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Reform of the *Electromagnetic Fields and Waves* course in the new era

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ABSTRACT: To meet the needs of the new era, the teaching methods of the *Electromagnetic Fields and Waves* course were revised. The first modification was to the course syllabus. Then, experiments of electromagnetic wave measurements (wavelength, standing wave ratio) were added to the teaching process; the practice content was increased; and, gradually, a benign school-enterprise co-operative mode was formed. Teaching material had to be changed drastically; especially, in the latter part of the course. Special topics instruction was introduced and tedious theoretical derivation was transformed into numerical programming. Using simulations, the internal laws and characteristics were summarised. Finally, on-line course teaching was introduced. These changes substantially increased student opportunities for hands-on operation.

INTRODUCTION

In 2013, there were 1,047 universities offering an engineering specialty, which was 91.5% of the total number of universities. There were 452.3 million undergraduate students, with 32 percent in engineering education. On June 19, 2013, at the International Engineering Union Conference, held in Seoul, South Korea, the Washington Accord plenum unanimously accepted China as the twenty-first signatory. The Washington Accord is the world's most influential agreement in providing mutual recognition of international engineering degrees. The engineering education standard and engineer professional competence standard under the agreement, generally, are acknowledged as the authoritative requirements for the professional competence of engineering graduates and engineers. Having been accepted into the Washington Accord, China's engineering education has developed rapidly, and is being highly ranked in the world. Also, the quality of China's engineering education has started to be recognised by the international community. However, China's engineering education, generally, cannot keep up with the needs of current national construction, making it urgent that the quality of engineering education be improved.

The Chinese Ministry of Education issued a document in 2011, *A Plan for Educating and Training Outstanding Engineers* (shortened as *Outstanding Engineers*) [1]. The plan stressed: *The Outstanding Engineers Education Programme is a major reform project for higher education to implement the national long-term education reform and development planning outline (2010–2020)* [2]. The aim of this plan is to build an innovative, modern, industrialised nation with advanced human resources. At the end of 2015, three governmental bodies jointly issued *The Guidance to Leading Local Universities to Transform to become Application-Oriented* (shortened as *the Guidance*) [3]. *The Guidance* emphasised China's educational [system] …*should be transformed to serving local economic and social development, to the integration of production and teaching, to the co-operation between schools and enterprises and to cultivating application-oriented talent*... [3].

This new era should map out a new road to industrialisation with Chinese characteristics, as well as building an innovation-oriented country and enhancing competitiveness. This would generate new requirements for higher engineering education. China has an urgent need for the reform of higher engineering education, including training models and evaluation systems. Training needs to reinforce the links between universities and industry. Students' engineering practice and innovation ability need to be further improved and engineering education teaching enhanced, especially, for young engineering teachers [4].

The Chinese government has issued many documents urging that the role of cultivating practical talent in universities be strengthened. Xidian University has risen to the challenge and there has been in-depth reform of all the engineering specialties. The authors are familiar with Xidian's outstanding engineer's education and the practical situation at Weinan Normal University. The *Electromagnetic Fields and Waves* (EMFW) course was selected as a pilot for teaching reform.

REVISION OF THE SYLLABUS

Electromagnetics, Advanced Mathematics and Vector Analysis are the prerequisites for the EMFW course [5]. The EMFW course, in turn, is the foundation course for the following: The Principle and Application of Sensors; Photoelectric Information Technology; Photoelectric Detection and Signal Processing; High Frequency Circuits; Microwave Technology, Antennas and Propagation; Microwave Communication, etc.

The teaching of EMFW under the original syllabus was organised as follows. On the basis of university physics, the fundamental law and analytic method of the macroscopic electromagnetic field (EMF) were discussed. This enabled the students to analyse the basic characteristics of the EMFW. It also cultivated students' scientific thinking, and laid the necessary foundation for the study of the electronic information technology majors. But, this syllabus failed to highlight *the Guidance*'s thought of *school …to serve the local economic and social development* and failed to reflect the pedagogical tasks put forward in the *Guidance*, viz., *…it should be the social-economic development and the advancement of industrial technology that drives curriculum reform [with] more focus on training the learner's technical skills and innovative and entrepreneurial abilities* [3]. A revised syllabus needs to embody a focus on enabling students to obtain field-related analysis and calculation methods, as well as the use of theory to solve problems.

The original syllabus did not include laboratory work; the total class time was 54 hours. The revised course includes the basic parameters measurement of the electromagnetic wave experiment (WMW) and the standing wave ratio (SWR) experiment; the total increases to 66 hours.

