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The Resonant Characteristics of Eccentric Circular and Concentric Circular-elliptical Ring Microstrip Antennas

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Abstract To study the resonant characteristics of eccentric circular and concentric circular-elliptical ring microstrip antennas, the method, which is connected with the concentric ring microstrip antenna and based on the perturbation, is employed to calculate resonant wave numbers. Comparisons of calculations with reference for the fundamental mode are also presented, agreement is very good for small eccentricity.

Key words resonant wave number; microstrip antenna

0 Introduction

Microstrip antennas have been studied extensively because of their many advantages over conventional antennas[1,2]. In this paper, the special ring microstrip antennas shown in Fig. 1a and Fig. 1b are analyzed for resonant wave numbers. Obviously, it is difficult to obtain pure analytical solution to these problems due to complicated boundary shape. In fact, the shape shown in Fig. 1a and Fig. 1b can be considered as the perturbation of the well-known annular microstrip antenna with radius R_1 and R_2 as shown in Fig. 1c. Hence, a special analytical shape perturbation method, originally developed in connection with eccentric spherical cavities by Kanellopoulos and Fikioris[3], and then developed for metallic waveguides and electromagnetic wave scattering from an infinite cylinders by J. A. Roumeliotis et al[4,5], is employed to obtain the resonant wave numbers of eccentric circular and concentric circular-elliptical ring microstrip antennas. Using appropriate translational addition theorem for circular cylindrical wave functions, we are able to reduce problem to an infinite determinant equation for the resonant wave numbers. When eccentricity is small, it is not difficult to obtain the resonant wave numbers. Results for the fundamental mode TM_{11} are compared with those measured with the resonant wave method[6] and calculated with the points matching

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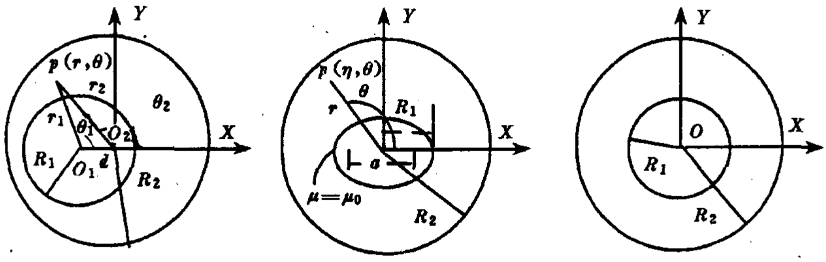


(a) eccentric circular　(b) concentric-elliptical　(c) concentric

Fig. 1　Geometry of ring microstrip antenna

method[1], the agreements are very good for small eccentricity. In addition, concentric circular-elliptical ring microstrip antenna is also partially analyzed by similar method.

1　Theory

The configuration of the eccentric circular ring microstrip antenna analyzed in this paper is shown in Fig. 1a, ε_r is the relative permittivity of the substrate, and its thickness h is assumed to be very small compared with wavelength λ. Assuming $e^{j\omega t}$ time variation, electric field E_z due to current source must satisfy the following equations[1,2]:

$$(\nabla_T^2 + k_{nm}^2)E_z = -\mathrm{j}\omega\mu J_z, \tag{1}$$

$$\frac{\partial E_z}{\partial n} = 0 \quad \text{on the magnetic wall}, \tag{2}$$

where ω is the angular frequency. The above problem can be solved using Green's function $G(s,s_0)$, the solution for E_z then becomes

$$E_z = \iint G(s,s_0)J(s,s_0)\mathrm{d}s. \tag{3}$$

The Green's function is expressed as

$$G(s,s_0) = \mathrm{j}\omega\mu h \sum_n \frac{\phi_{nm}(s)\phi_{nm}(s_0)}{k_{nm}^2 - k^2}, \tag{4}$$

where ϕ_{nm} and k_{nm} are eigenfunctions and eigenvalues for the n,m mode of the patch, respectively, s_0 stands for source point $s_0(r_0,\theta_0)$, s stands for field point $s(r,\theta)$, $k^2 = K_0^2\varepsilon_r$, K_0 being free space wave number, ϕ_{nm} must satisfy the following wave equation and boundary condition

$$(\nabla_T^2 + k_{nm}^2)\phi_{nm} = 0, \tag{5}$$

$$\left\{\frac{\partial\phi_{nm}}{\partial n}\right\}_{r_1=R_1, r_2=R_2} = 0 \quad \text{on the magnetic wall C.}$$

