ELEKTRİK, VOL.1, NO.3, October 1993, ©TÜBİTAK EMO

Dielectric Coated Vertically Magnetized Ferrite Slab for Electronically Scanning Mm-Wave Antennas

Özlem AYDIN, Altunkan HIZAL
Electrical and Electronics Engineering Dept.
Middle East Technical University
Ankara, 06531 TURKEY
e-mail: a11060@trmetu.bitnet

Abstract

In this paper, radiation characteristics of dipole sources located in a grounded and perpendicularly magnetized ferrite slab are investigated. Beam scanning at millimeter-wave frequencies is obtained by varying a DC magnetic field at suitable conditions. The problem is formulated in the form of transversal field equations with respect to the direction of the DC magnetic filed. The asymmetrical coupled transmission line representation is used to solve the Fourier transformed transversal field equations in the ferrite slab. Far fields are evaluated using the method of steepest descent. This method can easily be applied to radiation problems in stratified anisotropic and isotropic media, which are magnetized perpendicularly. Radiation patterns of an Hertzian magnetic dipole in a grounded ferrite slab are obtained at 22-35 GHz. Effects of the magnitude of the DC bias field, the thickness of the ferrite slab, and the frequency on radiation patterns are examined. It is observed that approximately ± 35 degrees continuous beam steering can be obtained by varying the DC bias field.

Keywords: *Propagation in anisotropic media, ferrite loaded antennas.*

1. Introduction

In recent years, electronically scanning antennas are widely used in various applications, especially in millimeter-wave radars, since mechanically scanned millimeter-wave radar antennas lack the rapid scanning capability. This paper, deals with the radiation from dipole sources in a transversely unbounded, perpendicularly magnetized ferrite slab on a ground plane. It is shown that, this structure has a beam steering feature controlled by an applied DC magnetic field at millimeter-wave frequencies.

Ferrite materials have been used in a large number of microwave devices for many years, but only recently they have been considered for use with planar antenna systems. When a large, constant and uniform magnetic field is applied to a ferrite slab, it exhibits tensor permeability. This enables control of various radiation characteristics of the antenna by adjusting an externally applied DC magnetic field.

The electromagnetic waves radiated by dipoles in an infinitely extended gyrotropic medium have been examined by many authors, [1]-[4]. There have been some solutions to the radiation problems of sources in stratified systems with anisotropic media, [5]-[10]. In [7], fourth order partial differential equations have been obtained from Maxwell equations, but this procedure is complex and numerically difficult to handle. As an alternative approach, Fourier transformed matrix method has been used in [8]. In this method transversal field components are evaluated using complex matrices. In both papers, electromagnetic fields are obtained using the method of moments (Galerkin approach). In [9] and [10], to obtain Green's function, Maxwell's equations are arranged into a compact matrix form in the spectral domain and are solved in terms of exponential matrix functions characteristic of each region. The same procedure is modified so that isotropic layers can also be included in the analysis, [11]. These methods are cumbersome and lengthy. However, circuit modelling based on transverse equivalent transmission line modelling [12] is a more systematic approach and is straightforwardly adaptable to computer aided analysis for such layered structures. Furthermore, it gives a physical insight into the radiation problem. It also seems that matching of the field at the interfaces and at the source could more easily be achieved by the network procedure presented in this paper.

Equivalent transmission line formulation has been applied only to isotropic multilayer structures to find spectral domain Green's function, [12], [13]. In this paper, using the formulation given in Section 2, the solution of Maxwell field equations in stratified media including perpendicularly magnetized anisotropic media has been reduced to the solution of asymmetric coupled transmission line equations in anisotropic media, subject to the required continuity conditions at the interfaces and to the specified boundary conditions. First, far fields of an infinitesimally small magnetic dipole positioned in a grounded ferrite slab are evaluated asymptotically by the method of steepest descent. Radiation patterns are presented in Section 3.1, at different frequencies. Then, the results are generalized for the two layer structure in Section 3.2. Dependence of patterns on DC magnetic field, thickness of the ferrite slab and frequency are examined.

2. Formulation

The geometry of the problem under investigation is shown in Figure 1. The ferrite slab with thickness d is placed on a perfect conductor. The structure is assumed to be infinite in the transverse direction. An external, uniform DC magnetic field B_0 is applied to the slab perpendicularly. The source is an infinitesimally small magnetic dipole at $z = z'$. The free space extends beyond the ferrite slab to infinity. Sinusoidal excitation and lossless media are assumed throughout the analysis.

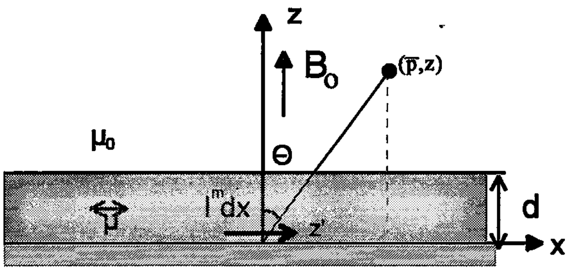

Figure 1. Physical structure of the problem for an excitation by an Hertzian magnetic dipole

Ferrite medium in the presence of a steady external magnetic field B_0 along the z-axis can be characterized by a scalar permittivity ϵ and a tensor permeability

$$\overleftrightarrow{\mu} = \overleftrightarrow{\mu}_t + \hat{z}\hat{z}\mu_o, \tag{1a}$$

$$\overleftrightarrow{\mu_t} = \mu_o \begin{bmatrix} 1+\chi & j\kappa \\ -j\kappa & 1+\chi \end{bmatrix}, \tag{1b}$$

where

$$\chi = \frac{\omega_0 \omega_m}{\omega_0^2 - \omega^2}, \quad \kappa = \frac{\omega \omega_m}{\omega_0^2 - \omega^2}, \quad \omega_m = \gamma \mu_0 M_s, \quad \omega_0 = \gamma B_o, \tag{1c}$$

where M_s is the saturation magnetization constant of the ferrite, ω is the angular applied frequency, γ is the gyromagnetic ratio (ratio of the magnetic moment to the angular momentum), ω_o (resonance frequency of a ferrite) is the vector precession angular velocity directed along B_0, [14].

