INTERNATIONAL JOURNAL OF MICROWAVE AND OPTICAL TECHNOLOGY,

VOL.5 NO.3 MAY 2010

Polarized Switchable Microstrip Array Antenna Printed on LiTi Ferrite

Naveen Kumar Saxena, Nitendar Kumar[1], Pradeep Kumar Singh Pourush and Sunil Kumar Khah*[2]

Microwave Lab, Department of Physics, Agra College Agra, PIN 282002 (U.P) India.
Email: Nav3091@rediffmail.com, ppourush@yahoo.co.in

[1]Solid State Physics Laboratory, Timarpur, Delhi, PIN 110007 India.
Email: Nitendar@rediffmail.com

[2] Department of Physics, Jaypee University of Information Technology, Waknaghat, Solan-173215 (India)
E-mail: sunil_khah@rediffmail.com

Abstract: **Radiation characteristics of a polarized switchable microstrip planar array of circular patch antenna printed on synthesized LiTi ferrite substrate with a normal magnetic bias field are analysed. Normaly upto X-band, the em-waves propagation is studied by the Pozar's quasi TEM waves (extraordinary waves) but for the study in X-band spin wave exchange term (ω_r) in the magnetostatic wave analysis is also incorporated which depends upon the static internal field (H_{ex}). The substituted polycrystalline ferrite with DC magnetic biasing is offers number of novel magnetic and electrical characteristics including switchable and polarized radiations from a microstrip antenna. In such a case of antenna radiation, most of the power will be converted into mechanical waves and little radiates into air. Under such condition the antenna become switch off, in the sense of effectively absence as radiator.**

Key words: **Ferrites, microstrip antenna, microwave, dielectric constant, magnetic field, directive gain.**

I. INTRODUCTION

Ferrite is one of the important magnetic materials which are used as in both types single and polycrystalline. Some novel characteristics of polycrystalline ferrite over normal dielectric material make it very useful in microwave antenna applications. Different types of polycrystalline ferrites have their specific advantages such as Li substituted ferrites has high dielectric constant, low sintering temperature etc. than other substituted ferrites. Beam steering, gain and bandwidth enhancement, RCS control, surface wave reduction, switchable and electronic tunability are some of the unique and inherent features of ferrite based microstrip antennas and arrays [1-8]. The integration of ferrite technology into microstrip printed circuit antenna is of considerable interest due to its numerous advantages and potential applications. Applied magnetic field changes the permeability of ferrite which in turn alters the electrical properties of material, correspondingly changing the antenna properties. Under these conditions it is possible to change the antenna characteristics with the variation of externally applied DC magnetic field under certain favorable conditions.

The present communication paper, the study of tunable antenna with the concept of generation of the magnetostatic and spin wave has been developed by taking a 4×4 array of circular patches printed on LiTi ferrite substrate in an X band (10 GHz.) of microwave frequency range.

II. THEORY

The array geometry is shown in fig. 1. It consists of 16 identical elements of radius ‘a’ printed on LiTi ferrite substrate of thickness ‘h’. The dielectric constant and saturation magnetization ($4\pi M_s$) of substrate is 17.5 and 2200 Gauss respectively.

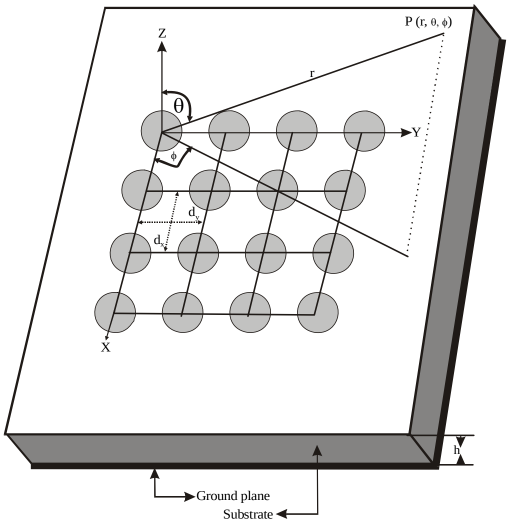

Fig.1. Geometry of 4×4 array microstrip circular patch antenna

With a plane wave propagating in the perpendicular direction of slab with a magnetic bias field applied longitudinally. Due to elasticity of the spin (magnetic) system, oscillations (precession) of the magnetic moments with the frequency of exciting force can exist and they are in resonance for the frequency equal to $\mu_o\gamma H_i$, where H_i is the internal field in the magnetic material. If these oscillations are excited in limited region of the ferrite sample, then due to elasticity of this system they will propagate with a defined velocity in the sample. This propagating disturbance represents magnetostatic and spin waves. These waves are generated when external magnetic field applied perpendicular to the magnetic vector of EM waves. MSW propagate perpendicularly on both sides to the EM wave's propagation [9-12].

