Discussion on Teaching Electromagnetic Field and Wave Course

Xianfeng Ye, Xianmin Zhang, Shilie Zheng, and Yang Du
Department of Information and Electronics Engineering
Zhejiang University, Hangzhou 310027, China

Abstract— We have already launched certain teaching reform that we combined the course Theory of Electromagnetic Field (including the antenna) and the course Microwave and Optical Guided Wave Technology into a single course, Electromagnetic Fields and Electromagnetic Wave. Although the depth and coverage of the course has increased, the course hours have been compressed. This requires teachers to make greater efforts and take more effective measures. So we have focused on three aspects of EM teaching. We have seized the keys of vector field theory to clear students' obstacles about mathematics, made students to understand the rigorous logic system of electromagnetic theory which deeply enhances the students' sense of innovation, and combined the theories with practical applications to improve their capabilities of applying knowledge and solving engineering problems.

1. INTRODUCTION

The course Theory of Electromagnetic Field and Wave is one of the most important technical foundation courses in electronic engineering. With the recent great advances in electronics and information technology, particularly in the internet technology as the representative of the network and communication technologies, the course teaching methodology should keep pace with them. We have already launched certain teaching reform that we combined the course Theory of Electromagnetic Field (including the antenna) and the course Microwave and Optical Guided Wave Technology into a single course, Electromagnetic Fields and Electromagnetic Wave. Although the depth and coverage of the course has increased, the course hours have been compressed. This requires teachers to make greater efforts and take more effective measures. First, we strengthen the foundations of mathematics and seize the heart of vector and field theory. Second, we have analyzed electromagnetic theory systematically and rigorously to cultivate innovative thinking ability of students. Finally, we introduce electromagnetic theory by combining it with practice applications.

2. STRENGTHENING FOUNDATIONS OF MATHEMATICS

This course is abstract and difficult for students to understand, mainly because students can not combine mathematical tools with the physical concepts. It is necessary to clear mathematical obstacles. The main mathematical tool of the course is the vector and field theory. For a vector field, divergence and curl are core concepts. The vector dot product and cross product have a wonderful correspondence with them.

Hamilton operator ∇ has a double feature with a vector and operator. It is an operator and also a vector, but it is different with the vector.

For example, from the perspective of vectors: Dot product can be exchanged.

$$\mathbf{A} \cdot \mathbf{B} = \mathbf{B} \cdot \mathbf{A}$$

However, as an operator, operator and field dot product can not be exchanged, that is,

$$\mathbf{A} \cdot \nabla \neq \nabla \cdot \mathbf{A}$$

Similarly, the cross product of two vectors can be counter-exchanged, that is,

$$\mathbf{A} \times \mathbf{B} = -\mathbf{B} \times \mathbf{A}$$

However, as an operator, the cross product with field can not be counter-exchanged, that is,

$$\mathbf{A} \times \nabla \neq -\nabla \times \mathbf{A}$$

When the ∇ as an operator acts on the field, it is just like as differential operator.

Only combining the field, the ∇ displays its physica meaning or it is just one operation symbol. From the micro perspective, divergence $\nabla \cdot \mathbf{D} = \rho$, $\nabla \cdot \mathbf{B} = 0$ can be indicated that electric field is active but magnetic field is passive. The Curl $\nabla\times$ displays contribution from the flow, $\nabla \times \mathbf{H} = \mathbf{J} + \frac{\partial \mathbf{D}}{\partial t}$, $\nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$.

By clarifying these relationships, We reduce the difficulty of students on mathematics.

3. ANALYZING ELECTROMAGNETIC THEORY SYSTEMATICALLY

Maxwell extracted from the essential characteristic of electromagnetic phenomena the concept of electric and magnetic fields from the Faraday line force, and using these two concepts he rewrote Coulomb's law, Ampere's law and Faraday's law. By conjecturing the displacement current, Ampere's Law was rewritten into the Ampere's full current law, and finally the construction of electromagnetic theory system was completed.

The introduction of displacement current has an important significance to the establishment of entire electromagnetic theory. The introduction of displacement current, make two curl equations of Maxwell $\nabla\times\mathbf{E}=-\frac{\partial\mathbf{B}}{\partial t}$, $\nabla\times\mathbf{H}=\mathbf{J}+\frac{\partial\mathbf{D}}{\partial t}$. The logic diagram of the introduction of displacement current is shown as Fig. 1.

