ANALYSIS OF ELECTROMAGNETIC SCATTERING FROM FINITE MICROSTRIP STRUCTURE

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ABSTRACT

It is shown how the two-dimensional equations for microwave planar circuits, which are in fact a generalization of the one-dimensional telegraphists equations, can be derived through a rigorous theory based on Maxwell's equations.

These equations are used in the thesis to calculate the dispersion of the fundamental and of the higher-order modes of propagation on microstrip lines, the losses on microstrip lines, and the components of the equivalent circuit for symmetric, asymmetric, and cascaded microstrip lines.

Keywords : Quassi TEM mode.

INTRODUCTION

Transmission structures used as circuit elements in microwave circuits normally have a planar configuration. For such a configuration the element characteristics are determined by the dimensions in a single plane. For example, the width of a microstrip line on a given dielectric substrate can be adjusted to control its impedance. The required planar dimensions of these circuit elements can be conveniently 0obtained by photolithography and photoetching of thin films. Employment of such techniques at microwave frequencies has led to the development of microwave integrated circuits There are several transmission structures that satisfy the requirement of being planar. The most common of these are the microstrip, the slotline, and the coplanar strips. Microstriplines are widely used transmission structures, mainly due to the fact that the mode of propagation on micrpstrip is almost TEM (qussi – TEM). Pure TEM lines consist of two separate perfect conductors surrounded by a homogeneous linear dielectric. Omy the triplate line belongs to this class. TEM modes are distinguished by having only transverse (to the direction of propagation) electric and magnetic field comp[onents. The TEM line is characterized by a phase velocity $v =$

$c_0/\sqrt{\varepsilon_r \mu_r}$ (c_0 is the velocity of lighrt in free space, ε_r is the relative permittivity, μ_r is the relative permeability), and a characteristic impedance Z_c, both of which are frequency independent.

Quasi-TEM lines also have two separated conductors, but unlike pure TEM lines, the area containing fields is filled with an inhomogeneous dielectric. This is the case for microstrip lines, which are composed of a non-magnetic substrate layer ($\mu_r = 1, \varepsilon_r > 1$) and air. A TEM wave should have a velocity Co in air and Co/$\sqrt{\varepsilon_r}$ in the substrate, and this apparent contadiction

overcome by considering a quasi-TEM mode of propagation on the line. The quasi-TEM mode has at least one longitudinal field component along the direction of propagation and has the property of approaching a pure TEM mode as the frequency ω approaches zero.

DEFINITION OF PLANAR CIRCUIT FIELD QUANTITIES

In planar structures the propagation of microwaves is two-dimensional if the thickness of the structure is much less than the minimal wavelength of the microwave spectrum. The following simplifications related to the electromagnetic field are assumed (Radulate and Tugulea, 1983):

a) The modes of propagation have the electric field E normal to the plates of the structure, while the magnetic field H is parallel to these plates (Figure – 1)

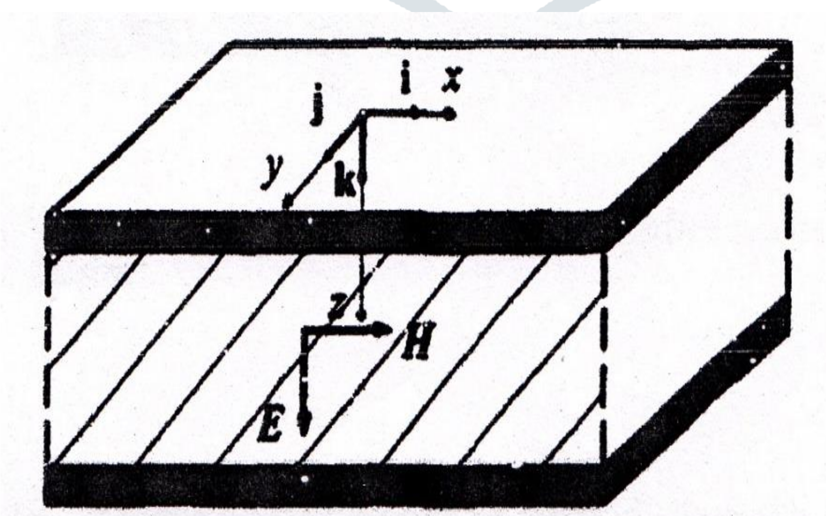

Fig. – 1 Segment of an arbitrarily shaped planar structure showing the fields orientation.

