

# 5 different superposition principles with/without test charge, retarded waves/advanced waves applied to electromagnetic fields or the photons

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## Abstract

In electromagnetic theory and quantum theory, there are superposition principle. Traditionally there are only one kind superposition principle. However, in this author's theory the retarded wave and advanced wave are all involved, the superposition become multiple. For example the author need to deal the problem how to superpose the retarded wave and the advanced wave. The author found that there are 5 different kinds of superpositions. The superposition principles have some differences. The research about these differences is a key to open the door of many physical difficulties. For example the particle and wave duality problem, and to judge which interpretation of the quantum mechanics is a correct one. The first two superposition principles are the superpositions with and without the test charges. The slight different superposition principles are the superposition with a retarded wave alone and the superposition with the advanced wave alone. According to theory of this author, the emitter sends the retarded wave, the absorber sends the advance wave. Hence, normal electromagnetic field actually is consist of retarded wave and advanced wave. This two waves together become the traditional electromagnetic fields. This kind of electromagnetic fields can be seen approximately as retarded wave only, this kind wave also has its own superposition. This kind of superposition is also different with the superposition when we consider the retarded waves alone and also the advanced waves alone. In this article this author will discuss the differences of these different superpositions. This author will also discuss the different physical result with a few different superposition principles. In this article this author will prove the superposition with test charge and the superposition with retarded waves alone or advance wave alone can be see one kind of superposition. This superposition is correct and can be derived from the mutual energy principle. This will be referred as first kind of superposition. The superposition without test charge and the superposition with the retarded waves and advanced waves can be seen as one kind of superposition. For this kind of superpositions are not correct naturally. This kind of super position are applied to N-charge's Poynting theorem. In order to make this superposition work, the self-energy principle have to

be applied. Without self-energy principle this kind of superpositions will violate the energy conservation law. Considering the self-energy conservation this kind of superposition become the superposition of first kind. This is referred as second kind of superposition. The third kind of superposition is for the traditional electromagnetic field. Here the traditional electromagnetic field means the electromagnetic field where the advanced waves are omit. When the advanced waves are omit doesn't mean the advanced waves do not exist, that is only means the retarded wave and the advanced wave are with nearly same intensity and can be treated together in some situation, for example, in wave guide, or in the free space where the absorber are uniformly distributed at infinite big sphere.

Only when the self-energy principle is accept, all kinds of superposition can be accept. However different superposition has different physical meanings. Otherwise only the superposition with test charge or the superposition with only one kind wave either retarded waves or advanced waves can be accepted. Hence, the discussion about the superposition also support the concept of the self-energy principle which means there must exist the time reversal waves. That also means the waves do not collapse but collapse back. Wave collapse means collapse to its target, for example, the retarded wave will collapse to an absorber and the advanced wave will collapse to an emitter. Wave collapse back means the retarded wave sent from emitter will collapse back to an emitter; The advanced wave sent from the absorber will collapse back to an absorber. Hence, one purpose of this article is to clarify the superposition principles, and another purpose is to support this author's electromagnetic field theory which is started from two new axioms the self-energy principle and the mutual energy principle.

Keywords: Poynting; Maxwell; Self-energy; Mutual energy; Mutual energy flow; Time reversal; Photon; Electromagnetic; Action-at-a-distance; Advanced wave; Advanced potential; Advanced field. Absorber theory; macroscopic, microscopic;

## 1 Introduction

Superposition principle is usually thought a self-explanatory principle. However, this author found that there are differences for different kinds of superpositions. Especially if we accept the advanced wave also as electromagnetic field similar to the retarded wave. It is naturally to ask also whether or not the retarded fields can be superposed to the advanced field? It is know that the retarded wave and advance wave all satisfy the Maxwell equations, hence, they are all electromagnetic field, hence it should be possible to superposed the retarded wave and the advanced wave. Whether or not the superposition principle can be applied, we can assume it can do it in the beginning, if this assumption doesn't conflict with any other theorem in electromagnetic field theory, the superposition can be accept. Other wise the superposition can not be accept.

## 1.1 Maxwell theory

In Maxwell theory the field can be superposed. That means for example for each charge the field satisfy the Maxwell equations,

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

$$\nabla \cdot \mathbf{B}_i = 0 \quad (2)$$

$$\nabla \times \mathbf{E}_i = \mathbf{J}_i + \frac{\partial \mathbf{D}_i}{\partial t} \quad (3)$$

$$\nabla \times \mathbf{H}_i = -\frac{\partial \mathbf{B}_i}{\partial t} \quad (4)$$

where  $\rho_i, \mathbf{J}_i$  are charge intensity and current intensity of  $i$ -th charge. Assume there are  $N$  charges, then the field can be superposed as following,

$$\mathbf{E} = \sum_{i=1}^N \mathbf{E}_i \quad (5)$$

$$\mathbf{H} = \sum_{i=1}^N \mathbf{H}_i \quad (6)$$

or

$$\xi = \sum_{i=1}^N \xi_i \quad (7)$$

where  $\xi = [\mathbf{E}, \mathbf{H}]$  and  $\xi_i = [\mathbf{E}_i, \mathbf{H}_i]$ . This is the superposition principle. This superposition are without any additional conditions.

## 1.2 Absorber theory

However there are lot of arguments about the above superposition principle. That is electromagnetic field is defined on the force of the charge, the magnetic field is defined on the force to a moved charge. The charge play a rule as a test charge. They have the argument that if the test charge is here, it is clear the force can be superposed, and hence the field also can be superposed. Because the electric field is defined by the electric force divided the charge.

$$\mathbf{F}_e = q\mathbf{E} \quad (8)$$

$$\mathbf{F}_h = q\mathbf{v} \times \mathbf{B} \quad (9)$$

where  $q$  is the charge amount of the test charge.  $\mathbf{F}_e$  is the force assumed to the charge.  $\mathbf{F}_h$  is the magnetic force exerted to the charge. However this doesn't mean that if you can superpose the two electric fields or two magnetic fields even if the test charge isn't there.

In the absorber theory of Wheeler and Feynman[1], they said that the electromagnetic fields have no their own freedom. They are adjunct fields to the action-at-a-distance[2].

We know that action take place among at least two objects for example an emitter and an absorber. Hence the retarded field of the emitter can be defined on the place of the absorber because the absorber can be applied as a test charge. The advanced field of the absorber can be defined on the place of the emitter, because the emitter can be applied as a test charge to the advanced field. When there is only one charge, there is no another charge as the test charge, the action between two charges cannot be built and hence the action cannot be existed. If the action cannot be existed, because the electromagnetic fields are adjunct fields to the action, which cannot be existed too. Any way without test charge it is possible the field cannot be defined correctly, if field themselves cannot be defined how they can be superposed?

The absorber theory of Wheeler and Feynman [1, 2] involved the field of advanced field. Advanced field, has also been said as advanced wave or advanced potential. In electromagnetic field theory advanced potential is used more often, in quantum physics, the advanced wave is used more often. The following we have to review the theories about the advance wave.

### 1.3 Review of the theory for photon and electromagnetic fields which the advanced wave is involved

Maxwell equations have two solutions, the retarded potential/wave and the advanced potential/wave. But it is not clear about the relationship of the retarded wave and the advanced wave from the Maxwell's theory. The theory of the action-at-a-distance from Schwarzs, Child-Tetrode and Fokker [16, 9, 17], the absorber theory of Wheeler-Feynman[1, 2] and the transactional interpretation of Cramer [5, 6] all supported the existence of the both retarded wave and advanced wave. According to the absorber theory, the current will send the retarded wave and advanced wave in the same time. Each has the half value of the total field. That means

$$\xi = \xi_r + \xi_a \quad (10)$$

Where  $\xi = [\mathbf{E}, \mathbf{H}]$  is the total electromagnetic field.  $\xi_r = [\mathbf{E}_r, \mathbf{H}_r]$  is the retarded field,  $\xi_a = [\mathbf{E}_a, \mathbf{H}_a]$ , is the advanced field.

W.J. Welch has introduced time-domain reciprocity theorem[18] in 1960. In 1963 V.H. Rumsey mentioned a method to transform the Lorentz reciprocity theorem to a new formula[15]. In early of 1987 this author has introduced the concept of mutual energy and the mutual energy theorem [11, 20, 19]. In the end of 1987 Adrianus T. de Hoop has introduced the time domain cross-correlation reciprocity theorem[7]. It can be proven that the cross correlation reciprocity theorem of de Hoop is the inverse Fourier transform of the mutual energy theorem of this author. Welch's reciprocity theorem is a special situation of the cross correlation reciprocity theorem. Rumsey reciprocity theorem has the same formula with the mutual energy theorem. Hence all these 4 theorems

are a same theorem in different domain: Fourier domain or time domain. In these theorems, the advanced waves were involved. These theorems are clear a reciprocity theorem, but this author believe it is also an energy theorem and hence, will call all these theorem as the mutual energy theorems.

This author noticed that the energy transfer in the empty space is more accurate by using the mutual energy theorem instead of the Poynting theorem. The Poynting theorem often lead to wrong results. For example, if we calculate the receiving energy or scattering energy of a small object, we should use the Poynting vector times the object's section area. However, that often offers a wrong result. Hence, some one create a concept "the effective scattering section area" which is much larger than the object's real section area. We use the Poynting vector times the effective scattering section area to calculate the received or scattered energy of the object. The effective scattering section area can be thousand times larger than the object's real section area. That actually means there is thousand times error if we use the Poynting theorem to calculate the energy received or scattered by a object.

This author also noticed that if the Poynting theorem together with superposition principle applied to a situation with  $N$  charges, there are conflicts to the energy conservation law [12].

This author combined the concept of mutual energy and the mutual energy theorem[11] with the concepts in absorber theory[1, 2] introduced the mutual energy principle. The theory of the mutual energy principle is further proven by introducing the energy conservation condition to the classical electromagnetic field theory of Maxwell, which also need to introduced the self-energy principle. The two new principles can be applied as two axioms for the electromagnetic field theory [12].

The self-energy principle tells us there should be 4 waves in the electromagnetic field theory instead of 1 or 2 waves. The 4 waves are the retarded wave, the advanced wave and the two time-reversal waves. The two time-reversal waves are the time-reversal wave corresponding to the retarded wave and the time-reversal wave corresponding to the advanced wave. The 4 waves completely balanced out or canceled. And hence, the waves cannot transfer energy in space.

The mutual energy principle tell us the retarded wave and the advanced wave must synchronized. Only one wave for example the retarded wave can not satisfy the mutual energy principle, and hence, a wave can not have the real physical effect. The retarded wave of the emitter and the advanced wave of the absorber can be superposed to produce the mutual energy flow which can carry energy in the space. There is also a time-reversal mutual energy flow. The energy of the photon can be described by the mutual energy flow. The time-reversal mutual energy flow is responsible to bring the half photon or partial photon back to the emitter if a race case happens and the two absorbers each received the energy of half photon. These new electromagnetic field theory is suitable not only the electromagnetic fields but also to the photonics.

## 1.4 The Maxwell equations and the superpositions

We often heard that the Maxwell field are linear, hence, the fields can be superposed. This author do not think this is true without any limitation. Hence, in this article the Maxwell equations for single charge and the Maxwell equations for superposed fields are believed as different Maxwell equations. This means this author does not believe Maxwell equations implied the superposition principle. This author will explicitly distinguish Maxwell equations and the superposition principle. This author will explicitly distinguish the Maxwell equations for a single charge or the Maxwell equation for the superposed fields. In the later section the reader will found in this article the superposition will also be divided as different superpositions according to whether the test charge appears or not. The superpositions also will be distinguished as the fields of the retarded waves alone, the fields of the advanced waves alone or the fields of traditional fields. The traditional field is a field used in the electromagnetic field theory where the advanced wave do not accept and hence the advanced wave has been merged to the retarded field.

Since in the author's electromagnetic field theory the advanced field is accept, the superposition needs to be distinguished with a few different situations.

## 2 Superposition principle

### 2.1 Superposition without test charge

Accounting the introduction we have known that about the superposition principle there are different opinions. Even they have different opinions, both sides claim they are the corrected superposition principle. In order to distinguish the two situations, the superposition without a test charge and the superposition with a test charge are explicitly given two names.

See Figure 1, there are 3 charges A, B, and C in the empty space (a empty space is a assumed space where is nothing else). Assume D is a at a place there is no any charge. It is clear the superposition of the 3 charges on the place D will be,

$$\xi_D = \xi_{AD} + \xi_{BD} + \xi_{CD} \quad (11)$$

where  $\xi_D = [\mathbf{E}_D, \mathbf{H}_D]$  is the electromagnetic field on the place  $D$ .  $\xi_{AD} = [\mathbf{E}_{AD}, \mathbf{H}_{AD}]$  is the field at the place  $D$  and produced by the charge  $A$ .  $\xi_{BD} = [\mathbf{E}_{BD}, \mathbf{H}_{BD}]$  is the field at place  $D$  produced by the charge  $B$ .  $\xi_{CD} = [\mathbf{E}_{CD}, \mathbf{H}_{CD}]$  is the field at the place  $D$  produced by the charge  $C$ . Hence, we have,

$$\mathbf{E}_D = \mathbf{E}_{AD} + \mathbf{E}_{BD} + \mathbf{E}_{CD} \quad (12)$$

$$\mathbf{H}_D = \mathbf{H}_{AD} + \mathbf{H}_{BD} + \mathbf{H}_{CD} \quad (13)$$

This kind of superposition is referred as superposition without test charge. Hence, the corresponding of the superposition principle is referred as the superposition principle without the test charge.

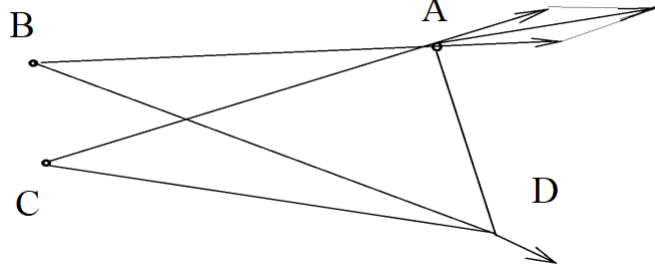


Figure 1: Assume there are 3 charges in the empty space. Charge  $A$ , Charge  $B$  and Charge  $C$ . We discuss the superposition on place  $D$  there are no charges and the superposition on the place  $A$ ,  $B$  or  $C$  where there is a charge.

It should be notice, in this author's electromagnetic field theory, the retarded wave and the advanced wave are all acceptable and hence, this superposition means the superposition with all kind fields include the retarded waves and also the advanced waves.

## 2.2 Superposition with test charge

In the place of  $A$ ,  $B$  and  $C$ , there are charges, hence the self-field are infinite. The self-field is the infinite big,

$$\begin{cases} \mathbf{E}_{AA} = \infty \\ \mathbf{E}_{BB} = \infty \\ \mathbf{E}_{CC} = \infty \end{cases} \quad (14)$$

And hence in any place with a charge, for example  $A$ , the field can only be superposed with the fields of the other two charges, for example,

$$\begin{cases} \mathbf{E}_A = \mathbf{E}_{BA} + \mathbf{E}_{CA} \\ \mathbf{H}_A = \mathbf{H}_{BA} + \mathbf{H}_{CA} \end{cases} \quad (15)$$

It is same to the fields of  $\xi_B = [\mathbf{E}_B, \mathbf{H}_B]$ ,  $\xi_C = [\mathbf{E}_C, \mathbf{H}_C]$  they can also only superposed with two charges. According to the absorber theory of Wheeler and Feynman, they support this kind of superposition. Because, there is a test charge, the field can be defined according to the action. For the superposition without test charge, according the absorber theory[1, 2] that this kind of superposition is not really correct because without test charge we cannot define the action, without action, the field cannot be defined correctly, if field cannot be defined correctly, the superposition can not be done too.

