A physical explanation on the wave propagation phenomena in microstrip lines

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Abstract In this paper, a physical explanation on wave propagation in microstrip lines is given which is successful in undergraduate electromagnetic theory class. Unlike axiomatic approaches starting from Maxwell's equation, the explanation informs students of the cause and effect of the electromagnetic wave propagation phenomena. Relations between electric field, magnetic field, and moving charges are described in detail, which helps student understand electromagnetic phenomena.

Keywords : Boundary condition, wave propagation, microstrip.

1. Introduction

Today's advances in the information technologies such as telecommunication, high speed electronics/computing, optics, robots, bioelectronics, home appliances are base on electromagnetic theory directly or indirectly, and the need for deep understanding of basic concepts in the field of electromagnetic (EM) increases[1]. In contrast to this trend, education on the EM theory has encountered hard time due to the decreased number of undergraduate students who registered in the course and graduate students majoring in this field. Many of the students are frustrated by the modern textbooks on the EM theory, which put an emphasis on Maxwell's equation and mathematical description[2, 3]. Although the axiomatic approach is efficient and compact in the development of the contents, it fails to give insight or intuition on the behaviour of electromagnetic waves. Above all, the topics on guided wave propagation are especially bothering students and instructors at the same time. Frequently, propagating waves are described by one of the mathematical solutions that satisfy boundary conditions on transmission line structures in frequency domain. The modal solutions keep their cross-sectional shape invariable despite the translation of observation coordinate. Students have hard time accepting the modal wave functions as a phenomenon of propagating waves, because they have never been told how they are generated and how they propagate in transmission lines. The frequency domain solution is a snapshot of a steady state electromagnetic field distribution when excited by a continuous wave signal generator. They do not inform students how electromagnetic waves are generated and propagate.

In this paper, the propagating phenomenon of electromagnetic waves is explained by way of qualitative interpretation of Maxwell's equations and the movement of charges on the metallic wave guiding structures.

2. Wave propagation phenomena in the microstrip line

To describe wave propagation qualitatively, it is needed that Maxwell's four equations be explained qualitatively. In Maxwell's four equations, two equations contain a curl operator and the other two contain divergence operator. The curl operator locates circulating field quantities, that is, the source terms in Faraday's law and Ampere's law generate fields whose field lines form closed loops. The divergence operator locates field quantities which are generated from a positive source and extend to infinity or a negative point source. Maxwell's equations inform us that there are two types of sources, charges and current. The current is a flow of moving charges. They generate circulating and diverging electric field and circulating magnetic field. On using the equations, directions of electric field and magnetic field lines can be conjectured by right hand rule. If the thumb point to the direction of source terms of Maxwell's equations, directions of circulating fields are determined by the remaining four fingers.

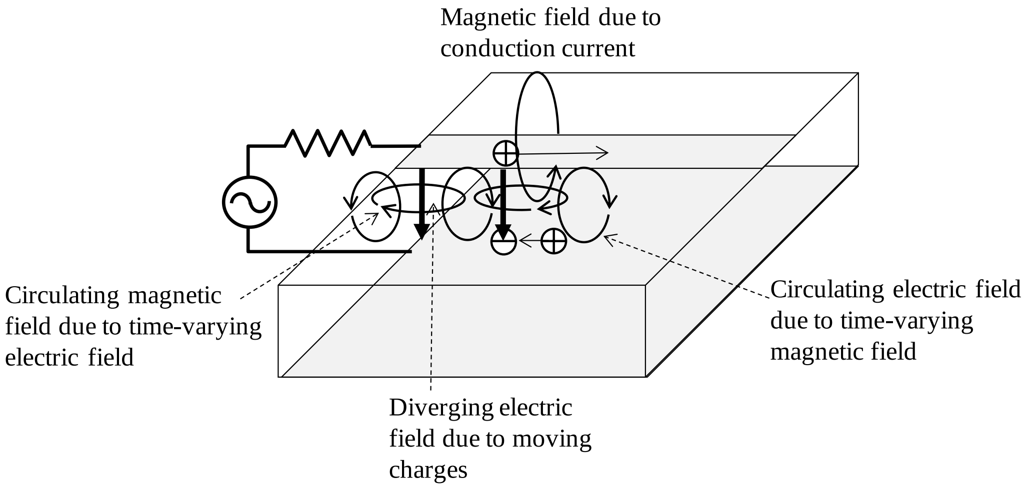

Fig.1. EM wave propagation as a result of chain reaction between electric field and magnetic field.

With the qualitative understanding, wave propagation in the transmission line can be described intuitively as shown in Fig. 1. With a voltage source applied at one end of the microstrip line, a local electric field is generated due to a potential gradient at that point. The instantaneous change of electric field is in essence a displacement flux density vector, which is the source of Ampere's law of Maxwell's equations. Due to the time-varying displacement flux vector, circulating magnetic field lines are generated in the direction of winding the input terminal. The generated time-varying magnetic field, in turn, becomes the source term of Faraday's law, which generates circulating electric fields around the region where time-varying magnetic fields exist. The circulating electric fields have an influence on the movement of charges on conductors which form a microstrip transmission line. The charges drift under the force of the electric field, which forms conduction current on the line trace and ground plane. The conduction current, in turn, becomes the source term of Ampere's law, which generates additional magnetic field around the conductors. Because the charges are moved by a circulating electric field the current on the line trace and that on the ground plane flow in opposite directions. The circulating electromagnetic field pair proceeds to on either direction from wave fronts. The chain reaction between them forms the propagation of electromagnetic wave. At the same time, the charges on the conductors make diverging electric fields which are generated from the positive charges on the line trace and sink to the negative charges on the ground plane.

Unlike the axiomatic explanation that mentions only the solution of differential equation satisfying boundary conditions, descriptive explanation which mentions the movement of charges, relation of time-varying electric field and magnetic field helps the student form insight into the wave propagation phenomena.

References

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