If the system coordinates is chosen as in figure 1, the fields can be expressed as

$$E = kE_z(x,y,t) \qquad 1$$

$$H = iH_x(x,y,t) + jH_y(x,y,t) \qquad 2$$

b) The field are independent of the coordinate normal to the plates.

Equations (1) and (2) describe rigorously only the case of the lossless structures. For lossy structure there is also a tangential component of the electric field which is neglected. For two opposite points of the plates, M and m', an electric voltage can be defined as (Figure – 2)

$$u(x,y,t) = \int_M^{M'} E dr = E_z h \qquad 3$$

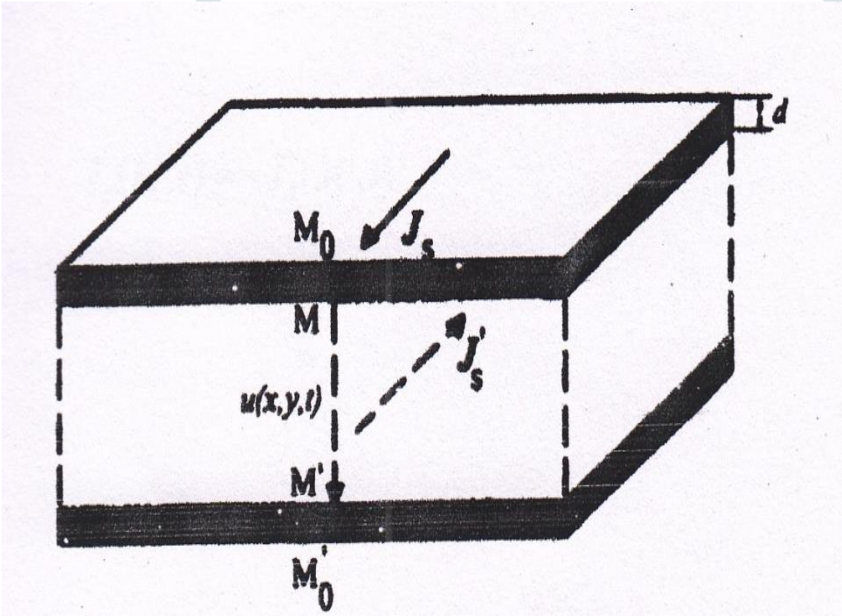

Fig. 2. Voltage between Plates and the direction of surface current density.

For each of the plates a surface current density of the equivalent current layer can be defined as

$$J_s(x,y,t) = \int_{M_o'}^{M} J(x,y,z,t)dz \qquad 4$$

$$J_s'(x,y,t) = \int_{M_o'}^{M'} J'(x,y,z,t)dz \qquad 5$$

The instantaneous current densities J and J' in the conducting plates are in general nonuniform due to the skin effect. In the case where the thickness d of the plates is much less than the penetration depth, the current densities are assumed independent od z and therefore

$$J_x = Jd \quad 6$$

$$J_s' = Jd \quad 7$$

The boundary conditions for the magnetic field are

$$H_M = J_s \, X \, k = H_{M'} = kXJ_s' \quad 8$$

Yielding

$$J_s(M,t) = -J_s'(M',t) \quad 9$$

and

$$H_x = J_{sy} \quad 10$$

$$H_y = -J_{sx} \quad 11$$

the conduction current density through the dielectric medium is

$$J_z = \sigma E_z \quad 12$$

Where σ is the conductivity of the dielectric. Finally one can observe that the fundamental quantities in the field theory of the planar circuits are E and H while in the circuit theory the corresponding quantities are u and J_s. the relationship between the two theories are ensured by equations (3) and (8).