### 2.3 Superposition all retarded fields or all advanced wave

In subsection 2.1. The superposition include all retarded wave and advanced wave. However some time we need the superposition only with only the retarded wave or only with advanced wave. Hence we need to define,

$$\xi_r = \sum_{i=1}^N \xi_{ri} \quad (16)$$

$$\xi_a = \sum_{j=1}^M \xi_{aj} \quad (17)$$

$\xi_r = [\mathbf{E}_r, \mathbf{H}_r]$  is the retarded wave.  $\xi_a = [\mathbf{E}_a, \mathbf{H}_a]$  is the advanced wave,  $\xi_{ri} = [\mathbf{E}_{ri}, \mathbf{H}_{ri}]$  is the retarded wave of the  $i$ -th charge.  $\xi_{aj} = [\mathbf{E}_{aj}, \mathbf{H}_{aj}]$  is the advanced wave of the  $j$ -th charge.

### 2.4 Superposition for the total field of the electromagnetic fields

We know that according to this author electromagnetic field theory [13], there is the advanced wave and the retarded wave. However in our traditional electromagnetic field theory only the retarded field is applied. We should say that, this traditional electromagnetic field theory is also very successful in most situations. However, this electromagnetic field actually are superposed field of the advanced field and the retard field, that means,

$$\xi_t = \xi_r + \xi_a \quad (18)$$

where  $\xi_t$  is traditional electromagnetic field.  $\xi_r$  is the retarded wave,  $\xi_a$  is the advanced wave.

If there are two different traditional fields, these two fields should be possible to be superposed which means that,

$$\xi_t = \sum_{i=1}^N \xi_{ti} \quad (19)$$

$\xi_{ti}$  are transitional field which is composed with the retarded waves and the advanced waves. The superposition principle to this kind of field is certainly different with the superposition principle described in a few last sub-sections. We will discussion this kind of superposition in details later.

### 2.5 Summarization

When we talk about superposition and superposition principles, we have to be clear that what kind of superposition is involved. We also need to know the differences of these superpositions. This article will discuss all the differences of these superposition and the superposition principles.



### 3 Conflict between the superposition principle without test charge and the energy conservation law

Wheeler and Feynman has noticed the problem of the definition of the field[1, 2]. Defined a field need a test charge. If field cannot be defined properly how it can be superposed? Hence, according their discussion, the superposition principle without test charge is problematic. This kind of superposition superpose all field of charges include the retarded wave and the advanced wave.

But Wheeler and Feynman did not offer a clear solution to solve this problem. They only ask the reader should avoid that kind of wrong field and hence, the wrong superposition (superposition without a test charge). Because according there absorber theory[2], the field has no its own freedom, the electromagnetic fields are only the adjective field of the action-at-a-distance. but action-at-a-distance needs at least two charges, one is emitter to produce the retarded wave, another is used as the test charge to measure the electromagnetic field. Hence, to define the electromagnetic field a test charge is needed. If define a electromagnetic field need a test charge. According their discussion, to superpose the electromagnetic field also need a test charge.

In this article this author will try to find the reason of the problem and offer a clear solution to this kind of superposition. Hence, this author will assume the superposition without test charge is allowed now. If this assumption lead to a conflict, this author will solve the problem in that time.

#### 3.1 The energy conservation law

Let us assume there are  $N$  charges in the empty space. Empty space is an abstract space there are nothing in it, no star no sun and no earth. We first calculate the total work have done by this  $N$  charges. This is clear that the work has done by  $N$  charge can be expressed as,

$$W = \int_{t=-\infty}^{\infty} \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV dt = 0 \quad (20)$$

where  $\iiint_V \mathbf{E}_i \cdot \mathbf{J}_j dV$  is the current of the  $i$ -th charge exerted a power to the  $j$ -th charge.

The above formula tell us, the total work is done for all charges are 0. This is self self-explanatory, because if a charge offer some work to the other charge, then the other charge's energy will increase, but in the same time the charge itself will lose equal part of the energy. To the total work has been done, somewhere the work increase is canceled by the work decrease at the other place. We will assume the above  $N$ -charge energy conservation law is self-explanatory.

### 3.2 Superposition principle without test charge

Assume that the superposition principle without test charge is correct. In the beginning I will assume this kind of superposition is correct, however I will point out this can lead a conflict to the energy conservation law and hence is not really correct. Substitute Eq.(5,6) to the Maxwell equations Eq.(1, 2, 3 and 4) we obtained the Maxwell equations for superposed field,

$$\nabla \cdot \mathbf{D} = \rho \quad (21)$$

$$\nabla \cdot \mathbf{B} = 0 \quad (22)$$

$$\nabla \times \mathbf{E} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t} \quad (23)$$

$$\nabla \times \mathbf{H} = -\frac{\partial \mathbf{B}}{\partial t} \quad (24)$$

where

$$\xi = \sum_{i=1}^N \xi_i \quad (25)$$

where  $\xi = [\mathbf{E}, \mathbf{H}]$  and  $\xi_i = [\mathbf{E}_i, \mathbf{H}_i]$ . The above formula is the superposition without test charge.

### 3.3 The Poynting theorem

The Poynting theorem can be derived from the above Maxwell equations Eq.(21-24). Assume the Poynting theorem is correct for the superposed field  $\xi = [\mathbf{E}, \mathbf{H}]$ , i.e.,

$$\begin{aligned} & - \iint_S (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma \\ & = \iiint_V \mathbf{E} \cdot \mathbf{J} dV + \iiint_V (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV \end{aligned} \quad (26)$$

In the above we have written  $\frac{\partial}{\partial t}$  as  $\partial$  for simplicity. This simplification will be used in the whole article. Apply the supposition principle without test charge Eq.(5,6) to the above formula we have,

$$\begin{aligned} & - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\ & = \iiint_V \sum_{i=1}^N \sum_{j=1}^N \mathbf{E}_i \cdot \mathbf{J}_j dV + \iiint_V \sum_{i=1}^N \sum_{j=1}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \end{aligned} \quad (27)$$

The above formula is referred as the Poynting theorem of  $N$  charges.

### 3.4 The 3 conditions to prove from the above $N$ charges Poynting theorem to the energy conservation law

Let us analysis, how we can derive the energy conservation law from the above Poynting theorem of  $N$  charges to the energy conservation law Eq.(20). There are 3 steps to lead the energy conservation law.

I. Self-energy terms:

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \mathbf{E}_i \times \mathbf{H}_i \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V \sum_{i=1}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad (28)
\end{aligned}$$

do not contributed to the energy transfer between the charge.

Hence, the above formula can be subtracted from the  $N$  charge of Poynting theorem Eq.(27), we obtain,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \quad (29)
\end{aligned}$$

This formula is referred as mutual energy formula. In the above formula if we can prove that

II.

$$\oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma = 0 \quad (30)$$

This means that the surface integral terms are 0.

III.

$$\int_{t=-\infty}^{\infty} dt \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV = 0 \quad (31)$$

This means the space energy terms are 0.

If the 3 conditions are met, we obtain,

$$\int_{t=-\infty}^{\infty} dt \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV = 0 \quad (32)$$

That will be the energy conservation law. Hence, it is clear the proof of energy conservation law needs the above 3 steps I, II. and III.

We can prove the step I and II but we cannot prove the steps I, we cannot prove all items in Eq.(28) are 0. However we just assume it is 0 for the time being, see what will happen.

### 3.5 Two charge situation

The above equation Eq.(29) can be rewritten as

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \cdot \mathbf{J}_j + \mathbf{E}_j \cdot \mathbf{J}_i) dV \\
& + \iiint_V \sum_{i=1}^N \sum_{j=1, j < i}^N [(\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) + (\mathbf{E}_j \cdot \partial \mathbf{D}_i + \mathbf{H}_j \cdot \partial \mathbf{B}_i)] dV \quad (33)
\end{aligned}$$

Assume  $N = 2$ , we obtain,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^2 \sum_{j=1, j < i}^2 (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^2 \sum_{j=1, j < i}^2 (\mathbf{E}_i \cdot \mathbf{J}_j + \mathbf{E}_j \cdot \mathbf{J}_i) dV \\
& + \iiint_V \sum_{i=1}^2 \sum_{j=1, j < i}^2 [(\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) + (\mathbf{E}_j \cdot \partial \mathbf{D}_i + \mathbf{H}_j \cdot \partial \mathbf{B}_i)] dV \quad (34)
\end{aligned}$$

or

$$\begin{aligned}
& - \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \\
& = \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \\
& + \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV \quad (35)
\end{aligned}$$

The differential formula of above formula is,

$$\begin{aligned}
& -\nabla \cdot (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \\
& = \mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1 \\
& + \mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1 \quad (36)
\end{aligned}$$

When  $N = 2$ , there is only two charges, For example one is the emitter and another is the absorber. The emitter sends the retarded wave which is  $\xi_1 = [\mathbf{E}_1, \mathbf{H}_1]$ . The absorber sends the advanced wave which is  $\xi_2 = [\mathbf{E}_2, \mathbf{H}_2]$ .

Eq.(35, 36) are mutual energy formula for two charges. Now we assume that the two charges are also possible two emitters or two absorbers. Any way there are two charges.

It is easy to discuss the situation there are only two charges. The results can be widen to the situation where we have  $N$  charges.

## 4 Welch's reciprocity theorem and the mutual energy theorem

Let us following the proof of Welch's reciprocity[18] to prove the two condition II. and III. We will only do this in two charge situation, the result can be easily widen to  $N$  charges.

### 4.1 To prove the surface integral is 0

Proof for

$$-\oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma = 0 \quad (37)$$

Assume the surface  $\Gamma$  is a sphere with infinite big radius. Assume the fields  $\xi_1 = [\mathbf{E}_1, \mathbf{H}_1]$  and  $\xi_2 = [\mathbf{E}_2, \mathbf{H}_2]$  are fields of two charges close to the center of the big sphere  $\Gamma$ . Welch assume that the two fields  $\xi_1$  and  $\xi_2$  one is retarded field and another is advanced field. When the retarded wave and the advanced wave reach the sphere, one is in a future time and another is in a past time. Hence, the two fields can not nonzero in the same time at the surface of  $\Gamma$ . Hence,  $\mathbf{E}_1 \times \mathbf{H}_2$  and  $\mathbf{E}_2 \times \mathbf{H}_1$  the two products must zero at the surface  $\Gamma$  and hence the surface integral above is zero. The proof finished.

Only when the two fields  $\xi_1 = [\mathbf{E}_1, \mathbf{H}_1]$  and  $\xi_2 = [\mathbf{E}_2, \mathbf{H}_2]$  one is retarded field and another is advanced field we can have the surface integral as 0. If the two field all the retarded field or all advanced fields we cannot prove the surface integral as 0 in general.

### 4.2 The energy in the empty space are 0

We need to prove:

$$\int_{t=-\infty}^{\infty} \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV dt = 0 \quad (38)$$

We have,

$$\int_{t=-\infty}^{\infty} \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV dt$$

$$\begin{aligned}
&= \int_{t=-\infty}^{\infty} \partial U dt \\
&= U|_{t=-\infty}^{\infty} \\
&= 0
\end{aligned} \tag{39}$$

where

$$\begin{aligned}
\partial U &= \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV \\
&= \partial \iiint_V (\epsilon_0 \mathbf{E}_1 \cdot \mathbf{E}_2 + \mu_0 \mathbf{H}_1 \cdot \mathbf{H}_2) dV
\end{aligned} \tag{40}$$

where  $\mathbf{D}_2 = \epsilon_0 \mathbf{E}_2$ ,  $\mathbf{B}_2 = \mu_0 \mathbf{H}_2$ , where  $\epsilon_0$  and  $\mu_0$  are permittivity and permeability constant. Space energy is,

$$U = \iiint_V (\epsilon_0 \mathbf{E}_1 \cdot \mathbf{E}_2 + \mu_0 \mathbf{H}_1 \cdot \mathbf{H}_2) dV \tag{41}$$

$U(-\infty)$  and  $U(\infty)$  are too stable energy stats, they should be equal to each other, and hence, there is  $U|_{t=-\infty}^{\infty} = 0$ .

### 4.3 The reciprocity of Welch

Integral with time to Eq.(35) we obtain,

$$\begin{aligned}
& - \int_{t=-\infty}^{\infty} \oiint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
&= \int_{t=-\infty}^{\infty} \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV dt \\
&+ \int_{t=-\infty}^{\infty} \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV dt
\end{aligned} \tag{42}$$

Substitute the Eq.(37,38) to the mutual energy formula above, we obtained,

$$\int_{t=-\infty}^{\infty} \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV dt = 0 \tag{43}$$

or

$$- \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt = \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV \quad (44)$$

This is the Welch's reciprocity theorem[18].

#### 4.4 The new reciprocity of Rumsey

V.H. Rumsey has introduced the new reciprocity theorem in 1961[15], which is similar to the Welch's reciprocity theorem, but it is in the Fourier domain.

$$- \iiint_V \mathbf{E}_2(\omega) \cdot \mathbf{J}_1(\omega) dV = \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(\omega) \cdot \mathbf{J}_2(\omega) dV \quad (45)$$

In this article, we will use same symbol to the electromagnetic field in the time-domain and in the Fourier domain. The difference can be distinguished by the two different variable  $t$  and  $\omega$ .

#### 4.5 The mutual energy theorem

The above formula is re-derived by this author in beginning of the 1987. The formula is referred as Mutual energy theorem[11, 20, 19]. The important is that this author realized that this formula is some kind of energy theorem instead of just a reciprocity theorem.

#### 4.6 The cross-correlation reciprocity theorem of de Hoop

de Hoop derived the cross-correlation reciprocity theorem in the end of 1987 based on the Welch's reciprocity theorem. The proof of Welch can be widen to the cross-correlation reciprocity theorem of de Hoop.

$$- \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_2(t + \tau) \cdot \mathbf{J}_1(t) dV dt = \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(t) \cdot \mathbf{J}_2(t + \tau) dV \quad (46)$$

It is clear that Welch's reciprocity is a spatial situation of de Hoop's reciprocity theorem, in which  $\tau = 0$ . It is also clear that the Rumsey's reciprocity theorem or the mutual energy theorem of this author are Fourier transform of the de Hoop's reciprocity theorem. Hence these 4 theorems can be seen as one theorem.

This author will call this 4 theorem as the mutual energy theorem, the reason is these theorems are reciprocity theorem no problem. But they are not only a pure reciprocity theorem like the Lorentz reciprocity theorem[3, 4, 14], they are also a energy theorem.

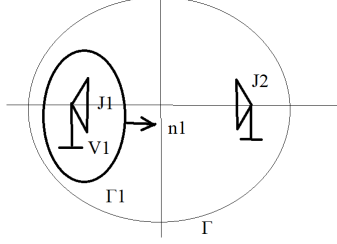


Figure 2: If the  $V_1$  is taken in which only has the current  $\mathbf{J}_1 \neq 0$ .

