Resonance of the Rectangular Microstrip Antennas on the Uniaxial Substrate with an Airgap

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Abstract: The resonance characteristic of microstrip antenna with an airgap between the substrate layer and ground plane is investigated. The study is performed by using a rigorous Green's function formulation in the spectral domain and Galerkin's moment method calculation. The numerical convergence using sinusoidal basis functions, the unknown surface current distribution in the rectangular patch, is discussed. Numerical result for the effects of airgap and patch length on the complex resonant frequencies of the rectangular microstrip structure are also presented

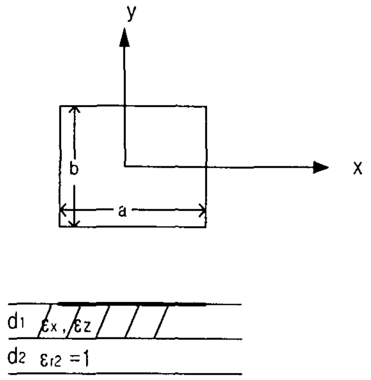
1. Introduction

Microstrip patch antennas have some well known advantages such as small size, lightweight, low profile, planar but conformal, geometry, easy to integrate MIC's MMIC's and low cost. Due to these and other relevant characteristics microstrip patch antennas technology has probably been the most rapidly developing topic in the antennas field in the last twenty years. Micorstrip patch antennas have been increasingly used in many application mostly in telecommunications but also in other areas[1]. Intensive research has been carried out to develop new techniques to overcome the microstrip patch antennas drawbacks. Specially, in the microstrip antennas design, it is important to ascertain the resonant frequencies of the antennas accurately because microstrip antennas have narrow bandwidths and can only operate effectively in the vicinity of the resonant frequency. The resonant frequencies of the a microstrip patch have been studied before[2]-[4] in conjunction with microwave integrated circuits. Narrow bandwidth is a particularly severe limitation so that a considerable effort is devoted to increasing the frequency agility of the antenna. One of the approaches is designing an antenna which can be tuned over a range of operating frequencies so that the same antenna can be used for several channels. It can be achieved by utilizing an adjustable airgap[5]-[6]. To In addition to, the plurality of substrate material used for microwave integrated circuits belongs to the alumina family. These materials are slightly anisotropic[7]. For example, sapphire, alumina, and a variety of alumina substrates are anisotropic. Also, Teflon-type substrates are usually ceramic-impregnated, which introduces anisotropic behavior and Duroid and Epsilam are a number of commonly used glass-filled and ceramic-filled polymeric materials.

The study of anisotropic microwave substrate is of interest for a least two reasons.[8] First, as the review article[7] points out, many practical substrates have a significant amount of anisotropy that can affect the performance of printed circuits and antennas, and thus accurate characterization and design must account for this effect. Second, it is possible that the use of such materials may have beneficial effects on circuit and antennas performance. The purpose of this paper is to present microstrip patch antennas on the uniaxial substrate and with an airgap. This study is investigated by using a rigorous Green's function formulation in the spectral domain[8] and Galerkin's moment method[9] calculation. Complex resonant frequencies will be obtained in this study, which provided the resonant frequencies.

2. Theoretical Formulation of the Problem

The geometry of a microstrip structure with an airgap is shown in Fig.1. The air gap(region1) with a thickness of t



and substrate thickness is d.

Fig.1. Rectangular patch on the uniaxial substrate with an airgap layer

The substrate layer is with a tensor $\overline{\overline{\varepsilon}}$. The dielectric is characterized by a permitt ivity tensor of the form

$$\overline{\overline{\varepsilon}} = \varepsilon_0 \begin{bmatrix} \varepsilon_x & 0 & 0 \\ 0 & \varepsilon_x & 0 \\ 0 & 0 & \varepsilon_z \end{bmatrix} \qquad (1)$$

The method of analysis follows the usual procedure. First, the solutions to the wave equation in Fourier-transformed domain are obtained for the different regions of the structure (free space, substrate, air gap). The solutions contain arbitrary coefficients, which are determined by applying the boundary condition across the interfaces, at infinity and on the ground plane. Enforcing the condition the tangential electrical fields vanish on the patch leads to two integral equations for the unknown patch currents in the transformed domain.

