Radiation Pattern of Circular Disc Antenna Printed on Isotropic or Uniaxially Anisotropic Substrate

Siham BENKOUDA, Sami BEDRA,
Electronics Department, University of Batna.
Batna 05000, ALGERIA.
bedra_sami@yahoo.fr

Imad BENACER, and Tarek FORTAKI
Electronics Department, University of Batna.
Batna 05000, ALGERIA.
t_fortaki@yahoo.fr

***Abstract*— in this work, the influence of uniaxial anisotropy in the substrate on radiation pattern of circular microstrip antenna is investigated theoretically. The analysis approach is based on the spectral-domain method of moments in conjunction with the stationary phase method. A new concise expression is derived for computing the radiation electric field. The validity of the solution is tested by comparing the computed results with the experimental data. Finally, numerical results of the variations of resonant frequency, bandwidth and radiation patterns of the structure for high order mode, with respect to anisotropy ratio of the substrate, for several values of substrate thickness and patch radius are also presented.**

Keywords-Circular-disk patch, galerkin approach, uniaxial anisotropic substrate, stationary phase method.

I. INTRODUCTION

Circular microstrip patch antenna has been found to be more advantageous with respect to other well-known patch antenna types due to its easy adaptability to circular polarization and wideband operations having smaller patch sizes. Thus it has been preferred in mobile and satellite communication applications [1].

Various designs and formulations of circular disk microstrip antenna structure having single patch or their arrays on isotropic layers have been presented in the literature [2]

With the increasing complexity of geometry and material property, designing these antennas requires more and more dedicated and sophisticated computer-aided-design (CAD) tools to predict the characteristics.

The method of moments (MoM) has been proven to be one of the most powerful CAD tools for solving this class of problems. Especially the effects of uniaxial type anisotropy on the resonant characteristics of circular-disk microstrip antenna have been investigated [1, 3-4] due to availability of this type of substances such as Sapphire, Boron Nitride and Epsilam-10.

In a very recent study [2, 5-6], resonant frequencies of circular microstrip resonators on the uniaxial dielectric and also some other media types are determined depending on the full-wave analysis. However, the effects of uniaxial anisotropy on radiation the resonant frequency and the bandwidth characteristics of a circular patch microstrip antenna for different structural parameter cases have not been included in literature.

In this contribution, our attention is to show and observe the effects of uniaxial anisotropic substrate on radiation pattern, the resonant frequency and half-bandwidth of a microstrip antenna.

The paper is organized as follows. In Section II, using a matrix representation of the dielectric anisotropic layer, a new approach to derive the dyadic Green's function of the problem is proposed. Although a single-layer microstrip antenna is considered in this paper, we show that it is quite straightforward to extend the analysis presented to structures involving stratified substrates, which are characterized by permittivity tensors. In Section III, the validity of the solution is tested by comparing the computed results with previously published data. The effects of the permittivity variation on the operating frequency are also investigated in Section III. Finally, concluding remarks are summarized in Section IV.

II. FORMULATION OF THE PROBLEM

The patch is assumed to be located on a grounded dielectric slab of infinite extent, and the ground plane is assumed to be perfect electric conductor, the circular patch with radius a and is embedded in a single substrate, which has a uniform thickness of d (see Fig.1), all the dielectric materials are assumed to be nonmagnetic with permeability μ_0. To simplify the analysis, the antenna feed will not be considered.

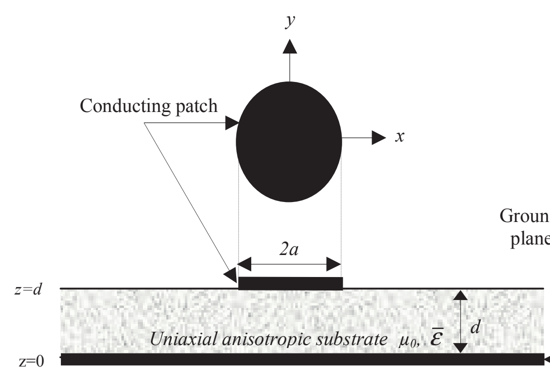


Figure 1. Geometry of circular-disk microstrip antenna.