## 5 The mutual energy flow and mutual energy flow theorem

### 5.1 The mutual energy flow theorem

Substitute Eq.(39) to the mutual energy formula Eq.(42) we obtain,

$$\begin{aligned}
 & - \int_{t=-\infty}^{\infty} \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
 & = \int_{t=-\infty}^{\infty} \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV dt
 \end{aligned} \tag{47}$$

In this time we do not take the surface  $\Gamma$  at infinite big sphere, hence the surface integral is not zero in general. Consider the volume  $V$  is at  $V_1$  in which only the current  $\mathbf{J}_1$ . See Figure 2

$$\begin{aligned}
 & - \int_{t=-\infty}^{\infty} \oint_{\Gamma_1} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
 & = \int_{t=-\infty}^{\infty} \iiint_{V_1} \mathbf{E}_2 \cdot \mathbf{J}_1 dV dt
 \end{aligned} \tag{48}$$

similarly we have,

$$\begin{aligned}
 & - \int_{t=-\infty}^{\infty} \oint_{\Gamma_2} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
 & = \int_{t=-\infty}^{\infty} \iiint_{V_2} \mathbf{E}_1 \cdot \mathbf{J}_2 dV dt
 \end{aligned} \tag{49}$$

or



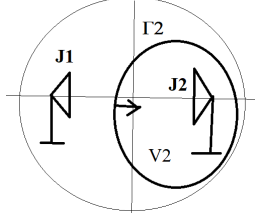


Figure 3: If the  $V_2$  is taken in which only has the current  $\mathbf{J}_2 \neq 0$ .

$$\begin{aligned}
& \int_{t=-\infty}^{\infty} \oint_{\Gamma_2} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
&= \int_{t=-\infty}^{\infty} \iiint_{V_2} \mathbf{E}_1 \cdot \mathbf{J}_2 dV dt
\end{aligned} \tag{50}$$

See Figure 3. In equation Eq.(50) we have changed the direction of the normal vector  $\hat{n}$  surface integral. Originally the direction  $\hat{n}$  is direct to the outside of the sphere  $\Gamma_2$ . After the change, the direction is from  $V_1$  to  $V_2$  hence, obtained a negative sign.

Substitute Eq.(38,39) to the Welch's reciprocity theorem Eq.(44), we obtain,

$$\begin{aligned}
& - \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt \\
&= \int_{t=-\infty}^{\infty} \oint_{\Gamma_1} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
&= \int_{t=-\infty}^{\infty} \iint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
&= \int_{t=-\infty}^{\infty} \oint_{\Gamma_2} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
&= \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV
\end{aligned} \tag{51}$$

See Figure 4. We have add a surface  $\Gamma$  which is a infinite big plane, Actually the surface can be taken in any place between the current  $\mathbf{J}_1$  and  $\mathbf{J}_2$ . The surface can be a complete surface like  $\Gamma_1$  and  $\Gamma_2$ . The surface is also can be a

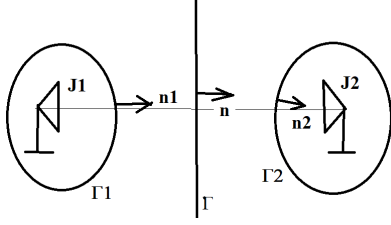


Figure 4: mutual energy flow can be calculate at  $\Gamma_1, \Gamma, \Gamma_2$ .

infinite open space like  $\Gamma$ . All the direction of the norm vector of the surfaces are from  $V_1$  to  $V_2$ .

It has been proved [11, 12] that

$$(\xi_1, \xi_2) = \int_{t=-\infty}^{\infty} \oiint_{\Gamma_1} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \quad (52)$$

is a inner product, that means,

$$(\xi_1, \xi_2) = (\xi_2, \xi_1) \quad (53)$$

$$(\xi_1, \gamma \xi_2) = \gamma (\xi_2, \xi_1) \quad (54)$$

$$(\xi_1, \xi_{21} + \xi_{22}) = (\xi_1, \xi_{21}) + (\xi_1, \xi_{22}) \quad (55)$$

$$(\xi, \xi) = 0 \iff \xi = 0 \quad (56)$$

Hence the mutual energy flow theorem can be re-written as,

$$\begin{aligned} & - \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt \\ & \quad = (\xi_1, \xi_2) \\ & \quad = \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV \end{aligned} \quad (57)$$

In the above formula, the inner product  $(\xi_1, \xi_2)$  can be taken in any surface between  $\mathbf{J}_1$  and  $\mathbf{J}_2$ .

We can assume that  $\mathbf{J}_1$  is the source which sends the retarded field.  $\mathbf{J}_2$  is a sink or absorber which sends the advance wave.  $\mathbf{J}_1$  and  $\mathbf{J}_2$  one must send retarded wave and another must sends the advanced wave, these are requirement of Eq.(37). We can see the mutual energy flow in Figure 5.

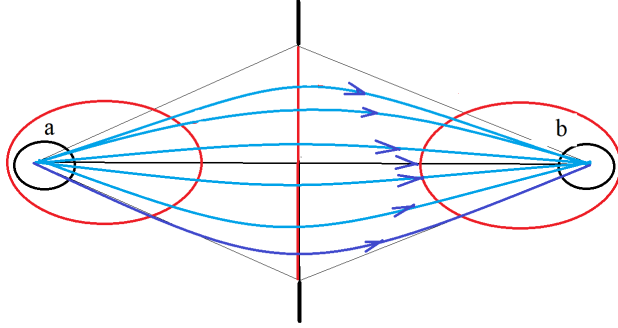


Figure 5: mutual energy flow can be calculate at  $\Gamma_1, \Gamma, \Gamma_2$ .

## 5.2 Orthogonality with same waves

We can see, the retarded wave sends from the emitter to the absorber can produce the mutual energy flow. What about the same wave for example the two retarded waves or the two advanced waves send from the two current  $\mathbf{J}_1$  and  $\mathbf{J}_2$ .

We assume the current  $\mathbf{J}_1$  and  $\mathbf{J}_2$  are not too close to each other, we assume the currents are all very short signals. Assume the two currents all send the retarded waves. Since in this situation, the two waves cannot be synchronized, That means the field cannot no zero in the same time at all the surfaces of  $\Gamma$ s, The  $\Gamma$  is the any surface between  $\mathbf{J}_1$  and  $\mathbf{J}_2$ .

For example assume the retarded wave of  $\xi_1$  which is sent by current  $\mathbf{J}_1$  reached the  $\mathbf{J}_2$  at the time  $t$ , in this time  $\mathbf{J}_2$  send a retarded wave  $\xi_2$ . The two wave can only no zero in the same time at the time  $t$  and at the place of the  $\mathbf{J}_2$ , after time  $t$  or before time  $t$  the two field  $\xi_1$  and  $\xi_2$  are not nonzero in the same time in and surface  $\Gamma$ , hence we have,

$$(\xi_1, \xi_2) = \int_{t=-\infty}^{\infty} \oiint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt = 0 \quad (58)$$

This can be referred as second mutual energy flow theorem, that means the two retarded waves are orthogonal in the surface  $\Gamma$  where  $\Gamma$  is any surface between the currents  $\mathbf{J}_1$  and  $\mathbf{J}_2$ . It should be noticed that if there is a surface the above integral is 0, there will no any energy can be sent from the emitter to the another emitter. In the above we have proved there is only one surface the above integral is possible not zero other surface are all zero. And hence, in this situation there is no any energy can be sent from an emitter to another emitter. This is also true for the two absorbers which sends the advanced waves.

If the mutual energy flow between two retarded wave are zero, that is clear we have,

$$\begin{aligned}
& - \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt \\
& = (\xi_1, \xi_2) = 0 \\
& = \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV dt
\end{aligned} \tag{59}$$

That means a retarded wave cannot send any energy to another emitter. Similarly, an advanced wave cannot send any energy to an absorber.

Please notice, a current actually send the retarded wave and advance wave in the same time. They send half retarded potential and half advanced potential[1, 2]. However we can think that the currents are two currents one is a emitter which sends out the retarded wave, the another is a absorber which sends the advanced wave.

The sun can been seen to have many emitters, the black clothes can be seen to have many absorbers. Actually the sun can receive energy also and has lot of absorbers in it too. The black clothes have also many emitters inside which can send retarded waves, however, we can see the sun as all emitters for simplification. We can see that the black clothes are only absorbers for simplification.

It should be noticed that in the later section when the self-energy principle is introduced, there is the time-reversal waves. Hence, if the charge with current send half retarded wave and half advance wave, if the advanced wave cannot meet another retarded wave from another charge, this advanced wave will be canceled by its corresponding time-reversal wave, and hence, no any physical effect to the space and, hence, can be omit. In this situation this charge is a pure emitter. It only sends out the retarded wave.

## 6 The mutual energy principle

### 6.1 A clear look at the proof of Welch's reciprocity theorem

If we have a clear look to the proof of Welch's reciprocity theorem, we can found it is can be started from the Poynting theorem

$$\begin{aligned}
& - \iint_S (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma \\
& = \iiint_V \mathbf{E} \cdot \mathbf{J} dV + \iiint_V (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV
\end{aligned} \tag{60}$$

and also for the two charges we have

$$\begin{aligned}
& - \iint_S (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma \\
& = \iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad i = 1, 2 \quad (61)
\end{aligned}$$

Assume the superposition principle, without test charge is correct, that means

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 \quad (62)$$

$$\mathbf{H} = \mathbf{H}_1 + \mathbf{H}_2 \quad (63)$$

Substitute Eq.(62,63) to the Eq.(60) we have,

$$\begin{aligned}
& - \iint_{\Gamma} \sum_{i=1}^2 \sum_{j=1}^2 (\mathbf{E}_i \times \mathbf{H}_j) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^2 \sum_{j=1}^2 \mathbf{E}_i \cdot \mathbf{J}_j dV + \iiint_V \sum_{i=1}^2 \sum_{j=1}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \quad (64)
\end{aligned}$$

Subtracting Eq.(61) from the above formula we obtain,

$$\begin{aligned}
& - \iint_{\Gamma} \sum_{i=1}^2 \sum_{j=1, j \neq i}^2 (\mathbf{E}_i \times \mathbf{H}_j) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^2 \sum_{j=1, j \neq i}^2 \mathbf{E}_i \cdot \mathbf{J}_j dV + \iiint_V \sum_{i=1}^2 \sum_{j=1, j \neq i}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \quad (65)
\end{aligned}$$

or

$$\begin{aligned}
& - \iint_{\Gamma} \sum_{i=1}^2 \sum_{j=1, j < i}^2 (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^2 \sum_{j=1, j < i}^2 (\mathbf{E}_i \cdot \mathbf{J}_j + \mathbf{E}_j \cdot \mathbf{J}_i) dV \\
& + \iiint_V \sum_{i=1}^2 \sum_{j=1, j < i}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j + \mathbf{E}_j \cdot \partial \mathbf{D}_i + \mathbf{H}_j \cdot \partial \mathbf{B}_i) dV \quad (66)
\end{aligned}$$

or

$$- \oiint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma$$

$$\begin{aligned}
&= \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \\
&+ \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV \quad (67)
\end{aligned}$$

This is the mutual energy formula of 2 charges. After this, similar to last section we can obtain Welch's reciprocity theorem. Actually the Welch's reciprocity theorem is largely this way to prove. The only thing different is I started from Poynting theorem, Welch started from the Maxwell equations directly.

We can see in the proof there is a step to prove Welch's reciprocity theorem which is the subtraction. From Eq.(64) subtract Eq.(61), this has no problem. That is because we just need to prove a reciprocity theorem. The reciprocity is only formula in the electromagnetic field theory. However if we need to prove the Welch's reciprocity theorem is an energy conservation law or energy theorem that is not enough.

You cannot subtract Eq.(61) unless all self-energy terms in Eq.(61) are zero, that means, we need to prove

$$- \iint_S (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = 0 \quad (68)$$

$$\iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV = 0 \quad (69)$$

$$\iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV = 0 \quad (70)$$

where,

$$i = 1, 2 \quad (71)$$

If the above terms are not zero, there is always some energy is lost in the empty space, and hence, the energy is not conserved. In case there is  $N$  charges, the corresponding formula is Eq.(28). Hence, if we need to prove the energy conservation law of Eq.(20), all term in Eq(28) must be as zero.

## 6.2 The mutual energy principle

In order to obtain to solve the problem of the formula Eq.(68, 69, 70), the author assume the problem is at the Maxwell equations. If the Maxwell equations has the problem, we can give up the Maxwell equations, in that case, the Poynting theorem can be give up too. In this case, we do not need the Eq.(61) to be satisfied, and hence, do not need each terms in Eq.(61) all zero. In this way perhaps we can obtain the energy conservation law of Welch's reciprocity Eq.(59).

In case we thought the Maxwell equations have problem, there need something else can replace Maxwell equation as axioms of the electromagnetic field

theory. The author thought the mutual energy formula Eq.(67) for  $N = 2$  situation and the formula Eq.(29) for  $N$  is very large situation are a good candidate. This formula is referred as the mutual energy principle. The mutual energy principle now can be applied as a axiom of the electromagnetic field theory.

### 6.3 Starting from the mutual energy principle

We rewrite the formula Eq.(67),

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV \\
& + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \tag{72}
\end{aligned}$$

and

$$\begin{aligned}
& - \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \\
& = \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \\
& + \iiint_V [(\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1)] dV \tag{73}
\end{aligned}$$

Now they are axioms, both for  $N > 2$  and  $N = 2$  situations. We started from  $N = 2$  situation, the differential formula of Eq.(73) can be written as,

$$\begin{aligned}
& -\nabla \cdot (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \\
& = (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) \\
& + (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2) + (\mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) \tag{74}
\end{aligned}$$

considering the vector differential formula

$$\nabla \cdot \mathbf{E}_1 \times \mathbf{H}_2 = \nabla \times \mathbf{E}_1 \cdot \mathbf{H}_2 - \mathbf{E}_1 \cdot \nabla \times \mathbf{H}_2 \tag{75}$$

$$\nabla \cdot \mathbf{E}_2 \times \mathbf{H}_1 = \nabla \times \mathbf{E}_2 \cdot \mathbf{H}_1 - \mathbf{E}_2 \cdot \nabla \times \mathbf{H}_1 \tag{76}$$

we have

$$-(\nabla \times \mathbf{E}_1 \cdot \mathbf{H}_2 - \mathbf{E}_1 \cdot \nabla \times \mathbf{H}_2 + \nabla \times \mathbf{E}_2 \cdot \mathbf{H}_1 - \mathbf{E}_2 \cdot \nabla \times \mathbf{H}_1)$$

$$\begin{aligned}
&= \mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1 \\
&+ \mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1
\end{aligned} \tag{77}$$

or

$$\begin{aligned}
&\mathbf{E}_1 \cdot (\nabla \times \mathbf{H}_2 - \mathbf{J}_2 - \partial \mathbf{D}_2) + \mathbf{E}_2 \cdot (\nabla \times \mathbf{H}_1 - \mathbf{J}_1 - \partial \mathbf{D}_1) \\
&+ \mathbf{H}_1 \cdot (-\nabla \times \mathbf{E}_2 - \partial \mathbf{B}_2) + \mathbf{H}_2 \cdot (-\nabla \times \mathbf{E}_1 - \partial \mathbf{B}_1) = 0
\end{aligned} \tag{78}$$

Considering the  $\mathbf{E}_1 \neq 0$ ,  $\mathbf{E}_2 \neq 0$  and  $\mathbf{H}_1 \neq 0$ ,  $\mathbf{H}_2 \neq 0$  we obtain,

$$\nabla \times \mathbf{E}_1 = -\partial \mathbf{B}_2 \tag{79}$$

$$\nabla \times \mathbf{H}_1 = \mathbf{J}_1 + \partial \mathbf{D}_1 \tag{80}$$

$$\nabla \times \mathbf{E}_2 = -\partial \mathbf{B}_1 \tag{81}$$

$$\nabla \times \mathbf{H}_2 = \mathbf{J}_2 + \partial \mathbf{D}_2 \tag{82}$$

We obtains two group Maxwell equations.

#### 6.4 The two wave must synchronized

Now let us to see whether we can obtained only one Maxwell equations from the mutual energy principle. Assume

$$\mathbf{E}_1 \neq 0, \mathbf{H}_1 \neq 0, \mathbf{J}_1 \neq 0 \tag{83}$$

$$\mathbf{E}_2 = 0, \mathbf{H}_2 = 0, \mathbf{J}_2 = 0 \tag{84}$$

Substitute the above to Eq.(78) we obtain,

$$\nabla \times \mathbf{H}_1 - \mathbf{J}_1 - \partial \mathbf{D}_1 < \infty \tag{85}$$

$$-\nabla \times \mathbf{E}_1 - \partial \mathbf{B}_2 < \infty \tag{86}$$

That means

$$\mathbf{E}_1 < \infty, \mathbf{H}_1 < \infty \tag{87}$$

This is not a reasonable electromagnetic field. It is same if we assume

$$\mathbf{E}_2 \neq 0, \mathbf{H}_2 \neq 0, \mathbf{J}_2 \neq 0 \tag{88}$$

$$\mathbf{E}_1 = 0, \mathbf{H}_1 = 0, \mathbf{J}_1 = 0 \tag{89}$$

we will obtained,

$$\mathbf{E}_2 < \infty, \mathbf{H}_2 < \infty \tag{90}$$



This is also not a reasonable electromagnetic field. These tell us, the mutual energy principle Eq.(78) or Eq.(74) do not allow a solution there is only one electromagnetic field. That means that, the two electromagnetic fields must exist together. That also means the two electromagnetic field which satisfy the two Maxwell equations Eq.(79 - 82) must be synchronized.

