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2×2 Array of circular patches on LiTiZn ferrite substrate

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Abstract

Rectangular array of four elements of microstrip circular patches modeled on LiTiZn ferrite substrate is presented. Here we have considered LiTiZn ferrite as a substrate which has been synthesized by the solid state reaction technique (SSRT). In this paper we present a comparison of radiation pattern and other parameters when the antenna array is biased perpendicularly with varying magnetic field. The array antenna using LiTiZn with magnetic biasing, reports a reduction of radiation of side-lobes with increased directivity with better radiation power response.

Keywords. Substituted ferrite, microstrip array antenna, X-band frequency range.

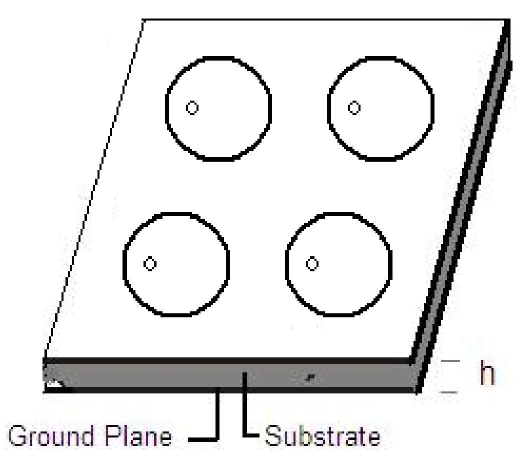
List of symbols

f_r = resonant frequency; h= height of substrate; 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; ε_r= dielectric constant; ε_{eff} = effective dielectric constant; μ_r = initial permeability; μ_{eff} = effective permeability; K_d= ordinary propagation constant; $K_{e,\pm}$ =extraordinary propagation constant; w= angular frequency; 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; H= bias field; λ= wavelength; $4\pi M_s$= saturation magnetization; ϒ= gyromagnetic ratio (2.8 MHz / Oe.).

Introduction

The integration of ferrite technology into microstrip printed circuit antenna has numerous advantages and potential applications. In recent years, biased ferrite material for microstrip antenna structures has attracted noticeable attention. 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 as Li substituted ferrites has high dielectric constant, low sintering temperature etc. than other substituted ferrites. The reason for using ferrite materials in microstrip structures is that the applied magnetic field changes the permeability and thus the electrical properties of material, which in turn changes the antenna properties. The significance of this is that it is possible to change the antenna characteristics through the DC magnetic field applied externally. 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, which have been discussed by numbers of investigators in recent years (Pozar, 1992; Batchelor & Langley,1997; Pourush *et al*. 2000; Bharadwaj *et al*., 2001). In the present paper, the concept of tunable antenna has been developed by taking a 2×2 array of circular patches printed on LiTiZn ferrite substrate in the X band (10 GHz.) of microwave frequency range.

Fig. 1. Geometry of 2×2 array microstrip circular patch antenna



Theory

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

For a biased ferrite substrate, a normal incident plane wave may excite two types of waves (ordinary and extraordinary wave). In the case of normal incident magnetic field biasing ordinary wave is same as the plane wave in the dielectric slab. On the other hand, the extraordinary wave is a TE mode polarized parallel to the biasing direction with its phase propagation constant Ke (Paladino *et al*., 1964; Pozar, 1992).

$$K_e = \frac{w}{c}\sqrt{\epsilon_{eff} \times \mu_{eff}} \qquad (1)$$

$$K_d = \frac{w}{c}\sqrt{\epsilon_{eff}} \qquad (2)$$

$$\mu_{eff} = \frac{\mu^2 - k^2}{\mu} \qquad (3)$$

$$\mu = 1 + \frac{w_o w_m}{w_o^2 - w^2} \qquad (4)$$

$$k = \frac{w w_m}{w_o^2 - w^2} \qquad (5)$$

where

$w_o = \gamma H_o$ and $w_m = \gamma 4\pi M_s$

where H_o is the bias field, $(4\pi M_s)$ is the saturation magnetization, γ is the gyromagnetic ratio as γ = 2.8 MHz/Oe. The frequency range of negative μ_{eff} is:

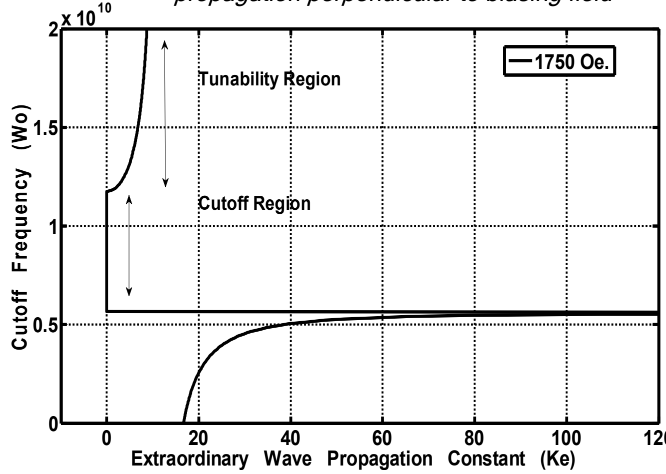
$$[w_o(w_o + w_m)]^{1/2} < w < (w_o + w_m) \qquad (6)$$