For the infinite medium plane wave solution of the equations of motion including the spin wave "exchange" term and neglecting losses then permeability tensor components are:

$$\mu = 1 + \frac{\omega_r \omega_M}{\omega_r^2 - \omega^2} \quad and \quad \kappa = \frac{\omega\, \omega_M}{\omega_r^2 - \omega^2} \qquad (1)$$

The resonance frequency ω_r will be

$$\omega_r = \omega_o + \omega_{ex}\alpha_l^2 k^2 \qquad (2)$$

For propagation perpendicular to the direction of the d-c magnetic field ($\theta_k = 90$):

$$k^2 = \omega^2 \epsilon \mu_o \frac{(\omega_r + \omega_M)^2 - \omega^2}{\omega_r^2 + \omega_r \omega_M + \omega^2} \qquad (3)$$

This is biquadratic in ω giving two roots for the extraordinary wave. The dispersion relation for ω as a function of k, for the biquadratic equation (3) is given by:

$$\omega^2 = \frac{\frac{k^2}{\epsilon\mu} + (\omega_r + \omega_M)^2 \pm \left\{ \left[\frac{k^2}{\epsilon\mu} + (\omega_r + \omega_M)^2\right]^2 - 4(\omega_r^2 + \omega_M\omega_r)\frac{k^2}{\epsilon\mu} \right\}^{1/2}}{2} \qquad (4)$$

on plotting the dispersion relation (4) then we got a curve between frequency (ω) and propagation constant (k) for a particular value of external magnetic field (H_o). The value of propagation constant (k) becomes zero twice at which the frequency known as cutoff frequency which is due to the generation of three types of waves: quasi TEM, Magnetostatic and Spin waves. Spin wave excitation is the result of exchange forces between atoms. Magnetostatic waves are of two types (1) Surface MSW (2) Volume MSW [11-13].

A. Surface MSW:

Surface magnetostatic waves are the most common and well investigated class of magnetostatic waves. These waves propagate in ferromagnetic materials magnetized in the layer plane perpendicularly to the direction of the magnetic field. The dispersion relation of surface MSW with spin wave exchange term, given as follows:

$$\omega^2 - \omega_H(\omega_M + \omega_r) + \frac{\omega_M^2}{2(1 + \tanh^{-1}(kt))} \qquad (5)$$

Surface MSW band limits:

$$\mu_o\gamma\sqrt{H(H + M_o)} \le \omega \le \mu_o\gamma H\left(H + \frac{M_o}{2}\right) \qquad (6)$$

Surface MSW in metal coated ferrite:

$$\omega \leq \mu_o \gamma (H + M_s) \qquad (7)$$

B. Volume MSW:

These types of waves generally produce dominantly in the layered structure perpendicular to surface MSW propagation or magnetized layer. The dispersion relation of volume MSW with spin wave exchange term, given as follows:

$$\omega^2 = \omega_r \left[\omega_r + \frac{\omega_M}{1 + \left(\frac{m\pi}{kt}\right)^2} \right] \qquad (8)$$

Volume MSW band limits:

$$\mu_o \gamma H \leq \omega \leq \mu_o \gamma \sqrt{H(H + M_s)} \qquad (9)$$

For the design of antenna array the dimensions of each element of antenna are calculated using [14]

$$f_r = \frac{K_{nm} c}{2\pi a_{eff} \sqrt{\varepsilon_r \mu_r}} \qquad (10)$$

Using the pattern multiplication approach and neglecting mutual coupling between the elements, the normalized form of the array factor for the present geometry is obtained and given below:

$$AF = 0.0625 \frac{\sin\{2(kd_x \sin\theta \cos\varphi + \beta_x)\}}{\sin\{0.5(kd_x \sin\theta \cos\varphi + \beta_x)\}}$$

$$\times \frac{\sin\{2(kd_y \sin\theta \sin\varphi + \beta_y)\}}{\sin\{0.5(ka_y \sin\theta \sin\varphi + \beta_y)\}} \qquad (11)$$