In the subsection 4.1 we have shown that in order to make the surface integral vanish, see Eq.(37) the two electromagnetic fields must one is retarded field and another is advanced field. Eq.(37) being established is a condition for Welch's theorem Eq.(44) or the mutual energy theorem Eq.(45). This means that the synchronized two electromagnetic field needs to be one is the retarded wave and another needs to be advanced wave. This way, we can prove the mutual energy theorem or Welch's reciprocity theorem from the mutual energy principle. Now the mutual energy theorem or Welch's reciprocity theorem are energy conservation law. Hence, we have proved the energy conservation law from the mutual energy principle.

## 6.5 Wave collapse

The author has assumed the mutual energy principle is the axiom and give up the Maxwell equations as axioms. However from the mutual energy principle we obtained the Maxwell equations again. This means that Maxwell equations can be give up as axiom, but even we started from new axiom which is the mutual energy principle, the Maxwell equations are still established. The Maxwell equations can be seen as theorems now.

Maxwell equations are established, that means the Poynting theorem also need to be established. Hence, Eq.(61) is also established. And the terms in the Eq.(61) cannot be zero. That means we cannot obtained Eq.(68-70). This means that we still cannot prove the energy conservation law Eq.(44) or Eq.(20) for  $N = 2$  and  $N > 2$  situations, if we started from Maxwell equations or Poynting theorem with the superposition without test charges. This is also the reason this author will introduce the mutual energy principle. This author realize that even the Maxwell equations and Poynting theorem has problem the mutual energy formula still correct. Hence the author use the mutual energy formula as axiom and call it as mutual energy principle.

We often heard that wave can be collapsed. In case Eq.(68-70) cannot be satisfied, we begin to think perhaps wave collapsed, that means the retarded wave send from the emitter will collapsed to the absorber. The advanced wave sends from the absorber will collapsed to the emitter.

Wave collapse cannot be accept, because if wave is collapsed, the self-energy terms will contribute to additional energy terms to the Welch's reciprocity theorem Eq.(44) or the mutual energy theorem Eq.(45). Widen from the charges  $N = 2$  to  $N > 2$  we cannot obtain the energy conservation law Eq.(20).

Hence, wave collapse cannot be accept, this author thought another possibility is the wave is collapse back, that means the wave is not collapse to its target but its source. That means the retarded wave sends out from the emitter will

collapse back to the emitter. The advanced wave sends out from the absorber will collapse back to the absorber.

## 6.6 Generalized the mutual energy theorem or energy conservation law

We have proved the mutual energy theorem for  $N=2$ , situation. This is easy to generalized to where  $N > 2$  situation. Generalized mutual energy theorem is,

$$W = \int_{t=-\infty}^{\infty} \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV dt = 0 \quad (91)$$

proof: We have the mutual energy principle,

$$\begin{aligned} & - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\ & = \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV \\ & + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \end{aligned} \quad (92)$$

or

$$\begin{aligned} & - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma \\ & = \iiint_V \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \cdot \mathbf{J}_j + \mathbf{E}_j \cdot \mathbf{J}_i) dV \\ & + \iiint_V \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j + \mathbf{E}_j \cdot \partial \mathbf{D}_i + \mathbf{H}_j \cdot \partial \mathbf{B}_i) dV \end{aligned} \quad (93)$$

Considering,

$$\begin{aligned} & \int_{t=-\infty}^{\infty} dt \iiint_V \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j + \mathbf{E}_j \cdot \partial \mathbf{D}_i + \mathbf{H}_j \cdot \partial \mathbf{B}_i) dV \\ & = \int_{t=-\infty}^{\infty} \partial U dt U|_{-\infty}^{\infty} = U(\infty) - U(-\infty) = 0 \end{aligned} \quad (94)$$

where

$$U = \mathbf{E}_i \cdot \mathbf{D}_j + \mathbf{H}_i \cdot \mathbf{B}_j \quad (95)$$

Now let us to prove,

$$\oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j < i}^N (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = 0 \quad (96)$$

We need to prove if

$$\oint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = 0 \quad (97)$$

for any given group  $i, j$ . Assume  $\xi_i = [\mathbf{E}_i, \mathbf{H}_i]$ ,  $\xi_j = [\mathbf{E}_j, \mathbf{H}_j]$  has 3 situations, both are retarded wave, both are advanced wave, one is retarded wave, one is an advanced wave. We have proved that if one is retarded wave and one is advanced wave the above formula is 0. Now let us to prove if the two fields both are retarded field the above formula is also 0.

Assume  $\xi_i = [\mathbf{E}_i, \mathbf{H}_i]$  and  $\xi_j = [\mathbf{E}_j, \mathbf{H}_j]$  are all retarded field. Let us assume that  $\xi_1 = [\mathbf{E}_1, \mathbf{H}_1]$  and  $\xi_2 = [\mathbf{E}_2, \mathbf{H}_2]$  are all retarded field, we have the mutual energy principle of two charge which is,

$$\begin{aligned} & - \int_{t=-\infty}^{\infty} \iiint_{V_1} \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt \\ & = (\xi_1, \xi_2) = 0 \\ & = \int_{t=-\infty}^{\infty} \iiint_{V_2} \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV dt \end{aligned} \quad (98)$$

This means,

$$\int_{t=-\infty}^{\infty} \iiint_{V_1} \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt = 0 \quad (99)$$

$$\int_{t=-\infty}^{\infty} \iiint_{V_2} \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV dt = 0 \quad (100)$$

The mutual energy principle tell us

$$- \int_{t=-\infty}^{\infty} dt \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma$$

$$\begin{aligned}
&= \int_{t=-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \\
&+ \int_{t=-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV \quad (101)
\end{aligned}$$

we have,

$$\begin{aligned}
&\int_{t=-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV \\
&= \int_{t=-\infty}^{\infty} \partial U dt U|_{-\infty}^{\infty} = U(\infty) - U(-\infty) = 0 \quad (102)
\end{aligned}$$

where

$$U = \iiint_V (\mathbf{E}_1 \cdot \mathbf{D}_2 + \mathbf{H}_1 \cdot \mathbf{B}_2) dV \quad (103)$$

considering

$$- \int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma = \int_{t=-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \quad (104)$$

Considering Eq.(99,100), the right side of the Equation is 0. Hence, the left side of the above formula is also 0. That means if any two pair retarded fields the surface integral

$$\int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma = 0 \quad (105)$$

The same reason we can obtained that if the two fields are all advanced field we have also above formula. The two fields only can have 3 situations, (1) the two fields all are retarded field, (2) the two fields all are advanced field and (3) the two fields one is retarded and one is advanced. In the 3 situations, we all have,

$$\int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = 0 \quad (106)$$

or

$$\int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \times \mathbf{H}_j + \mathbf{E}_j \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = 0 \quad (107)$$

Substituting Eq.(107, 94) to Eq.(92) we obtain,

$$\int_{t=-\infty}^{\infty} dt \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV = 0 \quad (108)$$

We obtain the energy conservation law.

## 7 Discussion the conflict again started from mutual energy principle

From the above discussion we have known that if we started from Poynting theorem and the superposition without test charge we cannot derive the energy conservation law. However if we add the self-energy principle. The conflict can be eliminate and hence the superposition without test charge is allowed. This lead us to introduce the self-energy principle. In this section we started from mutual energy principle but do not assume the self-energy principle, let us seen what situation will happen.

### 7.1 Assume mutual energy principle is assumed

In this section we assume the mutual energy principle is established. But we do not assume the self-energy principle.

From above discussion we have know that if the mutual energy principle is established, for example we have,

$$\begin{aligned} & - \oiint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\ & = \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV \\ & + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \end{aligned} \quad (109)$$

For N=2, we have

$$\begin{aligned} & - \int_{t=-\infty}^{\infty} dt \oiint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \\ & = \int_{t=-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \end{aligned}$$

$$+ \int_{t=-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV \quad (110)$$

$$\nabla \times \mathbf{E}_1 = -\partial \mathbf{B}_2 \quad (111)$$

$$\nabla \times \mathbf{H}_1 = \mathbf{J}_1 + \partial \mathbf{D}_1 \quad (112)$$

$$\nabla \times \mathbf{E}_2 = -\partial \mathbf{B}_2 \quad (113)$$

$$\nabla \times \mathbf{H}_2 = \mathbf{J}_2 + \partial \mathbf{D}_2 \quad (114)$$

This two group Maxwell equation must synchronized. This two group Maxwell equation lead to two Poynting theorem,

$$- \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E}_1 \cdot \mathbf{J}_1 dV + \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_1 + \mathbf{H}_1 \cdot \partial \mathbf{B}_1) dV \quad (115)$$

$$- \oint_{\Gamma} (\mathbf{E}_2 \times \mathbf{H}_2) \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E}_2 \cdot \mathbf{J}_2 dV + \iiint_V (\mathbf{E}_2 \cdot \partial \mathbf{D}_2 + \mathbf{H}_2 \cdot \partial \mathbf{B}_2) dV \quad (116)$$

or

$$- \oint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad (117)$$

In general we have this also means,

$$- \sum_{i=1}^N \oint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = \sum_{i=1}^N \iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \sum_{i=1}^N \iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad (118)$$

Add the above formula to Eq.(109) we have,

$$\begin{aligned} & - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\ & = \iiint_V \sum_{i=1}^N \sum_{j=1}^N \mathbf{E}_i \cdot \mathbf{J}_j dV \\ & + \iiint_V \sum_{i=1}^N \sum_{j=1}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \end{aligned} \quad (119)$$

This formula is obtained from the mutual energy principle Eq.(109), hence, it should be equal to Eq.(109). This will mean their difference will be 0, i.e., all terms of following

$$-\sum_{i=1}^N \oint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = \sum_{i=1}^N \iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \sum_{i=1}^N \iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad (120)$$

Will be 0. That is,

$$-\oint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad (121)$$

will be 0. Or,

$$-\oint_{\Gamma} (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = 0 \quad (122)$$

$$\iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV = 0 \quad (123)$$

$$\iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV = 0 \quad (124)$$

However, the above cannot be 0, because if it is 0, then

$$\xi_i = [\mathbf{E}_i, \mathbf{H}_i] = 0 \quad (125)$$

This means all electromagnetic field will be 0. This is clear wrong. All electromagnetic field cannot be 0. This conflict will lead us to introduce the self-energy principle in the following section.

## 8 Self-energy principle

### 8.1 Time-reversal transform

According the end of last section, this author assume the wave collapse back, that means there are the waves which satisfy to the time-reverse equations. That means that there is a new kind of electromagnetic field  $[\mathbf{e}, \mathbf{h}, \mathbf{j}]$  which can be described as the collapse back process. The time-reversal transform, which satisfies,

$$\mathbf{x} \longrightarrow \mathbf{x} \quad (126)$$

$$t \longrightarrow -t \quad (127)$$

$$\frac{\partial}{\partial t} \longrightarrow \frac{\partial}{\partial(-t)} = -\frac{\partial}{\partial t} \quad (128)$$

$$\mathbf{v} = \frac{d\mathbf{x}}{dt} \longrightarrow \frac{d\mathbf{x}}{d(-t)} = -\frac{d\mathbf{x}}{dt} = -\mathbf{v} \quad (129)$$

$$\mathbf{E} \longrightarrow \mathbf{e} \quad (130)$$

$$\mathbf{H} \longrightarrow \mathbf{h} \quad (131)$$

$$\mathbf{J} = \rho \mathbf{v} \longrightarrow \rho(-\mathbf{v}) = -\mathbf{j} \quad (132)$$

Apply this to Maxwell equations,

$$\begin{cases} \nabla \times \mathbf{E} = -\partial \mathbf{B} & \longrightarrow & \nabla \times \mathbf{e} = \partial \mathbf{b} \\ \nabla \times \mathbf{H} = \mathbf{J} + \partial \mathbf{D} & \longrightarrow & \nabla \times \mathbf{h} = -\mathbf{j} - \partial \mathbf{d} \end{cases} \quad (133)$$

In Eq.(133) offers the equations the time-reversal electromagnetic field should satisfy. This equations is referred as time-reversal Maxwell equations. According to this equations, the Poynting theorem can also have the time-reversal Poynting theorem,

$$\begin{cases} -\iint_S (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E} \cdot \mathbf{J} dV + \iiint_V (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV \\ \longrightarrow \\ -\iint_S (\mathbf{e} \times \mathbf{h}) \cdot \hat{n} d\Gamma = -\iiint_V \mathbf{e} \cdot \mathbf{j} dV - \iiint_V (\mathbf{e} \cdot \partial \mathbf{d} + \mathbf{h} \cdot \partial \mathbf{b}) dV \end{cases} \quad (134)$$

When we have the time-reversal waves, even equation Eq.(68-70) cannot be satisfy but we can have,

$$-\iint_S (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma + \iint_S (\mathbf{e} \times \mathbf{h}) \cdot \hat{n} d\Gamma = 0 \quad (135)$$

$$\iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V \mathbf{e} \cdot \mathbf{j} dV = 0 \quad (136)$$

$$\iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV + \iiint_V (\mathbf{e} \cdot \partial \mathbf{d} + \mathbf{h} \cdot \partial \mathbf{b}) dV = 0 \quad (137)$$

This means that the corresponding energy terms of the time reversal field just canceled the corresponding energy terms of the normal electromagnetic fields.

Please notice, it is possible the author has make a mistake in Eq.(137), if we make mistake, the correct formula is,

$$-\iint_S (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma - \iint_S (\mathbf{e} \times \mathbf{h}) \cdot \hat{n} d\Gamma = 0 \quad (138)$$

$$\iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV - \iiint_V \mathbf{e} \cdot \mathbf{j} dV = 0 \quad (139)$$

$$\iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV - \iiint_V (\mathbf{e} \cdot \partial \mathbf{d} + \mathbf{h} \cdot \partial \mathbf{b}) dV = 0 \quad (140)$$

That means it is possible this author make a mistake in the signs. But anyway this author means all contribution of self-energy terms are canceled.



The energy terms of the normal electromagnetic field will be canceled by the unnormal electromagnetic fields. Eq.(135-137) tell us also the self-energy terms do not transfer the energy.

## 8.2 Self-energy principle

Since now we have the new electromagnetic field which is time reversal electromagnetic field, the original electromagnetic field will referred as normal electromagnetic field. Here the normal fields satisfy the Maxwell equations. The time-reversal field satisfy the time-reversal Maxwell equations Eq.(133). The time-reversal fields are unnormal electromagnetic fields.

There exist time reversal fields which can cancel the corresponding electromagnetic field is referred as self-energy principle. This is the starting point of the author's new electromagnetic field theory. It will be applied as axiom. According to this new principle, there are 4 kinds of waves: the retarded wave, the advanced wave, the time-reversal wave corresponding to the retarded wave, the time-reversal wave corresponding to the advanced wave. The retarded wave and the advanced wave are normal electromagnetic fields. The time reversal electromagnetic fields are unnormal electromagnetic fields.