The following expressions can be used to expand eigenfunctions

$$\phi_{nm} = \sum_{i=0}^{\infty}(J_i(k_{nm}r_1) - N_i(k_{nm}r_1)J_i'(k_{nm}R_{1g})/N_i'(k_{nm}R_{1g}))(A_i\cos i\theta_1 + B_i\sin i\theta_1) \quad r_1 \geqslant R_1,$$

where r_1 and r_2 are distances from field point to the inner, outside circular center, respectively, and J, N are the cylindrical Bessel functions. R_{1g}, R_{2g} are the effective radius of circular due to fringing field[1,2]:

$$R_{1g} = 2R_1 - R_1\left[1 + \frac{2h}{\pi R_1 \varepsilon_r}\left(\ln\frac{\pi R_1}{2h} + 1.7726\right)\right]^{\frac{1}{2}},$$

$$R_{2g} = R_2\left[1 + \frac{2h}{\pi R_2 \varepsilon_r}\left(\ln\frac{\pi R_2}{2h} + 1.7726\right)\right]^{\frac{1}{2}},$$

where R_1 and R_2 are the inner and outer circular geometry radius with an eccentricity d. The boundary condition $\left\{\frac{\partial\phi_{nm}}{\partial n}\right\}_{r_2=R_{2g}}=0$ leads to the following definition[3]:

$$u_{pi}(x_2, x_1) = J'_p(x_2) - N'_P(x_2)J'_i(x_1)/N'_i(x_1),$$

where $$k_{nm}R_{g1} = x_1,\quad k_{nm}R_{2g} = x_2.$$

The resonant wave numbers are expressed in the form of perturbation[2~4]

$$k_{nm}(d) = k_{nm}(0)(1 + g_{nm}(k_{nm}(0)d)^2 + \cdots), \tag{6}$$

where $k_{nm}(0)$ can be obtained from $u_{nn}(x_1^0, x_2^0)=0$, for $d=0, x_i=x_i^0, i=1,2$. g_{nm} can be obtained from the following expressions

$$g_{nm} = \left[\frac{dd_{nn}(x_1^0)}{dx_1}\right]^{-1}\left[\frac{d'_{n+1,n}d'_{n,n+1}}{d_{n+1,n}} + e_{nm}\frac{d'_{n-1,n}d'_{n,n-1}}{d_{n-1,n}d_{n,n-1}}\right]$$

$$n = 1,2,\cdots, m = 1,2,\cdots \quad e_{1m} = 0,\quad e_{nm} = 1,\quad n > 1, \tag{7}$$

where $d_{11}=u_{11}(x_1^0, x_2^0)$, $d''_{11}=-\frac{3}{8}u_{11}(x_1^0, x_2^0)$, $d_{nn}=u_{nn}(x_1^0, x_2^0)$, $d'_{n+1,n}=-\frac{1}{2}u_{n+1,n}(x_1^0, x_2^0)$, $n\geqslant 1$ for odd TM modes. For even TM modes, a similar g_{nm} can also be obtained. The even or odd mode is referred to the E_Z component in TM modes.

Referring to concentric circular-elliptical ring microstrip antennas as shown in Fig. 1b,

$$R_1 = \frac{a}{2}\cosh\eta_0,\quad x_1 = t\cosh\eta_0,\quad x_2 = kR_{2g},\quad r_1 = \frac{a}{2}\sinh\eta_0,$$

$$a^2 = 4(R_1^2 - r_1^2),\quad \eta_0 = \tanh^{-1}\left(\frac{r_1}{R_1}\right),\quad t = \frac{ka}{2},$$

eigenfunctions that satisfy the boundary condition $\left\{\frac{\partial\phi_{nm}}{\partial n}\right\}_{r_2=R_{2g}}=0$ can be written in the following form:

$$\phi_{nm} = \sum_{i=0}^{\infty}(J_i(k_{nm}r) - N_i(k_{nm}r)J'_i(k_{nm}R_{2g})/N'_i(k_{nm}R_{2g}))(A_i\cos i\theta_1 + B_i\sin i\theta_1),\quad r\leqslant R_2. \tag{8}$$