Maxwell's equations in ferrite media in the presence of both electric current $\vec{J}$ and magnetic current $\vec{M}$ sources are

$$\vec{\nabla} \times \vec{E} = -j\omega(\overleftrightarrow{\mu} \bullet \overleftrightarrow{H}) - \vec{M}, \tag{2a}$$

$$\vec{\nabla} \times \vec{H} = j\omega\epsilon \vec{E} + \vec{J}\ . \tag{2b}$$

By taking scalar and vector products of (2) with the unit vector $\hat{z}$, following equations for the transverse (to z) field components are obtained

$$-\frac{\partial}{\partial z} \vec{E_t} = j\omega\mu_0 \left(\frac{\overleftrightarrow{\mu_t}}{\mu_0} + \frac{\vec{\nabla}_t \vec{\nabla}_t}{k^2} \right) \bullet (\vec{H_t} \times \hat{z}) + \vec{M_{te}} \times \hat{z}, \tag{3a}$$

$$-\frac{\partial}{\partial z} \vec{H_t} = j\omega\epsilon \left(\overleftrightarrow{1_t} + \frac{\vec{\nabla}_t \vec{\nabla}_t}{k^2} \right) \bullet (\hat{z} \times \vec{E_t}) + \hat{z} \times \vec{J_{te}} \tag{3b}$$

where

$$k_0^2 = \omega^2 \mu_0 \epsilon_0, \quad k^2 = k_0^2 \epsilon_r \tag{3c}$$

and $\overleftrightarrow{1_t}$ represents the transverse unit dyadic and

$$\vec{M_{te}} \times \hat{z} = \vec{M_t} \times \hat{z} + \frac{1}{j\omega\epsilon} \vec{\nabla_t} J_z, \tag{3d}$$

$$\hat{z} \times \vec{J_{te}} = \frac{1}{j\omega\mu_0} \vec{M_t}\, M_z + \hat{z} \times \vec{J_t}\ . \tag{3e}$$

Longitudinal (z) components in terms of the tangential fields and excitation sources are

$$E_z = \frac{1}{j\omega\epsilon} \left(\vec{\nabla}_t \times \vec{H_t} \bullet \hat{z} - J_z \right), \tag{4a}$$

$$H_z = -\frac{1}{j\omega\mu_0} \left(\vec{\nabla}_t \times \vec{E_t} \bullet \hat{z} + M_z \right). \tag{4b}$$

Two dimensional Fourier transformation

$$\tilde{E}(\vec{k_t}, z) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} \vec{E_t}\,(\rho, z) e^{j\vec{k_t} \bullet \vec{\rho}} d\rho, \tag{5a}$$

$$\vec{k_t} = k_x \hat{x} + k_y \hat{y}, \quad \vec{\rho} = x\hat{x} + y\hat{y}, \tag{5b}$$

is applied to equations (3.a) and (3.b) to derive the following linear differential equation system:

$$-\frac{\partial}{\partial z}\tilde{E}_t = j\omega\mu_0 \left(\frac{\overleftrightarrow{\mu_t}}{\mu_0} - \frac{\vec{k}_t\vec{k}_t}{k^2} \right) \bullet (\tilde{H}_t \times \hat{z}) + \tilde{M}_{te} \times \hat{z}, \tag{6a}$$

$$-\frac{\partial}{\partial z}\tilde{H}_t = j\omega\epsilon \left(\overleftrightarrow{1}_t - \frac{\vec{k}_t\vec{k}_t}{k_2} \right) \bullet (\hat{z} \times \tilde{E}_t) + \hat{z} \times \tilde{J}_{te}. \tag{6b}$$

We can represent transverse electromagnetic fields as a superposition of orthogonal transverse vector mode fields, by decomposing $\tilde{E}_t, \tilde{H}_t, \tilde{J}_{te}$ and $\tilde{M}_{te}$ into $\hat{k}_t$ and $\hat{k}_t \times \hat{z}$ components

$$\tilde{E}_t = E'\hat{k}_t + E''(\hat{k}_t \times \hat{z}), \tag{7a}$$

$$\tilde{H}_t = H'(\hat{z} \times \hat{k}_t) + H''\hat{k}_t, \tag{7b}$$

$$\tilde{J}_{te} = J_e'\hat{k}_t + J_e''(\hat{k}_t \times \hat{z}), \tag{7c}$$

$$\tilde{M}_{te} = M_e'(\hat{z} \times \hat{k}_t) + M_e''\hat{k}_t. \tag{7d}$$

The above expressions (7) are substituted into set of equations given in (6) and the following transmission line type of equations are obtained

$$\frac{d}{dz}V = \begin{bmatrix} Z_1 & Z_m \\ Z_m & Z_2 \end{bmatrix} I + \begin{bmatrix} v_0' \\ v_0'' \end{bmatrix}, \tag{8a}$$

$$V = \begin{bmatrix} E' \\ E'' \end{bmatrix}, \quad I = \begin{bmatrix} -H' \\ H'' \end{bmatrix}, \tag{8b}$$

$$Z_1 = -j\omega\mu_0 \left(1 + \chi - \frac{k_t^2}{k^2} \right), \quad Z_2 = j\omega\mu_0(1+\chi), \quad Z_m = \omega\mu_0\kappa \tag{8c}$$

System of homogeneous equations for voltages on the asymmetric coupled lines are solved (e^{-jKz} variation is used for voltages and currents). Solution of the resulting eigenvalue problem leads to the propagation constants K_c and K_π which correspond to in-phase and anti-phase waves respectively

$$K_{c,\pi} = \pm\sqrt{k^2(1+\chi) - (1+\frac{\chi}{2})k_t^2 \pm \sqrt{\chi^2\frac{k_t^4}{4} + k^2\kappa^2(k^2-k_t^2)}}. \tag{9}$$