The curl equations show presence of coupling beween $\mathbf{E}$ and $\mathbf{H}$, and two-way conversions between time and space, that is, $\mathbf{E}$ converted into $\mathbf{H}$, then $\mathbf{H}$ into $\mathbf{E}$; the time change $\frac{\partial}{\partial t}$ converted into the space change $\nabla\times$, then the space change $\nabla\times$ converted to the time change $\frac{\partial}{\partial t}$. It is just this two-way change that reveals the existence of electromagnetic waves.

Maxwell's electromagnetic theory predicted the existence of electromagnetic waves. Electromagnetic wave is not a result through perception but a logical reasoning one. It is a sure existence which was confirmed by the German physicist Hertz in the experiment. The establishing process of electromagnetic theory could make students to recognize the logic of the relationship in the electromagnetic theory, and appreciate the power of logical reasoning and Maxwell's creative spirit. So, we have analyzed electromagnetic theory systematically and rigorously to cultivate innovative thinking ability of students.

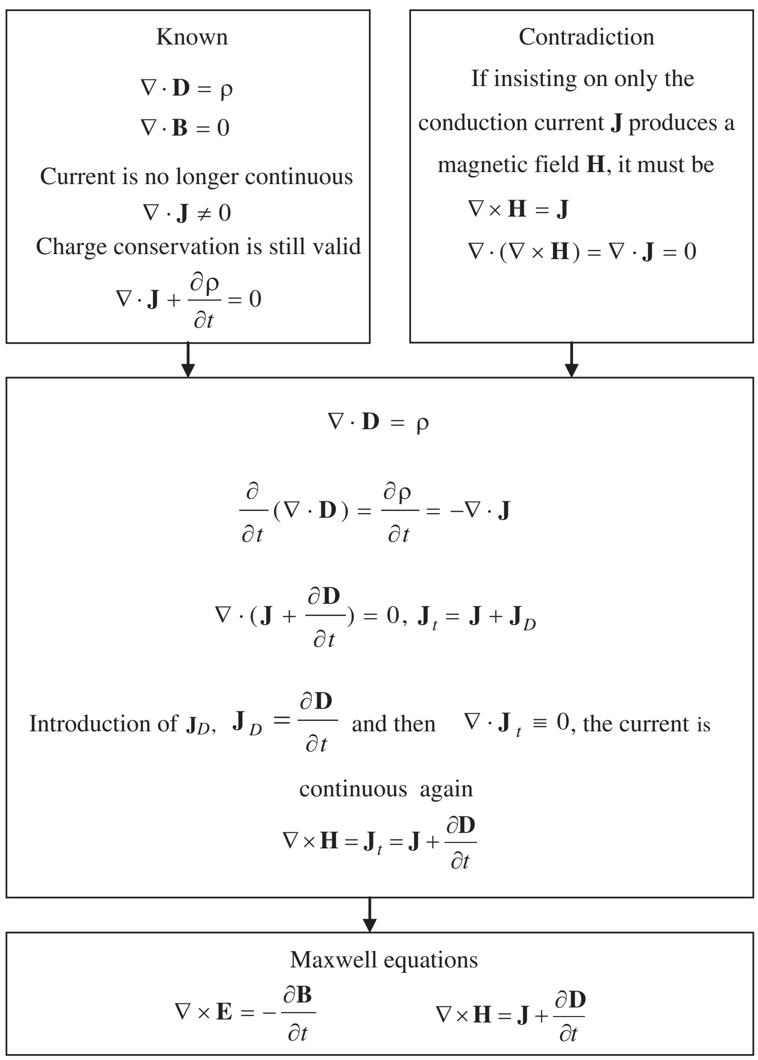

Figure 1: The logic diagram of the introduction of displacement current.

4. COMBINING ELECTROMAGNETIC THEORY WITH APPLICATIONS

Electromagnetic theory is abstract, but the application is extensive. During the course we select the content and problems about new technologies, such as communication, networking, radar, navigation, remote sensing and so on.

An antenna is an essential component in a radio communication system that is needed in both the transmitting and receiving terminals. Several types of antennas have been developed for various applications. For example, we introduce the principles and applications of patch antenna (also called microstrip antennas) in the class.

