MEASURING COMPLEX DIELECTRIC CONSTANT OF DIELECTRIC SLAB-COATED CONDUCTORS IN MILLIMETER WAVES BY RADIATING TECHNIQUE

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ABSTRACT

This paper describes a novel method for determining complex dielectric constant of dielectric slab-coated conductors. The constant may be found by measuring an angle θ_m of maximun radiation and two radiation angles θ_{1h}, θ_{2h} of half peak power from the leaky wave antenna. The method is specially useful for millmeter waves and can realize automatical measurement.

INTRODUCTION

In the past the determination of complex dielectric constant of microstrip substrate has often been accomplished via experimental means, mostly by the resonance schemes. However these methods can be used only in microstrip with thin substrate. In this paper we describe novel method for determining complex dielectric constant of dielectric slab-coated conductors. The new method is referred to as a radiating technique. The technique is specially useful for millimeter waves. Essential principle of the technique is as follows.

A leaky wave structure composed of an array of thin metallic rectangular strip is made of a dielectric slab-coated conductors. Complex dielectric constant ε_r of the slab is still unknown. The geometry of the leaky wave structure is shown in Fig.1. The thickness and the length of the dielectric slab are h and L, respectively, d is the length of the period, W is width of the strip. A horn is used as feed of the structure. Complex dielectric constant of the dielectric slab may be found by measuring an angle θ_m of maximun radiation and two radiation angles θ_{1h} and θ_{2h} of half peak power from the leaky wave antenna.

ANALYSIS

The structure shown in Fig. 1 is a periodically loaded, basically slow, traveling wave one. First, we find a relation between the paremeters h, d, W, ε_r and the complex propagation constant k_z along the leaky wave structure where $k_z=\beta+j\alpha$, β and α represent corresponding phase and attenuation constant. We employ Green's function method in the Fourier transform of spectral domain. Referring to Fig. 1, let us consider a y-polarized wave traveling along the z-direction. The dielectric slab is supposed to be infinite in the y-z plane. In this case the expression for $\tilde{G}$, the Fourier transform of spatial-domain Green's function for the E-field of y-direction line source located at a distance x_0 above the dielectric suface (referring to Fig. 2), is given by (1)

$$\tilde{G}(x,\varsigma)=\frac{\mu_0}{j2k_{x1}}\{\exp(-jk_{x1}|x-x_0|$$

$$+R\exp(-jk_{x1}|x+x_0|)\} \qquad (1a)$$

where

$$R=\frac{jk_{x1}-k_{x2}\,ctg(k_{x2}h)}{jk_{x1}+k_{x2}\,ctg(k_{x2}h)}$$

$$k_{x1}^2=k_0^2-\xi^2,\qquad k_{x2}^2=\varepsilon_r k_0^2-\xi^2$$

k_0: free-space propagation constant.

In our case the line sourse is located at the dielectric suface, $x_0=0$. So expression (1a) has following simple form

$$\tilde{G}(x,\xi)=\frac{\mu_0\exp(-jk_{x1}x)}{jk_{x1}+k_{x2}\,ctg(k_{x2}h)}\qquad(1b)$$

The current distribution on the strip in the z-direction is supposed to be[2]

$$J_\nu(z)=\frac{\exp(-jk_z)}{k_0\sqrt{w^2-\bar{z}^2}}\cdot\sum_{\nu=0}^{+\infty}(-j)^\nu A_\nu\cos(W_\nu(\bar{z}+w))\qquad(2)$$

where $\bar{z}=z-nd\quad(n=0,\ \pm1,\ \pm2,\ \pm3\cdots)$

$w=W/2$

$W_\nu=\nu\pi/W\quad(\nu=0,\ 1,\ 2,\ 3\cdots)$

The Fourier transform of the current distribution is

$$\tilde{J}_\nu(\xi)=\frac{2\pi}{k_0 d}\sum_{n=-\infty}^{+\infty}\delta(\xi-k_z-\xi_n)\cdot\sum_{\nu=0}^{+\infty}A_\nu F_\nu(\xi_n)\qquad(3)$$

where

$$F_\nu(\xi_n)=\frac{\pi}{2}\left[J_0\left(\xi_n w+\frac{\nu\pi}{2}\right)+(-1)^\nu J_0\left(\xi_n w-\frac{\nu\pi}{2}\right)\right]$$

$$\xi_n=\frac{2n\pi}{d}$$

$J_0(x)$: the Bessel function

$\delta(x)$: the delta function.

The total field is sum of the electric fields generated by the periodic array of strips. Therefore the transfom of the total field is

$$\tilde{E}(\xi)=\tilde{G}(0,\xi)\tilde{J}_\nu(\xi)\qquad(4)$$

The total E-field on any strip is equated to zero. The structure shown in Fig. 1 is a periodic one. By Floquet's theorem, it is enough to consider a single period, for example n=0. So that

$$\int_{-\infty}^{+\infty}E(z)\Psi(z)dz=\int_{-\infty}^{+\infty}\tilde{E}(0,t)\frac{\sin(t-\xi)}{t-\xi}dt=0\qquad(5)$$

where $\Psi(z)=\exp(j\xi z)[U(z+w)-U(z-w)]$

$U(x)$: the unit step function.