CULTIVATING STUDENTS' PRACTICAL ABILITY

The revised syllabus increases the hands-on opportunities for students to solve practical problems. Therefore, electromagnetic (EM) experiments need to be developed and laboratories should be available for students to undertake additional experiments in their spare time.

The EM experiments mainly involve the measurement of the wavelength (EMW) or standing wave ratio (SWR), the latter being the basic experiment chosen here. An SWR measurement can determine the field distribution on a transmission line by measuring impedance, wavelength, phase shift, attenuation, Q value and other parameters.

Different measurements require different measuring methods and most EMFW experiments have both direct and indirect methods of measurement, such as wavelength and SWR. Different measurement methods usually have their own conditions, such as the range of measurements. Careful consideration is required when determining the specific measurement method. For waveguides, a direct or indirect measurement can be used to determine the location of wave nodes. The waveguide and nodes are depicted in Figure 1 and Equation (1).

$$\lambda_g = 2\left|T'_{min} - T_{min}\right| \tag{1}$$

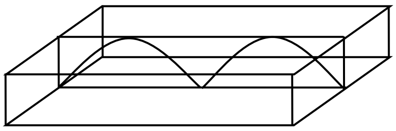

Figure 1: Field intensity distribution in waveguide.

For the indirect method, the free wavelength and the waveguide wavelength λ_g satisfy Equation (2). In the experiments, frequency is measured and converted to the free wavelength $\lambda = 3\times10^8 / f$. Then, Equation (2) is used to calculate the waveguide wavelength λ_g :

$$\lambda g = \frac{\lambda}{\sqrt{1 - \left(\frac{\lambda}{2a}\right)^2}} \tag{2}$$

where a = 2.286 cm.

The SWR is defined as $\rho = \frac{|E|_{max}}{|E|_{min}}$, and for a small-signal:

$$\rho = \frac{|E|_{max}}{|E|_{min}} = \sqrt{\frac{I_{max}}{I_{min}}}\,. \tag{3}$$

Therefore, the measurement of the SWR, ρ, is transformed into the measurement of the crystal current.

For the direct method of measuring the SWR, the maximum and the minimum points of the standing wave electric fields are determined, and the SWR calculated using Equation (3).

The indirect method of measuring the SWR involves measuring values in the vicinity of the minimum point of the field-strength distribution in the standing wave pattern. Figure 2 shows the minimum value and equal values on each side of the minimum, distance W apart. The distribution Equation (4) for the standing wave field is given as:

$$\rho = \sqrt{1 + \frac{1}{\sin^2\left(\frac{\pi W}{\lambda g}\right)}} \tag{4}$$

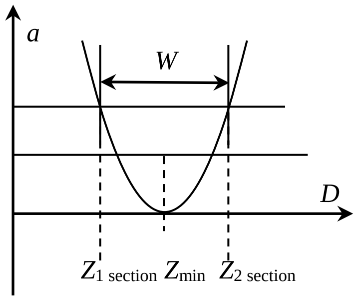

Figure 2: Field distribution near the minimum point.

The EMFW experiment provides an opportunity for students to apply theoretical knowledge and to understand the working principles of a variety of experimental devices. Real mastery of the subject requires theory to be combined with practice, and students generally regard the EMFW experiment as necessary.

Internship students, through practical experience, come to know the principles and performance of electrical equipment in the workplace, where they can solve problems and suggest improvements. This will gradually evolve into a school-enterprise co-operative model [6].

COMPUTER SIMULATION TO COMBINE THEORY AND PRACTICE

The authors' research papers can be used as material in the course; this can promote students' ability to solve practical problems. For example, the paper, S*tudy on the characteristics of EMF distribution in a rectangular waveguide* [7], is introduced in Chapter 7 of the textbook as *Guided EMW* [8].

According to the transverse magnetic (TM) wave definition, the EMF in the waveguide is determined by E_z according to Equation (5):

$$\begin{gathered} \frac{\partial^2 E_z}{\partial x^2} + \frac{\partial^2 E_z}{\partial y^2} + k^2 E_z = 0 \\ E_z\big|_{x=0} = 0, E_z\big|_{x=a} = 0, E_z\big|_{y=0} = 0, E_z\big|_{y=b} = 0 \end{gathered} \tag{5}$$

The solution is:

$$E_z(x,y,z) = E_m \sin(\frac{m}{a}x)\sin(\frac{n}{b}y)e^{-\gamma z}, \text{(m=0,1,2,3...)(n=0,1,2,3...)}. \tag{6}$$

E_m is determined by the excitation source. The transmission factor γ is defined as:

$$\gamma = \sqrt{(\frac{m\pi}{a}x)^2 + (\frac{n\pi}{b}y)^2 - k^2}\ , \tag{7}$$

When the transmission factor γ is real, it is an attenuation factor, and the EMW cannot be transmitted in the waveguide. A necessary condition for the effective propagation of an EMW in the waveguide is that the transmission factor γ is imaginary and γ is called the phase shift.

