Teaching and Learning Electromagnetic Plane Wave Reflection and Transmission using 3-D TV

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***Abstract*—In this paper, teaching and learning electromagnetic (EM) plane wave reflection and transmission using 3-D TV are presented. The necessary equipment setup for 3-D TV demonstration within a classroom setting is described. For 3-D TV, its 3-D contents comprising left and right images are generated in real time by a program on notebook PC. Projected onto the 3-D TV screen, these images will combine appropriately to enable stereoscopic view through the use of 3-D glasses. To enhance interactive teaching and learning, the notebook PC can be controlled remotely, e.g. using wireless keyboard and mouse. Besides 3-D TV, a standalone app is also available on iPad to provide more effective touch-based interactivity, while allowing seamless teaching and learning anytime, anywhere. The features that are available on iPad app and notebook PC program are highlighted and elaborated. They are applicable to EM plane wave reflection and transmission for general oblique incidence and polarization. The instructor is able to input or change various parameters and rotate the view angles for interactive teaching. Based on the parameters, the 3-D animations of incident, reflected and transmitted waves can be visualized in real time. Through different cases of incident angles, the visualizations on iPad and 3-D TV are illustrated and compared. The stereoscopic visualization on 3-D TV is demonstrated to exhibit protruding field vectors, thus providing additional depth perception. This allows the students to identify clearly each wave and improves their learning of plane wave reflection and transmission.**

***Index Terms*—Teaching and learning EM, EM education, 3-D TV, plane wave, reflection and transmission**

I. INTRODUCTION

Teaching electromagnetic (EM) theory is still a challenging task to date due to its abstract nature involving many complex mathematical and vectorial concepts. Relying only on textbooks and lecture materials, many students often find the course demanding and difficult to master, leading to undesirable lost of interest. Initiatives have been undertaken in the past to enhance the teaching and learning of EM by using computer-based softwares and simulation tools in class [1]-[4]. These softwares provide visualization to help the students to better understand various EM topics.

Among the EM topics, plane wave reflection and transmission [5], [6] constitute one in which visualization could greatly help students to understand the fundamentals of EM wave polarization, propagation and interaction with media. In [3], a MATLAB-based computer software is developed to provide visualization of plane wave incident onto the interface between two dielectric media. With the recent wide availability of mobile devices, such kind of software could be extended for these handheld devices such as pads and phones. This is in line with our previous efforts to enhance teaching and learning of EM topics on microwave transmission line circuits [7], [8] and polarization [9], [10] by leveraging on the affordances of mobile devices. Compared to computers, mobile devices provide more effective touch-based interactivity and more importantly, they allow seamless teaching and learning anytime, anywhere. Still, as plane wave reflection and transmission involve field vectors in 3-D space, visualization from mobile devices may not convey the complete spatial information due to lack of depth perception. To provide the necessary depth perception for enhancing visualization in 3-D space, one could resort to 3-D TV that is a common household product. All this while, 3-D TV [11], [12] has been mostly used for entertainment in movies or gamings to enhance consumers' 3-D experience. In fact, the use of 3-D TV should not be confined only for entertainment, but could be used for educational purposes as well. This is where the 3-D TV could be exploited to aid our EM teaching and learning. Furthermore, it can also be utilized conveniently in classroom or at home.

In this paper, teaching and learning EM plane wave reflection and transmission using 3-D TV are presented. To the best of our knowledge, this is the first time the use of cost-effective 3-D TV is reported to enhance interactive EM teaching and learning in classroom. The necessary equipment setup for 3-D TV demonstration within a classroom setting will be described. The 3-D contents comprising spatially offset images for left and right eyes will be generated by a program on notebook PC and displayed on 3-D TV. (Such program is available for download at the website http://www.ntu.edu.sg/home/eeltan/TEL3DTV.html.) Using 3-D glasses, the users would be able to experience stereoscopic view with depth perception. To enhance interactive teaching and learning, the notebook PC can be controlled remotely, e.g. using wireless keyboard and mouse. Besides 3-D TV, a standalone app (called 'EMwaveRT' on App Store) is also available on iPad to provide more effective touch-based interactivity, while allowing seamless teaching and learning anytime, anywhere. The features of the iPad app and notebook PC program will be highlighted and elaborated. Through