## 8.3 The mutual energy principle for time-reversal wave

We can apply the time-reversal transform to the mutual energy principle and obtain the mutual energy principle for time-reversal waves, which are,

$$\begin{aligned} & \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{e}_i \times \mathbf{h}_j \cdot \hat{n} d\Gamma \\ = & \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{e}_i \cdot \mathbf{j}_j dV + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{e}_i \cdot \partial \mathbf{d}_j + \mathbf{h}_i \cdot \partial \mathbf{b}_j) dV \end{aligned} \quad (141)$$

for  $N > 2$  and

$$\begin{aligned} & \oint_{\Gamma} (\mathbf{e}_1 \times \mathbf{h}_2 + \mathbf{e}_2 \times \mathbf{h}_1) \cdot \hat{n} d\Gamma \\ & = \iiint_V (\mathbf{e}_1 \cdot \mathbf{j}_2 + \mathbf{e}_2 \cdot \mathbf{j}_1) dV \\ & + \iiint_V [(\mathbf{e}_1 \cdot \partial \mathbf{d}_2 + \mathbf{h}_1 \cdot \partial \mathbf{b}_2) + (\mathbf{e}_2 \cdot \partial \mathbf{d}_1 + \mathbf{h}_2 \cdot \partial \mathbf{b}_1)] dV \end{aligned} \quad (142)$$

For the time-reversal wave we also do not apply the time-reversal Maxwell equations as the axioms, but apply above time-reversal mutual energy principle as the axioms. Started from the above time-reversal mutual energy principle we can obtained the time-reversal Maxwell equations, similar to Eq.(79-82)

$$\nabla \times \mathbf{e}_1 = \partial \mathbf{b}_2 \quad (143)$$

$$\nabla \times \mathbf{h}_1 = -\mathbf{j}_1 - \partial \mathbf{d}_1 \quad (144)$$

$$\nabla \times \mathbf{e}_2 = \partial \mathbf{b}_2 \quad (145)$$

$$\nabla \times \mathbf{h}_2 = -\mathbf{j}_2 - \partial \mathbf{d}_2 \quad (146)$$

Similar to the mutual energy principle, the time reversal mutual energy principle can prove a mutual energy theorem for time reversal mutual energy flow. This author believe the energy of the photon is transferred by the mutual energy flow, hence, the photon is the mutual energy flow. This author also believe that the time reversal mutual energy flow can eliminate the half photon or partial photons. In case two advanced waves from two absorbers race a retarded wave sent from a emitter, each absorber is possible to obtain only an energy of a half photon or partial photon. In this case, the charge in the absorber spring from low energy level to a high level, but since there is only a half energy, it is not enough. In this case, the charge will return the lower energy level, and hence, the time reversal mutual energy will bring the energy of the half photon back to the emitter.

#### 8.4 The not synchronized electromagnetic field is also allowed

In the subsection 6.4, we have said the two wave must synchronized. After we have the time-reversal wave, now we can allow that the waves only satisfy one Maxwell equations for example the retarded wave. In this situation, since there is no any mutual energy produced, this retarded wave will send their energy to infinite far away in the space, however, thanks the exist of the time-reversal wave, which will cancel the energy of this wave. Hence, there is no any energy will be lost in the empty space. The energy sends from the emitter will return to the emitter. The energy or negative energy sends out from absorber will received by the absorber. The absorber sends out the advanced wave which have the energy with negative sign. The absorber actually receive energy and not sends the energy out.

This kind waves is ghost wave, because it is sent out, but there is the time reversal wave which collapse back and hence the wave do not carry any energy. We can also call this wave as probability wave, the probability wave carry some probability but not energy. The probability is that this wave has the chance become a real thing, in that case this retarded wave has met an advanced wave and hence, two waves become synchronized. In that case the mutual energy flow will be built. And a photon is produced. The energy is sent form the emitter to the absorber.

## 8.5 Summary

Since now we have the self-energy principle Eq.(135-137), the self-energy terms Eq.(28) do not transfer energy, this will guarantee that the mutual energy principle is established and also the energy conservation law Eq.(20) can be established. For this article, one of the purpose is the discussion of the superposition principle. Now we have proved that in order to obtain the superposition principle without test charge, the self-energy principle must be accept. In the next section we will come back to the discussion of the superposition for details.

## 9 The superposition principle

### 9.1 Derive superposition principle form the mutual energy principle

This author will not apply the superposition principle as an axiom. The superposition principle will be derived from the mutual energy principle.

Assume there are charges  $N_1$  which send the retarded wave and charge  $N_2$  which send advanced wave. Assume the  $N_1$  charge is inside the volume  $V_1$  and the charge  $N_2$  are at inside of volume  $V_2$ . We know that  $N = N_1 + N_2$  for the  $N$  charges,  $V_1 \subset V$ ,  $V_2 \subset V$ ,  $V_1 \cap V_2 = 0$ . There is the mutual energy principle Eq.(29) which can be rewritten as,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV \\
& + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \tag{147}
\end{aligned}$$

Consider the retarded wave is orthogonal to the retarded waves, and the advanced wave is orthogonal to the advanced waves, i.e.,

$$\begin{aligned}
& 0 = \\
& - \oint_{\Gamma} \sum_{i=1}^{N_1} \sum_{j=1, j \neq i}^{N_1} \mathbf{E}_{1i} \times \mathbf{H}_{1j} \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^{N_1} \sum_{j=1, j \neq i}^{N_1} \mathbf{E}_{1i} \cdot \mathbf{J}_{1j} dV \\
& + \iiint_V \sum_{i=1}^{N_1} \sum_{j=1, j \neq i}^{N_1} (\mathbf{E}_{1i} \cdot \partial \mathbf{D}_{1j} + \mathbf{H}_{1i} \cdot \partial \mathbf{B}_{1j}) dV \tag{148}
\end{aligned}$$

$$\begin{aligned}
0 &= \\
& - \oint_{\Gamma} \sum_{i=1}^{N_2} \sum_{j=1, j \neq i}^{N_2} \mathbf{E}_{2i} \times \mathbf{H}_{2j} \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^{N_2} \sum_{j=1, j \neq i}^{N_2} \mathbf{E}_{2i} \cdot \mathbf{J}_{2j} dV \\
& + \iiint_V \sum_{i=1}^{N_2} \sum_{j=1, j \neq i}^{N_2} (\mathbf{E}_{2i} \cdot \partial \mathbf{D}_{2j} + \mathbf{H}_{2i} \cdot \partial \mathbf{B}_{2j}) dV \quad (149)
\end{aligned}$$

The above formula is because the second mutual energy flow theorem Eq.(59). Hence, only the term of retarded wave with the advanced wave need to be considered. Substitute Eq.(148-149) to Eq.(147), hence, we have,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} (\mathbf{E}_{1i} \times \mathbf{H}_{2j} + \mathbf{E}_{2j} \times \mathbf{H}_{1i}) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} (\mathbf{E}_{1i} \cdot \mathbf{J}_{2j} + \mathbf{E}_{2j} \cdot \mathbf{J}_{1i}) dV \\
& + \iiint_V \sum_{i=1}^{N_1} \sum_{j=1}^{N_2} (\mathbf{E}_{1i} \cdot \partial \mathbf{D}_{2j} + \mathbf{H}_{1i} \cdot \partial \mathbf{B}_{2j} + \mathbf{E}_{2j} \cdot \partial \mathbf{D}_{1i} + \mathbf{H}_{2j} \cdot \partial \mathbf{B}_{1i}) dV \quad (150)
\end{aligned}$$

Writing,

$$\mathbf{E}_1 = \sum_{i=1}^{N_1} \mathbf{E}_{1i}, \quad \mathbf{H}_1 = \sum_{i=1}^{N_1} \mathbf{H}_{1i} \quad (151)$$

$$\mathbf{E}_2 = \sum_{j=1}^{N_2} \mathbf{E}_{2j}, \quad \mathbf{H}_2 = \sum_{j=1}^{N_2} \mathbf{H}_{2j} \quad (152)$$

We have,

$$\begin{aligned}
& - \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \\
& = \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \\
& + \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV \quad (153)
\end{aligned}$$

We get the mutual energy principle between two region,  $V_1$  and  $V_2$ . We have assume in volume  $V_1$  all charges are emitters. In the volume  $V_2$  all charges are absorbers.

Since  $\mathbf{E}_1$  is retarded wave,  $\mathbf{H}_2$  is advanced wave,  $\mathbf{E}_1 \times \mathbf{H}_2$  cannot nonzero in the same time at  $\Gamma$ .  $\Gamma$  is at infinite big sphere. This is also true to  $\mathbf{E}_2 \times \mathbf{H}_1$  hence, we have,

$$\iint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma = 0 \quad (154)$$

We also have,

$$\begin{aligned} & \int_{t=-\infty}^{\infty} \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV dt \\ &= \int_{t=-\infty}^{\infty} dU = U(\infty) - U(-\infty) = 0 \end{aligned} \quad (155)$$

where

$$U = \iiint_V (\mathbf{E}_1 \cdot \mathbf{D}_2 + \mathbf{H}_1 \cdot \mathbf{B}_2) dV \quad (156)$$

This further lead,

$$\int_{t=-\infty}^{\infty} \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV dt = 0 \quad (157)$$

or

$$- \int_{t=-\infty}^{\infty} \iiint_{V_1} (\mathbf{E}_2(t) \cdot \mathbf{J}_1(t)) dV dt = \int_{t=-\infty}^{\infty} \iiint_{V_2} (\mathbf{E}_1(t) \cdot \mathbf{J}_2(t)) dV dt \quad (158)$$

This is the mutual energy theorem, it is also the Welch's reciprocity theorem. It also the energy conservation law for two systems  $\zeta_1 = [\mathbf{E}_1, \mathbf{H}_1, \mathbf{J}_1]$ ,  $\zeta_2 = [\mathbf{E}_2, \mathbf{H}_2, \mathbf{J}_2]$ . The two system satisfy the superposition formula Eq.(151, 152). From the above energy conservation law, this kind of superposition is the superposition with the retarded wave alone or the superposition with the advanced wave alone.

This kind of superposition also can be seen as with a test charge. The test charge for the retarded wave is the absorber in the region  $V_2$ . The test charge for the advanced wave is the emitter in the region  $V_1$ . The retarded wave is only need to be calculated at the region  $V_2$  and the advance wave is only need to be calculated at the region  $V_1$ . Hence for the above energy conservation law, actually we only need the superposition with test charges. We do not need the superposition without test charge. The superposition with test charge and

the superposition with the retarded wave alone or the superposition with the advanced wave along can be seen as one kind of superposition, it can be referred as the first kind of superposition.

This means we obtained the superposition principle from the mutual energy principle, but it is the superposition first kind. The superposition with test charge is enough for the mutual energy theorem (energy conservation law). Since this kind of superposition can be derived from the mutual energy principle, hence, the superposition principle do not need to be as an axiom in the electromagnetic field theory of this author.

The above result can be further widened. Eq.(151,152) tell us, in the region  $V_1$  all the retarded field can be superposed. In the region  $V_2$  all the advanced wave can be superposed. In this formula, we can see that the field,  $\xi_1 = [\mathbf{E}_1, \mathbf{H}_1]$ ,  $\xi_2 = [\mathbf{E}_2, \mathbf{H}_2]$  can be defined on whole space. It is not defined only on the test charge. Even there is no the test charges. Actually in this situation, we have superposed all the field ether advanced waves or the retarded waves. Hence, seems that the all the retarded wave can be superposed. All the advanced wave can be superposed. The test charges do not need.

## 9.2 Further discussion for the superposition

Last subsection tell us, if started from the mutual energy principle we can derive the superposition principle first kind. All retarded waves can be measured with an absorber hence they can be superposed. All advanced waves can be measured with an emitter, they also can be superposed. Hence we do not need a real test charge here to define the superposition. The only thing is this kind of field are same kind of field. Hence, if there is a charge, it can be measured.

What about the superposition without any restriction, that is the superposition without any test charge, the field can be retarded and also can be advanced? In this situation, from the section 3 to section 7 we have proved, that if the self-energy principle is established, which means the formula Eq.(135-137) is established, we can obtain the mutual energy principle, and hence, we can obtained the same superposition as the last subsection. However, if the formula Eq.(135-137) is not established, in general we get conflict between the superposition principle (superposition without test charge and the superposition with different waves the retarded and the advanced) and the energy conservation law.

Hence, if we believe the superimposition principle without test charge, include retarded wave and advanced wave, we have to accept the self-energy principle. That means the time-reversal waves must exist.

In other hand, if we have accepted the self-energy principle, the superposition without any restriction also can be accept. Hence, we have proved the superposition of the second kind which include the superposition without test charge, the superposition with the retarded wave and the advanced wave.

All 4 kinds of superposition which are all allowed. This permission of all kinds of superposition is not automatic, it is only true when we have modified the electromagnetic field theory, especially accepted the self-energy principle.

Perhaps now we can understand why the Wheeler and Feynman speak about the electromagnetic field has no its own freedom. After we have accept the self-energy principle, now we will allow the electromagnetic field to have its own freedom. The electromagnetic field can be defined without test charge. Even without test charge, the electromagnetic fields can be superposed.

We have choose the mutual energy principle as axioms. This is not necessary, if we do not apply mutual energy principle as axioms, we can apply the Maxwell equations as axioms. However, in that case we have to speak there must have two group Maxwell equations which have to be synchronized. One group is for retarded wave, one is for the advanced wave. We need also to use the time-reversal Maxwell equation as axioms. The superposition principle cannot be derived from Maxwell equations that need to an additional axiom.

In case the mutual energy principle is the axiom, the two groups Maxwell equations (for retarded wave and for the advanced wave) and the superposition principle plus a text descriptive the condition of synchronization of the two kinds of waves are replace by one formula that agree with the principle that an axiom should be as simple as possible. Another advantage is even the retarded wave and the advanced wave do not need to be defined in the axiom, this kind of concept can be derived. Apply the mutual energy principle as principle also will make the whole electromagnetic field theory much simpler. This is because the energy conservation law (or the mutual energy theorem Eq.(158)) and the mutual energy flow theorems can be easily derived from mutual energy principle. Most the real electromagnetic field problem can be solved with the mutual energy theorems. Maxwell equations also can be derived from the mutual energy principle. Started from Mutual energy principle two groups of Maxwell equations will automatically synchronized. We do not need a sentence to say that. Most radiation phenomenon can be derived from the mutual energy principle. The superposition principle of the first kind (with test charges or all retarded wave/advanced wave) can also be derived form the mutual energy principle. That kind of superposition is enough in most situations.

The self-energy principle only will be applied to the more deep physical problem for example the interpretation of the quantum mechanics, the duality of the wave and particle, and also the problem like this article which kind of superposition can be allowed. The self-energy principle allows the superposition without the test charges. After we have the self-energy principle the restriction on the superposition of the electromagnetic fields is removed. This means any waves include retarded wave, advanced wave, with or without test charge can all be superposed.

### 9.3 The second kind of superposition

In this section we will discuss the superposition without test charge in details, this also means in this superposition the retarded wave and advanced wave are all included, in this situation the superposition is strongly dependent to the self-energy principle.

We have proved this kind of superposition is OK if the self-energy principle is

accept. That means this kind of superposition together with self-energy principle doesn't conflict with energy conservation law. Now our task is changed, we assume we have the self-energy principle and the mutual energy principle, we would like to derive the superposition without any restrictions, i.e. without test charge, without limitation to the retarded waves alone or the advanced waves alone. This means we will discuss the superposition without a test charge and without any restriction.