Consider a 2-D electric current distribution as

$$\vec{J}(\vec{R'}) = \hat{x}J_x + \hat{y}J_y \qquad (2)$$

which is actually mounted on a anisotropic slab, as shown in Fig.1. In the case, the electrical field produced by the electric current distribution $\vec{J}(\vec{R'})$, can be expressed (whereas and subseq-uentlly a time dependence, $e^{-j\omega t}$, has been assumed) as follows: Where $\overline{\overline{G}}(\vec{R},\vec{R}')$ is the electrical field dyadic Green's function for electric current sources. If $\vec{J}(\vec{R'})$ spreads over a finite planar region s', then the electrical field can be can be calculated by the following surface integral :

$$E(R) = -j\omega\mu_0 \iint_{s'} \overline{\overline{G}}(\vec{R},\vec{R}')\cdot\vec{J}(\vec{R}')ds' \qquad (3)$$

Now, we will define the two-dimensional Fourier transformation as follows:

$$E(x,y,z) = \frac{1}{4\pi^2}\int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E^T(k_x,k_y,z)\cdot e^{jk_x x}e^{jk_y y}dk_x dk_y \qquad (4a)$$

$$E^T(k_x,k_y,z) = \int_{-\infty}^{\infty}\int_{-\infty}^{\infty} E(x,y,z)\cdot e^{-jk_x x}e^{-jk_y y}dxdy \qquad (4b)$$

Taking the Fourier transform to the both sides of (3b), we can then rewrite (3b) in spectral domain as[10]:

$$E^T(k_x,k_y,z) = -j\omega\mu_0 \overline{\overline{G}}^T(k_x,k_y,z,z')\cdot\vec{J}^T(k_x,k_y,z) \qquad (5)$$

In the equations as above, the coordinate (x',y',z') represents the source location while the notation (x,y,z) denotes the field point. The superscript T used elsewhere in the work stands for the domain after the Fourier transform.

Using the spectral domain immittance approach[11], we can obtain the following equation after some algebraic manipulation:

$$\begin{bmatrix} E_x^T \\ G_y^T \\ G_z^T \end{bmatrix} = -j\omega\mu_0 \begin{bmatrix} G_{xx}^T & G_{xy}^T & G_{xz}^T \\ G_{yx}^T & G_{yy}^T & G_{yx}^T \\ G_{zx}^T & G_{zy}^T & G_{zz}^T \end{bmatrix} \begin{bmatrix} J_x^T \\ J_y^T \\ 0 \end{bmatrix} \qquad (6)$$

where spectral domain Green dyadic component to be used given by

$$Q_{xx}^T = -\frac{j}{\omega\varepsilon_0}\left[\frac{k_x^2\varepsilon_z k_b \sin(k_b d)}{\varepsilon_x\beta^2 T_m}D_m + \frac{k_y^2 k_0^2 \sin(k_a d)}{\beta^2 T_e}D_e\right] \qquad (6a)$$

$$Q_{xy}^{T}=-\frac{j}{\omega\varepsilon_0}\left[\frac{k_xk_y\varepsilon_zk_b\sin(k_bd)}{\varepsilon_x\beta^2T_m}D_m-\frac{k_xk_yk_0^2\sin(k_ad)}{\beta^2T_e}D_e\right] \tag{6b}$$

$$Q_{yy}^{T}=-\frac{j}{\omega\varepsilon_0}\left[\frac{k_y^2\varepsilon_zk_b\sin(k_bd)}{\varepsilon_x\beta^2T_m}D_m+\frac{k_x^2k_0^2\sin(k_ad)}{\beta^2T_e}D_e\right] \tag{6c}$$