The concentric elliptical wave functions are used to expand above circular cylindrical ones with the well-known formulas[7]:

$$Z_{ii}(k_{nm}r)\cos 2i\theta = \frac{\sqrt{8\pi}}{\varepsilon_i}\sum_{m=0}^{\infty}[B_{2i}^e(t, 2m)/M_{2m}^e(t)]Se_{2m}(t, \cos\theta)Ze_{2m}(t, \cosh\eta),$$

$$Z_{ii+1}(k_{nm}r)\cos(2i+1)\theta = \frac{\sqrt{8\pi}}{\varepsilon_i}\sum_{m=0}^{\infty}[B_{2i+1}^e(t, 2m+1)/M_{2m+1}^e(t)]\cdot Se_{2m+1}(t, \cos\theta)Ze_{2m+1}(t, \cosh\eta),$$

$$Z_{ii}(k_{nm}r)\sin 2i\theta = \sqrt{8\pi}\sum_{m=1}^{\infty}[B^{o}_{2i}(t,2m)/M^{o}_{2m}(t)]\cdot$$
$$So_{2m}(t,\cos\theta)Zo_{2m}(t,\cosh\eta) \quad i \geqslant 1,$$
$$Z_{ii+1}(k_{nm}r)\sin(2i+1)\theta = \frac{\sqrt{8\pi}}{\varepsilon_i}\sum_{m=0}^{\infty}[B^{o}_{2i+1}(t,2m+1)/M^{o}_{2m+1}(t)]\cdot$$
$$So_{2m+1}(t,\cos\theta)Zo_{2m+1}(t,\cosh\eta),$$

in which η,θ are the transverse elliptical cylindrical coordinates; $Z_X = aJ_X + bN_x$ ($x = i, o_m$ and e_m) are the general Bessel functions and the even and odd general radial Mathieu functions, respectively; Se and So are the even and odd angular Mathieu functions; $B_i^{e,o}(t,m)$ are the expansion coefficients for the Mathieu functions, and $M_m^{e,o}(t)$ are their corresponding normalization constants; $\varepsilon_i = 0.5$ for $i=0$ and $\varepsilon_i = 1$ for $i \geqslant 1$. The boundary condition $\left\{\frac{\partial\phi_{nm}}{\partial n}\right\}_{\eta=\eta_0} = 0$ and the orthogonality of the Se, So can yield linear homogeneous equations the expansion coefficients A_i and B_i in (8) which are functions of the resonant wavenumber[3]. For even TM modes, when $t=0, x_i = x_i^0, i=1,2, k^0_{nm}(0)$ can be obtained from $u_{nn}(x_1^0, x_2^0) = 0$:

$$c_{00} = 2u_{00}(x_2^0,x_1^0), \quad c''_{00} = -\frac{1}{2}u_{00}(x_2^0,x_1^0), \quad c_{11} = u_{11}(x_1^0,x_2^0), \quad c''_{11} = -\frac{3}{8}u_{11}(x_1^0,x_2^0),$$

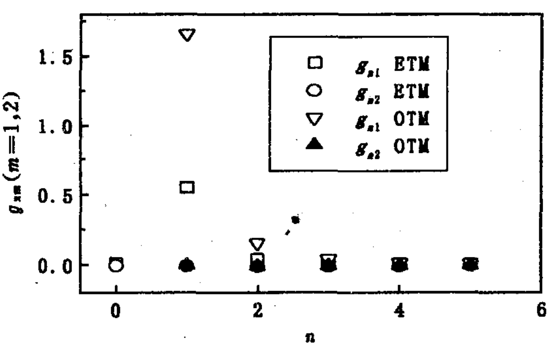
$$c_{nn} = u_{nn}(x_1^0,x_2^0), \quad c''_{nn} = -\frac{1}{4}u_{nn}(x_1^0,x_2^0), \quad n \geqslant 2,$$

$$c'_{10} = u_{10}(x_1^0,x_2^0), \quad c'_{01} = -u_{01}(x_1^0,x_2^0), \quad c'_{n+1,n} = -\frac{1}{2}u_{n+1,n}(x_1^0,x_2^0), \quad n \geqslant 0,1.$$

Therefore,

$$g_{nm} = \frac{\delta k_{nm}}{k^0_{nm}t^2} = -\left[x_1^0\frac{\mathrm{d}C_{nm}(x_1^0,x_2^0)}{\mathrm{d}x_1^0}\right]^{-1} C''_{nm}(k^0_{nm}) \quad n,m = 0,1,2\cdots \tag{9}$$

and for odd TM modes, similar formulas can be derived, but $n = 1,2,\cdots$. Fig. 2 gives the results of some g_{nm} for even TM and odd TM which are used to calculated resonant wave numbers by means of formula (6), but d is replaced by t.