The study of anisotropic substrates is of interest, however, the designers should, carefully check for the anisotropic effects in the substrate material with which they will work, and evaluate the effects of anisotropy.

Anisotropy is defined as the substrate dielectric constant on the orientation of the applied electric field. Mathematically, the permittivity of a uniaxial anisotropic substrate can be represented by a tensor or dyadic of this form [7].

$$\varepsilon = \varepsilon_0 \begin{bmatrix} \varepsilon_x & 0 & 0 \\ 0 & \varepsilon_x & 0 \\ 0 & 0 & \varepsilon_z \end{bmatrix} \tag{1}$$

ε_0 is the free-space permittivity. ε_x is the relative permittivity in the direction perpendicular to the optical axis. ε_z is the relative permittivity in the direction of the optical axis.

Many substrate materials used for printed circuit antenna exhibit dielectric anisotropy, especially uniaxial anisotropy [7].

In the following, the substrate material is taken to be isotropic or uniaxially anisotropic with the optical axis normal to the patch.

$$E(\rho,\phi,z) = \begin{bmatrix} E_\rho(\rho,\phi,z) \\ E_\phi(\rho,\phi,z) \end{bmatrix} = \sum_{n=-\infty}^{n=+\infty} e^{in\phi} \int_0^\infty k_\rho dk_\rho \overline{H}_n(\rho k_\rho).e_n(k_\rho,z) \tag{2}$$

$$H(\rho,\phi,z) = \begin{bmatrix} H_\phi(\rho,\phi,z) \\ -H_\rho(\rho,\phi,z) \end{bmatrix} = \sum_{n=-\infty}^{n=+\infty} e^{in\phi} \int_0^\infty k_\rho dk_\rho \overline{H}_n(\rho k_\rho).h_n(k_\rho,z) \tag{3}$$

The relation which connects the current $K_n(k_\rho)$ on the conducting plate with the electric field in the interface corresponding:

$$e_n(k_\rho,z) = \overline{G}(k_\rho).K_n(k_\rho) \tag{4}$$

Where $\overline{G}(k_\rho)$ is the dyadic function of Green in the field of the vectorial transforms of Hankel [7-9]. The dyadic function of Green is factorized in a diagonal matrix, having always the same form and independent of the geometry of the radiant plate.

We determined the tensor of Green for the structures considered. The tangential field electric is null on the conducting plate, which leads to an integral equation. To solve the integral equation, one applied the procedure of Galerkin which consists in developing the unknown distribution of the current on the circular patch in series of basis functions [3, 7] exit of the model of the cavity. Boundary conditions require that the transverse components of the electric field vanish on the perfectly conducting disk and the current vanishes off the disk, to give the following set of vector dual integral equations:

$$E_n(\rho,z) = \int_0^{+\infty} dk_\rho k_\rho \overline{H}_n(k_\rho \rho).\overline{G}(k_\rho).k_n(k_\rho) = 0, \quad \rho < a \tag{5}$$

$$K_n(\rho) = \int_0^{+\infty} dk_\rho k_\rho \overline{H}_n(k_\rho \rho).k_n(k_\rho) = 0, \quad \rho > a \tag{6}$$

The use of the method of the moments in the spectral field allowed the resolution of the system of dual integral equations. The method of the moments (procedure of Galerkin) allows the decomposition of the solution of an integral equation, according to a development of basis function, which is expressed in the form of a series of functions as follows:

$$K_n(\rho) = \sum_{p=1}^{P} a_{np} \Psi_{np}(\rho) + \sum_{q=1}^{Q} b_{nq} \Phi_{nq}(\rho) \tag{7}$$