If the waveguide wall, the boundary of the EMW, is an ideal conductor, the transverse component of the TM wave in a rectangular waveguide is given as:

$$
\begin{aligned}
E_x(x,y,z) &= -\frac{\gamma}{k_c^2}\frac{m\pi}{a}\cdot E_m\cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)e^{-\gamma z} \\
E_y(x,y,z) &= -\frac{\gamma}{k^2_c}\frac{n\pi}{b}\cdot E_m\sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)e^{-\gamma z} \\
H_x(x,y,z) &= \frac{j\omega\varepsilon}{k^2_c}\frac{n\pi}{b}\cdot E_m\sin(\frac{m\pi}{a}x)\cos(\frac{n\pi}{b}y)e^{-\gamma z} \\
H_y(x,y,z) &= -\frac{j\omega\varepsilon}{k_c^2}\frac{n\pi}{b}\cdot E_m\cos(\frac{m\pi}{a}x)\sin(\frac{n\pi}{b}y)e^{-\gamma z}
\end{aligned} \tag{8}
$$

Where ε is the permittivity of the waveguide and, then, the cut-off wave number K_c is given by:

$$
k_c = \sqrt{k_x^2 + k_y^2} = \sqrt{(\frac{m\pi}{a}x)^2 + (\frac{n\pi}{b}y)^2} \tag{9}
$$

The field vector direction at a point was determined from the field vector components, using a MATLAB simulation.

The EMW mode was selected with m = 1; n = 1; the rectangular side a = 38.0 mm, side b = 17.2 mm; the waveguide was set to vacuum; EM frequency = 10 GHz; the excitation source amplitude = 1 and time t = 5 s; the cross section position was selected as 12 m away from the starting position along the Z direction of the EMW propagation in the waveguide.

The TM_{11} EMW distribution in the inner cross section (x-y plane) of the waveguide was simulated by using the first two formulas of Equation (8) (after normalisation), as shown in Figure 3a. Selecting a middle plane at the narrow edge (y = 8.6 mm), a segment (12.0-12.3 m) along the z-direction of the waveguide, the electric field distribution of the TM_{11} wave at the longitudinal section (z-x plane) of the waveguide was simulated by using the first Equation (8) and Equation (6) as seen in Figure 3b.

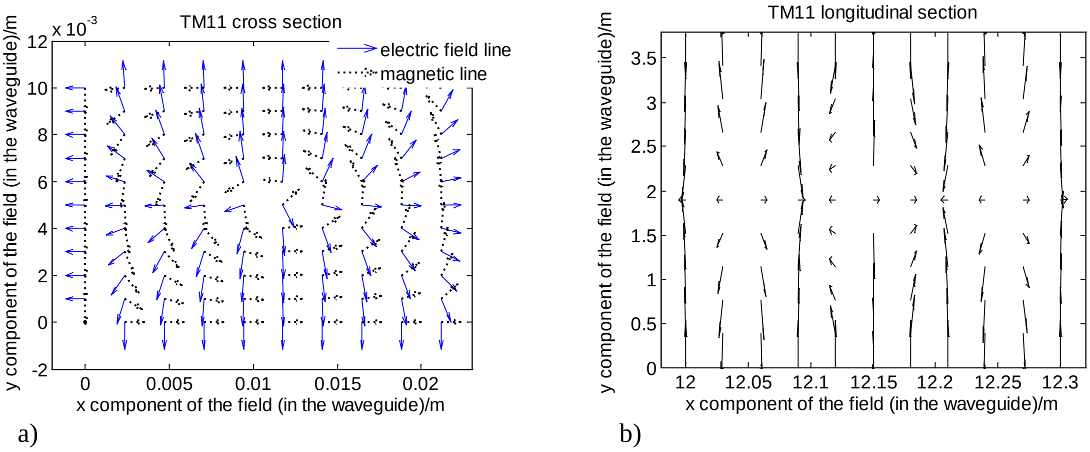

Figure 3: The TM11 EMF distribution in a rectangular waveguide; a) at a rectangular waveguide cross-section; b) at a rectangular waveguide longitudinal profile.

With the same parameters, the cross section TE11 EMF distribution and longitudinal TE11 magnetic field distribution were simulated. The results are shown in Figure 4a and Figure 4b.

