

Microstrip Rectangular Patch Antenna Printed on LiTi Ferrite with Perpendicular DC Magnetic Biasing

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Abstract: Characterization of a tunable & switchable microstrip rectangular patch antenna printed on synthesized LiTi ferrite substrate with a normal magnetic bias field is presented. In this paper the concept of switching and tuning are described by magnetostatic and spin waves phenomenon. The DC magnetic biasing generate these both type of waves which response a number of novel magnetic and electrical characteristics including switchable and polarized radiations from a microstrip antenna. In such a case of substituted polycrystalline ferrite antenna due to the 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. The preparation of ferrite by the solid state reaction technique is also précised with the short description of electric and magnetic properties.

Index Terms: Substituted ferrite, microstrip patch antenna, magnetostatic waves, spin waves, X-band frequency range.

List of Symbols

| | |
|----------------------|--|
| f_r | = resonant frequency |
| h | = height of substrate |
| λ | = wavelength |
| a_i | = inter-atomic space |
| s | = side length of rectangular patch |
| β_x, β_y | = progressive phase excitation difference along x and y direction respectively |
| d_x, d_y | = element separation along x and y direction respectively |
| α | = attenuation constant |
| β | = phase constant |
| β_0 | = propagation constant in vacuum |
| ϵ_r | = dielectric constant |
| μ_{eff} | = effective permeability |
| μ, κ | = permeability tensor components of μ_{eff} |
| T | = relaxation time |
| H_0 | = applied bias field |
| ΔH | = magnetic resonance width of ferrite |
| ω | = angular frequency of incident e-m-waves |
| ω_0 | = 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.) |

1. Introduction

In the present era of high frequency communication, 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 (Pozar et al., 1993, 1992, 1988; Fukusako et al., 1998).

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 for the C-band and S-band but not for the X-band (Dixit et al., 2000; Batchelor et al., 1997; Ufimtsev et al., 2000; Horsfield et al., 2000).

In the present paper, the concept of tunable antenna with the magnetostatic and spin wave has been developed by rectangular patch printed on LiTi ferrite substrate in the X band.

2. Theory

The geometry of antenna is shown in fig. 1. The patch of length 'L' and width 'W' printed on LiTi ferrite substrate of thickness 'h'. The dielectric constant and saturation magnetization ($4\pi M_s$) of substrate is 16 and 2200 Gauss respectively. There are many feeding techniques available but due to the brittleness of substrate stripline feeding is preferred.

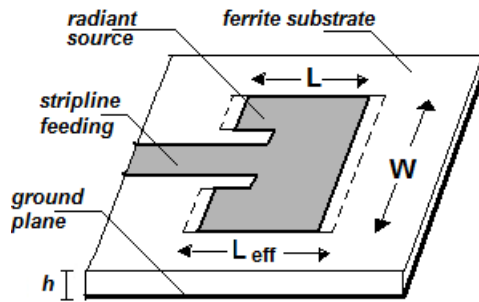


Figure 1. Geometry of microstrip rectangular patch antenna.

Consider a plane wave propagating in the perpendicular direction of slab with a magnetic bias field applied longitudinally. As a result of 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 $\mu_0\gamma H_i$, 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 [Lax et al, 1962].

If we consider the infinite medium plane wave solution of the equations of motion including the spin wave "exchange" term and neglecting losses then the dispersion relation for ω as a function of k , for the biquadratic equation (4) is given by:

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

If we plot the dispersion relation (5) 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 (Lax et al, 1962; Kabos et al, 1994; Sodha et al, 1981).

