathbf{E}_{10}) \quad (126)$$

Magnetic field $\mathbf{H}_2$ and electric field $\mathbf{I}_2$ have the same phase,

$$\mathbf{H}_2 = j\mathbf{H}_1 = j\mathbf{H}_{10} \quad (127)$$

Therefore, the mixing Poynting vector of mutual energy flow is,

$$\begin{aligned} \mathbf{S}_m &= \mathbf{S}_{12} + \mathbf{S}_{21} \\ &= \frac{1}{2}(\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1) \\ &= \frac{1}{2}((j\mathbf{E}_{10}\exp(-jkr)) \times (j\mathbf{H}_{10}\exp(-jkr))^* \\ &\quad + (-j(j\mathbf{E}_{10}\exp(-jkr)))^* \times (\mathbf{H}_{10}\exp(-jkr))) \\ &= \frac{1}{2}(\mathbf{E}_{10} \times \mathbf{H}_{10}^* + \mathbf{E}_{10}^* \times \mathbf{H}_{10}) \quad (128) \end{aligned}$$

Comparison (118) (128)

$$\mathbf{S}_m = \Re \mathbf{S}_{11}^{(C)} \quad (129)$$

The above formula shows that under the condition of satisfying Silver-Mueller radiation (when there are uniformly distributed absorbers), the real part of mutual energy flow is consistent with that of Poynting energy flow of classical electromagnetic theory. Therefore, in this case, we can still use Poynting vector to represent energy flow. Comparing (118) (128), we found that in this case

$$\mathbf{E}_1 \times \mathbf{H}_2^* = \mathbf{e}_1 \times \mathbf{h}_1^* \quad (130)$$

Consider $\mathbf{E}_1 = \mathbf{e}_1$ (the author temporarily believes that the two electric fields are consistent and do not need to be modified).

$$\mathbf{H}_2 = \mathbf{h}_1 \quad (131)$$

This shows that the magnetic field newly defined by the author $\mathbf{H}_2$ and the magnetic field obtained by classical electromagnetic method $\mathbf{h}_1$ are consistent. From $\mathbf{H}_2$ we can judge $\mathbf{H}_1$

$$\mathbf{H}_1 \sim -j\mathbf{H}_2 \sim -j\mathbf{h}_1 \quad (132)$$

The above formula is for the far field. We don't have the superscript and subscript f . We know the far field of the retarded magnetic field $\mathbf{H}_1$ unlike the classical magnetic field $\mathbf{h}_1$ is given by Maxwell's equation. For far field of magnetic field $\mathbf{H}_1$ we can get its far-field component from this case. As for the near field, it is consistent with the magnetic field of the classical electromagnetic field theory, so it has,

$$\mathbf{H}_{1n} = \mathbf{h}_{1n} \quad (133)$$

$$\mathbf{H}_1 = \mathbf{H}_{1n} + \mathbf{H}_{1f} = \mathbf{h}_{1n} - j\mathbf{h}_{1f} \quad (134)$$

The above formula is consistent with (47). However (47) is guessed, while (134) is more like derived. In short, if the Silver-Mueller radiation condition is satisfied, we can still calculate the electromagnetic radiation energy by using the classical electromagnetic field Poynting theorem. Therefore, the author does not mean to give up the definition of classical magnetic field. The use of the magnetic field defined by the author is more to consider the conservation relationship of electromagnetic energy and to interpret quantum mechanics.

4.3. Electric Field and Energy Flow of Dipole Antenna

For dipole antenna, the classical electromagnetic field theory tells us that the electric field and magnetic field are,

$$\begin{aligned} h_\phi &= \frac{1}{4\pi} I \Delta l j k \left(\frac{1}{jkr} + 1 \right) \frac{\exp(-j\mathbf{k} \cdot \mathbf{r})}{r} \sin\theta \\ &= \frac{1}{4\pi} I \Delta l \left(\frac{1}{r} + jk \right) \frac{\exp(-j\mathbf{k} \cdot \mathbf{r})}{r} \sin\theta \\ e_\theta &= \frac{j\omega\mu_0}{4\pi} I \Delta l \left(\frac{1}{(jk)^2 r^2} + \frac{1}{jkr} + 1 \right) \frac{\exp(-jkr)}{r} \sin\theta \quad (135) \end{aligned}$$