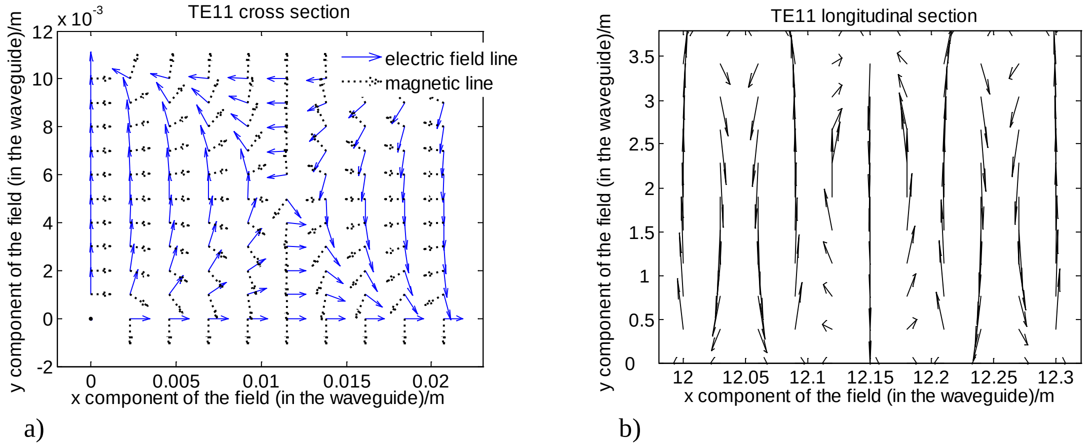

Figure 4: The TE_{11} EMF distribution in a rectangular waveguide; a) at a rectangular waveguide cross-section; b) at a rectangular waveguide longitudinal profile.

The simulation of the transverse electric (TE) wave and TM wave for single-mode transmission in the rectangular waveguide show that the electric field is perpendicular to the magnetic field inside the waveguide. For the TM wave, the waveguide surface is perpendicular to the electric field and parallel to the magnetic field; the TE wave is the reverse. The EMF has a standing wave distribution along the x and y axes.

For the TM wave, there is no longitudinal component of the magnetic field in the waveguide; the TM_{11} wave has a magnetic flux line around the z–axis at every half wavelength in the z–axis direction, and the adjacent magnetic force lines are wound in opposite directions. For the TE wave, there is no longitudinal component of the electric field in the waveguide; the TM_{11} wave corresponds to the electric fluxline around the z–axis, and the adjacent electric fluxlines circulate in opposite directions.

Comparing Figure 3 and Figure 4, the TM_{11} and TE_{11} electric and magnetic fields have exchanged positions. For the effective transmitted EMW in the waveguide, the electric field and magnetic field with the same polarisation direction have a phase difference of $\pm\pi/2$.

The textbook Chapter 7, *Guided EMW*, introduces a special topic: *Propagation features of the dominant mode of the rectangular waveguide EMW* [8].

Similarly, in Chapter 5, Uniform Plane Wave Propagation in an Unbounded Space; and in Chapter 6, Uniform Plane Wave Reflection and Transmission, respectively, are special topics, Research of the Propagation Characteristics of Polarised EMW at a Media Interface [9]; Propagation Characteristics of a Plane Wave at a Good Conductor Surface [10]; Reflection and Transmission of a Plane Wave at Different Media Interface [11]; and Plane Wave Propagation in Multilayer Media [12].

MATERIAL USED FOR AN ON-LINE OPEN CLASS

On-line teaching is a future direction for teaching reform. Students learning on-line could choose an examination immediately and so gain credits for part of the course.

The authors chose the first chapter, Vector Analysis, and the second chapter, The Basic Rule of EMF, in the textbook EMFW for the on-line course teaching content.

Attached sites:

- Xidian University teaching platform: http://lib.xidian.edu.cn/jxfzpt/index.jhtml
- Xidian University teaching platform network teaching integrated platform: http://218.195.46.21/meol/main.jsp
- Weinan Normal University video open class: http://www.wnu.edu.cn/szxy1/spgkk.htm
- Weinan Normal University on-line learning platform: http://online.enetedu.com/wntc
- Xidian University Networking Academy: http://www.xdwy.com.cn/

CONCLUSIONS

Teaching reform is still at an exploratory stage and the experiment content in the future will continue to evolve and strengthen. The above studies can strengthen the students' programming ability; a skill, which must be mastered by telecommunications students. These studies include the authors' teaching and research results, which will need further refinement when used in teaching practice.

It may take a considerable amount of time and effort to create an on-line open course but, once done, it can be efficiently used and popularised broadly. Judging by trial results, this way of teaching is popular with teachers and students. Teachers reduce the burden of teaching in practice, students enjoy the one-to-one interaction and the teaching effect is very good.

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