Relationships between voltages (i.e. transversal field components) are given as

$$\frac{v_2}{v_1} = -\frac{K^2+a_1}{b_1}, \frac{i_2}{i_1} = -\frac{b_1}{K^2+a_2}, \tag{10a}$$

$$a_1 = -k^2(1+\chi) + k_t^2, \tag{10b}$$

$$b_1 = j\kappa(k^2 - k_t^2), \tag{10c}$$

$$a_2 = -(1+\chi)(k^2 - k_t^2). \tag{10d}$$

Thus, perpendicularly magnetized ferrite slab can be represented by asymmetric coupled lines in the network model. However, in the isotropic case $Z_m = 0$, so free space can be modelled by transmission lines with characteristic impedances of the TE and TM modes.

Let us reconsider the geometry in Figure 1. The excitation source is an Hertzian magnetic dipole with a magnetic current distribution

$$\vec{M} = I^m dx \delta(\vec{\rho})\delta(z) \tag{11}$$

where $\delta(.)$ is Dirac's δ-function.

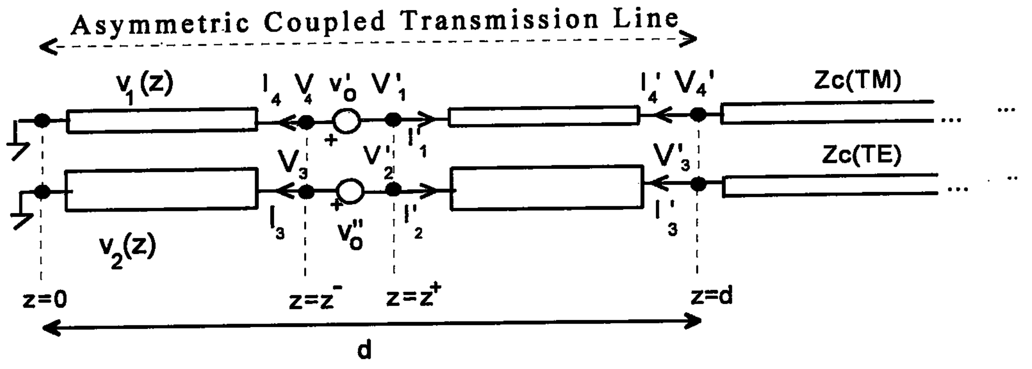

Figure 2. Associated network model of the problem

The equivalent network model of this structure is as shown in Figure 2. In the model voltage sources represent magnetic dipole with values

$$v_0' = -I^m dx \frac{k_y}{k_t}, \quad v_0'' = I^m dx \frac{k_x}{k_t}. \tag{12}$$

Using the impedance or admittance matrices of asymmetric coupled lines given in [15], fields at the ferrite-air boundary can be found in terms of excitation

$$\begin{bmatrix} v_1(d) \\ v_2(d) \end{bmatrix} = \begin{bmatrix} P'(k_t) & Q'(k_t) \\ P''(k_t) & Q''(k_t) \end{bmatrix} \begin{bmatrix} v_0' \\ v_0'' \end{bmatrix} \tag{13}$$

where P', P'', Q', Q'' are evaluated from transmission line relations [16] and are given in the Appendix.

To find the Green's function in far zone of the antenna method of steepest descent can be used [17]. This allows the far fields to be calculated directly from the Green's function

$$E_r \sim 0, \tag{14a}$$

$$E_\theta(\theta,\phi) \sim -j\frac{I^m dx}{2\pi} k_0 \frac{e^{-jk_0 r}}{r} \frac{e^{j\varphi(\theta)}}{sin\theta} \left(P'(k_t)k_y - Q'(k_t)k_x\right), \tag{14b}$$

$$E_\phi(\theta,\phi) \sim -j\frac{I^m dx}{2\pi} k_0 \frac{e^{-jk_0 r}}{r} \frac{e^{j\varphi(\theta)}}{tan\theta} \left(P''(k_t)k_y - Q''(k_t)k_x\right), \tag{14c}$$

where k_t is evaluated at the saddle point $k_t = k_0 \sin \theta$.

3. Results and Discussion

3.1. Single Ferrite Slab On A Ground Plane

Far field patterns of an Hertzian magnetic dipole antenna in a grounded ferrite slab for different parameters of ferrite are presented in this section. In the given examples the dipole is located on a ground plane so that radiation from slot antenna or other aperture type antennas mounted on a ground plane could be easily found . The orientation of the dipole is in x-direction. It is assumed that the ferrite slab is fully saturated.

As seen from (1), elements of the permeability tensor of ferrite are changed with saturation magnetization constant, the operating frequency and the applied magnetic field. Thus, radiation patterns can be controlled by changing these parameters. Due to magnetized ferrite slab, beam splitting occurs, compared to one main beam in isotropic case. Mostly beam splits into two, but as seen in Figure 5 beam splits into four when suitable conditions are met. It is observed that radiation patterns are symmetric with respect to $\theta = 0$ (z-axis). Thus, only one half of them has been plotted. The symmetry in radiation patterns is due to the fact that ferrite is magnetized perpendicularly. It is shown in [11] that for different orientations of magnetization, the symmetry does not hold.

The most important result of this analysis is that continuous beam steering occurs at millimeter-wave frequencies when the applied DC magnetic field is changed. The mechanism of scanning can be explained qualitatively by the fact that the phase velocity of the individual spectrum of plane waves making up the field, varies with the DC magnetic field.