DEFINITION OF PLANAR CIRCUIT PARAMETERS

In Figure an elementary parallelepiped *ABCDA'B'C'D'* is considered. Which will enable us to define the two-dimensional parameters. On the opposite faces *ABCD* and *A'B'C'D'* the electric charges are equal

$$\pm \Delta q = \pm \rho_s \Delta x \Delta y = \pm \varepsilon E_z \Delta x \Delta y$$

Where P_s is the surface charge density and ε is the permittivity of the material between the plates. The elementary capacitance is

$$\Delta C = \frac{\Delta q}{u} = \frac{\varepsilon}{h}\Delta x \Delta y \ .$$

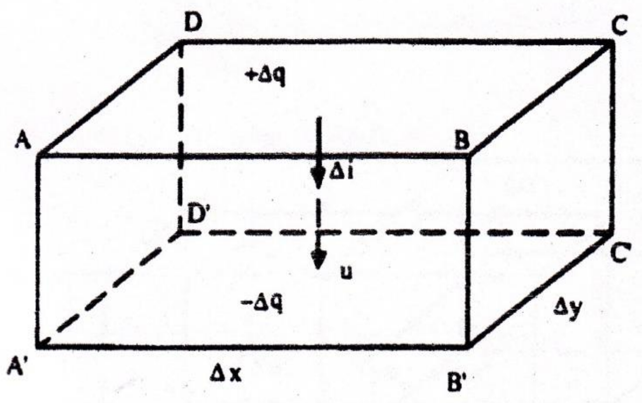

Fig. 3 Definition of the capacitance and the conductance.

Thus the capacitance per unit area is

$$C = \lim_{\Delta x,\Delta y \to 0} \frac{\Delta C}{\Delta x \Delta y} = \frac{\varepsilon}{h} \ . \qquad 13$$

The conduction current through the dielectric medium is

$$\Delta i = J_z \Delta x \Delta y = \sigma E_z \Delta x \Delta y$$

and the elementary conductance is

$$\Delta G = \frac{\Delta i}{u} = \frac{\sigma}{h}\Delta x \Delta y \ .$$

the conductance per unit area is

$$G = \lim_{\Delta x,\Delta y \to 0} \frac{\Delta G}{\Delta x \Delta y} = \frac{\sigma}{h} \ . \qquad 14$$

in Figure 4 two rectangularly contours $\Gamma_x = abb'a'$ and $\Gamma_y = cdd'c'$ are considered.