P and Q correspond to the number of basis functions of $\Psi_{np}(\rho)$ and $\Phi_{nq}(\rho)$, respectively, a_{np} and b_{nq} are the mode expansion coefficients to be sought. The corresponding VHT of the current is given by

$$K_n(\rho) = \sum_{p=1}^{P} a_{np} \Psi_{np}(\rho) + \sum_{q=1}^{Q} b_{nq} \Phi_{nq}(\rho) \tag{8}$$

Substitute the current expansion (8) into (5). Next, multiplying this one by $\rho\Psi^{+}{}_{nk}(\rho)$ (k=1,2..., P) and by $\rho\Phi^{+}{}_{nl}(\rho)$ (l=1,2...,Q), and while integrating from 0 to a, and using the Parseval's theorem for the vectorial transforms of Hankel [7], we obtain a system of linear P+Q algebraic equations for each mode n which can be written in the matrix form:

$$\overline{Z}_n.C_n = 0 \tag{9}$$

where:

$$\overline{Z}_n = \begin{bmatrix} (\overline{Z}_n^{\Psi\Psi}{}_n)_{P\times P} & (\overline{Z}_n^{\Psi\Phi})_{P\times Q} \\ (\overline{Z}_n^{\Phi\Psi}{}_n)_{Q\times P} & (\overline{Z}_n^{\Phi\Phi}{}_n)_{Q\times Q} \end{bmatrix}, \qquad c_n = \begin{bmatrix} (a_n)_{p\times 1} \\ (b_n)_{q\times 1} \end{bmatrix} \tag{10}$$

Each element of under matrix is given by:

$$\overline{Z}_n^{VW}(i,j) = \int_0^{+\infty} dk\rho V_{ni}^{+}(k_\rho).\overline{G}(k_\rho).W_{nj}(k_\rho) \tag{11}$$

where V and W represent either Ψ or Φ. For every value of the integer n, the system of linear equations (9) has non-trivial solutions when

$$\det\left[\overline{Z}_n(\omega)\right] = 0 \tag{12}$$

This equation (12) is called characteristic equation. For the research of the complex roots of this equation, the method of Müller is used. It requires three initial points which must be closer if possible to the solution sought to ensure a fast convergence.

Generally the real part (f_r) of the solution represents the frequency of resonance of the structure, the imaginary part (f_i) indicates the losses of energy per radiation and the report ($2f_i/f_r$) gives the band-width and the quantities $Q=(f_r/2f_i)$ indicated the factor of quality [7].

III. NUMERICAL RESULTS AND DISCUSSION

In order to confirm the computation accuracy of the approach described in the previous section, Table 1 shows the results for the resonant frequencies and bandwidth of the different resonant modes of circular microstrip antenna on isotropic substrate have been compared with previously published results [3].

TABLE I. COMPARISON OF RESONANT FREQUENCIES OF THE FIRST FOUR MODES OF A CIRCULAR MICROSTRIP ANTENNA ON A DIELECTRIC SUBSTRATE (*a* =7.9375 *mm*, $\varepsilon_x = \varepsilon_z = 2.65$, *d* = 1.5875 *mm*).

Modes	Results of [3]		Our Results	
	Resonant frequency f_r (GHz)	***Bandwidth BW (%)***	***Resonant frequency f_r (GHz)***	***Bandwidth BW (%)***
TM^{11}	6 1703	5.23	6.22	5.27
TM^{12}	17.056	9.69	17.27	9.74
TM^{21}	10.401	5.13	10.48	5.16
TM^{01}	12.268	11.06	12.37	11.13

Fig. 2 depicts that the variation of dominant mode resonant frequency with the variation of patch radius (*a/h*). The antenna parameters for this studies are *d=0.49mm*, $\varepsilon_r = 2.43$. Here we have compared our computed values with the measurements done by [3]. This plot indicates that the present model shows excellent agreements with the measurements for all values of patch radius.