It is seen from Figure 3 that 20 GHz antenna possesses scanning in a 35 degree angular range with a ferrite of $\mu_0 M_s = 0.3$ Tesla, and ferrite thickness $d = 7mm$ when B_0 changes from 0.07 Tesla to 0.095 Tesla. At 26.5 GHz, right beam moves from 30 to 0 degrees (while the symmetric one moves from -30 to 0 degrees) with the change of DC magnetic field from 0.04 Tesla to 0.065 Tesla, as shown in Figure 4. As seen from Figure 5, the shape of the pattern changes and the beam steers with the variation of the bias field at 35 GHz, with a ferrite slab of $\mu_0 M_s = 0.48$ Tesla and $d = 7mm$. Pattern with four beams is observed when B_0 is 0.265 Tesla, but as B_0 increases, the pattern acquires a double-lobed shape. The other effect observed in Figures 3, 4, 5 is that directivity increases with increasing B_0. Beam steering is also obtained by frequency variation. In Figure 6, for a ferrite slab of $\mu_0 M_s = 0.3$ Tesla and $d = 7mm$, beam moves from 50 (-50) to 15 (-15) degrees when frequency changes from 19.8GHz to 20.2GHz.

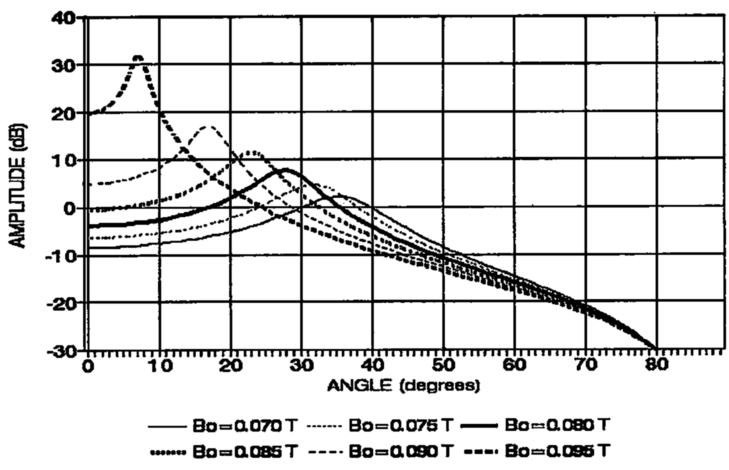

Figure 3. Radiation patterns for various B_0 at f=20GHz, d=7mm, $\mu_0 M_s = 0.3$T, ϵ_f=1

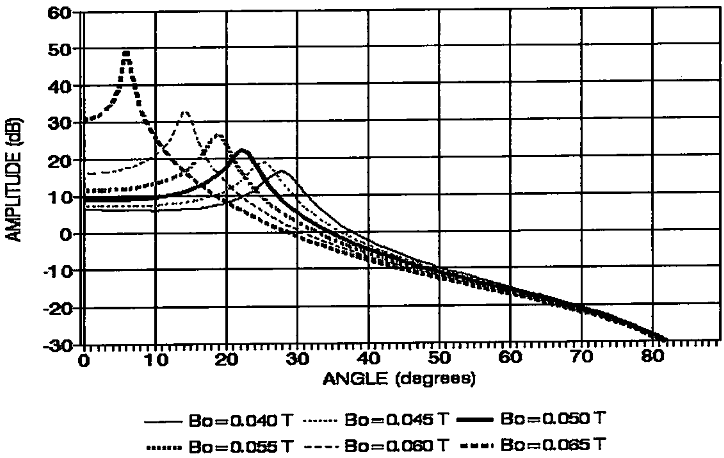

Figure 4. Radiation patterns for various B_0 at f=26.5GHz, d=8.5mm, $\mu_0 M_s$ = 0.3T, ϵ_f =14

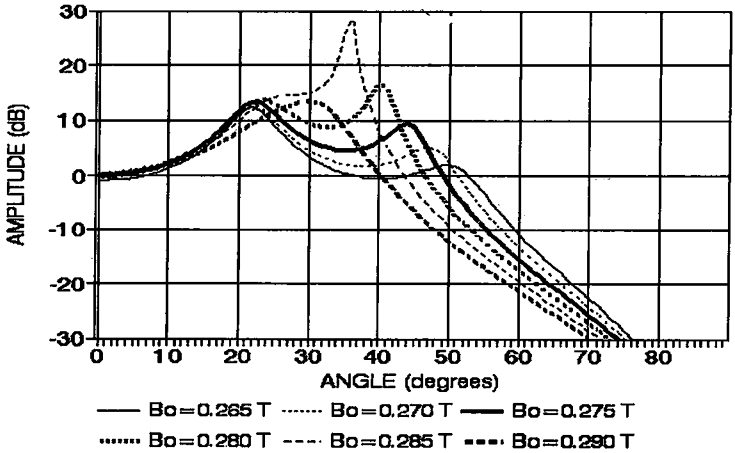

Figure 5. Radiation patterns for various B_0 at f=35GHz, d=7mm, $\mu_0 M_s$ = 0.48T, ϵ_f =1

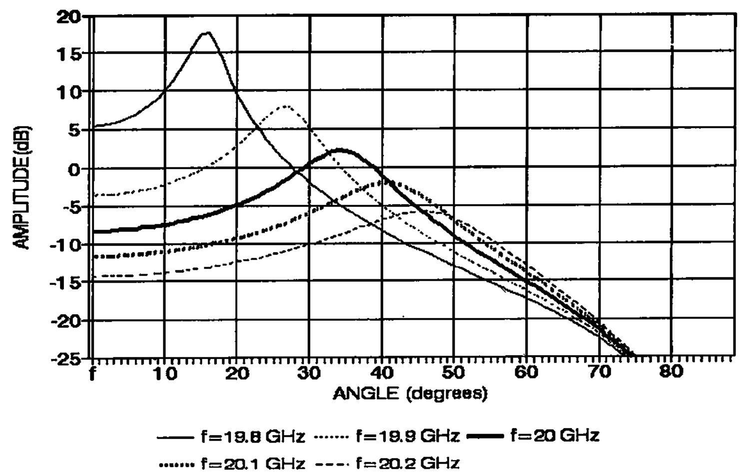

Figure 6. Radiation patterns for different frequencies when $B_0 = 0.07T$, $d = 7mm$, $\mu_0 M_s = 0.3T$, $\epsilon_f = 1$

Change in the thickness of the ferrite slab causes the movement of the beam. An example is given in Figure 7. Obviously, in order to steer the beam, changing the slab thickness is not a practical solution, but these results can be used to find the optimum thickness for the required scanning region and power considerations. Also note that, radiated power changes as the direction of the main beam changes.