$$Q_{xy}^{T}=Q_{yx}^{T} \tag{6d}$$

$$Q_{xz}^{T}=Q_{yz}^{T}=Q_{zz}^{T}=0 \tag{6e}$$

where

$$T_e=\varepsilon_x\cos(k_bt)[\varepsilon_zk_1\cos(k_bt)+jk_b\sin(k_bd)]+j\varepsilon_z\sin(k_bt)\left[\frac{\varepsilon_z}{\varepsilon_x}k_b\cos(k_bd)+j\frac{\varepsilon_xk_bk_1}{k_b}\sin(k_bd)\right]$$

$$T_e=\cos(k_1t)[k_a\cos(k_at)+jk_1\sin(k_ad)]+$$

$$D_m=\varepsilon_zk_b\cos(k_1t)\sin(k_bt)+\varepsilon_x\varepsilon_zk_1\sin(k_1t)\sin(k_bt)$$

$$D_e=k_1\cos(k_1t)\sin(k_bd)+k_a\sin(k_bd)\sin(k_1t)$$

$$k_0^2=\omega\mu_0\varepsilon_0,\quad k_a^2=\varepsilon_xk_0^2-\beta^2,\quad k_b^2=\varepsilon_xk_0^2-\varepsilon_x\beta^2/\varepsilon_z$$

By applying the Gerlerkin's Moment method the electric field integral equation has been discretized into a compact matrix equation written as:

$$\begin{bmatrix}(Z_{kn}^{xx})_{N\times N} & (Z_{km}^{xy})_{N\times M}\\ (Z_{kn}^{yx})_{M\times N} & (Z_{kn}^{yy})_{M\times M}\end{bmatrix}\begin{bmatrix}(I_{xn})_{N\times 1}\\ (I_{yn})_{M\times 1}\end{bmatrix}=\begin{bmatrix}V_{xn}\\ V_{ym}\end{bmatrix} \tag{7}$$

where

$$Z_{mn}=\int\vec{J}_m\cdot\vec{E}_nds=\frac{jZ_0}{4\pi^2k_0^2}\iint F_m^*\cdot Q^T\cdot F_ndk_xdk_y$$

Since the resonant frequencies are defined to be the frequency at which the fields and the current can sustain themselves without a driving source, i.e. V_{xn} and V_{yn} in are vanished. Therefore, for the existence of nontrivial solutions, the determinant of the [Z] matrix must be zero.

3. Numerical result.

The basis function $\vec{J}_{xn}$ and $\vec{J}_{ym}$ for the following numerical calculations are selected to be sinusoidal function as:

$$\vec{J}_{xn}=x\sin\left[\frac{p\pi}{a}(x+\frac{a}{2})\right]\cos\left[\frac{q\pi}{b}(y+\frac{b}{2})\right] \tag{8a}$$

$$\vec{J}_{xn}=x\sin\left[\frac{p\pi}{a}(x+\frac{a}{2})\right]\cos\left[\frac{q\pi}{b}(y+\frac{b}{2})\right] \tag{8b}$$

The combination of p, q, r and s depends on the mode numbers n and m. So we have to carry out numerically calculation equation (7) using Gaussian quadrature and the transformation of the polar coordination system.

For a patch on a single anisotropic substrate(t=0) the resonant frequency is shown in Fig.2, plotted versus anisotropy. Note that the result for the isotropic case (ε_x=ε_z=2.3) agrees very well with the one given by Itoh and Menzel[2].

