Study of Linear Array of Microstrip Hexagonal Patch Antenna Printed on LiTi Ferrite under External Magnetic Biasing

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Abstract—*Characterization of a tunable & switchable microstrip hexagonal patch linear array antenna printed on synthesized LiTi ferrite substrate with a normal magnetic bias field is presented. The DC magnetic biasing offers number of novel magnetic and electrical characteristics including tunable and polarized radiations from the microstrip antenna. In such a case of substituted polycrystalline ferrite antenna with DC biasing, 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. Some electric and magnetic properties of substrate is also described with precise SSRT method of substrate material preparation*

Index Terms- *Substituted ferrite, microstrip patch antenna, X-band frequency range, etc.*

List of Symbols

f_r	=	resonant frequency
h	=	height of substrate
a_{eq}	=	equivalent radius of patch
s	=	side length of hexagonal 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
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 1^{st} kind
J_{n-1}	=	$(n-1)^{th}$ order Bessel`s function of 1^{st} kind
H	=	bias field
λ	=	wavelength
$4\pi M_s$	=	saturation magnetization
ϒ	=	gyromagnetic ratio (2.8 MHz / Oe.)

I. Introduction

In recent year's works, different types of common geometry like circular, rectangular and triangular have been studied with high dielectric substrate. Hexagonal geometry has its own specific advantage over other geometry which is enhanced as well in array position. In present scenario biased ferrite material for microstrip antenna structures also gaining an important role as in both types single and polycrystalline structure. Some characteristics of different types of polycrystalline ferrite over normal dielectric material make it very useful in the integration of ferrite technology into microstrip printed circuit antenna which has numerous advantages and potential applications. 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 [1-6]. In the present paper, the concept of tunable antenna has been developed by taking a four element linear array of hexagonal 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 4 identical elements of side length‘s’ and equilateral 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.

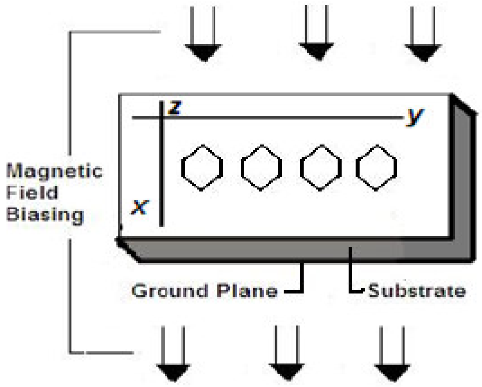

Fig.1. Geometry of linear array of microstrip hexagonal patch antennas

It has been established that, for a biased ferrite slab, 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 [1, 8].

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

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

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

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

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

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 $\gamma = 2.8\, MHz./Oe.$ In the case of extraordinary mode, the propagation constant depends on the basic parameters, given as

$$\left(\frac{K_e}{K_d}\right)^2 = \frac{(w_o + w_m)^2 - w^2}{w_o(w_o + w_m) - w^2}$$

It is seen that, when μ_{eff} is negative, the extraordinary wave is decaying even if the material is lossless. The frequency range of negative μ_{eff} is:

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

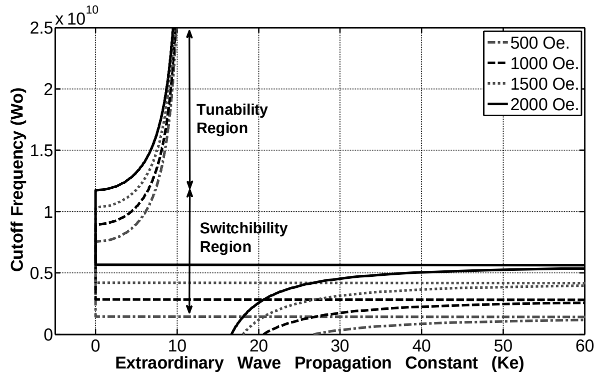

Fig.2. Dispersion curve (f Vs. K) for plane wave propagation perpendicular to biasing field

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. Table 1 presents antenna function under extraordinary wave propagation.

Table 1: 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

III. Synthesis of Substrate

LiTi ferrite synthesized from the basic components of lithium ferrites In this work a typical composition of LiTiMg ferrite having room temperature magnetization ($4\pi M_s$) of 2200 gauss (± 5%) & Curie temperature (T_c) of 325 ^{0}C (± 5%) & synthesized using solid state reaction technique (SSRT). The ingredients required for the preparation of these ferrites were calculated on the basis of chemical formula. A small amount of Mn^{3+} ion was 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 [6, 7]. In order to avoid Lithia at high temperatures of sintering, Bi_2O_3 (0.25 wt %) was added as sintering aid [8]. Analytical grade chemicals were used for the preparation of the material. The stoichiometric ratio of the chemicals was thoroughly mixed in a polypropylene jar containing the zirconium balls & distilled water was 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 was 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 were finally sintered at 1050°C for four hours. The heating and cooling cycle of the samples was carried out in the air atmosphere of furnace. The sintered sample so obtained was subjected to cutting, grinding, polishing etc. in order to get specific size and shape. The important material properties such as magnetic and electrical properties were studied [9].