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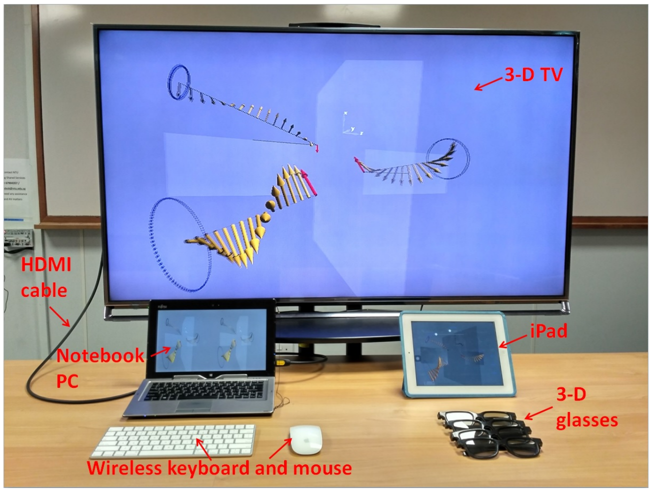


Fig. 1. Photo of equipment setup for interactive teaching and learning using 3-D TV.

Fig. 2. Photo of 3-D TV demonstration in class on plane wave reflection and transmission.

different cases of incident angles, the visualizations on iPad and 3-D TV will be illustrated and compared. Some feedback and survey tests are also conducted to gauge the students' general response and the improvement of their understanding on the EM topic. The paper will be organized as follows. In Section II, teaching and learning EM using 3-D TV in classroom are introduced. In Section III, various features of the iPad app and notebook PC program are explained, along with concise mathematical equations and formulae. Section IV illustrates the visualizations of various animations on iPad and 3-D TV. The additional depth perception provided by the stereoscopic visualization on 3-D TV is demonstrated. The feedback and survey tests conducted on students are also presented.