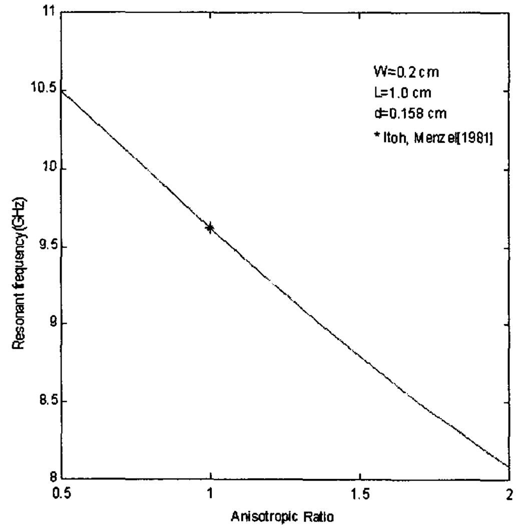


Fig.2. The resonant frequency versus anisotropy ratio for a patch antenna on a single layer(ε_x=ε_z=2.3)

For rectangular patch on a single substrate with an airgap, the resonant frequency is shown in Fig.3, plotted versus airgap length. Note that the result for the isotropic case(ε_x=ε_z=2.35) agrees very well with the one given by Wong[8]. Also, positive uniaxial substrate(ε_x==1.88, ε_z=2.35) and negative uniaxial substrate(ε_x=2.82 ε_z=2.35 represents Fig.3. It is found that resonant frequency is shifted to higher frequencies for the positive uniaxial case and, on the other hand, is shifted to lower frequencies for the negative uniaxial case. In Fig.5 the resonant frequency is plotted versus patch length for three different values of anisotropy for patch.

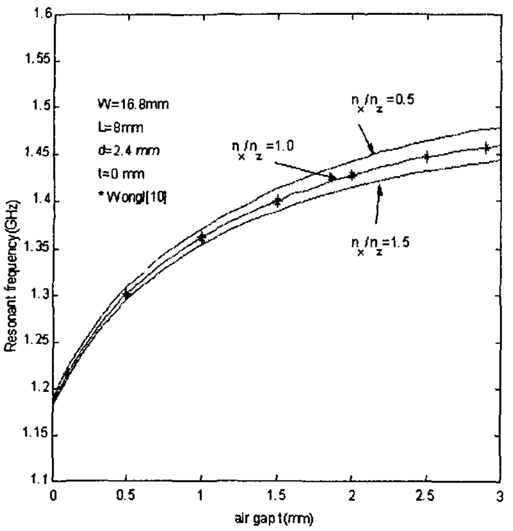


Fig. 4. The resonant frequency of the complex resonant for the microstrip structure

Note also that for a patch length of 5mm, anisotropy ratio is decreased from 0.5 to 1.5, the resonant frequency decreases from 14.55GHz to 18.44GHz

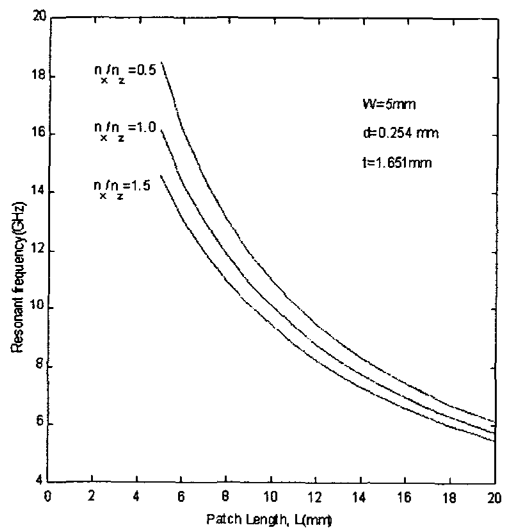


Fig. 4. The resonant frequency versus patch length for three values of anisotropy ratio

4. Conclusion

The effect of dielectric anisotropy on the resonant frequency of a rectangular microstrip patch with an airgap has been studied. Both full-wave analysis and the spectral domain immittance approach have been used to derive the matrix for the patch, from which the resonant frequency have been determined. Numerical results for the resonant frequency have been presented for a patch with an airgap.

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