The frequency limits define the approximate range within and around which the ferrite exhibit interesting microwave characteristics. The use of the biased field is to control the properties of the extraordinary wave which results a polarized switchable antenna. The antenna is off when extraordinary waves propagate with negative μ_{eff}. The dispersion curve for this array geometry for four values of biasing is given in Fig. 2.

Synthesis of substrate

LiTiZn ferrite synthesized from the basic components of lithium ferrites. The ingredients required for the preparation of these ferrites have been calculated on the basis of chemical formula. A small amount of Mn^{3+} ion has been also incorporated in the basic composition in order to suppress the formation of Fe^{2+} ions in the ferrites and to influence megnetostriction being a John Teller ion (Van Uitert,1956; Pourush & Dixit, 1998). In order to avoid Lithia at high temperature of sintering, Bi_2O_3 (0.25 wt %) has been added as sintering aid (Paladino *et al*., 1964). Analytical grade chemicals have been used for the preparation of the material. The stoichiometric ratio of the chemicals has been thoroughly mixed in a polypropylene jar containing the zirconium balls and distilled water has been used as a mixing agent. The presintering of the mixed powder has been carried out at ~ 750°C in a box furnace and soaking time was kept 4 hours. The sieved material has been pressed in disk (antenna substrate) and toroidal shapes with the help of suitable dies and using hydraulic pressing technique at pressure of 10 ton/cm^2. The substrates and toroidals have been finally sintered at 1050°C for four hours. The heating and cooling cycle of the samples has been carried out in the air atmosphere of furnace. The sintered samples so obtained have been subjected to cutting, grinding, polishing etc, in order to get specific size and shape (Pran Kishan *et al*., 1985). The single-phase spinel nature of the samples has been confirmed by X-ray diffraction (XRD) patterns obtained by using Cu-K_α radiation. The microstructure studies of the sample have been carried out by scanning electron microscopy (SEM). Vibrating Sample Magnetometer (VSM) has been used to determine the magnetic properties of the samples. For dielectric measurements, rectangular pellets of size 25 mm × 13 mm × 7 mm have been used. The dielectric measurements have been performed from 8 to 12 GHz by a VNA E8263B Agilent Technology impedance analyzer. The value of the real part of dielectric constant (ε') of the ferrite samples has been calculated using formula $\varepsilon' = Ct/\varepsilon_0 A$ where 'ε_0' is the permittivity of free space = 8.854 × 10^{-12} F/m, 'C' is the capacitance of specimen, 't' is the thickness of specimen and 'A' is the area of sample in square meter. The density measurement has been done by a small experiment based on Archimedes' principle. Remanence and Coercive Force have been measured by B-H loop setup applied to coiled toroid sample at 50 Hz.

Fig.2. Dispersion curve (f Vs. K) for plane wave propagation perpendicular to biasing field



The Curie temperature for the LiTiZn ferrite samples has been determined by using a simple experimental setup based on gravity effect in the laboratory. The ferrite specimen has been made to attach itself to a bar magnet through a mild steel rod due to the magnetic attraction

Table 1. The electrical and magnetic properties of LiTiZn ferrite substrate

LiTiZn Ferrite Characteristics	Values
Magnetic Saturation ($4\pi M_s$)	2200 Gauss
Curie Temperature (T_c)	385 K
Density (ρ)	4.21 grams/cm^3
Remanence	0.90
Coercivity	1.50
Dielectric Constant (ε)	16
Resonance Line Width (ΔH)	370 Oersteds
Loss Tangent ($\tan\delta$)	< 0.0005

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and combination was suspended inside the furnace. A chromel-alumel thermocouple has been attached with the sample holder to read the temperature of the specimen. As the temperature of the system was increased, at a particular temperature the specimen losses it spontaneous magnetization and become paramagnetic. This temperature is known as Curie temperature. At this temperature specimen fall downward due to gravity. The electrical and magnetic properties of LiTiZn ferrite substrate has been experimentally calculated in laboratory which is listed in Table 1.