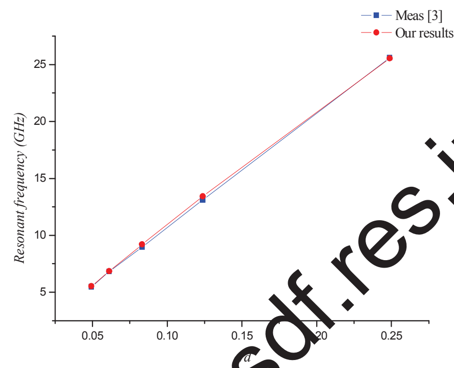


Figure 2. Theoretical and experimental variation of dominant mode resonant frequency as a function of patch radius (a/d), parameters as in Table 1.

Next the effect of uniaxial anisotropy on the resonant frequency, bandwidth and radiation pattern of the structure is analyzed.

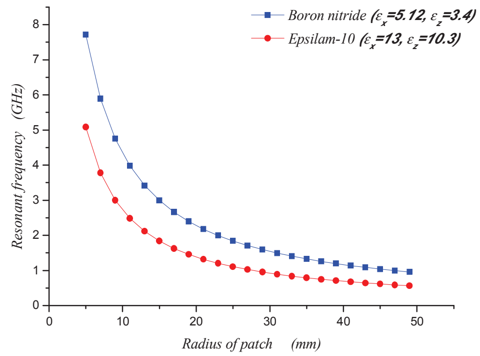
The anisotropy ratio is defined as

$$AR = \varepsilon_x / \varepsilon_z \tag{13}$$

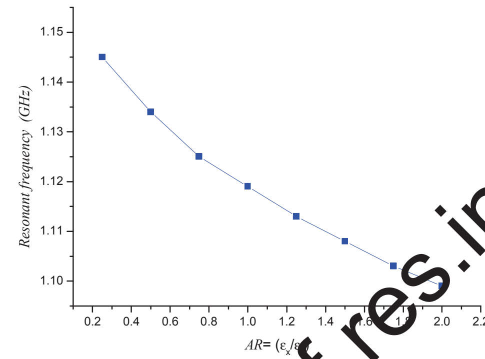
It is clear that anisotropy ratio take the value of '1' for the isotropic case. In this study AR>1 type uniaxial anisotropy is called as positive anisotropy and AR<1 case is called as negative uniaxial anisotropy, it is clear that anisotropy ratio take the value of '1' for the isotropic case [1].

Fig. 3(a) depicts the influence of the patch radius on the resonant frequency of a circular microstrip antenna for two anisotropic dielectric substrates: Boron nitride $(\varepsilon_x = 5.12, \varepsilon_z = 3.4)$, Epsilam-10 $(\varepsilon_x = 13, \varepsilon_z = 10.3)$. The substrate has thickness *d*=1.27mm and the radius patch is varied from 5mm to 50mm. As it can be seen, the resonant frequencies reduce considerably when the dielectric substrates change from Boron nitride to Epsilam-10. Also it observed that the resonant frequency increases with the patch radius. The effect of uniaxial anisotropic substrate on the bandwidth of circular microstrip antenna is also studied. The results in Fig. 3(b) present the variation of antenna bandwidth with two anisotropic dielectric substrates: Boron nitride and Epsilam-10.

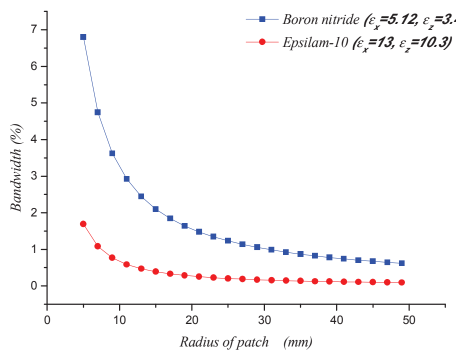
In Fig. 4(a), the resonant frequency decreases with increasing anisotropy ratio, whereas in Fig. 5(a), the resonant frequency increases with increasing anisotropy ratio.