We have the mutual energy principle, which is,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N \mathbf{E}_i \cdot \mathbf{J}_j dV \\
& + \iiint_V \sum_{i=1}^N \sum_{j=1, j \neq i}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \tag{159}
\end{aligned}$$

We have know that started from the mutual energy principle we can obtained two group Maxwell equations which must synchronized. Any way we can obtained the Maxwell equations for all electromagnetic fields which can be retarded or advanced. It should be notice that this Maxwell equations are the Maxwell equations for single charge. Started from this Maxwell equations for single charge we can obtained the corresponding Poynting theorem which is,

$$- \iint_S (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \tag{160}$$

This is also the Poynting theorem for single charge. Please notice in this section we do not assume Maxwell equations as the axiom of the electromagnetic fields. Instead we assume the mutual energy principle is the axioms. Started from the mutual energy principle we proved that Maxwell equations still satisfied but the Maxwell equations must grouped as one retarded wave and one retarded wave, they must synchronized. Any way started from mutual energy principle we still obtained Maxwell equation and hence the Poynting theorem Eq.(160). We can added Eq.(160) to the mutual energy principle we obtained,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^N \sum_{j=1}^N \mathbf{E}_i \times \mathbf{H}_j \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^N \sum_{j=1}^N \mathbf{E}_i \cdot \mathbf{J}_j dV
\end{aligned}$$



$$+ \iiint_V \sum_{i=1}^N \sum_{j=1}^N (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \quad (161)$$

Substitute,

$$\mathbf{E} = \sum_{i=1}^N \mathbf{E}_i, \quad \mathbf{H} = \sum_{i=1}^N \mathbf{H}_i \quad (162)$$

We have,

$$- \oiint_{\Gamma} \mathbf{E} \times \mathbf{H} \cdot \hat{n} d\Gamma = \iiint_V \mathbf{E} \cdot \mathbf{J} dV + \iiint_V (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV \quad (163)$$

Hence, it seems we obtained the superposition without test charge. However we should mention here that Eq.(161) is still a correct equation, that means its left side is equal to the right side. But Eq.(161) and hence, Eq.(163) is not an energy conservation law. In the traditional electromagnetic field theory, Poynting theorem is always seen as an energy conservation law. Here it is not an energy conservation law. The reason is the self-energy principle, which is,

$$- \iint_S (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma + \iint_S (\mathbf{e} \times \mathbf{h}) \cdot \hat{n} d\Gamma = 0 \quad (164)$$

$$\iiint_V \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V \mathbf{e} \cdot \mathbf{j} dV = 0 \quad (165)$$

$$\iiint_V (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV + \iiint_V (\mathbf{e} \cdot \partial \mathbf{d} + \mathbf{h} \cdot \partial \mathbf{b}) dV = 0 \quad (166)$$

This tell us that in the formula Eq.(160), each terms do not carry energy. If we need to calculated the total energy transferred, the self-energy term should be taken away. After the self energy terms is taken away we get still the mutual energy principle Eq.(159).

The above discussion tell us we can apply the superposition for  $N$ -charge to the Poynting theorem, to get the  $N$ -charge Poynting theorem Eq.(161), however this  $N$ -charge Poynting theorem Eq.(161) is not an energy conservation law. We still need to apply the self-energy principle. The self-energy principle allow us to take away the self-energy terms from the  $N$ -charge Poynting theorem, afterwards, the rest terms is a energy conservation law. Afterwards we still get the mutual energy principle Eq.(160). We know that the mutual energy principle support the superposition with test charge. Hence we still get the superposition with test charge.

Self-mutual energy principle can help us to solve the problem of the superposition without test charge. The superposition with test charge and the superposition without test charge still two different kind of superpositions.

The superposition of first kind is speak to the mutual energy principle. The superposition of the second kind is speak to the  $N$ -charge's Poynting theorem, since the Poynting theorem is not a energy conservation law, this kind of superposition still need to apply the self-energy principle to correct it, after the correction the superposition of first kind become also the second kind of superposition. Please notice here is only when we applied the self-energy principle, the second kind of superposition can be corrected to the first kind of superposition. It is not automatically the second kind of superposition can be equal to the first kind of superposition.

#### 9.4 Example 1

In order to fully understand the concept of superposition without test charge and superposition and with a test charge, let us see an example. Many things we have already done before, but it is still worth to repeat it again in an example.

Assume there are two charges, one is a emitter and another is an absorber. The emitter has the current  $\mathbf{J}_1$  and the absorber has the current  $\mathbf{J}_2$ .

If we started from the superposition of the second kind, i.e. without test charge. The field is possible retarded or advanced. We know that the two fields of the two waves can be superposed, that means we have

$$\mathbf{E} = \mathbf{E}_1 + \mathbf{E}_2 \quad (167)$$

$$\mathbf{H} = \mathbf{H}_1 + \mathbf{H}_2 \quad (168)$$

The above superposition is the superposition without any restriction, the superposition can without any test charge and the superposition can be the retarded wave and also the advanced wave.

We can assume that the superposition of the two fields satisfy Maxwell equations, and hence also satisfy the Poynting theorem. Hence, we have,

$$\begin{aligned} & - \oint_{\Gamma} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma \\ &= \iiint_V \mathbf{E} \cdot \mathbf{J} dV + \iiint_V (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV \end{aligned} \quad (169)$$

Substituting Eq.(167,168) to the above Poynting theorem Eq.(169), we obtain,

$$\begin{aligned} & - \oint_{\Gamma} \sum_{i=1}^2 \sum_{j=1}^2 (\mathbf{E}_i \times \mathbf{H}_j) \cdot \hat{n} d\Gamma \\ &= \iiint_V \sum_{i=1}^2 \sum_{j=1}^2 \mathbf{E}_i \cdot \mathbf{J}_j dV + \iiint_V \sum_{i=1}^2 \sum_{j=1}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \end{aligned} \quad (170)$$

This is the Poynting theorem of the two charges. This formula have two parts, one is the mutual energy part which is,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^2 \sum_{j=1, j \neq i}^2 (\mathbf{E}_i \times \mathbf{H}_j) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^2 \sum_{j=1, j \neq i}^2 \mathbf{E}_i \cdot \mathbf{J}_j dV + \iiint_V \sum_{i=1}^2 \sum_{j=1, j \neq i}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_j + \mathbf{H}_i \cdot \partial \mathbf{B}_j) dV \quad (171)
\end{aligned}$$

another part is the self-energy part,

$$\begin{aligned}
& - \oint_{\Gamma} \sum_{i=1}^2 (\mathbf{E}_i \times \mathbf{H}_i) \cdot \hat{n} d\Gamma \\
& = \iiint_V \sum_{i=1}^2 \mathbf{E}_i \cdot \mathbf{J}_i dV + \iiint_V \sum_{i=1}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i) dV \quad (172)
\end{aligned}$$

We can assume the self-energy part has no contribution to the energy transfer, since all self energy terms are canceled by the corresponding time-reversal waves. That means we have,

$$- \oint_{\Gamma} \sum_{i=1}^2 (\mathbf{E}_i \times \mathbf{H}_i - \mathbf{e}_i \times \mathbf{h}_i) \cdot \hat{n} d\Gamma = 0 \quad (173)$$

$$\iiint_V \sum_{i=1}^2 (\mathbf{E}_i \cdot \mathbf{J}_i + \mathbf{e}_i \cdot \mathbf{j}_i) dV = 0 \quad (174)$$

$$\iiint_V \sum_{i=1}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i + \mathbf{e}_i \cdot \partial \mathbf{d}_i + \mathbf{h}_i \cdot \partial \mathbf{b}_i) dV = 0 \quad (175)$$

Hence, the self-energy part can be take away from the Poynting theorem of the two charges Eq.(170). Hence we derived the Eq.(171). The mutual energy part can be rewritten as,

$$\begin{aligned}
& - \oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \\
& = \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV \\
& + \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV \quad (176)
\end{aligned}$$

Assume  $\Gamma$  is infinite big sphere. Since we know that the two fields, if one is retarded field and another is advanced field, we can have,

$$\oint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma = 0 \quad (177)$$

We also know that,

$$\begin{aligned} & \int_{-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_2 + \mathbf{H}_1 \cdot \partial \mathbf{B}_2 + \mathbf{E}_2 \cdot \partial \mathbf{D}_1 + \mathbf{H}_2 \cdot \partial \mathbf{B}_1) dV \\ &= \int_{-\infty}^{\infty} \partial U dt = U|_{-\infty}^{\infty} = U(\infty) - U(-\infty) = 0 \end{aligned} \quad (178)$$

where,

$$U = \mathbf{E}_1 \cdot \mathbf{D}_2 + \mathbf{H}_1 \cdot \mathbf{B}_2 \quad (179)$$

Here,  $U(\infty)$  and  $U(-\infty)$  are two stable states. The total energy should not changed. Hence we have  $U(\infty) = U(-\infty)$ .

Substituting Eq.(178) and Eq.(177) to Eq.(176) we obtain,

$$\int_{-\infty}^{\infty} dt \iiint_V (\mathbf{E}_1 \cdot \mathbf{J}_2 + \mathbf{E}_2 \cdot \mathbf{J}_1) dV = 0 \quad (180)$$

This can be written as,

$$- \int_{-\infty}^{\infty} dt \iiint_{V_1} \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV = \int_{-\infty}^{\infty} dt \iiint_{V_2} (\mathbf{E}_1(t) \cdot \mathbf{J}_2(t)) dV \quad (181)$$

This is Welch's reciprocity theorem, the mutual energy theorem or the energy conservation law, this formula tell us the field at the place  $\mathbf{J}_2$  is  $\mathbf{E}_1(t)$ . The field at the place  $\mathbf{J}_1(t)$  is only the field of  $\mathbf{E}_2(t)$ . We know that in the palace  $V_2$ ,  $\mathbf{J}_2$  is the test charge,  $\mathbf{E}_1(t)$  is the field which has been test with this test charge. In the place  $V_1$ ,  $\mathbf{J}_1$  is the test charge, the field  $\mathbf{E}_2(t)$  is the field measured with this test charge. Hence, actually we have applied the superposition principle with the test charge at the places  $V_1$  and  $V_2$ . In the formula Eq.(181) we only need the superposition of the first kind, i.e. with a test charge.

In this example it is clear the superposition without test charge and the superposition with test charge can be united, because we started from the superposition without test charge and Maxwell equations, in the end we obtained the superposition with the test charge, the key is the self-energy principle Eq.(173-175).

This example is a situation for single photon. The emitter sends the retarded field, the absorber sends the advanced field. The two fields can be superposed.

The energy is transferred from emitter to the absorber is through the mutual energy flow which can be written as,

$$- \int_{-\infty}^{\infty} dt \iiint_{V_1} \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV = (\xi_1, \xi_2) = \int_{-\infty}^{\infty} dt \iiint_{V_2} (\mathbf{E}_1(t) \cdot \mathbf{J}_2(t)) dV \quad (182)$$

where

$$(\xi_1, \xi_2) = \int_{-\infty}^{\infty} dt \iint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \quad (183)$$

$Q = \iint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \hat{n} d\Gamma$  is the mutual energy flow.  $(\xi_1, \xi_2)$  is the energy transferred through the mutual energy flow. The  $\Gamma$  can be taken on any closed surface between  $V_1$  and  $V_2$ .  $(\xi_1, \xi_2)$  is the energy of the photon. Hence we can say that the photon is the mutual energy flow.

Single photon system needs the exist of the an emitter and an absorber. The photon “knows” its target which is the specific absorber in the very beginning.

From this example it is clear that the superposition with test charge is an energy corrected superposition. The superposition without test charge is an energy wrong superposition, however the self-energy principle can help the superposition without test charge to become an energy corrected superposition which is the superposition with test charge.

## 9.5 Example 2

Assume we have two absorber charges and one emitter charge. The current of absorbers are  $\mathbf{J}_{21}$  and  $\mathbf{J}_{22}$ . The current of the emitter is  $\mathbf{J}_1$ . The fields of the absorbers are  $\xi_{21} = [\mathbf{E}_{21}, \mathbf{H}_{21}]$  and  $\xi_{22} = [\mathbf{E}_{22}, \mathbf{H}_{22}]$ . The field of the emitter is  $\xi_1 = [\mathbf{E}_1, \mathbf{H}_1]$ . We can have,

$$\xi_2 = \xi_{21} + \xi_{22} \quad (184)$$

where

$$\xi_2 = [\mathbf{E}_2, \mathbf{H}_2] = [\mathbf{E}_{21} + \mathbf{E}_{22}, \mathbf{H}_{21} + \mathbf{H}_{22}] \quad (185)$$

In this case we also have Eq.(181) which means,

$$- \iiint_{V_1} (\mathbf{E}_{21}(t) + \mathbf{E}_{22}(t)) \cdot \mathbf{J}_1(t) dV = \iiint_{V_2} \mathbf{E}_1(t) \cdot (\mathbf{J}_{21}(t) + \mathbf{J}_{22}(t)) dV \quad (186)$$

This tell us, in the place of absorber  $V_1$ , the two advanced fields of the absorbers can be superposed. This kind of superposition is the first kind of superposition, i.e., with a test charge. The test charge is  $\mathbf{J}_1(t)$ .

In most situation, this kind of superposition is enough. This kind of superposition can also be widen to the situation for all advanced waves can be superposed.

If we have considered the self-energy principle Eq.(173-175), the superposition without any restriction can also be allowed. This has been seen from the whole derivation process.

It should be notice that the superposition of two fields of the two absorbers only happened at the situation of the quantum entangled situation [10]. This is the situation when we in the beginning has one higher energy photon with 0 spin. This photon go through some nonlinear substance and will becomes two entangled photons. This two photons have half energy as the original one. The two lower energy photon also have different spins, if the first lower energy photon is left spin, another lower energy photon must have the right spin, this will keep their angle moment conservative with the higher energy photon. Hence we have obtain the normal entanglement situation.

From understand of the author, the superposition is only happened in the quantum entangle situation. We often speak about that before the measurement a quantum system, the system is taken as a superposition state, that is very wrong. Before the quantum measurement, the mutual energy did not happened. The advanced wave has not released. Hence, all the possibility can be possible. But here has no any physical fields are superposed. The author do not agree that before a quantum measurement, the quantum system is a superposition state of all possible status. This is a very wrong statements.

### 9.6 Example 3

Assume we have two emitter charges and one absorber charges. The current of emitters are  $\mathbf{J}_{11}$  and  $\mathbf{J}_{12}$ . The current of the absorber is  $\mathbf{J}_2$ . The fields of the emitters are  $\xi_{11} = [\mathbf{E}_{11}, \mathbf{H}_{11}]$  and  $\xi_{12} = [\mathbf{E}_{12}, \mathbf{H}_{12}]$ . The field of the absorber is  $\xi_2 = [\mathbf{E}_2, \mathbf{H}_2]$ . We can have,

$$\xi_1 = \xi_{12} + \xi_{11} \quad (187)$$

Where

$$\xi_1 = [\mathbf{E}_1, \mathbf{H}_1] = [\mathbf{E}_{11} + \mathbf{E}_{12}, \mathbf{H}_{11} + \mathbf{H}_{12}] \quad (188)$$

In this case we also have Eq.(181) which means,

$$- \iiint_{V_1} \mathbf{E}_2(t) \cdot (\mathbf{J}_{11}(t) + \mathbf{J}_{12}(t)) dV = \iiint_{V_2} (\mathbf{E}_{11}(t) + \mathbf{E}_{12}(t)) \cdot \mathbf{J}_2(t) dV \quad (189)$$

This tell us, in the place of absorber  $V_2$ , the two retarded fields of the emitters can be superposed. This kind of superposition is a superposition with test a charge.

In most situation this kind of superposition is enough. This kind of superposition can also be widen to the situation for all retarded waves or all the advanced waves.

If we have considered the self-energy principle Eq.(173-175), the superposition without any restriction can be allowed. This has been seen from the whole derivation process.

The above is also a kind of entangled situation. This time the two retarded field from the emitter are superposed.

I believe this kind of the entangled situation should also exist. This can be proved by a future experiment. For example we can using lower energy photon to bombard the nonlinear material used in the Spontaneous parametric down-conversion experiment[10]. If the two lower energy photon can be convert to one higher energy photon, this situation has happened. Hence, this is the inverse process of the Spontaneous parametric down-conversion experiment[10].