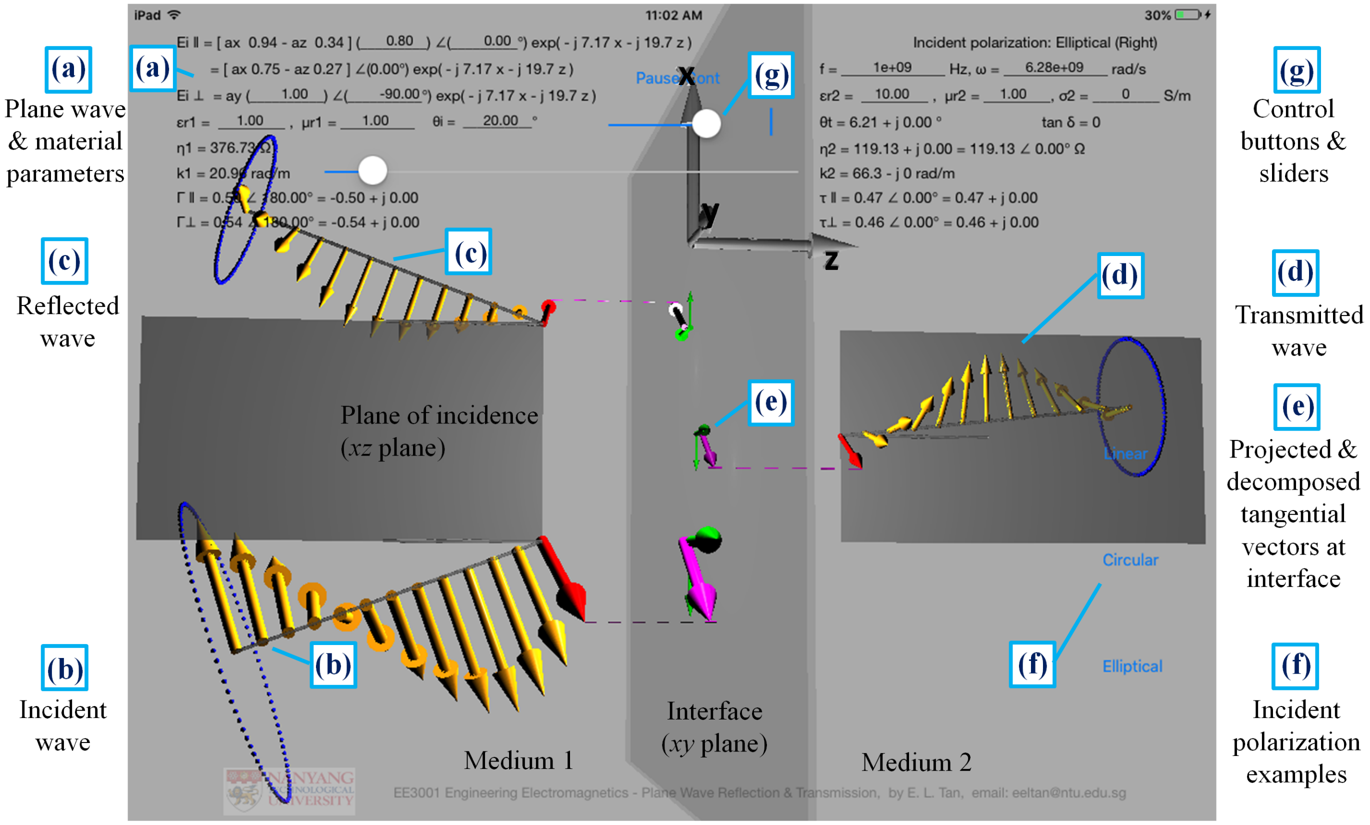
II. TEACHING AND LEARNING USING 3-D TV

To enhance teaching and learning using 3-D TV, the appropriate 3-D contents comprising spatially offset images for left and right eyes are to be generated. These spatially offset images are presented to left and right eyes separately from the 3-D TV screen through polarized filters such as 3-D glasses, thus providing the stereoscopic visualization with additional depth perception. To achieve this within a classroom setting, the necessary equipment setup for 3-D TV demonstration is described below. Fig. 1 shows a photo of equipment setup for interactive teaching and learning using 3-D TV. The equipment shown in the photo consists of:

- 60” 3-D TV
- HDMI cable
- 3-D glasses
- Notebook PC
- Wireless keyboard and mouse
- iPad

For 3-D TV, its 3-D contents comprising left and right images are generated in real time by a program on notebook PC. The left and right images are then projected from the notebook PC onto the 3-D TV screen via VGA or HDMI cable for viewing by all students in class. The students should wear 3-D glasses in class to view the 3-D contents and experience the 3-D perception. To enhance interactive teaching and learning, the notebook PC can be controlled remotely, e.g. using wireless keyboard and mouse, for real-time generation of 3-D contents. With such remote control, the instructor is able to input or change various parameters and rotate the view angles to suit his/her teaching interactively, while moving around the classroom for closer interaction with students. If the wireless keyboard and mouse are unavailable, one may resort to USB keyboard and mouse (with less movability), along with USB cable extensions if needed.

Besides 3-D TV, a standalone app that shares most features of the notebook PC program above is also available on iPad. Such iPad app has additional advantages of providing more effective (‘human-friendly’) touch-based interactivity, while allowing seamless teaching and learning anytime, anywhere. In the subsequent sections, the features that are available on the iPad app and notebook PC program will be highlighted and elaborated, along with illustration and comparison of the visualizations on iPad and 3-D TV. Alternative to the projection from notebook PC, it may even be possible to setup projection from mobile device directly to 3-D TV, e.g. using special adapter and cable or wireless connection. This is not implemented in our work due to many considerations, including the limitations of adapter and cable length, as well as the need for wireless connection setup, external power charging of pad/phone (for longer-hour classes), or requiring 3-D TV with more advanced capabilities. (The authors’ 3-D TVs at home and in classroom do not possess such capability nor



Ei ∥ = [ax 0.94 - az 0.34] (0.80) ∠(0.00 °) exp(- j 7.17 x - j 19.7 z)
= [ax 0.75 - az 0.27] ∠(0.00°) exp(- j 7.17 x - j 19.7 z)
Ei ⊥ = ay (1.00) ∠(-90.00 °) exp(- j 7.17 x - j 19.7 z)
εr1 = 1.00 , μr1 = 1.00 θi = 20.00 °
η1 = 376.73 Ω
k1 = 20.96 rad/m
Γ ∥ = 0.50 ∠ 180.00° = -0.50 + j 0.00
Γ⊥ = 0.54 ∠ 180.00° = -0.54 + j 0.00

Incident polarization: Elliptical (Right)
f = 1e+09 Hz, ω = 6.28e+09 rad/s
εr2 = 10.00 , μr2 = 1.00 , σ2 = 0 S/m
θt = 6.21 + j 0.00 ° tan δ = 0
η2 = 119.13 + j 0.00 = 119.13 ∠ 0.00° Ω
k2 = 66.3 - j 0 rad/m
τ ∥ = 0.47 ∠ 0.00° = 0.47 + j 0.00
τ⊥ = 0.46 ∠ 0.00° = 0.46 + j 0.00

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Fig. 3. Overview screenshot of the plane wave reflection and transmission app on iPad.

accessories.)

