Development of Simulation Program on Electromagnetic Wave Propagation

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Abstract- **The research proposed the development of simulation program on electromagnetic wave propagation to be used as an instructional media in electromagnetic wave course. The developed simulation program is based on the GUI function of MATLAB program consisting of GUI-input parameter window, calculating menu, and graphical display window. The performance of developed simulation program evaluated by 5 experts was more appropriated level ($\bar{X}$ = 4.20, S.D.=0.20). After implementing the developed simulation program by using a sampling group from Rajamangala University of Technology Phra-Nakhon, Faculty of Industrial Education, the students' satisfaction was at high level ($\bar{X}$ = 4.41, S.D.=0.42). As results, the developed simulation program can be used appropriately in the teaching of electromagnetic wave course. Moreover, it also helps the learner to have more knowledge and skills consistent to expected learning outcome of engineering curriculum.**

Keywords- **GUI-MATLAB, Simulation program, Wave propagation.**

I. INTRODUCTION

Nowaday, undergraduate has studied continuously in electromagnetic engineering course because of it is a fundamental subject that is important and necessary for engineering education. In the teaching of telecommunication engineering, modern technology will focus on the high frequency circuit design, wireless communication and etc. Thus students should have the basic knowledge in electromagnetic fields and wave as well. Howover, in the surveying the problem issues, we found that feedback' information from teachers and students was presented and suggested as follows: 1) the most electromagnetic equations in vector form have complication that provide students to disregard in learning. Moreover, students must have highly imagination to understanding the theory and really principle of electromagnetic wave, 2) the most teaching methods are lecture and exercise test thus students are boring and inattentive in learning and teaching, 3) the instructional media is unsupported and inappropriate in teaching, don't diversified and don't have adequate in a classroom [1], [2].

Presently, various electromagnetic simulators are applied in the teaching of engineering such as Sonnet, CST, IE3D and etc. Most simulation are used in research

and development to create modern innovation [3] but don't support to learning and teaching in classroom as efficiently. Thus, several researchers have be developed the electromagnetic simulators [1], [2] based on Matlab software, C⁺⁺ programming, and etc. In this paper, the development of simulation program on electromagnetic wave propagation engineering education was preposed based on GUI function of MATLAB. The developed simulation program can calculate and illustrate the electromagnetic wave propagation, polarization and waveguided wave distribution. In order to determined learning activities using the electromagnetic simulator, learners will be able to have high learning achievement.

II. THEORY

Electromagnetic waves are formed when an electric field couples with a magnetic field. The magnetic and electric fields of an electromagnetic wave are perpendicular to each other and to the direction of the wave.

A. Polarization

Considering the sweep by the time of the electric field ector of the wave at any position, the electric field equation in the direction of x and y will propagate in the z direction and written in the form of the electric field equation in terms of the time domain equation [4],

$$E = \left| E^+_{xo} \right| \cos(wt - bz + q^+)\overset{\text{v}}{a}_x + \left| E^-_{xo} \right| \cos(wt + bz + q^-)\overset{\text{v}}{a}_x . \quad (1)$$

Similarly, the equation of the magnetic field in the term of the time domain is as follows,

$$H = \frac{\left| E^+_{xo} \right|}{h} \cos(wt - bz + q^+)\overset{\text{v}}{a}_y - \frac{\left| E^-_{xo} \right|}{h} \cos(wt + bz + q^-)\overset{\text{v}}{a}_y \quad (2)$$

When defining the angular difference between the electric field in the x and y direction, we have $q_x = q_y = q$ and then write the relationship equation as follows,

$$E = \left(\left| E_{xo} \right| \overset{\text{v}}{a}_x + \left| E_{yo} \right| \overset{\text{v}}{a}_y \right) \cos(wt - bz + q) . \quad (3)$$

The angle of transmission in the Tilt angle between the electric field (E) and the x-axis is as follows,

$$t = \tan^{-1} \frac{\left| E_{yo} \right|}{\left| E_{xo} \right|} . \quad (4)$$
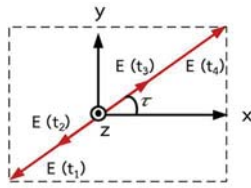
Figure 1. Linear Polarization

Linear polarization can be considered when the different angle between two directions of electric field is zero, as shown in Figure 1, for the horizontal polarization if the E-field angle is 0° and vertical polarization if the E-field angle is 90°.

