Realizing the Visualization of Plane Wave in Conductive Medium by MATLAB Graphics Technology

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Abstract: The matlab program is usually used to make simulation of electromagnetic distribution and the transmission of waves, which dynamically shows the propagation of waves. This article focuses on simulating the dynamic process of the propagation, reflection and refraction of uniform plane wave in a different medium.

1. Introduction

The electromagnetic fields and waves is a kind of compulsory basic course of undergraduates with electronic communication major, which mainly researches the basic properties and rules of electromagnetic fields and waves, in order to solve some practical engineering problems, so that they can be closely co-ordinated with microwave technology and antenna technology courses. In the teaching process, students generally reflect that the course is theoretical, and the concepts are abstract, and it contains a large number of mathematical formulas, leading to a large amount of computation. Whether electromagnetic fields or waves, they are both invisible and cannot be touched. The fact is that teachers feel hard to teach while students feel hard to understand is currently a common phenomenon. Because of matlab’s powerful features and visual simulation environment, it provides simulation conditions for teaching electromagnetic fields and waves. Matlab has a large number of two-dimensional and three-dimensional graphics functions, which helps students understand and master the law of electromagnetic fields and waves propagation. In this paper, the use of matlab for the simulation of propagation, reflection and refraction of uniform plane wave in a different medium has achieved good teaching results.

2. The propagation of uniform plane wave in a conductive medium

Let’s the propagation of electromagnetic waves along the z-axis direction in the plane perpendicular to the z-axis, the points have the same intensity of electromagnetic field amplitude and direction of vibration, i.e., only the size of the electric and magnetic fields related to z, and it independent of x and y, so the electromagnetic wave is uniform plane wave.

2.1 The simulation processes of electromagnetic conductive medium

Uniform plane wave in the sea simulation’s process is as follows, according to the known parameters, calculate the number of $\frac{\sigma}{\omega \varepsilon}$ to judge the medium is good or bad conductor. And then calculate the number of $\alpha, \beta, \eta, \phi$. Setting the for loop takes T as the independent variable. The instantaneous value of the electric fields and magnetic fields are written in the loop. Calling the matlab meshgrid, plot3, pause and other functions, to simulate the graphics of electric and magnetic fields.

2.2 The simulation of waves of different frequencies in the same medium

Set a uniform plane with a frequency of $m = 3181,000$ as an example, let’s assume $E = E_x$ and the amplitude is $W/m$.

2.2.1 Transmission of $f = 1kHz$ in conductive medium

When $f = 1kHz$, $\frac{\sigma}{\omega \varepsilon} = 8.9 \times 10^5 >> 1$, so the sea water is a good conductor. Then $x = \sqrt{\frac{\omega \varepsilon}{2}} = 0.0443/m, \beta = \sqrt{\frac{\omega \varepsilon}{2}} = 0.043rad/m, \delta = 7.9577m$. Therefore, the transient expression of...
electric field is \( \mathbf{E}(z,t) = \mathbf{e}_x \times e^{-0.04\pi} \cos(2\pi \times 10^6 t - 0.04\pi) \), while the transient expression of magnetic field is \( \mathbf{H}(z,t) = \mathbf{e}_y \times 0.71e^{-0.04\pi} \cos(2\pi \times 10^6 t - 0.04\pi - 45^\circ) \), a time waveform of the electromagnetic wave shown in Fig 1, the electric fields strength is the vertical and the magnetic is horizontal. By graphics can visually see the electric and magnetic fields amplitude is attenuated.

Fig 1 the transmission of \( f = 1\text{kHz} \)

2.2.2 Transmission of \( f = 1\text{MHz} \) in conductive medium

When \( f = 1\text{MHz} \), \( \frac{\sigma}{\omega \epsilon} = \frac{\sigma}{2\pi f \epsilon_0 \epsilon} = 890 >> 1 \), so the sea water is a good conductor. So the situation is \( \alpha = \sqrt{\frac{\omega \mu \sigma}{2}} = 1.26\pi\mu \rho / m, \beta = \sqrt{\frac{\omega \mu \sigma}{2}} = 1.26\pi\text{rad} / m \). Therefore, the transient expression of electric field is \( \mathbf{E}(z,t) = \mathbf{e}_x \times e^{-1.26\pi} \cos(2\pi \times 10^6 t - 1.26\pi) \), while the transient expression of magnetic field is \( \mathbf{H}(z,t) = \mathbf{e}_y \times 0.71e^{-1.26\pi} \cos(2\pi \times 10^6 t - 1.26\pi - 45^\circ) \). At a certain time, the electromagnetic wave is shown in Fig 2, By graphics can visually see the electric and magnetic fields amplitude is attenuated and the electromagnetic wave is still TEM wave, electric field and magnetic field is in the phase difference, and the amplitude of the electric field and the magnetic field is attenuated by the transmission distance, and the propagation distance in the sea is shorter.