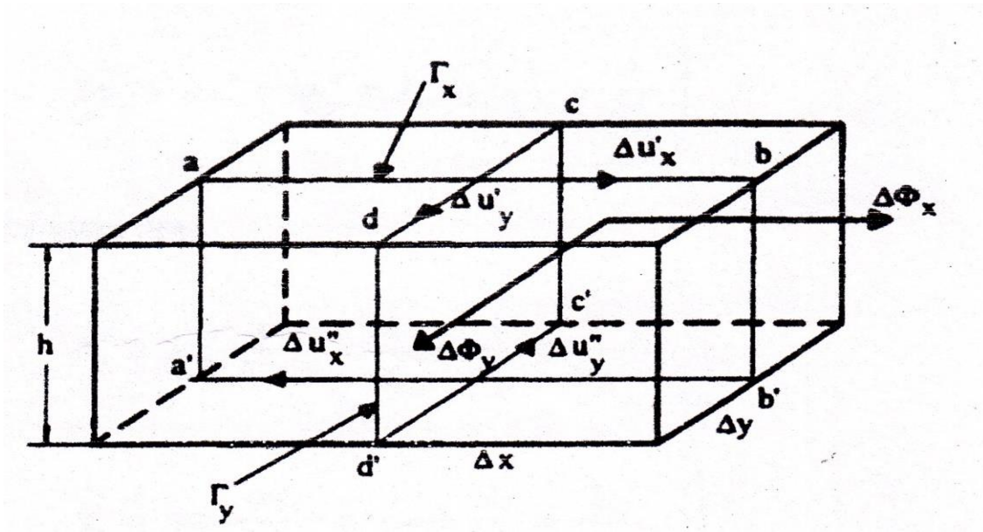

Fig. 4 Definition of the inductance and the resistance.

The magnetic flux through the surfaces bounded by the considered contours are

$$\Delta\Phi_x = \mu_x H_x h\Delta y = \mu_x J_{sy} h\Delta y$$

The inductances $\Delta\Phi_y = \mu_y H_y h\Delta x = -\mu_y J_{sx} h\Delta x$. per square are

$$L_x = -\lim_{\Delta x \to 0} \frac{\Delta\Phi_y}{J_{sx}\Delta x} = \mu_y h \quad 15$$

$$L_y = \lim_{\Delta y \to 0} \frac{\Delta\Phi_x}{J_{sy}\Delta y} = \mu_x h \; . \quad 16$$

For isotropic media ($\mu_x = \mu_y \equiv \mu$) $L_x = L_y = \mu h$. the voltage along the plates are (Figure – 4)

$$\Delta u_x = \Delta u_x' + \Delta u_x'' = J_{sx}\Delta x\left(\frac{1}{\sigma_{sx}'} + \frac{1}{\sigma_{sx}''}\right)$$

$$\Delta u_y = \Delta u_y' + \Delta u_y'' = J_{sy}\Delta y\left(\frac{1}{\sigma_{sy}'} + \frac{1}{\sigma_{sy}''}\right).$$

The resistances per square are

$$R_x = \lim_{\Delta x \to 0} \frac{\Delta u_x}{J_{sx}\Delta x} = \frac{1}{\sigma_{sx}'} + \frac{1}{\sigma_{sx}''} \equiv \frac{1}{\sigma_{sx}} \quad 17$$

Where σ'_{sx} , σ''_{sx} , σ'_{sy} ,and σ''_{sy} , are the surface conductivities for the upper plate (') and for the lower plate (") in the x and y directions, respectively. For isotropic media $(\sigma_{sx} = \sigma_{sy} \equiv \sigma_s)$ $R_x = R_y \equiv I/\sigma_s$, $\sigma_s\ \sigma_c d$, where σ_c is the conductivity of the plates.

APPLICATIONS OF THE TWO-DIMENSIONAL EQUATIONS

Based on the two-dimensional equations, the following applications were developed and the results obtained were compared with those available in the literature:

- A model to calculate the dispersion for the fundamental mode and simultaneously, that for the higher-order modes of propagation;
- A modified model to include the losses, for the computation of both the dispersion and the attenuation, simultaneously;
- A simple equivalent circuit for symmetric and symmetric step discontinuities in microstrip lines, along with efficient formulas to compute the scattering parameters, saving considerable computer resources;
- An equivalent circuit and an analytic formula for the computation of the scattering parameters of a double step discontinuity that gives acceptable results, when compared to result by full-wave methods and to experimental data, reducing the computer time by two orders of magnitude as compared to that required by full-wave techniques;
- A simple model and equation to resonant frequencies of microstrip circular and ring resonators with inhomogeneous dielectrics.

CONCLUSION

The two –dimensional equations for microwave planar circuits have been successfully used in the analysis of specific phenomena in microstrip lines. These equations are in fact a generalization of the classical, one-dimensional transmission line equations. The two-dimensional equations allow the inclusion of losses in the analysis of microstrip structures.