From this, the Poynting vector is calculated,

$$S_r = \frac{1}{2} e_\theta h_\phi^* = \frac{I^2 \Delta l^2}{8\lambda^2} \eta_0 \left(1 - j \frac{1}{(kr)^3} \right) \frac{\sin^2\theta}{r^2} \quad (136)$$

$$S_{rf} = \frac{1}{2} e_\theta h_\phi^* = \frac{I^2 \Delta l^2}{8\lambda^2} \eta_0 \frac{\sin^2\theta}{r^2} \quad (137)$$

The above formula is the Poynting energy flow of the classical electric field theory. According to the discussion in the previous section, this energy flow is actually the mutual energy flow S_m . Current here J_2 It's not just an absorber with an infinite radius. Due to the existence of these absorbers, the Silver-Mueller boundary condition at infinity is satisfied. We can also get further information,

$$E_{\theta f} = e_{\theta f} = \frac{j\omega\mu_0}{4\pi} I \Delta l \frac{\exp(-jkr)}{r} \sin\theta \quad (138)$$

Define the magnetic field,

$$H_{\phi f} = -jh_{\phi f} = \frac{1}{4\pi} I \Delta l \left(\frac{k}{r} \right) \exp(-j\mathbf{k} \cdot \mathbf{r}) \sin\theta \quad (139)$$

If the above formula is used to calculate Poynting's theorem

$$S_{rf} = \frac{1}{2} E_{\theta f} H_{\phi f} = j \frac{I^2 \Delta l^2}{8\lambda^2} \eta_0 \frac{\sin^2\theta}{r^2} \quad (140)$$

The above formula is the Poynting energy flow calculated according to the electric field and magnetic field defined by the author. This energy flow emits reactive power. This is just in line with the author's mutual energy theory.

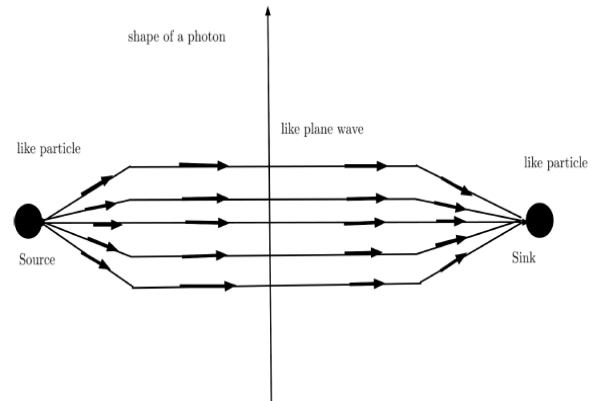


Figure 8. Shape of a photon, in the middle it like plane wave, in the two ends (the source and the sink) it like a particle.

4.4. Comments

In the above discussion, it seems that the author defines a magnetic field, and then applies this newly defined magnetic field to support the author's theory that Poynting's theorem does not transfer energy. In fact, it depends on whether the magnetic field defined by the author is reasonable. According to the magnetic field defined by the author, the magnetic field is completely consistent with the quasi static electromagnetic field near the current. However, if the magnetic field is defined according to the traditional method, there is always a far-field component near the conductor, which does not maintain the same phase as the current. Therefore, the magnetic field defined by the author is more in line with the definition of quasi static magnetic field. On the contrary, the magnetic field including radiation in the classical electric field theory is not quite consistent with the definition of quasi static magnetic field. In this way, the self energy flow and mutual energy flow calculated by using the magnetic field

defined by the author are consistent with the quasi static electromagnetic field. Therefore, the new magnetic field defined by the author is reasonable.

5. Photon

It is considered that photon is composed of retarded wave and advanced wave of pure full plane wave

The wave of photon emitted by the source is a retarded wave, and the wave emitted by the sink is a advanced wave. It is assumed that these waves are initially spherical waves. However, when the two waves are synchronized, the retarded wave can only move in the sink direction, and the advanced wave can only move in the source direction. At this time, they become plane waves or quasi plane waves. At this time, we say that the retarded wave is guided by the advanced wave, and the advanced wave is also guided by the retarded wave. Both retarded and advanced waves are plane waves (or quasi plane wave) along the direction of light line, just like waves propagating in optical fibers. In this case, the previous examples in section 3.3, 3.4 are applicable to the establishment of photon model. Of course, we also need normalization for photons [19]. That is, let the mutual energy flow be consistent with the energy of a photon.

$$(\xi_1, \xi_2) = \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2^* + \mathbf{E}_2^* \times \mathbf{H}_1) = \hbar\nu \quad (141)$$

We can see that when section 3.3, 3.4 are used as the model for photon, it is very close to the model of transactional interpretation of the quantum mechanics. In transactional interpretation the two waves the offer wave and the confirm wave have a handshake. In the mutual energy theory, the two energy flows S_{12} and S_{21} play the role of offer wave and confirm wave.