The single-phase spinel nature of the samples was confirmed by X-ray diffraction (XRD) patterns obtained by using Cu-K_α radiation. The microstructure studies of the sample were carried out by scanning electron microscopy (SEM). Vibrating Sample Magnetometer (VSM) was used to determine the magnetic properties of the samples. For dielectric measurements, rectangular pellets of size 15mm × 6mm × 3mm were used. The dielectric measurements were conducted from 8 to 13 GHz. by a VNA E8263B Agilent Technology. The value of the real part of dielectric constant (ε') of the ferrite samples was 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 in square meter. The density measurement has been done by a small experiment based on Archimedes' principle. Remanence and Coercive Force measure by B-H loop setup applied to coiled toroid sample at 50 Hz.

The Curie temperature for the LiTi ferrite samples has been determined by using a simple experimental setup based on gravity effect in the laboratory. The ferrite specimen is made to attach itself to a bar magnet through a mild steel rod due to the magnetic attraction and combination is suspended inside the furnace. A chromel-alumel thermocouple is attached with the sample holder to read the temperature of the specimen. As the temperature of the system is 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 LiTi ferrite substrate is experimentally calculated are presented in table 2.

Table 2: The electrical and magnetic properties of LiTi ferrite substrate

LiTiMg Ferrite Characteristics	Values
Magnetic Saturation ($4\pi M_s$)	2200 Gauss
Curie Temperature (T_c)	385 K
Density (ρ)	4.3 grams/cm^3
Remanence	0.91
Coercivity	1.50
Dielectric Constant (ε)	17.5
Resonance Line Width (ΔH)	520 Oersteds
Loss Tangent ($\tan\delta$)	< 0.0005

IV. SIMULATION AND CHARACTERIZATION

The dimensions of each element are calculated by following equations:

$$f_r = \frac{1.1K_{nm}c}{2\pi s\sqrt{\epsilon_r \mu_r}}$$

The above equation is based on the transmission line model. 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 hexagonal patch microstrip antenna is obtained as follow:

$$E_{\theta t} = j^n \frac{ka_{eq}Ve^{-jkr}}{2r} cosn\varphi \frac{sin(khcos\theta)}{khcos\theta} \times \{J_{n+1}(ka_{eq}sin\theta) - J_{n-1}(ka_{eq}sin\theta)\}$$

$$E_{\varphi t} = j^n \frac{ka_{eq}Ve^{-jkr}}{2r} cosn\varphi \frac{sin(khcos\theta)}{khcos\theta} \times \{J_{n+1}(ka_{eq}sin\theta) + J_{n-1}(ka_{eq}sin\theta)\}$$

where

$$a_{eq} = 0.9094\, s$$

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

The parameters related to patch characterization are calculated for biased and unbiased ferrite substrate, listed in table 3.

Table 3: Comparison of antenna`s parameters for unbiased and biased case

Parameters	Unbiased	Biased
Total Impedance (Z_{in})	244.87 ohms	167.85 ohms
Quality Factor (Q)	~12 %	~33 %
Bandwidth (BW)	~2 dB	~2 dB
Directivity Gain (D)	5.36	9.93
Radiation Power (P_r)	1.0 mW	1.5 mW

By the help of these parameters and mathematical software (Mathworks MatLab 7.1), the radiation patterns are plotted in fig. 3, 4 & 5 for E-plane, H-plane and array respectively for this geometry. These curves show a comparison between unbiased and biased substituted polycrystalline ferrite substrate array antenna. The total field pattern $R(\theta,\varphi)$ is generally obtained from the relation [9-11]:

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

The value of $R(\theta,\varphi)$ are computed for a case taking source frequency f = 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 $d_x = d_y = \lambda/2\ cm$ and progressive phase excitation is $\beta_x = \beta_y = 0$.

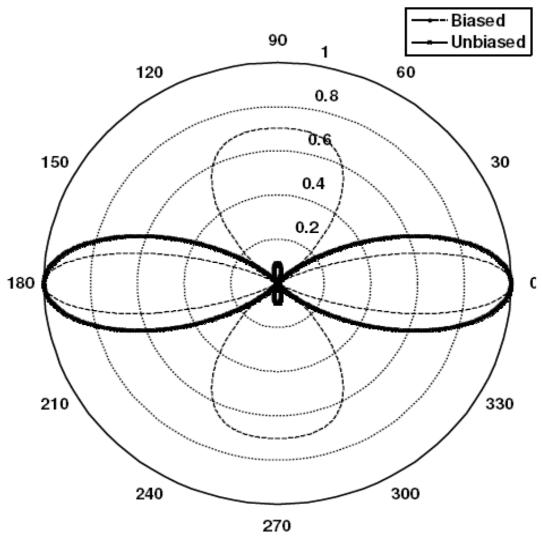

Fig. 3 Comparison of E-plane pattern of microstrip hexagonal patch antenna with RHCP for unbiased case and biased case