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 classical dispersion equations first published by Damon and Eshbach in 1961, so that these wave also known as Damon-Eshbach waves. The dispersion relation of surface MSW with spin wave exchange term, given as follows:

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

Surface MSW band limits:

$$\mu_0\gamma \sqrt{H(H + M_o)} \leq \omega \leq \mu_0\gamma H \left(H + \frac{M_o}{2} \right) \quad (3)$$

Surface MSW in metal coated ferrite:

$$\omega \leq \mu_0\gamma (H + M_o) \quad (4)$$

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:

$$\omega^2 = \omega_r \left[\omega_r + \frac{\omega_M}{1 + \left(\frac{m\pi}{kt}\right)^2} \right] \quad (5)$$

Volume MSW band limits:

$$\mu_o\gamma H \leq \omega \leq \mu_o\gamma\sqrt{H(H + M_o)} \quad (6)$$

3. Synthesis Of Substrate

LiTi 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 magnetostriction being a John Teller ion (Uitert et al., 1956; Kishan et al, 1985). In order to avoid Lithia at high temperature of sintering, Bi_2O_3 (0.25 wt %) has been added as sintering aid (Randhawa et al, 2007). 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 $\sim 750^\circ C$ 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 $1050^\circ C$ 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.

The single-phase spinel nature of the samples has been confirmed by X-ray diffraction (XRD) patterns obtained by using $Cu-K_\alpha$ 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 $25 \text{ mm} \times 13 \text{ mm} \times 7 \text{ mm}$ have been used. The dielectric measurements have been performed from 8 to 12 GHz by a HP 4192A impedance analyzer. The value of the real part of dielectric constant (ϵ') of the ferrite samples has been calculated using formula $\epsilon' = Ct/\epsilon_0 A$ 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.

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 has been made to attach itself to a bar magnet through a mild steel rod due to the magnetic attraction 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 loses its 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 has been experimentally calculated in laboratory which is listed in table 1.

Table1. 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) | 500 K |
| Density (ρ) | 4.21 grams/cm^3 |
| Remanence | 0.90 |
| Coercivity | 1.50 |
| Dielectric Constant (ϵ) | 17.5 |
| Resonance Line Width (ΔH) | 370 Oersteds |
| Loss Tangent ($\tan \delta$) | < 0.0005 |

4. Simulation And Characterization

The dispersion curve for the material has been plotted and shown in fig. 2. It is clear 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 (10⁸). The rest part of curve represents MSW and Spin wave excitation. Spin wave excitation is the result of exchange forces between atoms.