(a)



(a)



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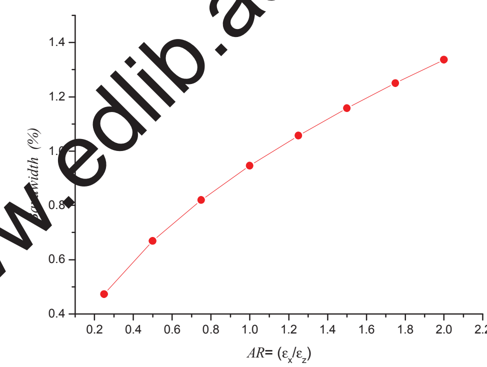


(b)

Figure 3. (a) Resonant frequency, (b) Bandwidth of circular microstrip antenna, versus radius patch and for two anisotropic dielectric materials, with substrate thickness, d=1.27mm.

The reason for this apparent contradiction is that in Fig. 4(a) ε_x is varied, so that the resonant frequency increases as ε_x decreases. In Fig. 5(a), ε_z is varied, so that the resonant frequency increases as ε_z decreases.

Therefore, in both cases, as the permittivity being changed decreases, the resonant frequency increases.

In Fig. 4(b) and 5(b) the variation of antenna bandwidth with respect to anisotropy ratio is shown. It is observed that in order to increase the bandwidth to achieve wider bandwidths, anisotropy ratio ($AR = \varepsilon_x / \varepsilon_z$) must be more than unity. Using an anisotropy ratio less than one leads to a high bandwidth suitable for resonator design.

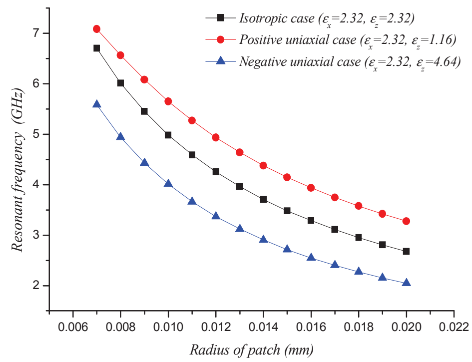
In Fig. 7, the radiation pattern of the TM11 mode in the E plane (*y-z* plane Fig. 7(a)) and in the H plane (*x-y* plane Fig. 7(b)), as a function of anisotropic dielectric substrate, are shown.

Figure 4. (a) Resonant frequency, (b) Bandwidth of circular microstrip antenna, versus anisotropy ratio, for different ε_x , a=50mm,ε_z=2.32, and d=1.27mm.

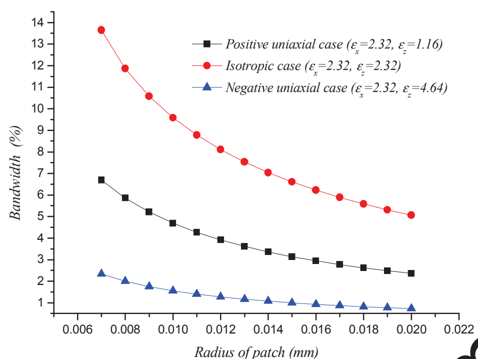
It is observed that when the circular patch is supported by Boron nitride and Epsilam-10 substrates, the antenna exhibits an increase in the directivity.

In Fig. 7 we compares the radiation patterns obtained for a circular disk microstrip antenna on uniaxial substrates with two different values of anisotropy ratio of 0.5 and 2. It is observed that the directivity of the antenna with greater value of anisotropy ratio is more than the smaller one.

This treatment has physical agreement with the results obtained in Fig. 4(a). We saw in Fig. 4(a) that the greater anisotropy ratio the greater resonant frequency and of course the smaller operating wavelength. Concerning that the patch size is frozen, the ratio of patch size to wavelength will be greater and accordingly we get greater directivity.