The total fields of the present array geometry can be expressed by the field of single element multiplied by array factor. Thus the far zone expressions for 4×4 planar array circular patch microstrip antenna are obtained [12-13]:

$$E_{\theta t} = j^n \frac{kaV e^{-jkr}}{2r} \cos n\varphi \frac{\sin(khcos\theta)}{khcos\theta}$$

$$\times \{J_{n+1}(ka\sin\theta) - J_{n-1}(ka\sin\theta)\} \qquad (12)$$

$$E_{\varphi t} = j^n \frac{kaV e^{-jkr}}{2r} \cos n\varphi \frac{\sin(khcos\theta)}{khcos\theta}$$

$$\times \{J_{n+1}(ka\sin\theta) + J_{n-1}(ka\sin\theta)\} \qquad (13)$$

where

$$k_{\pm} = \omega^2 \epsilon \mu_o \frac{(\omega_r + \omega_M)^2 - \omega^2}{\omega_r^2 + \omega_r \omega_M + \omega^2}^{1/2} \qquad (14)$$

Table 2: Antenna`s function based on the propagation of extraordinary waves.

Extraordinary Wave Propagation with Propagation Constant	Antenna Function
Negative μ_{eff}	Off
Positive μ_{eff} with k_+	Radiate with RHCP
Positive μ_{eff} with k_-	Radiate with LHCP

The total field pattern $R(\theta, \varphi)$ is generally obtained from the relation:

$$R(\theta, \varphi) = |E_{\theta t}|^2 + |E_{\varphi t}|^2 \qquad ($$

The polarization of antenna can be adjusted by the propagation constant listed in table 2. The parameters related to patch characterization are calculated for biased and unbiased ferrite substrate, listed in table 3.

III. RESULTS

The ferrite used in the present case is LiTi with the following properties

LiTi Ferrite Characteristics	Values
Magnetic Saturation ($4\pi M_s$)	2200 Gauss
Curie Temperature (T_c)	500 K
Density (ρ)	4.3 grams/cm^3
Remanence	0.91
Coercivity	2.2
Dielectric Constant (ε)	17.5
Resonance Line Width (ΔH)	520 Oersteds
Loss Tangent ($\tan\delta$)	< 0.0005

For the case of analysis the antenna parameters taken are source frequency 10 GHz, k=K+, ε_r = 17.5, h=0.165 cm , a_{eff} = 0.2104 cm and loss tangent = 0.0005. For the array the element separation $d_x = d_y = \lambda/2$ and progressive phase excitation is $\beta_x = \beta_y$.

The dispersion curve for the material has been plotted and shown in fig. 2. It is evident from the curve that when ferrite substrate is magnetized the propagation constant (k) vary with frequency and the initial linear part of curve represents quasi TEM wave excitation which is of very small order (10-100) in comparison of scale (10^8). The rest part of curve represents MSW and Spin wave excitation. Spin wave excitation is the result of exchange forces between atoms. From the figure it is observed that the absorbing power due to the MSW generation is in a particular limit. This particular limit depends upon the thickness of substrate, Resonance Line Width (ΔH) and external magnetic field orientation.

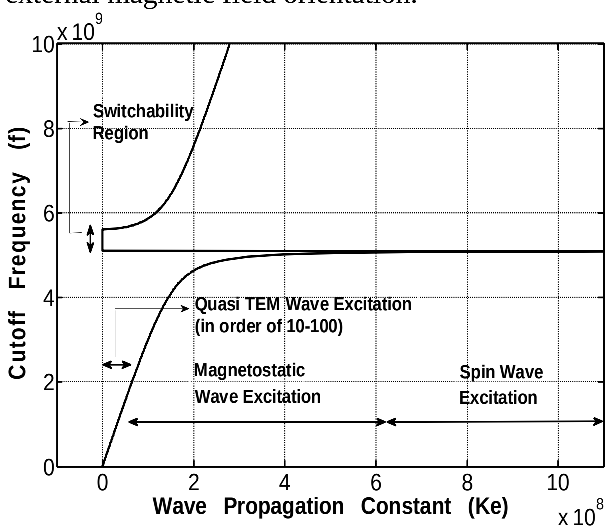

Fig. 2: Dispersion curve (f vs. k) of MSW in LiTi for incident plane wave perpendicular to the biased substrate by 750 Oe. magnetic field.

By the help of input parameters and using Mathworks MatLab 7.1, the radiation patterns are plotted in fig. 3, 4 & 5 for E-plane, H-plane and array respectively for the geometry under consideration. These curves show a comparison between unbiased and biased substituted polycrystalline ferrite substrate array antenna.