Figure 2 [1] shows a typical probefed rectangular patch antenna. The patch antenna consists of four major parts: The conductive patch, the dielectric substrate, the ground plane, and the feed line. Some of the advantages of patch antennas are:

- Low fabrication cost and complexity.
- Can be easily conformed to a curved surface of a vehicle or product.
- Resistant to shock and vibration.

Because of these, Patch antennas are used in several wireless applications like global positioning system (GPS) receivers, wireless LANs and radar sensors systems [1].

GPS patch antennas are widely used in GPS receivers. Also, a patch antenna can be easily mounted on the roof of a vehicle because of its planar structure.

Wireless LANs are deployed in office or other buildings. The physical link between the machine and the wireless access point dictates that the machine would have some kind of hemispherical radiation shape to cover all points above the machine almost equally, which makes patch antennas a good candidate.

Arrays of patch antennas could be used as near-range radar sensors. The array could be placed at the front of the car, so that the safety of driving has increased.

In addition to wireless communications and radar applications, electromagnetic waves can also be used in the wireless energy transfer.

Wireless energy transfer is currently the academic frontier. In the same way as the requirement of wireless communications, people are looking forward to a future when the energy supply could slipped the leash of the electrical wire. There are three types of methods having been researched. The first one is transferring energy over very high frequency (VHF, frequency $>$ 300 MHz) in the form of electromagnetic. When proper controls are put on the transfer antenna and receiver antenna, the energy transfer can be highly directional in such a high frequency field. The second one is transferring energy by loosely coupled transformer device of which primary side is separated from secondary side. The third one is transferring energy by the "strongly-coupled" resonances coupling of the mutual inducted magnetic field [2–4].

MIT in American did some research on principle simulation and experimental verification about technology of third type [3]. The basic principle of this technology is that two separate coils with same resonance frequency are possible to form a resonant system based on high frequency magnetic coupling and exchange energy in a high efficiency, while the coupling effect is weak between those objects with different resonance frequency. The medium of energy transfer is an alternating

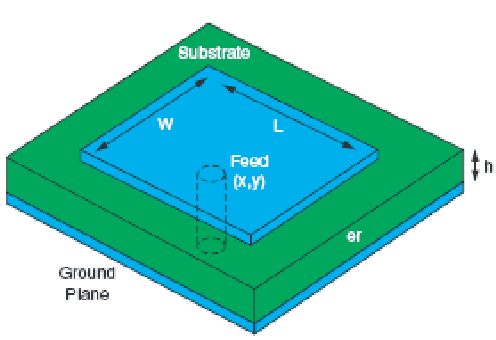

Figure 2: Structure of microstrip antenna.

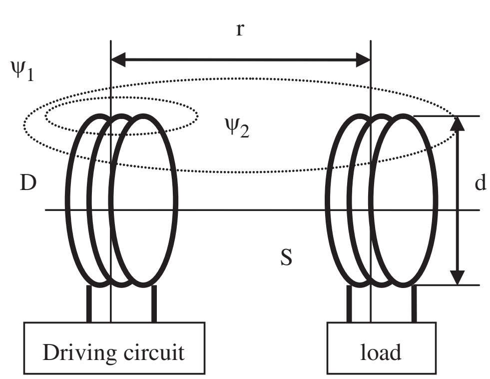

Figure 3: Structure of the wireless power transfer system.

magnetic field. In the Fig. 3 [4], resonator is composed of two coils and lumped parameters capacitance. Connected to the driving circuit, the driver coil D is used to generate magnetic field which is supposed to be either zero-order or one-order field. A part of flux (ψ_2) of these two close and coupled coils (D) intersects with each other besides the self-coupled flux (ψ_1).

By studying these these application examples, students' interest is stimulated. On the one hand students learn more knowledge about academic frontier of the electromagnetic theory and applications, on the other hand they have also more deeply understanded the theories of resonator, antenna and so on, and appreciated the importance of electromagnetic theory.

In short, we have focused on three aspects of EM teaching. We have seized the keys of vector field theory to clear students' obstacles about mathematics, made students to understand the rigorous logic system of electromagnetic theory which deeply enhances the students' sense of innovation, and combined the theories with practical applications to improve their capabilities of applying knowledge and solving engineering problems.

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