Circular polarization will provide that $|E_{xo}| = |E_{yo}| = E_o$ and the phase angle is $f_x - f_y = \pm 90^o$, as shown in Figure 2. The electric field wave equation is as follows,

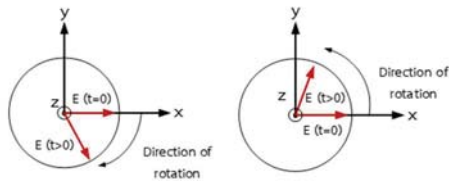$$E = E_o \left(\cos(wt - bz)\overset{\vee}{a}_x \mp \sin(wt - bz)\overset{\vee}{a}_y \right). \quad (5)$$

Figure 2. Circular polarization

Considering the value of the phase between the electric field in the x and y directions, if $f_x - f_y = 90^o$ which stated that "Right-hand polarization" and if $f_y - f_x = 90^o$ which stated that "Left-hand polarization", as shown in Figure 3.
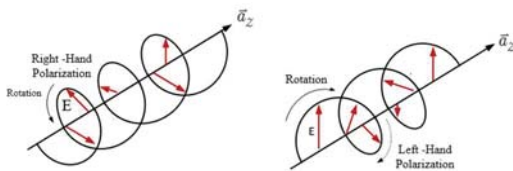

Figure 3. Rotation right-hand polarization and left-hand polarization

Considering the Elliptical polarization, it can be determined that the wave amplitude of $|E_{xo}| \neq |E_{yo}|$ and the phase angle is different of $f_x - f_y = f$, as shown in Figure 4. The electric field wave equations are as follows,

$$\left(\frac{E_x}{|E_{xo}|}\right)^2 - \frac{2E_x E_y \cos(Dq)}{|E_{xo}||E_{yo}|} + \left(\frac{E_y}{|E_{yo}|}\right)^2 = \sin^2(Dq) \quad (6)$$
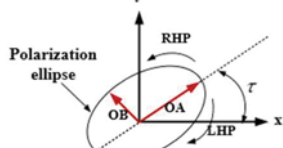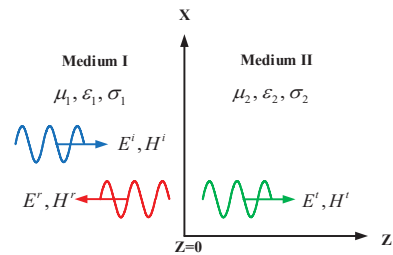

Figure 4. Elliptical polarization

Figure 5. Plane wave propagation in different mediums

B. Plan wave and propagation

Considering the incident wave of an electric field (E^i) and magnetic field (H^i) in boundary area between lossless medium I $(s_1 = 0)$ and perfect conductor of medium II $(s_2 = \yen)$, as shown in Figure 5, the reflected wave in direction -z of medium I, and transmitted wave in direction +z of medium II will occupation.

The lossless dielectric medium can be considered that the conductivity $s_1 = s_2 = 0$, when considering the incident wave in direction +z in the medium I at position of plan z=0, the relation equations of electric field and magnetic field are as follows,

$$E^i(z) = E^i e^{-jb_1 z}\overset{\vee}{a}_x \quad (7)$$

$$H^i(z) = \frac{E^i}{h_1} e^{-jb_1 z}\overset{\vee}{a}_y \quad (8)$$

Because of the discontinuous condition occurred at $z = 0$, the incident waves are divided into reflected waves propagating into medium I and a part of the wave will transmit through in the medium II. The reflected wave equation (E^r, H^r) at position $z = 0$ is written as follows,

$$E^r(z) = E^r e^{+jb_1 z}\overset{\vee}{a}_x \quad , \quad (9)$$

$$H^r(z) = \frac{1}{h_1}(-\overset{\vee}{a}_z) \times E^r(z) = -\frac{E^r}{h_1}e^{+jb_1 z}\overset{\vee}{a}_y, \quad (10)$$

and the transmitted wave equation (E^t, H^t) at position $z = 0$ is written as follows,

$$E^t(z) = E^t e^{-jb_1 z}\overset{\vee}{a}_x \quad , \quad (11)$$

$$H^t(z) = \frac{1}{h_2}\overset{\vee}{a}_z \times E^t(z) = \frac{E^t}{h_2}e^{-jb_2 z}\overset{\vee}{a}_y. \quad (12)$$

When b_2 is the phase constant in medium II and h_2 is the intrinsic impedance of medium II.