Table 3: Comparison of Antenna`s parameters for Unbiased and biased case

Parameters	Unbiased	Biased
Total Impedance (Z_{in})	166.77 ohms	109.50 ohms
Admittance (Y)	0.0059 mhos	0.0012 mhos
Quality Factor (Q)	~12 %	~12 %
Bandwidth (BW)	~2 dB	~2 dB
Directivity Gain (D)	9.43	10.48
Radiation Power (P_r)	1.5 mW	2.3 mW

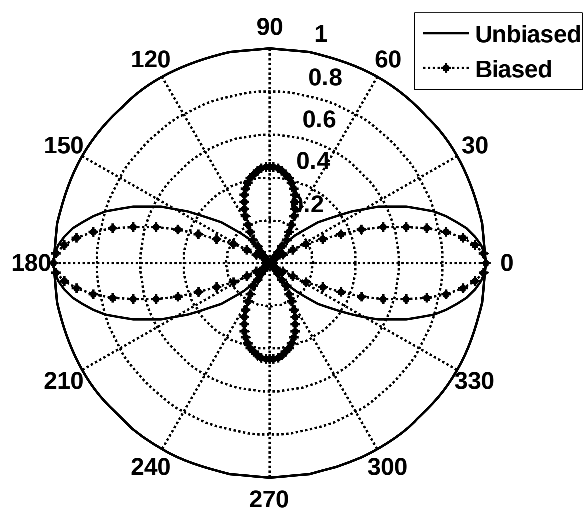

Fig. 3 Comparison of E-plane pattern of circular patch microstrip antenna with RHCP for unbiased case and biased case

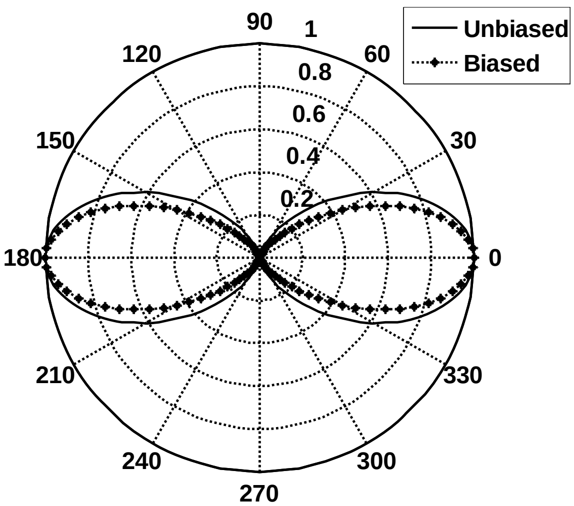

Fig. 4 Comparison of H-plane pattern of circular patch microstrip antenna with RHCP for unbiased case and biased case

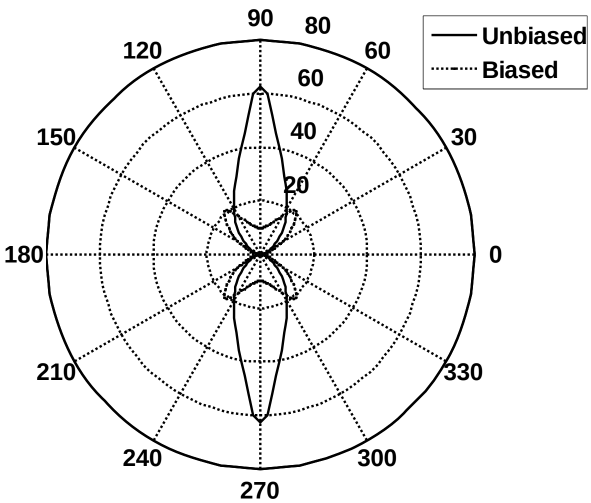

Fig. 5 Comparison of radiation pattern of 2×2 planar array of circular patch microstrip antenna with RHCP for unbiased case and biased case

V. CONCLUSIONS

It is evident from the dispersion effect on ferrite material that there should be a propagating and non-propagating region for an antenna. There is a frequency range bounded by limits, namely cutoff limit or resonance limit. In this where H_{eff} or k is negative, the em-waves are highly attenuating and therefore the antenna is effectively off as radiator. Some salient features of this array geometry are summarized as follow:

1. Comparison shows that on biasing, the radiation patterns becomes directive in nature and number of lobes are found to be increase than that of unbiased case.
2. It is evident from the dispersion curve that, for the given parameters, the cut-off limit is between 5 GHz. to 5.5 GHz. and tunable resonant region are below and above the cutoff limit. This property of antenna shows its switchable and tunable capability which can be varied as per requirement.
3. When the antenna is biased with DC magnetic field the parameters show that the directivity gain and radiation power are appreciably increase. Pattern also shows the beam steering which enhances the scanning power as well as radiation power of array antenna.
4. The size of patch is reduced considerable 35% comparable when designed on Quartz substrate. This reduction would certainly have a wide use in creating a miniaturization of an antenna system which has a potential application in space and cellular communication.