Table 2. Comparison of antenna`s parameters for unbiased and biased case

Parameters	Unbiased	Biased
Total Impedance (Z_{in})	993.21 ohms	110.26 ohms
Admittance (Y)	0.0005 mhos	0.0045 mhos
Quality Factor (Q)	~12 %	~33 %
Bandwidth (BW)	~2 dB	~2 dB
Directivity Gain (D)	3.5150	10.5021
Radiation Power (P_r)	1.5 mW	2.3 mW

Simulation and characterization

The dimensions of each element are calculated by following equations:

$$f_r = \frac{K_{nm}c}{2\pi a_{eff}\sqrt{\epsilon_r \mu_r}} \qquad (7)$$

The above equation is based on the Cavity model. 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 (Van Uitert,1956; Pran Kishan *et al.*, 1985).

$$AF = 0.0625\frac{sin\{2(kd_x sin\theta\ cos\varphi + \beta_x)\}}{sin\{0.5(kd_x sin\theta\ cos\varphi + \beta_x)\}} \times \frac{sin\{2(kd_y sin\theta\ sin\varphi + \beta_y)\}}{sin\{0.5(kd_y sin\theta\ sin\varphi + \beta_y)\}} \qquad (8)$$

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 2×2 planar array circular patch microstrip antenna are obtained as follow:

$$E_{\theta t} = j^n \frac{kaVe^{-jkr}}{2r} cosn\varphi \frac{sin(khcos\theta)}{khcos\theta} \times \{J_{n+1}(kasin\theta) - J_{n-1}(kasin\theta)\} \qquad (9)$$

$$E_{\varphi t} = j^n \frac{kaVe^{-jkr}}{2r} cosn\varphi \frac{sin(khcos\theta)}{khcos\theta} \times \{J_{n+1}(kasin\theta) + J_{n-1}(kasin\theta)\} \qquad (10)$$

where

$$\boldsymbol{k} = K_{\pm} = K_d\left(\frac{w_o + w_m \mp w}{w_o \mp w_m}\right)^{1/2} \qquad (11)$$

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

$$R(\theta,\varphi) = |E_{\theta t}|^2 + |E_{\varphi t}|^2 \qquad (12)$$

The value of $R(\theta,\varphi)$ are computed for a case taking source frequency $f = 10\ GHz., k = K_+, \epsilon_r = 16, h = 0.165\ cm$, a_{eff} = 0.2104 cm and loss tangent = 0.0005. For the array the element separation $d_x = d_y = \lambda/2\ cm$ and progressive phase excitation is $\beta_x = \beta_y = 0$. The parameters related to patch characterization are calculated for biased and unbiased ferrite substrate, listed in Table 3.

By the help of these parameters and mathematical software (Mathworks MatLab 7.1), the comparison of radiation patterns are plotted in Fig. 3-8 for E-plane, H-plane and array for this geometry. These curves show a comparison between unbiased and biased substituted polycrystalline ferrite substrate array antenna.

It is observed from the figures that pattern of array geometry are more directive in nature in case of biased ferrite (Sodha & Srivastav's, 1981; Pran Kishan *et al.*, 1985; Randhawa *et al.*, 2007).

Conclusions

Using SSRT we have synthesized LiTiZn polycrystalline ferrite substrate for 2×2 planar array antenna at 10 GHz. of microwave frequency range. The parameters used for the study of biased ferrite substrate are saturation magnetization ($4\pi M_s$) = 2200 Gauss and bias field H_o= 1720 Oe. While, for unbiased ferrite substrate bias field become H_o= 0 Oe. The radiation patterns and antenna`s characteristics are calculated and reported in Fig. 3-8 and Table 1, 2 respectively.

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 μ_{eff} is negative, the extraordinary wave is highly attenuating and therefore the antenna is effectively off as radiator. Some salient features of this array geometry are summarized as follow:

- Comparison shows that on biasing, the radiation patterns becomes directive in nature and power of side-lobes are found to be decreases than that of unbiased case.
- It is evident from the dispersion curve that, for the given parameters, the cut-off limit is between 1 GHz. to 2 GHz. and tunable resonant limit is about 2 GHz. to 10 GHz. This property of antenna shows its switchable and tunable capability which can be varied as per requirement.
- When the antenna is biased with DC magnetic field the parameters show that the directivity gain and radiation power are appreciably increase which enhances the scanning power as well as radiation power of array antenna.
- 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

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

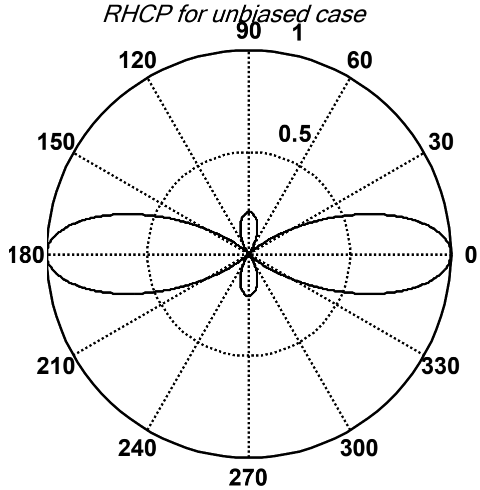


Fig. 4 Comparison of H-plane pattern of circular patch microstrip antenna with RHCP for unbiased case