Fig. 2 shows a photo of 3-D TV demonstration in class on plane wave reflection and transmission. To supplement the lecture materials projected on usual (2-D) wide-screen, a 3-D TV is placed in front of students, and the instructor demonstrates its 3-D contents interactively. While explaining various plane wave reflection and transmission phenomena, the 3-D TV could help in providing stereoscopic visualization to improve students' understanding. The students themselves may also continue exploring the topics using their own 3-D TV and other equipment at home (if available) for further learning at their own pace.

III. EM PLANE WAVE REFLECTION AND TRANSMISSION

In this section, the features that are available on iPad app (and also mostly on notebook PC program for 3-D TV) are first highlighted. They are applicable to EM plane wave reflection and transmission for general oblique incidence and polarization. Fig. 3 exemplifies an overview screenshot of the plane wave reflection and transmission app on iPad. The app features are identified and labeled in the figure. They shall be elaborated in more detail in the following. Medium 1 is the (lossless) incident medium that consists of incident and reflected waves, while medium 2 is the (possibly lossy) transmitted medium that consists of transmitted wave. The interface corresponds to the xy plane in our Cartesian coordinate system. The Cartesian axes are also displayed and labeled. The plane of incidence is defined as the plane containing the normal to the interface and direction of propagation of the incident wave [5]. It corresponds to the xz plane and can be identified as the rectangular surface extending normally to either side of the interface. Various plane wave and material parameters are displayed [labeled **(a)**], which may be input, changed or are calculated in real time. The E field expressions for incident parallel and perpendicular polarized waves are displayed as

$$E_i^{\|} = (\boldsymbol{a_x} \cos\theta_i - \boldsymbol{a_z} \sin\theta_i)\, E_{0i}^{\|} e^{-jk_1(x\sin\theta_i + z\cos\theta_i)} \tag{1a}$$

$$E_i^{\perp} = \boldsymbol{a_y} E_{0i}^{\perp} e^{-jk_1(x\sin\theta_i + z\cos\theta_i)} \tag{1b}$$

where θ_i is the incident angle, $E_{0i}^{\|}$ and $E_{0i}^{\perp}$ are the complex amplitudes of incident parallel and perpendicular polarized waves, respectively, and k_1 is the wave number in medium 1. The plane wave and material parameters that may be input or changed by the users are (all angles in degrees):

- incident angle, θ_i.
- magnitude and phase angle of $E_{0i}^{\|} = |E_{0i}^{\|}| \angle \phi_{0i}^{\|}$.
- magnitude and phase angle of $E_{0i}^{\perp} = |E_{0i}^{\perp}| \angle \phi_{0i}^{\perp}$.
- frequency f or angular frequency ω.
- relative permittivity and permeability of medium 1, ϵ_{r1} and μ_{r1}.

- relative permittivity, permeability and conductivity of medium 2, ϵ_{r2}, μ_{r2} and σ_2.

The plane wave and material parameters that are calculated in real time include [5], [6]:

- transmission angle based on Snell's law,

$$\theta_t = \sin^{-1}\left(\frac{\sqrt{\mu_1\epsilon_1}}{\sqrt{\mu_2\epsilon_2}}\sin\theta_i\right) \tag{2}$$

  where $\epsilon_1 = \epsilon_{r1}\epsilon_0$, $\epsilon_2 = \epsilon_{r2}\epsilon_0 - j\sigma_2/\omega$, $\mu_1 = \mu_{r1}\mu_0$ and $\mu_2 = \mu_{r2}\mu_0$. ϵ_0 and μ_0 are the free space permittivity and permeability respectively.
- loss tangent for medium 2, $\tan\delta = \frac{\sigma_2}{\omega\epsilon_{r2}\epsilon_0}$.
- intrinsic impedances and wave numbers for medium 1 and 2, $\eta_1 = \sqrt{\frac{\mu_1}{\epsilon_1}}$, $\eta_2 = \sqrt{\frac{\mu_2}{\epsilon_2}}$, $k_1 = \omega\sqrt{\mu_1\epsilon_1}$ and $k_2 = \omega\sqrt{\mu_2\epsilon_2}$.
- Fresnel reflection and transmission coefficients for parallel polarization,

$$\Gamma_\parallel = \frac{E_{0r}^{\parallel}}{E_{0i}^{\parallel}} = \frac{\eta_2\cos\theta_t - \eta_1\cos\theta_i}{\eta_2\cos\theta_t + \eta_1\cos\theta_i} \tag{3a}$$

$$\tau_\parallel = \frac{E_{0t}^{\parallel}}{E_{0i}^{\parallel}} = \frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_t + \eta_1\cos\theta_i}. \tag{3b}$$