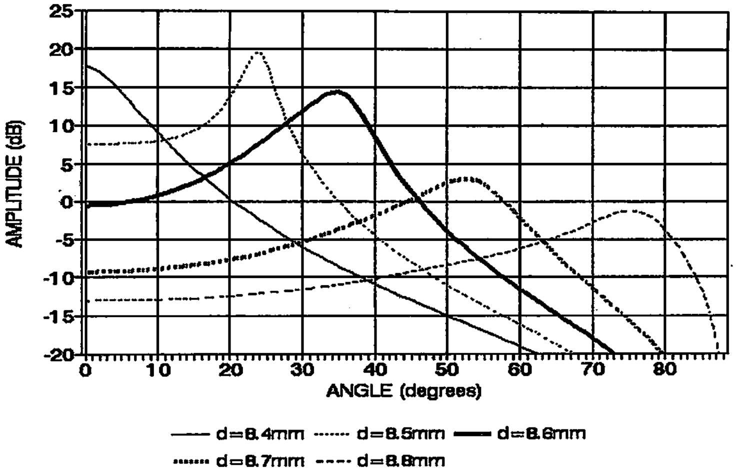

Figure 7. Radiation patterns for different d values at $f = 26.5GHz$, $B_0 = 0.046T$, $\mu_0 M_s = 0.3T$, $\epsilon_f = 1$

To operate at high frequencies, ferrites with high saturation magnetization values are required. For instance, although scanning does not occur at 35 GHz where ferrite saturation magnetization is 0.3 Tesla, it is seen from Figure 5 that the beam steers with a ferrite of saturation magnetization 0.48 Tesla. This is due to the fact that for very high frequencies, ω_0/ω can be very small and permeability cannot change significantly with B_0. However, when the ferrite saturation magnetization is large, a larger field can be applied, if possible, so that ω_0/ω is in a region where permeability varies.

Permeability of ferrite decreases with an increase in the applied DC magnetic field, [18]. Hence, phase velocity increases and refractive index decreases with an increase in bias. As a result, beams approach to the perpendicular axis when DC field gets larger. It is observed that beam steering occurs at those regions where the permeability varies most rapidly with ω_0/ω. For frequencies between 18-35 GHz beam steering is best achieved in the resonance region $(\omega_0/\omega > 1)$.

3.2. Two Layer (Dielectric-Ferrite) Structure

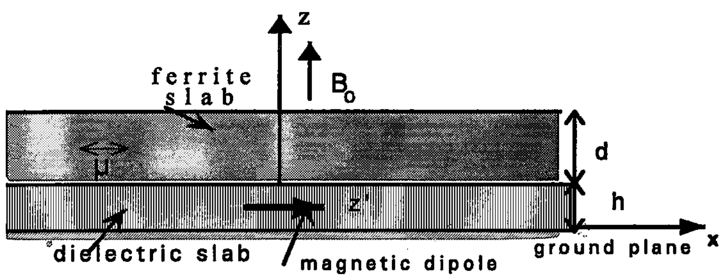

Figure 8. Dielectric-ferrite double layer structure

The method developed is used to analyze the grounded two layer (dielectric-ferrite) structure shown in Figure 8. Associated network model of this structure is shown in Figure 9. Right half of the symmetric patterns are plotted for 3 different thicknesses of dielectric layer at 26.5 GHz in Figure 10.