2.2.3 Transmission of \( f = 100\text{MHz} \) in conductive medium

When \( f = 100\text{MHz} \), \( \frac{\sigma}{\omega \epsilon} = \frac{\sigma}{2\pi f \epsilon_0 \epsilon} = 8.90 \), so the sea water is normal conductor. Then the situation is

\[
\alpha = \omega \sqrt{\mu \frac{1}{2} \left[ 1 + \left( \frac{\sigma}{\omega \epsilon} \right)^2 \right]^{-1}} = 11.97\pi\mu \rho / m, \beta = \omega \sqrt{\mu \frac{1}{2} \left[ 1 + \left( \frac{\sigma}{\omega \epsilon} \right)^2 \right]^{-1}} = 42.1\pi\text{rad} / m. 
\]

The transmission of wave is shown in Fig 3, compared with Fig 1 and Fig 2, the electric field and the magnetic field amplitude decay faster and faster.

Fig 3 the transmission of \( f = 100\text{MHz} \)

Fig 4 the curve of the skin depth in the sea water
2.2.4 Transmission of $f = 10 \text{GHz}$ in conductive medium

When $f = 10 \text{GHz}$, $\frac{\sigma}{\omega \varepsilon} = \frac{\sigma}{2\pi \varepsilon_0 \varepsilon_r} = 0.089 << 1$, $\alpha = \frac{\sigma}{2\sqrt{\varepsilon}} \approx 26.7\pi$, $\beta = \omega \sqrt{\varepsilon \mu} = 600\pi$.

The phase shift constant is the same as the ideal medium, the attenuation constant is independent of frequency, with the value increasing, the attenuation of electromagnetic wave is more rapidly than the situation of $f = 100 \text{MHz}$. The same kind of a medium is dielectrics or conductors, is not only related with the medium parameters, but also related with the frequency, the higher value of the frequency, the quicker decreasing of the electromagnetic wave in the medium. From the above analysis, the submarine should choose low frequency electromagnetic wave communication under the water.

2.2.5 The simulation of waves with different frequencies in the same medium

The calculation method of the skin depth is $\delta = \frac{1}{\sqrt{\mu \sigma}} = \frac{1}{\sqrt{\pi \times 4\pi \times 10^{-7} \times 4 \times f}} = 251.6463/\sqrt{f}$, with the frequency range from 10Hz to 1MHz, the curve of the skin depth shown in Fig 4. What can be seen from the figure is that with the increasing of the frequency, the decreasing of electromagnetic wave is faster in seawater, Therefore, in order to maintain lower attenuation, the frequency of electromagnetic wave must be lower.

2.3 The transmission of the same frequency in different medium

When a uniform plane wave transmitting in the copper, which electrical parameters is $\sigma = 5.7 \times 10^7 \text{S/m}$ and it is known to the wave propagation along the z-axis positive direction, let the formula is $E = \varepsilon_0 E_0 \text{ and the amplitude is 1V/m, so the value of } \alpha = \frac{\omega \sigma}{2\sqrt{\varepsilon}} \text{ and } \beta = \frac{\omega \sigma}{2\sqrt{\mu}} \approx 151\pi \text{rad/m, } \delta = \frac{1}{151\pi} \text{ and the skin depth is } \delta = 0.0021 \text{m}. The transmission distance of electromagnetic waves in copper, is only 1/1000 of which in the sea, so the attenuation of electromagnetic wave decreases faster in a good conductor, the greater of the conductivity, the shorter of the transmission distance. Therefore, the transmission of the electromagnetic waves is confined with the area near the surface of the conductor. When the media is the ideal conductor, the electromagnetic waves cannot enter inside of it.

3. Vertical incident electromagnetic wave in a conductive medium

When a uniform plane electromagnetic wave from a conductive medium incident to another in a conducting medium, the phase constant $k$ is complex, therefore, the electromagnetic wave is decreasing not only in the medium 1 but also in the medium 2, and the speed of attenuation is different, and the phase constants are different, too. Fig 5 defines the simulation of vertical incidence electromagnetic wave in a conductive medium.

4. Conclusion

Using the drawing function of matlab realizing the simulation of the abstract and invisible content in
electromagnetic fields and waves, which can help students understanding the curriculum and the teaching content. Meanwhile it can train the ability of the students in designing, writing, and debugging the program. In this paper, through MATLAB software to simulate the dynamic process of the propagation, reflection and refraction of uniform plane wave in a different medium, which has enriched the teaching content, and has stimulated students' interest in learning. We have achieved good teaching results.

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References