Substituting (4) into (5) we obtain

$$\sum_{n=-\infty}^{+\infty}\Phi(\xi_n,k_z)\frac{\sin(k_z+\xi_n-\xi)w}{(k_z+\xi_n-\xi)w}=0\qquad(6)$$

where

$$\Phi(\xi_n,k_z)=\sum_{\nu=0}^{+\infty}\frac{A_\nu F_\nu(\xi_n)}{j\eta+\xi\,ctg(\xi h)}$$

$$\eta=\sqrt{k_0^2-(k_z+\xi_n)^2}$$

$$\xi=\sqrt{\varepsilon_r k_0^2-(k_z+\xi_n)^2}$$

According to sampling theorem Eq. (6) providus us infinite sets algebraic equations

$$\sum_{\nu=0}^{l-1}B_{\mu\nu}A_\nu=0\quad(\mu=0,1,2\cdots)\qquad(7)$$

where

$$B_{\mu\nu}=\sum_{n=-m}^{m}\tilde{G}(\xi_n,k_z)F_\nu(\xi_n)\Omega(\xi_n)$$

$$\Omega(\zeta_n) = \frac{\zeta_n w \sin((\mu\pi/2) - \zeta_n)}{(\mu\pi/2)^2 - (\zeta_n w)^2}$$

Eq.(7) is sets of homogeneous equation. To make A_ν having a nontrivial solution, the determinant of Eq. (7) must equate zero

$$|B_{\mu\nu}| = 0 \qquad (8)$$

Eq. (8) is the relation we are seeking. Nex we express k_z in terms of the angles θ_m, θ_{1h}, θ_{2h}. The structure shown in Fig. 1 is designed such that $d \geqslant 0.5\lambda_0$ and only β_{-1} is in the visible region where λ_0 is free-space wavelength. By theory of traveling wave antennas [3], the pattern of the structure in the x-z plane is

$$|E(\theta)| \propto \frac{1}{\sqrt{\alpha^2 + (\beta_{-1} - k_0\cos\theta)^2}} \qquad (9)$$

From the equation (9) we may find the relation between β, α, and θ_m, θ_{1h}, θ_{2h}. They are

$$\beta = k_0\cos\theta_m + \frac{2\pi}{d} \qquad (10)$$

$$\alpha = -\left|\frac{k_0}{2}(\cos\theta_{1h} - \cos\theta_{2h})\right| \qquad (11)$$

Substituting (10), (11) and paremeters W, d, h, k_0 into (9), we can yield the desired complex dielectric constant of slab.

RESULTS

Complex dielectric constant of two diffrent slab-coated copper foils have been measured. One of them is FBD-2 slab-coated copper foil. The leaky-wave structure shown in Fig. 1 is made of FBD-2 slab-coated copper foil, d=5.6mm, W=1.6mm, h=3mm, L=200mm. The angles θ_m, θ_{1h}, θ_{2h} of measured patterns of the structure for different frequnces are listed Table 1. The complex dielectric constant ε_r computed in terms of θ_m, θ_{1h}, θ_{2h} are given in same table. The complex dielectric constant of other slab-coated copper foil is listed in table 2. Here the geometry of the leaky wave structure is that d=3mm, W=1mm, h=1.5mm, L=100mm. The angles θ_m, θ_{1h}, θ_{2h} of measured patterns of the structure are listed in Table 2, too. Error in ε_r depend on measuring error in the angles θ_m, θ_{1h}, θ_{2h}. Here $|\Delta\theta_m| = 0.5°$, $\Delta\theta_{1h} = \Delta\theta_{2h} = \pm 0.1°$, relative errors in $Re(\varepsilon_r)$ and $tg\delta$ are about 2% and 10‰, respectively. This method is simple and can measure the complex dielectric constant of a thick dielectric slab-coated conductor in millimeter waves and can realize automatical measurement.

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Table.1

f(Gc)	θ_m	θ_{1h}	θ_{2h}	$Re(\varepsilon_r)$	$tg\delta$
35.28	106.3°	105.1°	107.6°	2.92± 0.06	$(5.3\pm 0.5)\times 10^{-3}$
36.76	99.6°	98.2°	101.3°	2.90± 0.06	$(6.0\pm 0.6)\times 10^{-3}$
37.42	97.0°	95.6°	98.4°	2.90± 0.06	$(5.2\pm 0.5)\times 10^{-3}$

Table.2

f(GC)	θ_m	θ_{1h}	θ_{2h}	$Re(\varepsilon_r)$	$tg\delta$
35.05	62.2°	59.0°	65.0°	16.5± 0.3	$(8.4\pm 0.8)\times 10^{-3}$
36.04	54.8°	50.1°	57.3°	16.4± 0.3	$(11.4\pm 1.1)\times 10^{-3}$

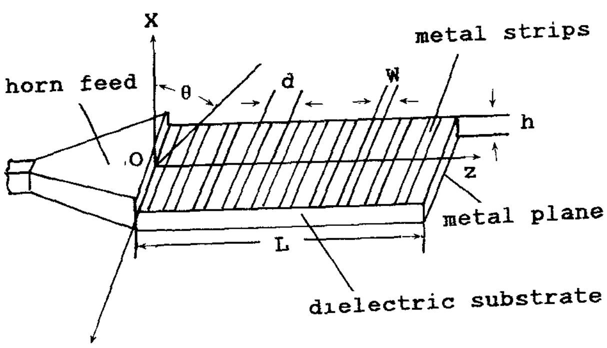

Fig. 1

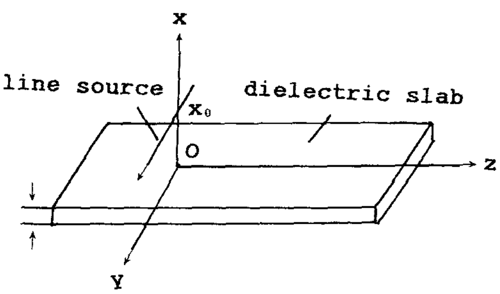

Fig.2