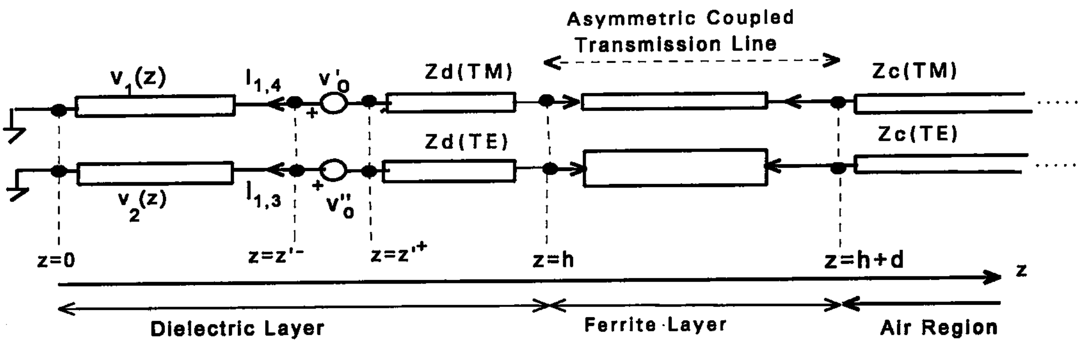

Figure 9. Network model of the structure shown in Figure 8

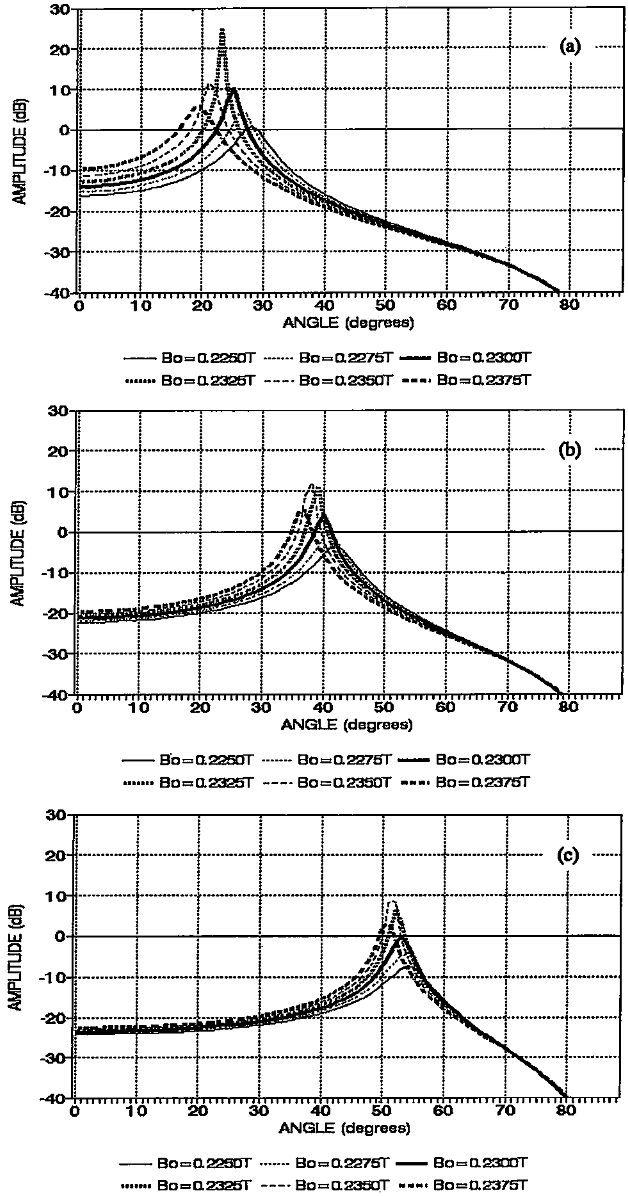

Figure 10. Radiation patterns of the double layer structure at $f = 26.5GHz$, $d = 6mm$, $\mu_0 M_s = 0.3T$, $\epsilon_f = 14$, $\epsilon_d = 2$, a) $h = 2mm$, b) $h = 2.3mm$, c) $h = 2.4mm$

Ferrite thickness of 6 mm is kept constant. It is observed that, beams move from $\theta = 30(-30)$ degrees to 20 (-20) degrees with a B_0 from 0.225 Tesla to 0.2425 Tesla when dielectric thickness is 2 mm in Figure 10.a, whereas in Figure 10.b dielectric thickness is 2.3 mm and beams steer from 45 (-45) degrees to 35 (-35) degrees with B_0 from 0.2 Tesla to 0.2175 Tesla. Increase in dielectric thickness does not affect the shape of the beam. The only effect is that different sectors can be scanned by using dielectrics with different thickness. Hence this structure provides more control on the radiation pattern and scanning of the main beam.

4. Conclusion

In this paper, a method to find the radiation of a planar source in a stratified system including perpendicularly magnetized ferrite media has been developed. For the first time in the literature, asymmetric coupled transmission line is used to represent perpendicularly magnetized ferrite slab. Network model of the layered structure with gyrotropic media is solved by using transmission line techniques.

The method has been applied to two geometries. First, far fields of a grounded ferrite slab excited by an Hertzian magnetic dipole have been evaluated. Secondly, a dielectric layer has been placed between ground and the ferrite slab to provide more control on the radiation pattern. The effects of changing applied magnetic field, frequency, and thickness of the layers have been examined. It is concluded that with such a conformal and planar antenna electronic scanning and beam shaping can be practically obtained at millimeter-wave frequencies by changing the applied DC magnetic field. Furthermore, this method can be used to analyze microstrip antennas with anisotropic slab and can be used in monolithic antenna design.

References

[1] E. Arbel and L.B. Felsen, 'Theory of radiation from sources in anisotropic media, part II: Point source in infinite, homogeneous, medium', from Symposium on Electromagnetic Theory and Antennas held in Copenhagen, edited by E.C. Jordan, pp. 421-459, 1962.

[2] H. Kogelnik and H. Motz, 'Electromagnetic radiation from sources embedded in an infinite anisotropic medium and the significance of the Poynting vector', from Symposium on Electromagnetic Theory and Antennas held in Copenhagen, edited by E.C. Jordan, pp. 477-493, 1962.

[3] R. Mittra and G. A. Deschamps, 'Field solution for a dipole in an anisotropic medium', from Symposium on Electromagnetic Theory and Antennas hed in Copenhagen, edited by E.C. Jordan, pp. 495-512, 1962.

[4] V. Daniele, 'The use of dyadic Green's functions for wave propagation in anisotropic media', Alta Frequenza, vol. 40, no.2, pp. 904-914, 1971.

[5] E. Arbel and L.B. Felsen, 'Theory of radiation from sources in anisotropic media, Part I: General sources in stratified media', from Symposium on Electromagnetic Theory and Antennas held in Copenhagen, edited by E. C. Jordan, pp. 391-420, 1962.

[6] V. Daniele and R. S. Zich, 'Radiation by arbitrary sources in anisotropic stratified media', Radio Science, vol. 1, no.8, pp. 63-70, 1973.

[7] C.M. Krowne, 'Green's function in the spectral domain for biaxial and uniaxial anisotropic planar dielectric structures', IEEE Trans. Antennas Propagat., vol.AP-32, pp. 1273-1281, December 1984.

[8] C.M. Krowne, 'Fourier transformed matrix method of finding propagation characteristics of complex anisotropic layered media', IEEE Trans. Microwave Theory Tech., vol.MTT-32, pp.1617-1625, December 1984.

[9] J.L. Tsalamengas and N.K. Uzunolu, 'Radiation from a dipole in the proximity of a general anisotropic grounded layer', IEEE Trans. Antennas Propagat., vol. AP-33, pp.165-172, February 1985.