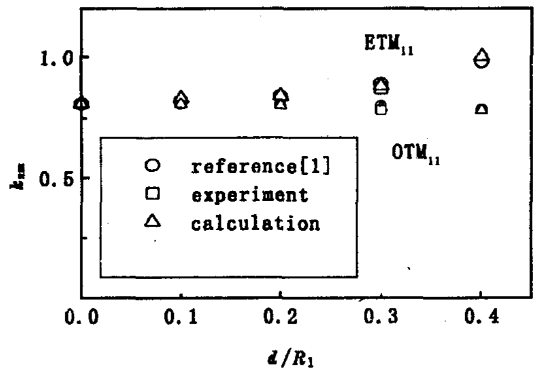


$R_2 = 3\,\text{cm}, R_1 = 2\,\text{cm}, a = 1\,\text{cm}, h = 0.15\,\text{cm}$, $\tan\delta = 0.0018, \varepsilon_r = 2.5$

Fig. 2 Curves g_{nm} vs. n for concentric circular-elliptical ring microstrip antennas

2 Theoretical and Experimental Results for the Fundamental Mode

The usefulness and accuracy of the method presented in this paper are shown through comparison of calculation with the experimental and calculated values from reference[1] for the microstrip antenna shown in Fig. 1a , the antenna is made of copper-clad 1.5mm thick Telflon fiber glass with a dielectric constant 2.5, and a loss tangent 0.0018,



$R_1=2$cm, $R_2/R_1=1.5$cm, $h=0.15$cm, $\tan\delta=0.0018$, $\varepsilon_r=2.5$

Fig. 3 The comparison of the calculation for the fundamental mode TM_{11} with the experiment and reference for eccentric circular microstrip antenna

and is fed by a coaxial probe, whose input impedance is 50Ω, the diameter is 1mm. In the experiment, the eccentricity is 0.3, it is found from Fig. 3 that the agreement between measurement and calculation is very good. In addition, we compared calculations with results from other method for various eccentricities, agreements are quite good for small eccentricity while discrepancies become noticeable as eccentricity increases. Results are shown in Fig. 3.

3 Conclusion

The special shape perturbation method is employed to analyze the resonant numbers of eccentric and concentric circular-elliptical ring microstrip antenna, and the usefulness and accuracy of the present method are verified from the fact that calculated values for the fundamental mode are agreement well with ones measured and calculated from the reference.

References

1 饶亲江. 任意形状微带天线谐振特性的分析. 电子科学学刊, 1993, 15(5): 551～555

2 Rao Qinjiang. The Resonant Wave Numbers of Eccentric Ring Microstrip Antennas for All Modes. International Journal of Infrared and Millimeter Wave, 1998, 19(1): 129～138

3 Kanellopoulos J D, Fikioris J G. Acoustic Resonant Frequencies in An Eccentric Spherical Cavity. J Acoust Soc Amer, 1978, 64(1): 286～297

4 Roumeliotis J A. Siddique Hossain A B M, Fikioris J G. Cutoff Wave Numbers of Eccentric Circular and Concentric Circular-Elliptic Metallic Wave Guides. Radio Science, 1980, 15(5): 923～937

5 Savaidis S P, Roumeliotis J A. Scattering by An Infinite Elliptic Dielectric Cylinder Coating Eccentrically A Circular Metallic or Dielectric Cylinder. IEEE Trans, Microwave Theory Tech, 1997, 45(10): 1792～1780

6 林昌禄. 天线测量技术. 成都: 电子科技大学出版社, 1987

7 Morse P N, Feshbach H. Methods of Theoretical Physics. New York: McGraw-Hill, 1953

偏心圆环及同心圆-椭圆环微带天线的谐振特性

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摘　要　为研究偏心圆环及同心圆-椭圆环微带天线的谐振特性，运用了一种以对同心圆环微扰为基础的计算方法，计算的谐振波数值与参考文献作了比较，在小偏心率的情况下，一致性很好。

关键词　谐振波数；微带天线
中图分类号　TN 8224

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