## 9.7 Summarization

The above examples tell us, even we started with the second kind of the superposition i.e., without test charge, if we consider the self-energy principle, in the end we will obtain a result of first kind of the superposition, the superposition with test charge, or we obtained the superposition of only one kind of fields, either retarded or advanced.

However if we do not consider the self-energy principle, we cannot obtained the energy conservation law (which is the Welch's reciprocity theorem).

This also tell us, the Welch's reciprocity theorem is not only a reciprocity, it is a energy theorem, it is an energy conservation law for two charges one is an emitter one is an absorber. The author has call the Fourier transform of the Welch's reciprocity theorem as the mutual energy theorem[11], this is correct, but it is not enough, Welch's reciprocity theorem is an energy conservation law. Eq.(20) can be seen as extension of the Welch's reciprocity theorem from charge 2 to  $N$  charges and which is an energy conservation law for  $N$  charges. It should be noticed that Eq.(20) is easy to been seen as a energy conservation law than Welch's reciprocity theorem. Since Welch's reciprocity theorem is usually not applied to two charges but two antennas. In the case of two antennas, Welch's reciprocity theorem discussed the energy transfer between the transmitting antenna to the receiving antenna. It is clear that it is only a part of the energy of the transmitting antenna transferred to the receiving antenna, hence, it is not a energy conservation law. This is also the reason when this author started the same problem, has called it as the mutual energy theorem. Even in the antenna situation, Welch's reciprocity theorem is not an energy conservation law, but it is still an energy theorem.

It is only in the recent year, when this author move the problem from the antenna to the charges, In this case, the author assume that in the empty space there are only  $N$  charges, we can derive the energy conservation law. In the empty space there are only  $N$  charges or 2 charges, this is a abstraction form. In the real situation, it is not possible to get a space where there are only two charges. Hence, this claim about a empty space with only  $N$  charges cannot be implemented in the real world. However the author think this kind of abstraction is very useful to make things clear.

## 10 The superposition for the traditional electromagnetic fields

The electromagnetic fields studied in the absorber theory[1, 2], and the author's theory[12], the retarded field and the advanced field are all assumed. In the traditional field theory there is only the retarded field. We know that the traditional electromagnetic field is also very successful in most situations. Hence, the author thought that the traditional electromagnetic field theory, it should be possible to be derived as approximate result of the author's new electromagnetic field theory in which the retarded field and the advanced field are assumed.

### 10.1 Traditional electromagnetic field

In the last a few sections we consider the situation with the retarded wave and the advanced wave. The author believe that this is a more accurate theory. Then the traditional electromagnetic field theory should be possible to be derived from this new theory. We can assume that the absorbers are uniformly distributed on a infinite big sphere, all the advanced fields contributed from the absorbers should equal to the retarded wave, in this situation, the traditional electromagnetic field will be two times as strong as the retarded field or advanced field. The traditional field can be seen as the summation of the retarded wave and the advanced wave. The traditional electromagnetic field can be seen as retarded field also.

### 10.2 Wave guide situation

In case of the wave guide, for example a cylinder wave guide. Assume one end of cylinder there are emitters. Assume in the another end of the cylinder there are the absorbers. Hence, there are transmitter and receiver on each end of the wave guide.

We assume that the absorbers can absorb all the waves sent from the emitters and without any reflections. In this case we can assume the advanced fields sends from these absorbers are nearly same as the retarded waves sent from the emitters. Hence, we have,

$$\mathbf{E}_a \simeq \mathbf{E}_r \quad (190)$$

$$\mathbf{H}_a \simeq \mathbf{H}_r \quad (191)$$

$$\mathbf{E} = \mathbf{E}_r + \mathbf{E}_a \simeq 2\mathbf{E}_r \quad (192)$$

where  $\mathbf{E}_r$  is the retarded field send from the end 1 which is the transmitter.  $\mathbf{E}_a$  is the advanced field send by the end 2 which is a receiver. In the wave guide.  $\mathbf{E}$  is the traditional electromagnetic fields which is consist of the retarded wave and the advanced wave. Usually we did not notice this, we will think this field is just produced only by the source which is the transmitter in one end of the wave guide.



According to the mutual energy principle the retarded wave and the advanced wave satisfy the mutual energy principle, which is,

$$\begin{aligned}
& - \oiint_{\Gamma} (\mathbf{E}_r \times \mathbf{H}_a + \mathbf{E}_a \times \mathbf{H}_r) \cdot \hat{n} d\Gamma \\
& = \iiint_V (\mathbf{E}_r \cdot \mathbf{J}_a + \mathbf{E}_a \cdot \mathbf{J}_r) dV \\
& + \iiint_V (\mathbf{E}_r \cdot \partial \mathbf{D}_a + \mathbf{H}_r \cdot \partial \mathbf{B}_a + \mathbf{E}_a \cdot \partial \mathbf{D}_r + \mathbf{H}_a \cdot \partial \mathbf{B}_r) dV \quad (193)
\end{aligned}$$

Assume the current  $\mathbf{J}_r$  is inside the volume  $V_1$ .  $V_1$  is the region close to  $\mathbf{J}_r$ .  $\Gamma_1$  is the boundary surface of  $V_1$ . In the above formula the volume  $V$  can be chosen as an region. If we take the mutual energy theorem on the volume  $V_1$ , we have,

$$\begin{aligned}
& - \oiint_{\Gamma_1} (\mathbf{E}_r \times \mathbf{H}_a + \mathbf{E}_a \times \mathbf{H}_r) \cdot \hat{n} d\Gamma \\
& = \iiint_{V_1} \mathbf{E}_a \cdot \mathbf{J}_r dV \\
& + \iiint_{V_1} (\mathbf{E}_r \cdot \partial \mathbf{D}_a + \mathbf{H}_r \cdot \partial \mathbf{B}_a + \mathbf{E}_a \cdot \partial \mathbf{D}_r + \mathbf{H}_a \cdot \partial \mathbf{B}_r) dV \quad (194)
\end{aligned}$$

This is because inside the volume  $V_1$ ,  $\mathbf{J}_a = 0$ , and hence,  $\mathbf{E}_r \cdot \mathbf{J}_a = 0$ . Consider Eq.(190) to the above formula we have approximately,

$$\begin{aligned}
& - \oiint_{\Gamma_1} (\mathbf{E}_r \times \mathbf{H}_r + \mathbf{E}_r \times \mathbf{H}_r) \cdot \hat{n} d\Gamma \\
& = \iiint_{V_1} \mathbf{E}_r \cdot \mathbf{J}_r dV \\
& + \iiint_{V_1} (\mathbf{E}_r \cdot \partial \mathbf{D}_r + \mathbf{H}_r \cdot \partial \mathbf{B}_r + \mathbf{E}_r \cdot \partial \mathbf{D}_r + \mathbf{H}_r \cdot \partial \mathbf{B}_r) dV \quad (195)
\end{aligned}$$

or

$$\begin{aligned}
& -2 \oiint_{\Gamma_1} (\mathbf{E}_r \times \mathbf{H}_r) \cdot \hat{n} d\Gamma \\
& = \iiint_{V_1} \mathbf{E}_r \cdot \mathbf{J}_r dV
\end{aligned}$$

$$+ 2 \iiint_{V_1} (\mathbf{E}_r \cdot \partial \mathbf{D}_r + \mathbf{H}_r \cdot \partial \mathbf{B}_r) dV \quad (196)$$

Considering Eq.(192)

$$\begin{aligned} -\frac{1}{2} \oint_{\Gamma_1} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma &= \frac{1}{2} \iiint_{V_1} \mathbf{E} \cdot \mathbf{J} dV \\ &+ \frac{1}{2} \iiint_{V_1} (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV \end{aligned} \quad (197)$$

The energy transferred on the wave guide is.

$$\frac{1}{2} \oint_{\Gamma_1} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma \quad (198)$$

Eq.(197) can be rewritten as,

$$\begin{aligned} -\oint_{\Gamma_1} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma &= \iiint_{V_1} \mathbf{E} \cdot \mathbf{J} dV \\ &+ \iiint_{V_1} (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV \end{aligned} \quad (199)$$

This is the Poynting theorem. Hence, even we started with mutual energy principle and assume there are retarded wave and the advanced wave, but we still can obtained the Poynting theorem for traditional electromagnetic field  $\xi = [\mathbf{E}, \mathbf{H}]$ . In this Poynting theorem, the field  $\mathbf{E} = \mathbf{E}_r + \mathbf{E}_a$  are superposition of the retarded wave and advanced wave and hence, two times as the field of only retarded wave. The above result is obtained inside a wave guide, but it can be widen further, see next sub-section.

It should be clear that even the traditional field  $\xi = [\mathbf{E}, \mathbf{H}]$  field satisfy Poynting theorem and hence, also satisfy the Maxwell equations, the transferred energy is only half what has been calculated by the electromagnetic field using Poynting theorem.

### 10.3 Widen the result to the case with a cone-beam wave guide

The above result can be easily widen to the situation instead of the cylinder wave guide, but a cone-beam wave guide. We can assume that the emitters are all at the vertex of the cone. In the other end there is uniformly distributed absorbers. In this situation the Eq.(190-192) still can be established. This will lead the same result as last sub-section. Hence, the traditional electromagnetic fields also satisfy the Poynting theorem for cone beam wave guide situation. It should be noticed that we have assume in one end of the cone-beam wave guide

the absorbers has been distributed uniformly. This assumption will lead the advance wave of the absorber close to equal to the retarded wave sent from the vertex of the cone.

#### 10.4 Further widen the result to free space

The free space can be also see as a cone beam wave guide, the only difference is this kind of the wave guide has the cone-beam angle as  $4\pi$ . The normal cone-beam wave guide the beam span angel is less  $4\pi$ . In case we have assume that the absorbers are uniformly distributed on the infinite big sphere, we can assume that the advanced wave of the absorber is approximately equal to the retarded wave.

It should be noticed that the condition above for widening the result is the absorbers uniformly distributed on the infinite big sphere. This condition is not easily to be met in any situation. In case there are two antenna, one is a transmitting antenna, another is a receiving antenna, there are absorbers in the back ground of the receiving antenna. The back ground can also receive the electromagnetic field which can be seen as a uniformly distributed on infinite big sphere. But since we have added a receiving antenna to the uniformly distributed absorbers, the total advanced fields sends out from the receiving antenna and the absorbers in infinite big sphere together can not be seen as uniformly distributed. The receiving antenna are close to the transmitting antenna, it can offer big influence to the emitter than other absorbers on the infinite big sphere. If the receiving antenna are very far away from the transmitting antenna, the influence of the receiving antenna to the transmuting antenna can be omit. In this situation we can also say that the absorbers are uniformly distributed on the big sphere when we discussion the problem of transmitting antenna.

In case we need to calculate some thing for example the directivity diagram of the receiving antenna. In this case we cannot assume the absorber are uniformly distributed. And hence, the traditional electromagnetic field theory will fail. This is also the reason we cannot directly calculate the directivity diagram of the receiving antenna with the traditional electromagnetic field theory. Normally in this situation we have to apply the Lorentz reciprocity theorem[3, 4] to find the directivity diagram. The correct way to calculate the directivity diagram of a receiving antenna is to apply the mutual energy theorem or Welch's reciprocity theorem. Since Lorentz reciprocity theorem is only a transform of the mutual energy theorem or Welch's reciprocity theorem, it can also obtained correct directivity diagram of a receiving antenna. However, this is not mean that the Lorentz reciprocity theorem is correct. It is wrong because it assume the receiving antenna also sent the retarded wave. Now it is clear that the receiving antenna sends the advanced field. Abort the wrong doing of the Lorentz reciprocity theorem the author will discuss it more detail in other article. Here, we only need to know that the absorbers are uniformly distributed, this condition is often to be violated. Only when the absorber can be seen as uniformly distributed we can thought the advance wave same as the retarded wave and

hence the traditional electromagnetic field theory can be applied.

In the traditional electromagnetic field Maxwell equations and the superposition principle can be applied. This superposition is only for the traditional field which is actually consist of the retarded wave and also the advanced wave.

### **10.5 Further widen the superposition principle to the traditional electromagnetic fields**

In case there is uniformly distributed absorbers, then the advanced wave can be seen approximately equal to the retarded wave. We known that the retarded waves can be superposed, If the absorber are uniformly distributed on the infinite big sphere, the advanced wave is approximately equal to the retarded wave. Hence the total field which is the traditional electromagnetic field will be two times of the retarded waves. The retarded wave can be superposed, since this traditional electromagnetic wave, similar to the retarded wave, can also be superposed.

Hence the traditional electromagnetic field can be superposed. Please notice, according to our discussion before, when we discussion the directivity diagram of the receiving antenna, this result is not suitable. In the case of directivity diagram of the receiving antenna, the concept of the traditional electromagnetic field will fail.

## **11 Energy of the superpositions**

In this section we discussion the energy of the different superpositions. The field can be superposed or not is not all we need to be discussion. The energy of the different superpositions should be also discussed. In this article we have discussed 5 different superpositions. Assume there two fields each have the same energy transferred, the question is how much the energy can be transferred by these 5 different superpositions?

### **11.1 The superposition of the retarded waves**

Assume there are two antenna each sends the retarded waves, assume the two antenna are very close to each other, in this situation, the field of the retarded wave can be superposed, hence the retarded wave has doubled, in this case the wave doubled, energy will 4 times as one antenna works alone.

This result is also true for the traditional field which are the retarded field together with the advanced field from uniformly distributed absorbers. If this traditional field doubled, the power after the superposition will 4 times larger. This is because in case the absorber has uniformly distributed on infinite big sphere we have proved that the traditional field satisfy Poynting theorem. From the Poynting theorem if the current  $\mathbf{J}$  is doubled, the radiation energy will 4 times as before.

## 11.2 The superposition of a retarded field send from the emitter and the advance field send from the absorber

We have said the superposition with retarded wave and advance wave is allowed, if we have accept the self-energy principle. However how much energy can be transferred for this kind of superposition? Think that the retarded field transfer the energy is positive. The advanced field transfer the energy is negative. Here the negative I mean that the advance field actually receiving energy, it is not really sending energy out. The advance wave sends from current time to the past time, but the source of the advance field actually receive energy from past. What will happen when this two kinds of fields superposed? If we think this situation should same as two retarded waves, the transferred energy will 4 times as there is only one wave. If we think the advance wave receive negative energy and hence, the retarded wave receiving positive energy, together should be 0. I thought the result perhaps is between 0 to 4, but what should be the correct answer?

Assume the  $\mathbf{J}_1$  sends retarded wave.  $\mathbf{J}_2$  sends advanced wave. Assume these two wave are synchronized and hence the mutual energy principle are satisfied. Hence we have the mutual energy flow theorem,

$$\begin{aligned}
 & - \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_2(t) \cdot \mathbf{J}_1(t) dV dt \\
 &= \int_{t=-\infty}^{\infty} \iint_{\Gamma} (\mathbf{E}_1 \times \mathbf{H}_2 + \mathbf{E}_2 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma dt \\
 &= \int_{t=-\infty}^{\infty} \iiint_V \mathbf{E}_1(t) \cdot \mathbf{J}_2(t) dV
 \end{aligned} \tag{200}$$

This formula offer us the energy transferred from the emitter to the absorber. This energy is the energy of a photon. The self-energy items,

$$\begin{aligned}
 & - \oiint_{\Gamma_1} (\mathbf{E}_1 \times \mathbf{H}_1) \cdot \hat{n} d\Gamma \\
 &= \iiint_{V_1} \mathbf{E}_1 \cdot \mathbf{J}_1 dV + \iiint_V (\mathbf{E}_1 \cdot \partial \mathbf{D}_1 + \mathbf{H}_1 \cdot \partial \mathbf{B}_1) dV
 \end{aligned} \tag{201}$$

is the self-energy of the retarded wave.

$$\begin{aligned}
 & - \oiint_{\Gamma_2} (\mathbf{E}_2 \times \mathbf{H}_2) \cdot \hat{n} d\Gamma \\
 &= \iiint_{V_2} \mathbf{E}_2 \cdot \mathbf{J}_2 dV + \iiint_V (\mathbf{E}_2 \cdot \partial \mathbf{D}_2 + \mathbf{H}_2 \cdot \partial \mathbf{B}_2) dV
 \end{aligned} \tag{202}$$

is the self-energy of the advance wave.