Reflection coefficient (G) and transmission coefficient (T) in terms of the intrinsic impedance of medium I and II are as follows,

$$G = \frac{E^r}{E^i} = \frac{h_2 - h_1}{h_2 + h_1}, \quad (13)$$

and

$$T = \frac{E^t}{E^i} = \frac{2h_2}{h_2 + h_1}. \quad (14)$$

2

The equation relations of G and T are as follows,

$$1 + G = T \qquad (15)$$

C. Waveguided wave distribution

In the ideal waveguide, the structural wall is a complete electrical conductor and in the waveguide is free space, the cross section is a rectangle consisting of sides a and b which are the dimensions along the x and y axes in the respective coordinates. The length of the waveguide conductor is the same as the z direction [5]. The waveguided wave distribution consists of 2 modes as TM mode (Traverse Magnetic Field) and TE mode (Traverse Electric Field), the relation equations of wave in waveguide are as follows,

1) The relationship equation of TM modes in rectangular waveguide is $E_z \neq 0$, $H_z = 0$. The wave equation is as follows,

$$\nabla_t^2 E_z = \frac{\partial^2}{\partial x^2} E_z + \frac{\partial^2}{\partial y^2} E_z = -k_c^2 E_z \qquad (16)$$

The wave components in the rectangular waveguide in mode TM_{mn} are written in equation following.

$$E_z = A \sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right) \qquad (17)$$

$$E_x = -j\frac{\beta k_x}{k_{c_{mn}}^2} A \sin\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right) \qquad (18)$$

$$E_y = -j\frac{\omega \varepsilon k_y}{k_{c_{mn}}^2} A \sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right) \qquad (19)$$

$$H_x = -j\frac{\omega \varepsilon k_y}{k_{c_{mn}}^2} A \sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right) \qquad (20)$$

$$H_y = -j\frac{\beta k_x}{k_{c_{mn}}^2} A \cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right) \qquad (21)$$

$$H_z = 0 \qquad (22)$$

The wavelength of the wave of TM_{mn} can present as follows,

$$\omega_{c_{mn}} = \frac{k_{c_{mn}}}{\sqrt{\mu\varepsilon}} = \frac{1}{\sqrt{\mu\varepsilon}}\left[\left(\frac{m\pi}{a}\right)^2 + \left(\frac{n\pi}{b}\right)^2\right]^{1/2} \qquad (23)$$

2) The relationship equation of TE modes in rectangular waveguide is $E_z = 0$, $H_z \neq 0$. The wave equation is as follows,

$$\nabla_t^2 H_z = \frac{\partial^2}{\partial x^2} H_z + \frac{\partial^2}{\partial y^2} H_z = -k_c^2 H_z \qquad (24)$$

The wave components in the rectangular waveguide in mode TE_{mn} are written in equation following.

$$H_z = B \cos k_x x \cos k_y y \qquad (25)$$

$$E_x = j\frac{\omega \mu k_y}{k_{c_{mn}}^2} B \sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right) \qquad (26)$$

$$H_y = -j\frac{\omega \mu k_x}{k_{c_{mn}}^2} A \cos\left(\frac{m\pi x}{a}\right)\sin\left(\frac{n\pi y}{b}\right) \qquad (27)$$

$$E_y = -j\frac{\omega \mu k_y}{k_{c_{mn}}^2} B \sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right) \qquad (28)$$

$$H_x = j\frac{\beta k_x}{k_{c_{mn}}^2} B \sin\left(\frac{m\pi x}{a}\right)\cos\left(\frac{n\pi y}{b}\right) \qquad (29)$$

$$E_z = 0 \qquad (30)$$

III. RESEARCH METHODOLOGY

The process of designing GUI simulation program on electromagnetic wave propagation is applied to the electromagnetic engineering education or related fields. The MATLAB based simulation program consists of 3 parts: 1) initial parameter window, 2) calculating menus and 3) display window. The developed simulation program based on the graphical user interface GUI function of MATLAB software illustrated in Figure 6.
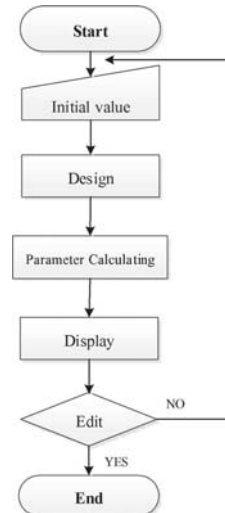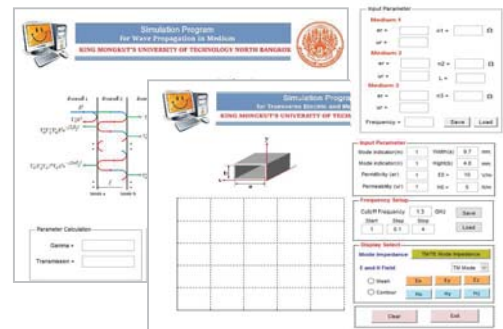

Figure 6. Simulation Diagram

Figure 7. Example of developed simulation program

IV. IMPLEMENTATION AND RESULTS

The implementation with simple group can been shown in Figure 8. The research has been presented in 3 sections including 1) the developed simulation program 2) the quality evaluation of simulation program 3) the student's satisfaction. And 4) the efficiency of simulation

3

program. The results of simulation program can be represented in Figure 9-10.