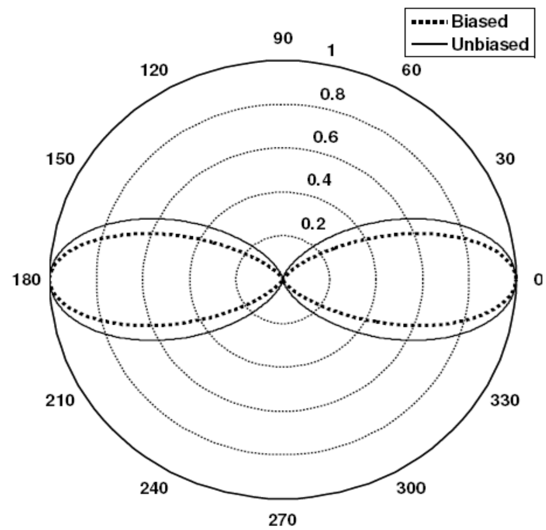

Fig. 4 Comparison of H-plane pattern of microstrip hexagonal patch antenna with RHCP for unbiased case and biased case

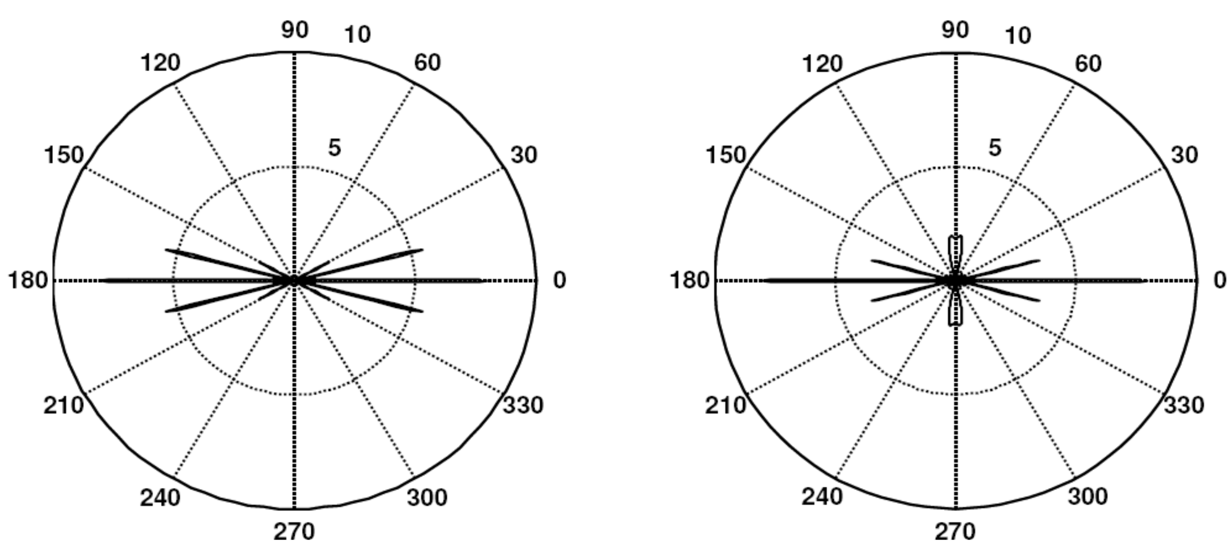

Fig. 5 Comparison of radiation pattern of linear array of four microstrip hexagonal patch antenna with RHCP for unbiased case and biased case

V. CONCLUSIONS

In this paper we have synthesized LiTi polycrystalline ferrite substrate using SSRT as a substrate for proposed antenna at 10 GHz. Investigation performed with parameters: saturation magnetization = 2200 Gauss, bias field Ho= 1720 Oe. and unbiased bias field Ho= 0 Oe. The radiation patterns and antenna`s characteristics are calculated and reported in fig. 3, 4, 5 and table 1, 2, 3 respectively. Some salient features of this array geometry are summarized as follow:

1. It is evident from the dispersion curve that, for the given parameters, the cut-off limit is between 0.1 GHz. to 1.2 GHz. and tunable resonant limit is about 1.2 GHz. to 2.4 GHz. This property of antenna shows its switchable and tunable capability which can be varied as per requirement.
2. Comparison shows that on biasing, the E-plane radiation patterns becomes directive in nature and the radiation power of some lobes are found to be increase than that of unbiased case.
3. Comparison shows that on biasing, the power of H-plane radiation patterns is found to be decrease than that of unbiased case.
4. When the antenna array is biased with DC magnetic field the parameters show that the directivity gain, quality factor 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.
5. 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.

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