The frequency range of applicability for these equations extends up to the cutoff frequency of the first TM mode, covering the practical operating range of the microstrip circuits.

REFERENCES

1. S. Akhrarzad and P. Jahus, "Dispersion of a microstrip line with a step discontinuity", Electronics Letters, Vol. 11, pp. 310 – 311, 1975.
2. H. A. Atwater, "Test of microstrip dispersion formulas", IEEE Trans. Microwave Theory Tech, vol. MTT-36, pp. 619-621, March 1988.
3. R. Baican, "Microwave Integrated Circuits", (in Romanian), Cluj-Napoca; Promedia-Plus,1996.
4. P. Bhartiya and i.J. Bahl, "Millimeter Wave engineering and Applications", New York, NY: John Wiley & Sons, 1984.
5. R. Bonetti and P. Tissi,"nalysis of Planar disk Networks", IEEE Trans. Microwave Theory Tech, vol. MTT-26, pp. 471-477, 1978.
6. T. Bryant and J. Weiss, "Parameters of microstrip transmission lines and of coupled pairs of microstrip lines", IEEE Trans. Microwave Theory Tech, vol. MTT-16, pp. 1021-1027, 1968.
7. H. J. Karlin, "A simplified circuit model for microstrip", IEEE Trans. Microwave Theory Tech, vol. MTT-21, pp. 589-591, Sept. 1973.
8. R. Collin, "Field Theory of Guided Waves", 2nd ed. Piscataway, NJ: IEEE Press, 1992.
9. E. J. Denlinger, "A frequency dependent solution for microstrip transmission lines", IEEE Trans. Microwave Theory Tech. vol. MTT-19, pp. 30-39, Jan. 1971.
10. B. Easter et al., "Theoretical and experimental methods for evaluating discontinuities in microstrip", The Radio and Electronic Engineer, vol. 48, pp. 73-84, 1978.
11. T. Edwards and R. Owens,"2-18 GHz dispersion measurements on 10-100 Ω microstrip lines on sapphire", IEEE Trans. Microwave Theory Tech. vol. MTT-24, pp. 506-513, Aug. 1976.
12. H. ermert, "Guided modes and radiation characteristics of covered microstrip lines", Arch. Electronik u. Ubertragungstechn., vol. 30, pp. 65-70, 1976.

13. A. L. Feldstein, L.R. Iavici and V. P. Smirnov, “Handbook of Elements of Guided Wave Techniques”, (inRussian), Moscow: sovietskoe Radio, 1967.

14. T. S. Fozley and Bridges, “dispersion characteristics of open microstrip using a direct VSW measurement approach”, Antenna Technology and Applied Electromagnetics Symp. Dig., Winnipeg, Aug. 5-7,1992.

15. R. Garge and I. Bahl, “Microstrip discontinuities”, Int. J. Electronics, Vol. 45, pp. 81-87, 1978.

16. W. Getsinger, “Microstrip dispersion model”, IEEE Trans. Microwave Theory Tech. vol. MTT-21, pp. 34-39, Jan. 1973.

17. F. Giannini, G. Bartolucci, and M. Ruggieri, “Equivalent circuit models for computer aided design of microstrip rectangular structures”, IEEE Trans. Microwave Theory Tech. Vol. MTT-40, pp. 378-388, February, 1992.

18. A. Gopinath et.al., “Equivalent circuit models for computer aided design of microstrip rectangular structures”, IEEE Trans. Microwave Theory Tech. Vol. MTT-40, pp. 378-388, February, 1992.

19. A. Gopinath, “Equivalent circuit parameters of microstrip step change in width and cross junctions”, IEEE Trans. Microstrip resonators”, IEEE Trans. Microwave Theory Tech., vol. MTT -13, pp. 676-692, 1965.

20. H. Green, “The numerical solution of some important Transmission-line problems”, IEEE Trans. Microwave Theory Tech. Vol. MTT-13, pp. 676-692, 1965.