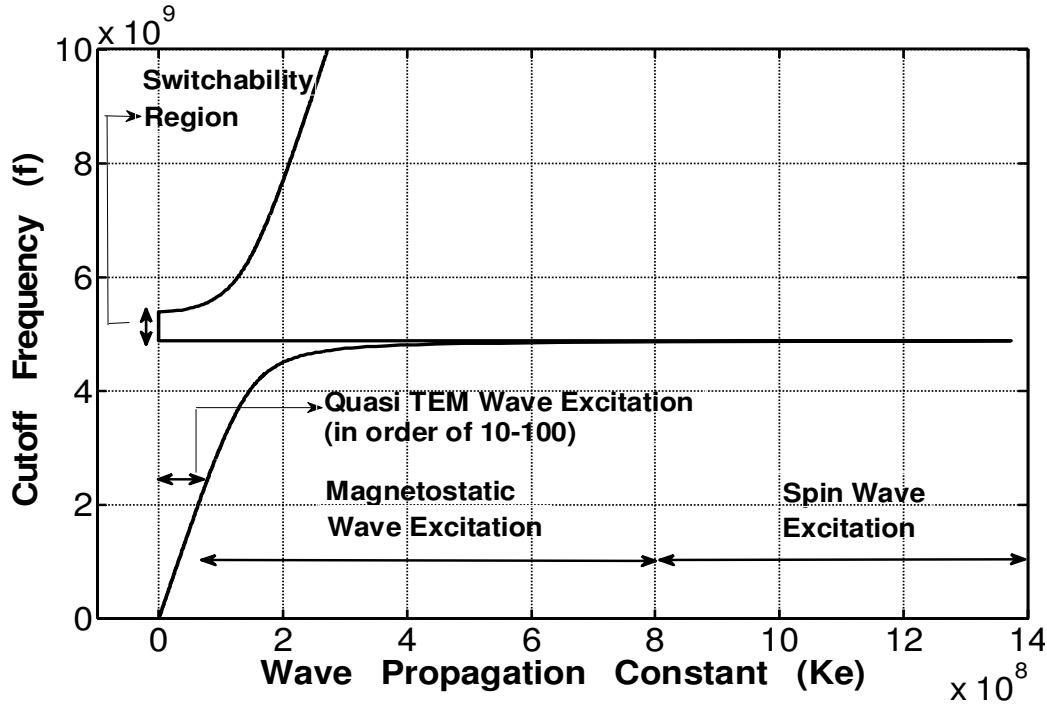


Figure 2. Dispersion curve (f vs. K) for plane wave propagation perpendicular to biasing field.

According to Fig. 2 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. Here obtained results are simulated and are in close agreement with results available in the literature.

The dimension of patch is calculated by following equations:

$$W = \frac{c}{2f \sqrt{\epsilon_{reff}}} \tag{7}$$

$$L = \frac{c}{2f \sqrt{\frac{(\epsilon_{reff} + 1)}{2}}} - 2 \Delta l \tag{8}$$

where

$$\left[\Delta l = 0.412 h \frac{(\epsilon_{reff} + 0.3)(a/h + 0.264)}{(\epsilon_{reff} - 0.258)(a/h + 0.8)} \right]$$

$$L_{eff} = L + 2\Delta l$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left(\frac{10h}{a} \right)^{-1/2}$$

These equations are based on Transmission Line model. Symbol a, b, h, is the width, length and thickness of the patch respectively. To obtain good performance, there are many feeding methods, such as CPW in the ground feeding microstrip antenna, and CPW with stub patch feeding slot antenna (Bahl et al, 1980; Balanis et al, 1982). Thus the far zone expressions for rectangular patch microstrip antenna are obtained as follow:

$$E_{\theta} = 0 \text{ and } E_{\phi} = -2jV_o W k F(\theta, \phi) \tag{9}$$

where V_o = voltage across the patch.

$$F(\theta, \phi) = \frac{\sin\left(\frac{kh}{2} \sin \theta \cos \phi\right)}{\frac{kh}{2} \sin \theta \cos \phi} \times \frac{\sin\left(\frac{kW}{2} \cos \theta\right)}{\frac{kW}{2} \cos \theta} \sin \theta$$

and

$$k_{\pm} = \omega^2 \epsilon \mu_0 \frac{(\omega_r + \omega_M)^2 - \omega^2}{\omega_r^2 + \omega_r \omega_M + \omega^2}$$

The polarization of antenna radiation can be decided by the propagation constant k as shown in table 2. 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 radiation patterns are plotted in fig. 3 & 4 for E-plane and H-plane respectively for this geometry. These curves show a comparison between unbiased and biased substituted polycrystalline ferrite substrate patch antenna.

The total field pattern $R(\theta, \varphi)$ is generally obtained from the relation [9-11]:

$$R(\theta, \varphi) = |E_{\theta t}|^2 + |E_{\varphi t}|^2 \quad (10)$$

The value of $R(\theta, \varphi)$ is computed for a case taking source frequency $f = 10 \text{ GHz}$, $k = k_+$, $\epsilon_r = 16$, $h = 0.165 \text{ cm}$, $s = 0.2104 \text{ cm}$ and loss tangent = 0.0005. For the array the element separation $d_x = d_y = \lambda/2 \text{ cm}$ and progressive phase excitation is $\beta_x = \beta_y = 0$.