However, the authors believe that the absorber can randomly emit advanced waves. All absorbers are emitting advanced waves at random. Only one absorber releases the advanced wave just when the retarded wave reaches, and the advanced wave and retarded wave are just synchronized. Therefore, the advanced wave and the retarded wave form a mutual energy flow. In this case, the author must explain that if there are advanced wave of multiple absorbers synchronized with one retarded wave, it will form a few half photons. The author has explained this situation [12], that is Quantum Entanglement.

6. Conclusion

Through the transformer, the author studies the propagation of energy flow in the quasi static field environment, and finds that the self energy flow, that is, the energy flow corresponding to the Poynting vector is reactive power, and the mutual energy flow is active power. Therefore, self energy flow does not transfer energy. Mutual energy flow transfers energy. This is consistent with the author's view of mutual energy theory. However, when it comes to the radiation field or the far field of the antenna, for example, considering the radiation far field of the dipole antenna, the self energy flow transmits the active power. At this time, the complex Poynting theorem fails because of its radiation term

$-\oint_{\Gamma} (\mathbf{e} \times \mathbf{h}^*) \cdot \hat{n} d\Gamma$ and current items $\iiint_V \mathbf{e} \cdot \mathbf{J}^* dV$ are not equal. This paper holds that this is a bug in the classical electromagnetic theory. This bug also appears in the principle of mutual energy and the theorem of mutual energy flow. In order to fix this bug, the author puts forward a new definition of magnetic field. According to this new definition of magnetic field, the solution of the electromagnetic field must first satisfy the Poynting theorem and the mutual energy flow theorem. At this time, the far-field radiation of self energy flow represented by Poynting theorem must be reactive power. Mutual energy flow must be active power in both far-field and near-field. Therefore, self energy flow does not participate in energy radiation. The phenomenon of electromagnetic radiation is completely completed by mutual energy flow. In addition, the author found that when the mutual energy flow passes through the receiving antenna and moves to the back of the receiving antenna, due to the reverse magnetic field of the receiving antenna, the two mixed Poynting vectors in the mutual energy flow S_{12} and S_{21} offset, so the mutual energy flow is zero. This indicates that the receiving antenna absorbs all the energy. The author found that the mutual energy flow is on the back of the transmitting antenna, and the mixed Poynting vector S_{12} is caused by the reverse magnetic field of the transmitting antenna and hence offset with S_{21} . so the mutual energy flow is zero. When the mutual energy flow passes through the transmitting antenna, the energy flow jumps from zero to a normal value. This indicates that the mutual energy flow is generated on the transmitting antenna. At the receiving antenna, the mutual energy flow is absorbed or annihilated. The mutual energy flow theorem ensures that the mutual energy flow is constant between the receiving antenna and the transmitting antenna, which just describes the characteristics of photons. Once a photon is generated, it maintains a constant energy flow until it moves to the sink and annihilates. After annihilation, the energy flow will be zero. Therefore, this paper further supports the author's view that the mutual energy flow is photon.

In this paper, the two components of mutual energy flow S_{12} and S_{21} are close to the two waves of transactional interpretation of John Cramer [7,8]. Therefore, this paper can also be regarded as a quantitative concrete realization of the qualitative theory of transactional interpretation. The important contribution of this paper is to define a new electromagnetic field. Due to the definition of this electromagnetic field, the bug in Poynting theorem and mutual energy principle have been repaired. The original magnetic field in classical electromagnetic theory is still useful. It is still suitable for many solutions of Maxwell's equation, and supports the theory of retarded vector potential and scalar potential. In addition, Maxwell's theory can also be regarded as the radiation phenomenon when the Silver-Mueller radiation condition is satisfied, that is, the environment is full of receiving antennas. The author's mutual energy theory is to discuss the electromagnetic radiation phenomenon when the transmitting antenna and receiving antenna are in the abstract empty space. The author's mutual energy theory can explain quantum phenomena, which can not be completed by classical electromagnetic theory.

A new magnetic field is defined in this paper. But no

new electric field is defined. The electric field has two components, the first component $-\frac{\partial}{\partial t}\mathbf{A}$, which is consistent with the magnetic vector potential and does not need to change the definition. Another part $-\nabla\phi$ is still unclear and needs further research. However, for the interpretation of quantum mechanics, we only need to consider the electric field in the plane perpendicular to the dipole antenna. At this case $\nabla\phi = 0$.

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