- Fresnel reflection and transmission coefficients for perpendicular polarization,

$$\Gamma_\perp = \frac{E_{0r}^{\perp}}{E_{0i}^{\perp}} = \frac{\eta_2\cos\theta_i - \eta_1\cos\theta_t}{\eta_2\cos\theta_i + \eta_1\cos\theta_t} \tag{4a}$$

$$\tau_\perp = \frac{E_{0t}^{\perp}}{E_{0i}^{\perp}} = \frac{2\eta_2\cos\theta_i}{\eta_2\cos\theta_i + \eta_1\cos\theta_t}. \tag{4b}$$

Based on the plane wave and material parameters above, the 3-D animations of incident [labeled **(b)**], reflected [labeled **(c)**] and transmitted [labeled **(d)**] waves can be visualized in real time. The incident, reflected and transmitted electric field vectors are all represented by yellow arrow cones distributed along their respective propagation axis for general oblique incidence. Their corresponding propagation axes all lie on the plane of incidence. Although they are represented along one propagation axis each, the fields are actually uniform throughout the phase plane perpendicular to the axis. This should be emphasized to the students during demonstration in class. Besides, notice that the incident and reflected waves in Fig. 3 have been displaced in order not to overlap each other (they do not correspond to Goos-Hänchen shift of finite-sized beams). Furthermore, the incident and reflected waves in medium 1 have also been separated from the transmitted wave in medium 2 at some distance displaced from the interface. This is again to prevent all these waves overlap each other obscuring their interactions right at the interface (where all waves meet). With such displaced arrangements, the students are able to visualize the 3-D animations of all incident, reflected and transmitted waves clearly. The polarization state of each wave, i.e. linear, circular or elliptical, as well as the (left or right) handedness, can also be identified clearly based on the animated trace of E vector tip, shown as blue dotted lines. All these animations are real-time interactive based on the parameters input or changed by the users. The red arrows correspond to the E vectors at the interface, whose tangential vectors are projected via dashed violet lines. The projected and decomposed x and y components of tangential vectors at the interface [labeled **(e)**] are displayed as violet and green arrows respectively. These tangential vectors satisfy the boundary condition for E fields at the interface as

$$\begin{aligned} &\boldsymbol{a_x}\left(E_{0i}^{\parallel}\cos\theta_i + E_{0r}^{\parallel}\cos\theta_r\right) + \boldsymbol{a_y}\left(E_{0i}^{\perp} + E_{0r}^{\perp}\right) \\ &= \boldsymbol{a_x}\left(E_{0t}^{\parallel}\cos\theta_t\right) + \boldsymbol{a_y}\left(E_{0t}^{\perp}\right). \end{aligned} \tag{5}$$

(Another equation may be written similarly for H fields.) Their components in animation greatly help to illustrate the matching of EM boundary condition in clear and convincing manner.

Various incident polarization examples [labeled **(f)**] that are closely in line with lecture materials are also available for teaching and learning. By tapping the corresponding linear, circular and elliptical buttons, it will automatically change all parameters to some preset incident polarization states and materials. This enables quick demonstration and viewing of the pertaining examples, without requiring the instructor or students to take time input or change the parameters. There are also other control buttons and sliders [labeled **(g)**] useful for user interface. All animations can be paused and continued via the 'Pause/Cont' button whenever needed, in order to allow one to view more clearly by rotating the view angles and zooming in/out. The short horizontal slider is used to adjust the opacity of the text to enable unobstructed view of the animations. The long horizontal slider is used to incrementally adjust various parameters, particularly the last one being input or selected. For instance, the incident angle can be increased incrementally with it, while the changes in wave animations can be observed instantaneously in real time. The vertical button is used to show or hide the projected and decomposed tangential vectors at the interface. For individual incident, reflected and transmitted fields, their tangential vectors can be shown or hidden when needed to illustrate each of them in sequel or all at once.

Most of the features elaborated above are also available on the notebook PC program for 3-D TV, except the buttons and sliders. While these buttons and sliders are well-suited for iPad user interface, they are replaced conveniently by (wireless) keyboard and mouse on notebook PC. The program on the notebook PC would generate not one but both left and right images to form the 3-D contents (with parallax) for 3-D TV. Fig. 4 shows the screenshot of left and right images on notebook PC, which include the incident, reflected and transmitted waves, as well as the plane of incidence, interface, projected and decomposed tangential vectors. Projected onto the 3-D TV screen, these images will combine appropriately to enable stereoscopic view through the use of 3-D glasses.