REFERENCES

[1] D.M. Pozar` "Radiation and Scattering Characteristic of Microstrip Antenna on Normally Biased Ferrite Substrate", *IEEE Trans. On Antenna and Propagation*, 1992, AP-40, pp.-1084-1092.

[2] D. M. Pozar and V. Sanchez, "Magnetic tuning of a microstrip antenna on a ferrite substrate," *Electronic Letters*, Vol. 24, pp. 729-731, June 9, 1988.

[3] L. Dixit, and P.K.S. Pourush, "Radiation characteristics of switchable ferrite microstrip array antenna", *IEE Proc. Microwave and Antennas Propagation*, Vol. 147, No. 2, pp. 151-155, April 2000.

[4] P.K.S. Pourush et.al. "Microstrip Scanned Array Antenna on YIG Ferrite Substrate", *Proc. International Symposium on Antennas and propagation*, Japan 2000.

[5] P.K.S. Pourush and L. Dixit, "A 2x2 Element Planar Phased array of Rectangular Microstrip Antenna on Ni-Co Ferrite Substrate at 10 GHz", *I.J. of Radio and Space Physics*, Vol. 27, pp. 289-226, 1998.

[6] P.K.S. Pourush and L. Dixit, "Wide-Band Scanned Array of Microstrip Antenna on Ferrite Substrate", *I.J. of Radio and Space Physics*, Vol. 73(B), pp. 485-492, 1999.

[7] K.K. Tsang and R.J. Langley, "Design of Circular Patch Antennas on Ferrite Substrate", *IEE Proc. Microwave Antenna Propagation*, Vol. 145(1), pp. 49-55, Feb. 1998.

[8] J.C. Batchelor and R.J. Langley, "Beam Scanning using Microstrip Line on Biased Ferrite", *Electronic Letters*, Vol. 33, No. 8, pp. 645-646, 1997.

[9] P.Y. Ufimtsev, R.T. Ling, and J.D. Scholler "Transformation of surface waves in homogenous absorbing layers," *IEEE Transaction on Antennas and Propagation*, Vol. 48, pp 214-222, Feb. 2000.

[10] B. Horsfield and J. A. R. Ball, "Surface wave propagation on grounded dielectric slab covered by a high-permittivity material," *IEEE Microwave and Guided wave letters*, Vol. 10, pp. 171-173, May 2000.

[11] B. Lax and K. Button, *Microwave Ferrite and Ferrimagnetics*, New York: McGraw-Hill, 1962.

[12] P. Kabos and V. S.Stalmachov, *Magnetostatic Waves and their Applications*, Chapman and Hall, 1994.

[13] M.S. Sodha and N.C. Srivastav, *Microwave Propagation in Ferrimagnetics*, Plenum Press, New York, 1981.

[14] I.J. Bahl and P. Bhartia, *Microstrip Antennas*, Artech House, Norwood, M.A, 1980.

LIST OF SYMBOLS

h = height of substrate
λ = wavelength
a_i = inter-atomic space
a = radius of patch
a_{eff} = effective radius of patch
β_x, β_y = progressive phase excitation difference along x and y direction respectively
d_x, d_x = element separation along x and y direction respectively
J_{n+1} = $(n+1)^{th}$ order Bessel`s function of first kind
J_{n-1} = $(n-1)^{th}$ order Bessel`s function of first kind
α = attenuation constant
β = phase constant
β_o = propagation constant in vacuum
ε_r = dielectric constant
μ_{eff} = effective permeability
μ, κ = permeability tensor components of μ_{eff}
T = relaxation time
H_o = applied bias field
ΔH = magnetic resonance width of ferrite
ω = angular frequency of incident e-m-waves
ω_o = external magnetic field angular frequency
ω_m = internal magnetic field angular frequency
ω_{ex} = internal magnetic field angular frequency due to exchange forces
μ' = real part of permeability
μ'' = dissipative part of permeability
χ' = real part of susceptibility
χ'' = dissipative part of susceptibility
$4\pi M_S$ = saturation magnetization
γ = gyromagnetic ratio (2.8 MHz / Oe.)