Figure 8. Implementation in classroom

A. The evaluating quality of simulation program.

The developed GUI function of MATLAB based simulation program in the teaching of electromagnetic wave propagation was evaluated by 5 experts who have experience in the teaching of telecommunication engineering or related. The findings have a more appropriate ($\bar{X}$=4.20,S.D.=0.20), as shown in Table I.
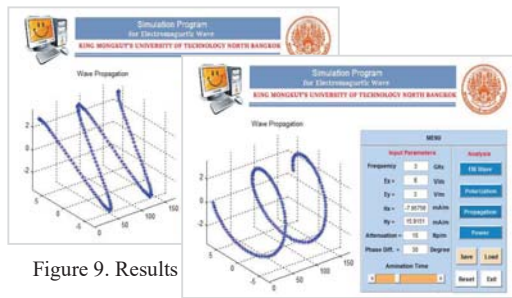

Figure 9. Results
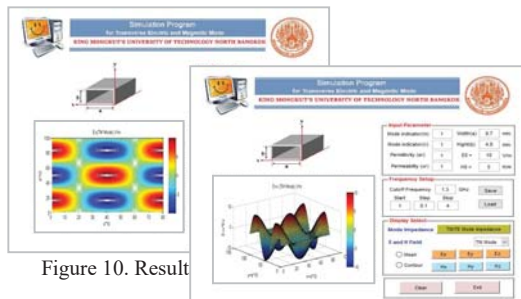

Figure 10. Result

TABLE I
The results of the quality of simulation program (N=5)

Evaluated topics	Appropriate Level		
	$\bar{X}$	S.D.	Interpret
1. Appropriation of simulation program	4.20	0.45	high
2. Accuration of simulation program	4.40	0.55	high
3. Easy to use	4.00	0.71	high
4. Appropriation of content and design	4.20	0.45	high
5. Encourage student to understand course content	4.20	0.45	high
Total	4.20	0.20	high

TABLE II
The students' satisfaction of simulation program (N=19)

Evaluated topics	Appropriate Level		
	$\bar{X}$	S.D.	Interpret
1. Appropriation of developed simulation	4.63	0.50	high
2. Accuration of simulated results	4.47	0.61	high
3. Easy to use	4.47	0.51	high
4. Appropriate for content and purpose	4.53	0.61	high
5. Encourage student to learn and attend	3.95	0.78	high
Total	4.41	0.42	high

B. The students' satisfaction

The developed GUI function of MATLAB based simulation program was implemented by 19 students who registered in the electromagnetic wave course in academic year 1/2017 at Rajamangala University of Technology Phra-Nakhon. The sample group was taught by using the developed simulation program. After learning all lessons, the students' satisfaction was evaluated using the questionnaire from the findings after teaching using the developed simulation program it was found that the students' satisfaction was at high level ($\bar{X}$=4.41,S.D.=0.42), as shown in Table II.

C. The evaluated results of efficiency of the simulation program.

In the trying out using 19 sampling students, students done the pretest before learning. In the teaching and learning of electromagnetic wave course in each lesson, teacher will provide the course contents, the learning activities, and measuring and evaluating the learning achievement respectively. The data gathering was analyzed for efficient validation by Meguigans's theory [6], as shown in Table III. We found that performace of developed simulation program was validated with the to Meguigans's theory equle to 1.27 according to Meguigans's formula (more than 1.0).

TABLE III
The efficiency of simulation program (N=19)

Test	Full score (point)	Minimum score	Maximum score	Mean value	Meguigans's theory
Pre-test	25	5	11	7.10	1.27
Post-test	25	17	25	20.36	

V. CONCLUSION

The development of MATLAB based simulation program of electromagnetic wave propagation has been presented for learning and teaching of electromagnetic engineering course. The developed simulation program is able to use in calculation and presentation of electromagnetic wave phenomenon such as, wave propagation, polarization and waveguided wave distribution. Becuase of the proformance of the developed

simulation was consistent to the standard criteria of Meguigans's formula and the students' satisfaction using the developed simulation program was also at a high level, the developed simulation program can be used as an instructional media to encourage students to have more various knowledge skills.

VI. REFERENCES

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