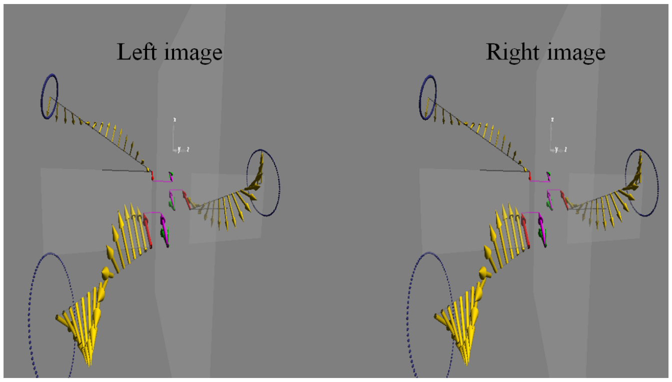

Fig. 4. Screenshot of left and right images on notebook PC.

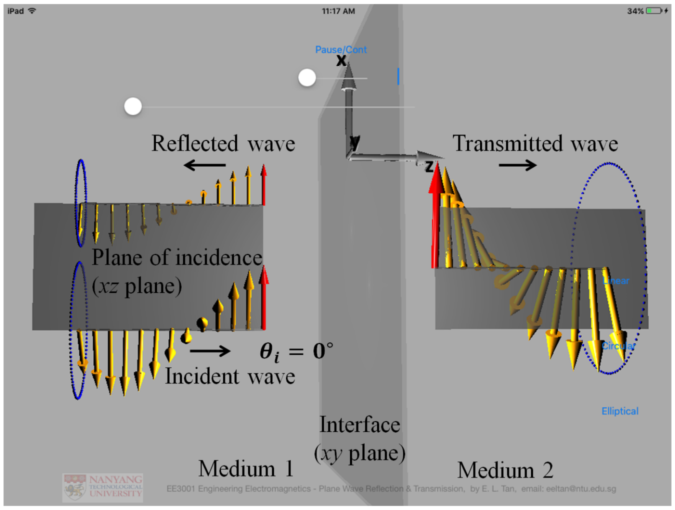

Fig. 5. Case of normal incidence, $\theta_i = 0°$ on iPad.

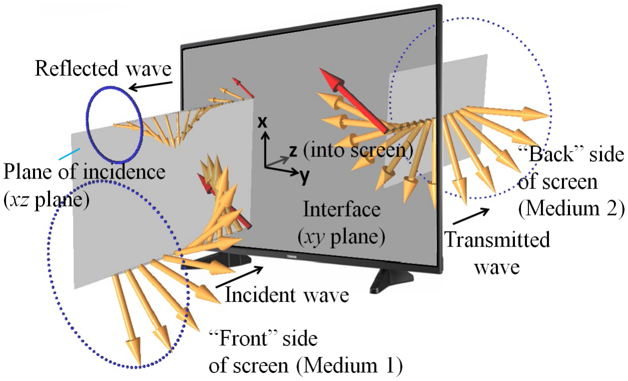

Fig. 6. 3-D impression for the case of normal incidence on 3-D TV screen.

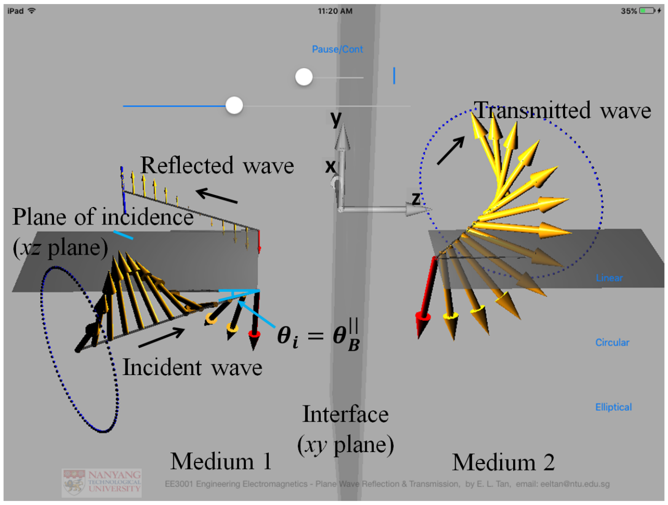

Fig. 7. Case of incident wave at Brewster angle, $\theta_i = \theta_B^{||}$ on iPad.

Note that one may need to set the 3-D TV screen aspect ratio properly for correct projection.