[10] J.L. Tsalamengas, 'Electromagnetic fields of elementary dipole antennas embedded in stratified general gyrotropic media', IEEE Trans. Antennas Propagat., vol.AP-37, pp.399-403, March 1989.

[11] I.Y. Hsia and N.G. Alexopoulos, 'Radiation characteristics of Hertzian dipole antennas in a nonreciprocal superstrate-substrate structure', IEEE Trans. Antennas Propagat., vol.AP-40, pp.782-790, July 1992.

[12] T. Itoh, 'Spectral domain immitance approach for dispersion characteristics of generalized printed transmission lines', IEEE Trans. Microwave Theory Tech., vol. MTT-28, pp.733-736, July 1980.

[13] N.K. Das and D.M. Pozar, 'A generalized spectral domain Green's function for multilayer dielectric substrates with application to multilayer transmission lines', IEEE Trans. Microwave Theory Tech., vol. MTT-35, pp.326-335, March 1987.

[14] R.E. Collin, Foundations for Microwave Engineering, McGraw Hill, Singapore, 1966.

[15] V.K. Tripathi, 'Asymmetric coupled transmission lines in an inhomogeneous medium', IEEE Trans. Microwave Theory Tech., vol.MTT-23, pp.734-739, September 1991.

[16] Ö. Aydın, 'Electronic beam scanning by a vertically magnetized ferrite slab', MS Dissertation, Elec. Eng. Dept. Middle East Tech. Univ., Ankara, 1992.

[17] L.B. Felsen and N. Marcuvitz, Radiation and Scattering of Waves, Prentice Hall, New Jersey, 1973.

[18] H.M. Schlicke, Essentials of Dielectromagnetic Engineering, John Wiley & Sons, 1961.

Appendix

$P'(k_t), P''(k_t), Q'(k_t), Q''(k_t)$ are found using the asymmetric coupled transmission line equations in [15] :

$$\begin{bmatrix} Q''(k_t) & P''(k_t) \\ Q'(k_t) & P'(k_t) \end{bmatrix} = -\underline{B}(d-z') \bullet [\underline{Y}_{sc}^{-1}(z') + \underline{A}^T(d-z')]^{-1} \tag{15}$$

$$\underline{Y}_{sc}(l) = \begin{bmatrix} Y_{33} & Y_{34} \\ Y_{43} & Y_{44} \end{bmatrix} \tag{16a}$$

where

$$Y_{33} = -j\frac{Y_{cl}\cot K_c l}{R_\pi^2(1-R_c/R_\pi)} - j\frac{Y_{\pi l}\cot K_\pi l}{R_c^2(1-R_\pi/R_c)}, \tag{16b}$$

$$Y_{34} = Y_{43} = j\frac{Y_{c1}\cot K_c l}{R_\pi(1-R_c/R_\pi)} + j\frac{Y_{\pi 1}\cot K_\pi l}{R_c(1-R_\pi/R_c)}, \tag{16c}$$

$$Y_{44} = -j\frac{Y_{c1}\cot K_c l}{(1-R_c/R_\pi)} - j\frac{Y_{\pi 1}\cot K_\pi l}{(1-R_\pi/R_c)}, \tag{16d}$$

$$Y_{c1} = \frac{1}{Z_{c1}} = -\frac{\omega\epsilon}{K_c},\ Y_{\pi 1} = \frac{1}{Z_{\pi 1}} = -\frac{\omega\epsilon}{K_\pi}. \tag{16e}$$

$$\underline{A}(l)=\begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix},\ \underline{B}(l)=\begin{bmatrix} b_{11} & b_{12} \\ b_{21} & b_{22} \end{bmatrix}, \tag{17a}$$

$$a_{11}=Z_{11}-\frac{Z_{13}}{Z_c''}b_{12}-\frac{Z_{14}}{Z_c'}b_{22},\ a_{12}=Z_{12}-\frac{Z_{13}}{Z_c''}b_{11}-\frac{Z_{14}}{Z_c'}b_{21}, \tag{17b}$$

$$a_{21}=Z_{12}-\frac{Z_{23}}{Z_c''}b_{12}-\frac{Z_{13}}{Z_c'}b_{22},\ a_{22}=Z_{22}-\frac{Z_{23}}{Z_c''}b_{11}-\frac{Z_{24}}{Z_c'}b_{21}, \tag{17c}$$

$$b_{11}=\frac{1}{d}\left(Z_{23}c_1-\frac{Z_{12}Z_{13}}{Z_c'}\right),\ b_{12}=\frac{1}{d}\left(Z_{13}c_1-\frac{Z_{12}Z_{14}}{Z_c'}\right), \tag{17d}$$

$$b_{21}=\frac{1}{d}\left(Z_{13}c_2-\frac{Z_{12}Z_{23}}{Z_c''}\right),\ b_{22}=\frac{1}{d}\left(Z_{14}c_2-\frac{Z_{12}Z_{13}}{Z_c''}\right), \tag{17e}$$

$$d=c_1c_2-\frac{Z_{12}^2}{Z_c'Z_c''},\ c_1=1+\frac{Z_{11}}{Z_c'},\ c_2=1+\frac{Z_{22}}{Z_c''}, \tag{17f}$$

$$Z_{11}=-j\frac{Z_{c1}\cot K_cl}{(1-R_c/R_\pi)}-j\frac{Z_{\pi1}\cot K_\pi l}{(1-R_\pi/R_c)}, \tag{18a}$$

$$Z_{12}=-j\frac{Z_{c1}R_c\cot K_cl}{(1-R_c/R_\pi)}-j\frac{Z_{\pi1}R_\pi\cot K_\pi l}{(1-R_\pi/R_c)}, \tag{18b}$$

$$Z_{13}=-j\frac{Z_{c1}R_c}{(1-R_c/R_\pi)\sin K_cl}-j\frac{Z_{\pi1}R_\pi}{(1-R_\pi/R_c)\sin K_\pi l}, \tag{18c}$$