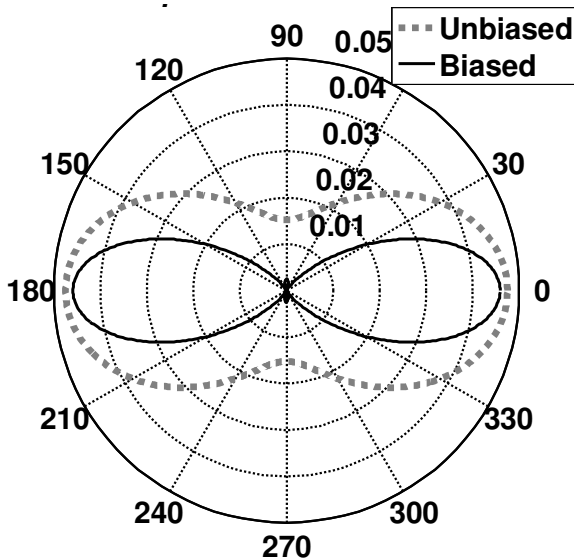


Figure 3. Comparison of E-plane pattern of rectangular patch microstrip antenna with RHCP for unbiased case and biased case.

Table 2 : Antenna's polarization function based on the propagation of magnetostatic and spin waves.

| Extraordinary Wave Propagation with Propagation Constant | Antenna Function |
|--|-------------------|
| Negative k | Off |
| Positive k_+ | Radiate with RHCP |
| Positive k_- | Radiate with LHCP |

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

| Parameters | Unbiased | Biased |
|------------------------------|------------|------------|
| Total Impedance (Z_{in}) | 32.54 ohms | 83.52 ohms |
| Quality Factor (Q) | ~7 % | ~7 % |
| Bandwidth (BW) | ~3 dB | ~3 dB |
| Directivity Gain (D) | 3.5 | 7.6 |
| Radiation Power (P_r) | 7.7 mW | 3.0 mW |
| Efficiency | 49 % | 49 % |

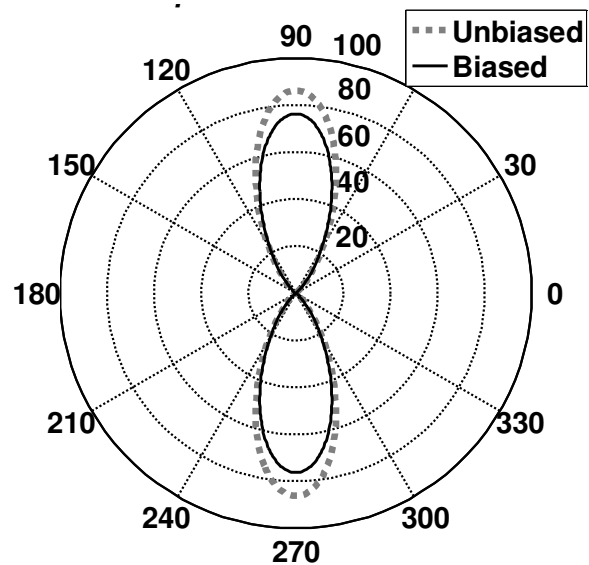


Figure 4. Comparison of H-plane pattern of rectangular patch microstrip antenna with RHCP for unbiased case and biased case.

Conclusions

The integration of ferrite technology into microstrip printed circuit antenna has numerous advantages and potential applications. In this paper we have synthesized LiTi polycrystalline ferrite substrate using SSRT as a substrate for microstrip rectangular patch 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 $H_0 = 1750$ Oe. While, for unbiased ferrite substrate bias field become $H_0 = 0$ Oe. The radiation patterns and antenna's characteristics are calculated and reported in fig. 3, 4 and table 1, 2, 3 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:

1. Comparison shows that on biasing, the radiation patterns becomes directive in nature. Directiveness can be observed by the comparison of E-plane pattern as shown in figure 3.
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 lies, except of the cutoff region. This property of antenna shows its switchable and tunable capability which can be varied as per requirement.
3. When the antenna became biased with DC magnetic field the parameters show that the directivity gain is increased but the radiation power is decreased accordingly. Measurement also shows the increasing of total impedance in the case of external DC biasing.
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.

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