IV. STEREOSCOPIC VISUALIZATION ON 3-D TV

In this section, through different cases of incident angles, the visualizations on iPad and 3-D TV are illustrated and compared. Consider a right-handed circularly polarized wave with $E_{0i}^{||} = 5\angle 0°$ and $E_{0i}^{\perp} = 5\angle - 90°$. The wave is incident from medium 1 ($\epsilon_{r1} = 2.25$, $\mu_{r1} = 1$) to medium 2 ($\epsilon_{r2} = 1$, $\mu_{r2} = 1$) at an incident angle θ_i. Fig. 5 first shows the case of normal incidence, $\theta_i = 0°$ on iPad. For clarity, we label the incident angle $\theta_i = 0°$ in the figure. At normal incidence, it can be seen that all incident, reflected and transmitted waves propagate in the direction normal to the interface. It should be pointed out that the rotation animations for the incident and transmitted E vectors indicate right-handed polarized waves, while for the reflected one it indicates left-handed polarized wave. To illustrate the stereoscopic visualization of the EM waves portrayed on 3-D TV, Fig. 6 shows the corresponding (viewers') 3-D impression for the case of normal incidence. (Note that such impression is for illustrative purpose only, since we are not able to show the actual stereoscopic view on paper.) The interface (xy plane) is assumed to align parallel to the TV screen, where the z direction points into the screen. In the illustration, the incident and reflected waves in medium 1 are located at the 'front' side of the screen. On the other hand, the transmitted wave in medium 2 is located at the 'back' side of the screen. The plane of incidence (xz plane) can be seen extending outward and inward to either side of the screen. The incident wave is seen traveling towards the screen and away from veiwers. The reflected wave is seen traveling out from screen towards the viewers, while the transmitted wave is traveling into the screen away from them. For stereoscopic visualization on 3-D TV, the field vectors (arrow cones) of incident, reflected and transmitted waves would appear protruding from the screen when viewed through 3-D glasses. Such stereoscopic visualization helps students to identify clearly the parallel and perpendicular components w.r.t. plane of incidence, as well as the propagation direction and polarization state of each wave.

The stereoscopic visualization on 3-D TV is applicable

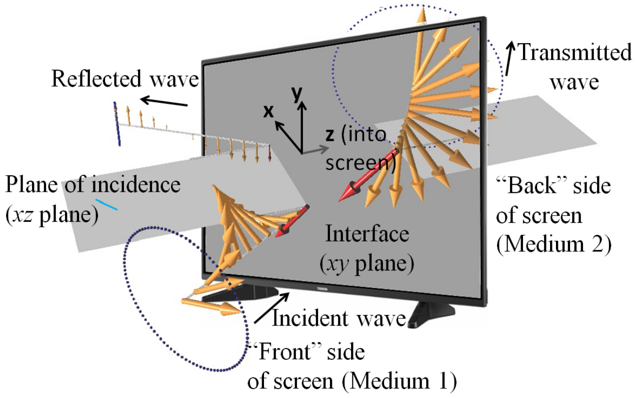

Fig. 8. 3-D impression for the case of incident wave at Brewster angle on 3-D TV screen.

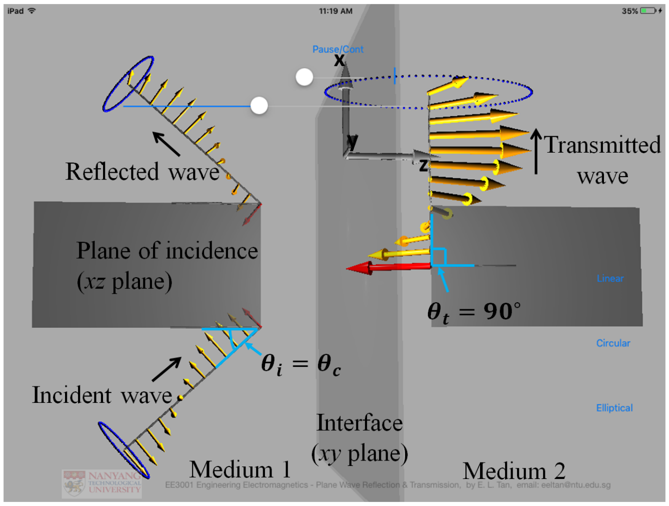

Fig. 9. Case of incident wave at critical angle, $\theta_i = \theta_c$ on iPad.