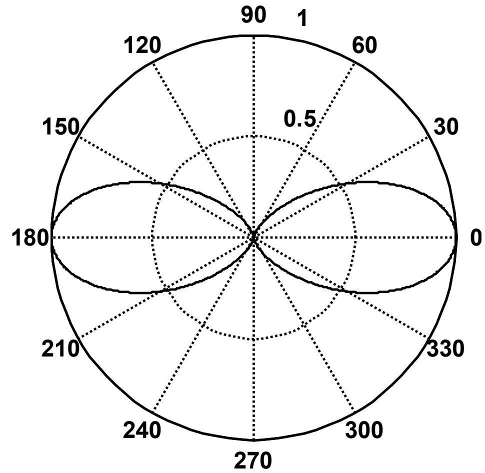


Fig. 5. Radiation pattern of 2×2 planar array of circular patch microstrip antenna with RHCP for unbiased case.

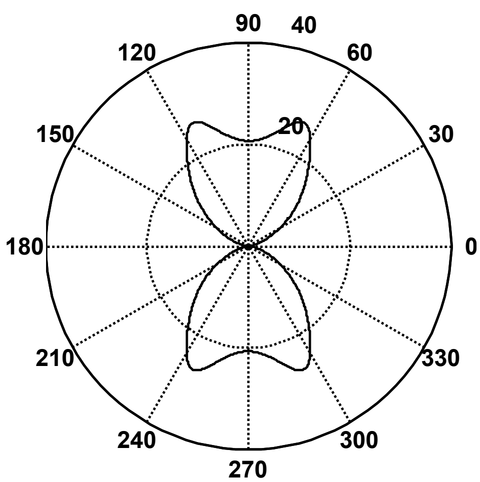


Fig. 6. Comparison of E-plane pattern of circular patch microstrip antenna with RHCP for biased case

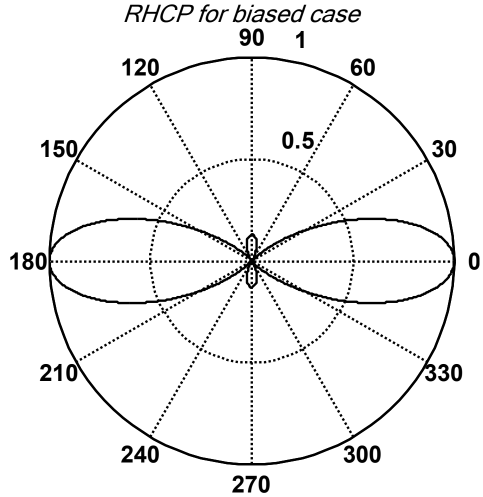


Fig. 7. Comparison of H-plane pattern of circular patch microstrip antenna with RHCP for biased case

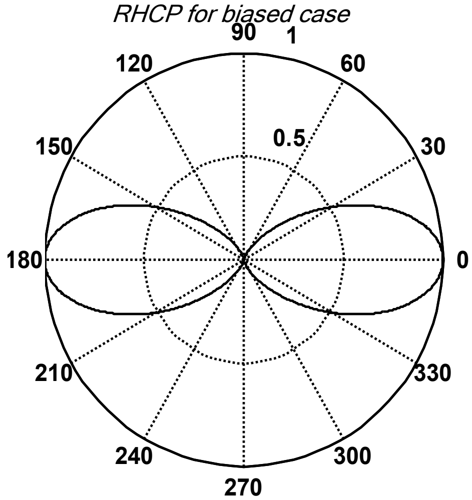
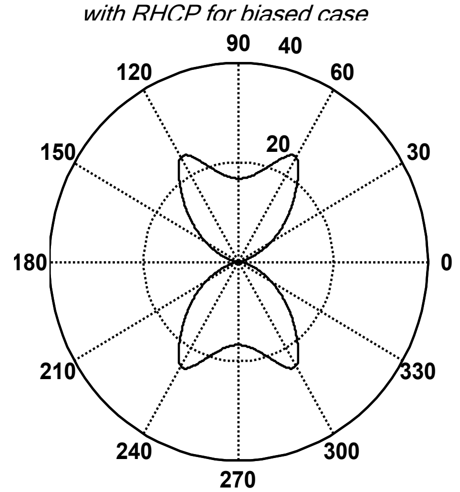


Fig. 8. Radiation pattern of 2×2 planar array of circular patch microstrip antenna with RHCP for biased case



miniaturization of an antenna system which has a potential application in space and cellular communication.

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