These two self-energy flow do not produce any energy transfer. If it transfer any energy, that means these waves are collapsed. However we have point out the wave are not collapsed but collapsed back, which means the self-energy principle should be accept which is,

$$- \oint_{\Gamma} \sum_{i=1}^2 (\mathbf{E}_i \times \mathbf{H}_i - \mathbf{e}_i \times \mathbf{h}_i) \cdot \hat{n} d\Gamma = 0 \quad (203)$$

$$\iiint_V \sum_{i=1}^2 (\mathbf{E}_i \cdot \mathbf{J}_i + \mathbf{e}_i \cdot \mathbf{j}_i) dV = 0 \quad (204)$$

$$\iiint_V \sum_{i=1}^2 (\mathbf{E}_i \cdot \partial \mathbf{D}_i + \mathbf{H}_i \cdot \partial \mathbf{B}_i + \mathbf{e}_i \cdot \partial \mathbf{d}_i + \mathbf{h}_i \cdot \partial \mathbf{b}_i) dV = 0 \quad (205)$$

This means all self-energy flows are canceled with the corresponding time reversal self-energy flow. All self-energy terms are canceled. Hence the two formula of Poynting theorem Eq.(201, 202) do not transfer any energy! This looks good, if they transfer energy, this energy will send to the whole space the energy eventually will be lost in our universe. The wave collapse can not be accepted. The reason is that, the wave collapse none can offer a formula to describe it. The another reason is the mutual energy flow theory has offered a correct energy conservation law for the two charges, there is no any room for some any other energy terms to transfer. If the self-energy flow also collapse, which will contributed some additional energy on the top of the energy conservation law, which will destroy the energy conservation law. And hence, that cannot be accept.

Hence, Eq.(200) offer us the energy transferred by this kind of superposition. This energy is not related to the self-energy flow but only the mutual energy flow, it is also nothing to do with concept the field is 2 times and then the energy will be 4 times.

### 11.3 The superposition of fields of two absorbers

Assume there are two absorber receive the retarded field sent from one emitter. This is the situation of the quantum entanglement. Assume there is a high frequency photon, it runs to the nonlinear substance, this nonlinear substance can be seen as the emitter which sends two low frequency photons out[10]. Here we speak about two photons that means this emitter has send a retarded wave in the same time. There are two absorbers which send two advanced waves to the emitter. Assume this two advanced waves are all synchronized to the retarded wave, that means they reach the emitter at the same time. We know that the emitter has obtain the energy from the input photon which is a higher energy photon. Since now there are two waves from two absorbers come to the emitter, The energy of the emitter is divided by two as two parts. Each absorber

can be obtained only one half of the energy. Since the two lower energy photons should have the same angular momentum as the original higher frequency photon. If the original photon has 0 angular momentum the two new photons can only have one with left spin and the other with right spin. Hence the two photons are entangled. This means if we have measured one of the photons which has left spin, we should know that the other photon has right spin. This way we can make the two photons have a total angular momentum of 0. In this case the angular momentum of two photons must be entangled.

In this situation there are two photons having been received. Hence, the two absorbers can only double the transferred energy.

#### 11.4 Can the time reversal field superpose to the normal electromagnetic field

In this article we have introduced the time reversal electromagnetic fields. The time reversal electromagnetic fields do not satisfy the same Maxwell equations. The electromagnetic field satisfies the Maxwell equations, the time-reversal electromagnetic field satisfies the time reversal Maxwell equations. Hence, the author does not assume that these two kinds of fields can be superposed. i.e.  $\mathbf{E}$  cannot be superposed with  $\mathbf{e}$ .  $\mathbf{H}$  cannot be superposed with  $\mathbf{h}$ . However they transfer the same amount of energy and, hence, cancel each other.

#### 11.5 Summary

According to the above discussion that if the traditional wave sent from the emitter is doubled, here the traditional wave are the waves in a waveguide or in free space but the absorbers are uniformly distributed on the infinite big sphere. Since in this situation the advanced wave and the retarded wave are the same, if the retarded wave is doubled the advanced wave sent back from the environment will also be doubled, the energy transfer will be 4 times as in the original situation.

If the retarded wave sent from an emitter and the advanced wave sent from an absorber are superposed. The two waves become an energy transfer pair, it can only transfer energy of 1 photon. This one photon is transferred by the mutual energy flow. The transferred energy (photon energy is smaller than the self energy flow of the emitter or the self-energy of the absorber). The self-energy flow doesn't have any contribution to the energy transfer (This is because there is the time-reversal wave which cancels the self-energy flow according to this author's theory).

If the advanced waves sent from two absorbers, the transferred energy can only have two times as before. In this case the retarded wave doesn't change, only the waves of the absorbers are changed.

It is the same if the two emitters send fields are received by one absorber. This absorber will receive two photons. In this case the field from two emitters is doubled but the field from the absorber doesn't double hence the transferred energy is only doubled instead of fourfold.

Hence according to author's electromagnetic field theory there are different superpositions, the energy transferred by the different superpositions cannot be simply thought the two fields superposed, the field will doubled and the energy transferred will be fourfold. We have to distinguish different situations.

## 12 the radiation reaction force or the self force

A accelerated electron will radiate electromagnetic fields and hence obtained a recoil force. This force is referred as reaction force or self force. It first studied by Abraham–Lorentz, and then Dirac. Later Wheeler and Feynman and so on. This force is related the energy sending out by the electron, hence how much energy is send out by an electron is important.

### 12.1 Abraham–Lorentz force

However in one situation, this result can be perceived which is the calculation of the recoil force of an electron. It is also often be called as Abraham–Lorentz force, the radiation reaction force or the self force. This calculation has been done first by Lorentz. When Lorentz try to solve the recoil force of a electron, he first calculated the energy radiation of the accelerated electron. If this energy is send out by the electron, the electron will obtained a recoil force. However when Lorentz apply this energy to calculate the recoil force, the force is doubled. Lorentz assume that the electron is not a point but a small sphere with radio  $10^{-15}$ meter. When the electron become small sphere, the recoil force can be reduced. When the sphere is around  $10^{-15}$ meter, the force just reduce to its half. And hence the correct result is achieved. This way Lorentz solve the problem. However, many scientists don't satisfy that the electron has a internal structure instead of a point. Dirac try to solve this problem by using advanced wave.

### 12.2 Dirac-Abraham–Lorentz force

When Dirac calculate the recoil force of an electron[8], he cannot apply the energy calculated by using the Poynting theorem. He need a half of that value. He give an expatiation that the retarded wave together with the advance wave will decrease the force to its half. His give an explanation that the force of the retarded wave is 1, the force of the advanced wave is  $\frac{1}{2}$  in value, but it is at the opposite direction. Hence, when they together, the total force will be  $\frac{1}{2}$ . Dirac applied the advanced wave to solve the problems.

### 12.3 Absorber theory

Wheeler and Feynman don't satisfy the explanation of Dirac, they spends much more ink to explain this fact of  $\frac{1}{2}$  [1, 2].



## 12.4 The energy transferred by the mutual energy flow

In the case of the absorber are uniformly distributed on the infinite big sphere, Eq.(199) still correct that is rewritten as,

$$\begin{aligned}
 -\frac{1}{2} \oint_{\Gamma_1} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma &= \frac{1}{2} \iiint_{V_1} \mathbf{E} \cdot \mathbf{J} dV \\
 + \frac{1}{2} \iiint_{V_1} (\mathbf{E} \cdot \partial \mathbf{D} + \mathbf{H} \cdot \partial \mathbf{B}) dV & \quad (206)
 \end{aligned}$$

The left side is the energy transferred by the mutual energy flow,

$$\frac{1}{2} \oint_{\Gamma_1} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma = \oint_{\Gamma_1} (\mathbf{E}_r \times \mathbf{H}_a + \mathbf{E}_a \times \mathbf{H}_r) \cdot \hat{n} d\Gamma \quad (207)$$

We know that the transferred energy calculated by Poynting theorem is  $\oint_{\Gamma_1} (\mathbf{E} \times \mathbf{H}) \cdot \hat{n} d\Gamma$ . Here  $V_1$  is a small region include the source  $\mathbf{J}_r$ .  $\Gamma$  is the outer surface of volume  $V_1$ . This means the energy transferred by the mutual energy flow is the half of the same energy calculated by Poynting theorem.

Perhaps some one will argue that if Poynting theorem make a mistake of  $\frac{1}{2}$  why so many engineer and scientist did not notice it?

The problem is for antenna we only interesting to know the directivity diagram which is no thing to do with the fact of  $\frac{1}{2}$ . If the antenna sends more or less the energy, the directivity diagram does not changed. Another reason is if the radiation energy is reduced or doubled we can can adjust the radiation resistance. After this adjustment, it will seems that the Poynting theorem is still can be satisfied. This also means Poynting theorem doubled the actually energy transferred for the radiation. Even the calculated energy is 2 time larger than what the real situation, we cannot perceive it.

## 12.5 The radiation force calculated by the mutual energy flow

Now we have found that the energy transferred by mutual energy actually less than it is calculated by the Poynting theorem. This energy just a half of the energy calculated by Poynting theorem. Hence, if we apply this result to the calculation of the recoil force (the radiation force or self force) of an electron we obtained the force will be half of that obtained by Poynting theorem. In this situation we do not need to assume that the electron is sphere with a radius of  $10^{-15}$  meter like Lorentz did.

The author's result is similar to the results of Dirac. Dirac thought it is the force of the retarded field and the force of the advanced field together become its half. In this author's theory, the energy transferred by the mutual energy flow is just the half of the energy calculated by the Poynting theorem. The mutual energy flow is consisted of the retarded wave and the advanced wave. The

authors explanation is not exactly same as the Dirac's thought. It is another way to explain the same constant  $\frac{1}{2}$ . This author's method is more nature, first the result is symmetry to the retarded wave and advanced wave. It is very difficult to understand why the advanced wave contributed a recoil force of  $-\frac{1}{2}$  of the retarded force. This is not symmetry to the retarded wave and the advanced wave. But if the mutual energy flow just half of the energy flow calculated by Poynting theorem, that is more nature. This author's result is easier to be accept than the explanation of the Wheeler and Feynman in absorber theory [1, 2].

## 12.6 The only problem

The author need to point out there still a conflict to the wave guide. The author believe the radiation energy calculated by mutual energy flow is correct even in the wave guide. However, in electrical engineering, we often heard the transferred energy and power is calculated by Poynting theorem. None perceive that the energy calculated has doubled. This is little bit strange.

There has two possibility, the energy transferred by the wave guide should still according to the Poynting theorem, the self-energy flow still has some contribution to energy transfer. The author's self-energy principle is not suitable to the wave guide situation. It is only suitable to the free space situation. The second the mutual energy flow calculation is correct to the energy flow of a wave guide. That means we just make mistake somewhere else, for example the definition of the load of the wave guide, or the definition of voltage of the input of the wave guide. This problem will left for the readers to found out.

## 13 Conclusion

### 13.1 United the two superposition principles

In this article we started two kinds of superposition principle, (1) is the superposition without a test charge. (2) is the superposition with a test charge. Since in the author's electromagnetic field theory the advanced wave is accept as physical wave, (3) the superposition with the retarded waves alone are considered. (4) the superposition with advanced waves alone are considered. The superposition for the traditional electromagnetic fields are also considered. The traditional electromagnetic field which is obtained by assuming the absorbers uniformly distributed on the infinite big sphere, and hence, the retarded wave and the advanced wave can be merged together become the one field: traditional fields.

The author has proved that started from the mutual energy principle, the superposition with retarded waves alone and the superposition with advanced waves alone are allowed. A absorber can be applied to test the fields of many emitters which are retarded waves. A emitter can be applied to test the fields from many absorber which are advanced waves. Hence, when we speak about

the superposition with test charges we also means the waves are either retarded waves or advanced wave but not both. This is because we cannot test the retarded field with a emitter and also cannot test the advanced wave with an absorber.

Maxwell equations and the Poynting theorem conflict with energy conservation. If we apply the superpositions with Poynting theorem, the calculated energy are more than the system really transferred. However we can apply the self-energy principle which tell us all the self energy flow has collapsed back by the time-reversal waves. Hence all self-energy flow should be take away from the N-charges Poynting theorem. After we take away the energy of the self-energy flow, we obtained the mutual energy principle. Hence the N-charge Poynting theorem together with self-energy principle is equal to the mutual energy principle. N-charge Poynting theorem is still correct as an equation (that means the left side of the formula is equal to the right side), however it is not correct as an energy conservation law! The energy conservation law is the mutual energy principle. An energy conservation law will require that each terms in the formula are total energy of some kind. For example, one term is total energy saved in the space, one term is total consumed energy from the absorbers, one time is total generated energy from the emitters.

If we accept the self-energy principle, N-charges Poynting theorem can also be accept, because it together with the self-energy principle will become the mutual energy principle. But we need to keep our brain clear. If the Poynting theorem or N-charges Poynting theorem alone, it has the problem, since it will conflict with the energy conservation. N-charges Poynting theorem allow the fields can be superposed without test charges. This superposition is only correct if we accept the self-energy principle. Because if we apply the self-energy principle to the N-charge Poynting theorem we obtained the mutual energy principle. Hence, we also obtained the superposition with test charge.

The superposition without test charge apply to Poynting theorem, we obtained the N-charge Poynting theorem, if we do not consider the self-energy principle, this kind of superposition is wrong. Since this superposition with N-charge Poynting theorem conflict to the energy conservation law.

We can proved that the above 5 different superpositions are all allowed. But if the self-energy principle is not applied. The superposition without test charge and the Maxwell equations will conflict with energy conservation law. The superposition with test charge has different meaning with the superposition without test charge. Hence self-energy principle is the key to united all kinds of the superpositions. This also tell us that the self-energy principle must to be accepted.

This article we started from the Maxwell equations and superposition principle without test charge, we first obtained the Poynting theorem of  $N$  charges. If self-energy principle are accepted we obtained the mutual energy formula (The formula of the mutual energy principle, here we started from Maxwell equations and the superposition principle, and hence, this is referred as formula instead of principle). From mutual energy formula we derived the Maxwell equations must be synchronized. In order to derived the energy conservation law, we need

the fields of the two Maxwell equations one must be retarded and one must be advanced. Hence the advance waves have to be accepted. If self-energy principle isn't accepted, we cannot obtain energy conservation law. Hence all kinds of superpositions cannot be derived. Hence, the self-energy principle must be accepted.

The advance waves also need to be accepted at the electromagnetic field theory. Without advance waves we cannot prove the energy conservation law from the mutual energy principle. After we accepted the advanced waves the superposition with retarded wave alone or with advanced wave alone have different meanings. Hence, these two kinds of superpositions need to be distinguished. Since we have retarded waves and advanced waves, the traditional electromagnetic fields in which only the retarded wave are allowed (which are a combination of retarded wave and advanced wave) also need to be distinguished. This way we obtained 5 different superpositions. However, if we accepted the self-energy principle, these 5 different superpositions are all allowed, but the meaning of which are quite different.

Without self-energy principle, we can still have the mutual energy principle. From the mutual energy principle we can obtain the superposition with test charge or the superposition with the retarded wave alone or the superposition with the advanced wave alone.

With self-energy principle, we can even suppose all the fields with advanced wave and the retarded wave in N-charge Poynting theorem, however this kind of superposition is different with the superposition of the retarded wave alone or the advanced wave alone.

The mutual energy flow can be applied to calculate the self force or Abraham-Lorentz force. It offers a suitable result.

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