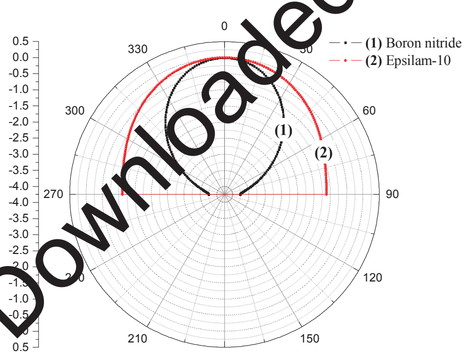


(a)

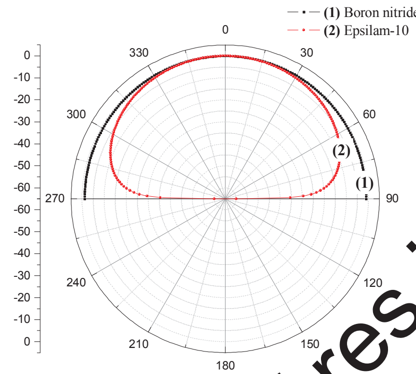


(b)

Figure 5. (a) Resonant frequency, (b) Bandwidth of circular microstrip antenna, versus patch radius, for different anisotropic dielectric substrates with substrate thickness, d=1.27mm.



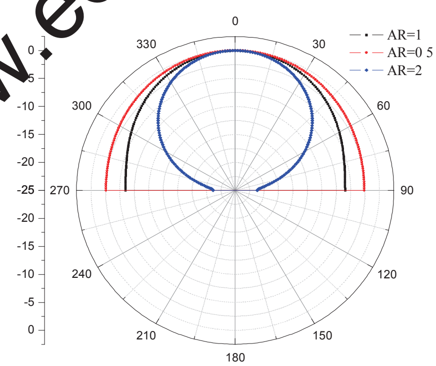
(a)



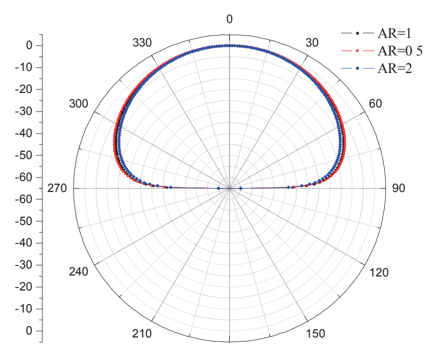
(b)

Figure 6. Radiation patterns of the fundamental resonant mode of a circular disk microstrip antenna on uniaxial substrate for two different dielectric substrate materials, h=1.27mm, a=10mm. (a) E plane, (b) H plane.

We also observe that the permittivity ε_z has a stronger effect on the radiation than the permittivity ε_x.



(a)



(b)

Figure 7. Radiation patterns of circular disk microstrip antenna on uniaxial substrate for two different values of anisotropy ratio, h=1.27mm, a=10mm. (a) E plane, (b) H plane.

The radiation pattern of an antenna becomes more directional as its ε_z increases. Another useful parameter describing the performance of an antenna is the gain.

IV. CONCLUSION

This work presents a full-wave analysis for the circular microstrip antenna printed on isotropic or uniaxial anisotropic media. The complex resonant frequency problem of structure is formulated in terms of an integral equation. Galerkin procedure is used in the resolution of the electric field integral equation, also the TM, TE waves are naturally separated in the Green's function.

Numerical results concerning the effect of isotropic substrate on the characteristics of the antenna are presented. The effects of a uniaxial substrate on the resonant frequency and radiation pattern of structures are considered in detail. It was found that the use of such substrates significantly affects the characterization of the microstrip antennas, and the permittivity ε_z along the optical axis has a stronger effect on the radiation of antenna. A comparative study between our results and those available in the literature shows a very good agreement. The accuracy of the method was checked by performing a set of results in terms of resonant frequencies and radiation patterns.

The analysis presented here can also be extended to study other parameters characterizing the circular patch antennas with various structures.

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