$$Z_{14}=-j\frac{Z_{c1}}{(1-R_c/R_\pi)\sin K_cl}-j\frac{Z_{\pi1}}{(1-R_\pi/R_c)\sin K_\pi l}, \tag{18d}$$

$$Z_{23}=-j\frac{Z_{c1}R_c^2}{(1-R_c/R_\pi)\sin K_cl}-j\frac{Z_{\pi1}R_\pi^2}{(1-R_\pi/R_c)\sin K_\pi l}, \tag{18e}$$

$$Z_{22}=-j\frac{Z_{c1}R_c^2\cot K_cl}{(1-R_c/R_\pi)}-j\frac{Z_{\pi1}R_\pi^2\cot K_\pi l}{(1-R_\pi/R_c)}, \tag{18f}$$

$$R_c=\frac{j\kappa k^2}{(\chi/2)k_t^2+\sqrt{(\chi^2k_t^4/4)+k^2\kappa^2(k^2-k_t^2)}}, \tag{19a}$$

$$R_\pi=\frac{j\kappa k^2}{(\chi/2)k_t^2-\sqrt{(\chi^2k_t^4/4)+k^2\kappa^2(k^2-k_t^2)}}, \tag{19b}$$

where Z_c' and Z_c'' are the TM and TE case characteristic impedances, respectively.

Dikey Manyetize Edilmiş Dielektrik Kaplı Ferit Dilimle Elektronik Tarama Yapabilen Milimetre Dalga Antenleri

Özlem AYDIN, Altunkan HIZAL

Elektrik, Elektronik Mühendisliği Bölümü,
Orta Doğu Teknik Üniversitesi, 06531, Ankara, Türkiye

Özet

Bu makalede, dik olarak manyetize edilmiş, iletken tabaka üzerindeki bir ferit dilim içinde yer alan dipollerin ışıma özellikleri incelenmiştir. Ferit dilime uygulanan DC manyetik alanı değiştirerek, milimetrik dalga frekanslarında sürekli bir tarama elde edilebileceği gösterilmiştir. Problem, DC manyetik alan yönüne dik alan denklemleriyle formüle edilmiştir. Fourier dönüşümü uygulanmış alan denklemlerini çözmek için, ferit dilim, asimetrik kuplajlı iletim hattı ile modellenmiştir. Işıma alanları, en dik azalma yöntemi (steepest descent method) kullanılarak bulunmuştur. Geliştirilen yöntem, izotropik ve dik manyetize edilmiş izotropik olmayan ortamlar içeren çok katmanlı sistemlerin ışıma problemlerine kolaylıkla uygulanabilir. Topraklanmış ferit dilim içindeki Hertz manyetik dipolu icin 22-35 GHz frekanslarında ışıma örüntüleri elde edilmiştir. DC alanın büyüklüğünün, ferit dilimin kalınlığının ve frekansın örüntüler üzerindeki etkileri incelenmiştir. DC besleme alanı değiştirilerek, ± 35 derecelik ışın demeti taraması elde edilebileceği gözlenmiştir.

Anahtar Sözcükler: *İzotropik olmayan ortamlarda yayılma, ferit antenler*

INSTRUCTIONS FOR CONTRIBUTORS

A. Submission of Manuscript

1. Send 4 copies of your paper to the editor. The paper shall be subject to a full review procedure and a decision whether to accept the paper will be taken by the editor based on the reviews. Typical review period is 3 months.

2. Enclose a separate sheet giving your preferred address for correspondence and return of proofs.

B. Style for Manuscript

1. First page must contain a title of the paper, author(s) names and affiliations, abstract (not more than 300 words), complete mailing address, telephone number, e-mail address if there is one and acknowledgement of financial or other support.

2. Manuscripts should be typewritten on one side of a white paper, double spaced throughout and with an ample margin.

3. Provide an introduction that includes a statement of the purpose and the contribution of the paper comparing it to the existing results in literature.

4. If appropriate, indicate advantages, limitations and possible applications of your contribution in a conclusion section.

5. References should appear in a seperate bibliography at the end of the paper. Use numerals in square brackets for the references.

C. Style for Illustrations

1. It is in the author's interest to submit illustrations that are sharp, noise-free and of good contrast. Drafting or art service cannot be provided by **ELEKTRİK**

2. Line drawings should be in black on white background. Maximum size of figures in restricted to 20 cm by 25 cm.

3. Photographs should be glossy prints, of good contrast and any reasonable size.

4. All figures must have a number and a caption. The captions must be typed on a seperate sheet. The proper position of each figure in the text should be indicated in the margin by a pencil.

D. Electronic Copies

1. In order to accelerate the typesetting process of the paper, once it is accepted, the authors are encouraged to send a diskette containing a LATEX file of the paper, including the figures translated into the picture environment of LATEX and the bibliography file in BIBTEX format.

2. The typesetting for **ELEKTRİK** shall be done in a LATEX environment with a special header. Therefore the authors should not be bothered in choosing their version of the article style in LATEX.

E. Subscription Rates

$50/year overseas, 100.000.-TL/year in Turkey (50.000 TL/year for students).

Correspondence address for subscription is given below:

Tübitak Yayınlar Daire Başkanlığı, Atatürk Bulvarı
221 Kavaklıdere, 06100 Ankara- TURKEY

EMO Ihlamur Sokak No: 10/1
Yenişehir, Ankara - TURKEY

F. Correspondence Address

1. Original Manuscripts should be send to the address:
Professor K. İnan, Editor ELEKTRİK,
P.O.Box 5 Kızılay, Ankara, Turkey.

All other correspondence should be sent to the address:
Professor K. İnan, Editor ELEKTRİK,
Electrical & Electronics Engineering Department,
Middle East Technical University Ankara, Turkey

2. Electronic copies may also be sent via e-mail to the address :
inan@trmetu.bitnet.