to EM plane wave reflection and transmission for general oblique incidence and polarization. Of particular interest, let us demonstrate the cases of oblique incidence at Brewster and critical angles. Fig. 7 shows the case of incident wave at Brewster angle, $\theta_i = \theta_B^{\parallel} = 33.69°$ on iPad. In this case, we deliberately rotate the scene at different orientation and view angle. The incident angle is labeled as $\theta_i = \theta_B^{\parallel}$ in the figure. From such view angle, it is seen that the reflected wave becomes linearly polarized perpendicular to the plane of incidence, as the parallel polarized components undergo zero reflection at Brewster angle, i.e., $\Gamma_{\parallel}(\theta_i = \theta_B^{\parallel}) = 0$. Meanwhile, the reflected wave appears located behind the incident wave. Since the reflected wave is partially obstructed by the incident wave on iPad, some students might encounter difficulty in viewing them without switching view angle. On the other hand, Fig. 8 shows the corresponding 3-D impression for the case of incident wave at Brewster angle on 3-D TV. The 3-D impression of the 'front' and 'back' sides of the screen can be interpreted similarly to that of Fig. 6 at different orientation and view angle. When viewed through 3-D glasses, the field vectors (arrow cones) of incident, reflected and transmitted waves would again appear protruding from the screen. With additional depth perception, the students can now properly distinguish between the reflected and incident waves. The reflected wave 'behind' may be visualized and identified more clearly as the perpendicular polarized component w.r.t. the plane of incidence. Next, Fig. 9 shows the case of incident wave at critical angle, $\theta_i = \theta_c = 41.81°$ on iPad. The incident angle is labeled as $\theta_i = \theta_c$ in the figure. In addition, the transmitted angle is labeled as $\theta_t = 90°$. At critical angle, total internal reflection commences, while the 'transmitted' wave is seen traveling along the interface [and decaying (evanescent) along z direction].

Thus far, the emphasis of this paper has been more on the 'technical' aspects of teaching and learning EM using 3-D TV, including equipment setup, features, equations, cases of interest etc., rather than on the pedagogy aspects. Still, some feedback and survey tests were carried out among 58 students taking the course EE3001 Engineering Electromagnetics at School of Electrical & Electronic Engineering, Nanyang Technological University, Singapore. On the survey of students' general response, 89% of the students agreed strongly or moderately that the 3-D TV provides depth sensation to help them identify easily the direction and position of various E field vectors. When being asked to rate the 3-D TV in regard to helping them visualize and understand reflection and transmission of plane waves, the students provided an average rating 8 out of 10. To gauge the improvement of their understanding on EM plane wave reflection and transmission after using 3-D TV, we further conducted pre- and post-tests before and after the 3-D TV was demonstrated. In particular, given that a right-handed circularly polarized wave is incident from medium 1 upon medium 2 (with $\epsilon_1 > \epsilon_2$) at Brewster angle, the students were being tested on the polarization type of the reflected wave. Prior to viewing the 3-D TV, 31% of the students answered correctly as linear polarization. Upon being tested further on the polarization component of the reflected wave, 26% of the students answered correctly as perpendicular component. While most EM textbooks provide the discussion for incidence at Brewster angle, it often remains difficult for most students to completely grasp the concept of reflection and transmission at this angle without visualizing the actual reflection and transmission mechanisms. On the other hand, with 3-D TV demonstration, the students would able to clearly visualize the reflection and transmission mechanism. For instance, from the 3-D impression in Fig. 8, it is easily identified by the students that the reflected wave is obviously linearly polarized with perpendicular component, i.e., the vertical component w.r.t the horizontal plane of incidence. Hence, in our test after viewing the 3-D TV, 93% of the students were able to answer correctly the polarization type and component of the reflected wave. Based on the promising response and tests results so far, it appears beneficial for demonstrating plane wave reflection and transmission on 3-D TV to more students undertaking the EM course.

V. CONCLUSION

In this paper, teaching and learning EM plane wave reflection and transmission using 3-D TV have been presented. The use of 3-D TV and a standalone app on iPad has been described. Various features of the iPad app and notebook PC program for 3-D TV have been explained, along with concise mathematical equations and formulae. The visualizations of various animations on iPad and 3-D TV have been illustrated and compared. In particular, the stereoscopic visualization on 3-D TV has been demonstrated to provide additional depth perception. The feedback and survey tests conducted on students have also shown that the use of 3-D TV could aid learning of EM plane wave reflection and transmission. The current application assumes EM plane wave reflection and transmission between two media, which is in line with the syllabus of most undergraduate EM courses. The application can be extended further for advanced analysis of plane wave reflection and transmission in multilayered media [13], [14]. Besides, the application of 3-D display is certainly not restricted to the topics of EM plane wave reflection and transmission. It can also be applied to other EM topics such as waveguides, antennas, etc. to aid visualization of EM fields within the 3-D space of various EM structures.

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