Rectangular Microstrip Array Antenna on Biased Polycrystalline Ferrite Substrate as Signal to Noise Enhancer

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Abstract- **This paper describes a rectangular microstrip array antenna printed on synthesized LiTi ferrite, work as a signal to noise enhancer in the X-band. The array antenna which consists of 16 rectangular patches works on the principle of inverse dynamic nonlinearity of magnetostatic waves in ferrite substrates. The computed electric and magnetic properties are presented which show the significance of substitution of Ti for antenna performance. The proposed antenna structure is suitable for an accurate and sensitive communication system.**

Index Terms- **Magnetostatic waves, rectangular patch array antenna, substituted ferrite, S/N enhancer.**

I. INTRODUCTION

In recent years microstrip array antennas have received much attention due to their several unique features such as light weight, conformal in nature, integration with circuit or active devices and easy to construct. Dielectric substrates are normally used for designing these antennas. However ferrite materials due to non-reciprocal behavior play an important role in these antennas. When the magnetic oscillations are excited in limited region of the ferrite sample, then due to elasticity of this system some waves are propagated with a defined band frequency in the sample. This propagating disturbance represents a magneto-static-wave which is generated with the power of incident EM waves. It is evident that magneto-static-waves are generated when external magnetic field applied perpendicular to the magnetic field vector of EM waves. MSW are of two types: Surface MSW and Volume MSW. These generated MSW can suppress the noise in a desired frequency band. Due to which the array geometry behave like a signal to noise enhancer [1-6]. In communication system, an antenna accepts many signals including noise. Here except desired frequency (signal), all signals are treated as noise for antenna which are removed or ignored by filters.

Resonance Line Width (ΔH) which represents the EM wave's absorption that depends on the thickness of the sample as well as material has been taken into account for investigation. But for this antenna geometry the thickness of the antenna substrate chosen like that it does not fully affect the propagation. Generally garnet film is used for generating Volume MSW as well as Surface MSW in the form of microstrip line as S/N filter which is also not affected by ΔH. In the present array antenna we have taken Li substituted ferrite (LiTi ferrite) due to high saturation magnetization ($4\pi M_s$ = 2200 Gauss), high Curie temperature (T_c = 500°K) which are very essential for optimum performance of microstrip antenna [7-8].

II. PRINCIPLE

Consider a plane wave propagating in the perpendicular direction of antenna substrate 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 $\mu_o\gamma H_i$, 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 a magneto-static-wave. Magneto-static-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.

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 following classical dispersion equations first published by Damon and Eshbach in 1961, so that these wave also known as Damon-Eshbach waves. The dispersion relation given as follows:

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

Surface MSW band limits:

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

Surface MSW in metal coated ferrite:

$$\omega \le \mu_o\gamma\,(H + M_o) \quad (3)$$

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 is given below.

$$\omega^2 = \omega_H\left[\omega_H + \frac{\omega_M}{1 + \left(\frac{m\pi}{kt}\right)^2}\right] \quad (4)$$

Volume MSW band limits:

$$\mu_o\gamma H \le \omega \le \mu_o\gamma\sqrt{H(H+M_o)} \quad (5)$$

During propagation all type of waves propagates (EM, Surface and Volume MSW) but due to the resonance of applied magnetic field, absorption of incident EMW in the form of generation of the MSW happens. Volume MSW generate dominantly in the layered structure so that in this antenna process Volume MSW generation is negligible which does not affect the propagation of EMW and antenna characteristics [9-11].

III. ANTENNA STRUCTURE AND FABRICATION

Antenna structure is shown in figure 1. Sixteen patches of rectangular shape [length (a) = 0.2922 cm and breadth (b) = 0.4932 cm] are modeled on LiTi ferrite substrate of thickness (h = 2 mm).

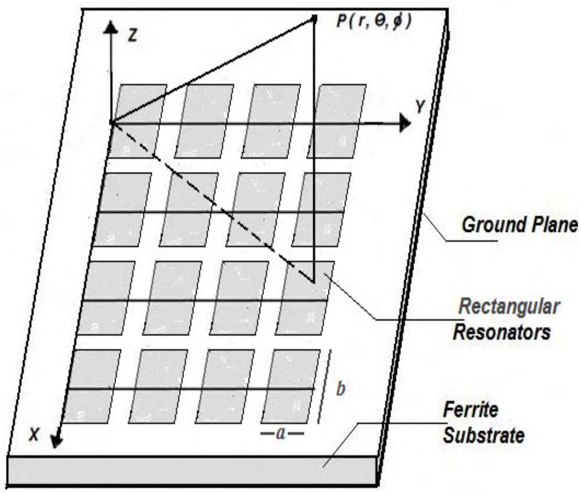

Fig: 1 Schematic diagram of antenna array of 16 elements

The separation between array elements is $d_x = d_y = \lambda/2\,cm$ and progressive phase excitation is $\beta_x = \beta_y = 0$. Each patch can be excited by a microstrip line connected to the edge or by a coaxial line from the back at the plane $\phi = 0$. The resonant frequency of the array geometry has been evaluated by the classical equation as follows:

$$f = \frac{c}{2\, a \sqrt{\varepsilon_{reff}}} \qquad (6)$$

where

$$a = \frac{c}{2\, f \sqrt{\frac{(\varepsilon_r + 1)}{2}}}$$

$$b = \frac{c}{2\, f \sqrt{\frac{(\varepsilon_{reff} + 1)}{2}}} - 2\Delta l$$

with

$$\Delta l = 0.412h \frac{(\varepsilon_{reff} + 0.3)\left({}^{a}/_{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left({}^{a}/_{h} + 0.8\right)}$$

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

Here equations are based on Transmission Line model. 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. Considering impedance matching of patches and microstrip lines, inset feeding structure is used. In order to obtain radiation field patterns, we have developed far zone fields expressions of this array geometry using vector wave function technique and pattern multiplication approach [12-14].

LiTi ferrite synthesized from the basic components of lithium ferrites In this work a typical composition of LiTi ferrite having room temperature magnetization (4πMs) of 2200 gauss (± 5%) and Curie temperature (T_c) of 500 K (± 5%) has been synthesized using solid state reaction technique (SSRT). 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 [15]. In order to avoid Lithia at high temperature of sintering, Bi_2O_3 (0.25 wt %) has been added as sintering aid [16]. 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 [17].

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 15mm × 6mm× 3mm 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 $\varepsilon' = Ct/\varepsilon_0 A$ 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.

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 is 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 LiTi ferrite substrate has been experimentally calculated in laboratory which is listed in table 1.

Table 1: The electrical and magnetic properties of LiTi ferrite substrate

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

IV. RESULTS AND DISCUSSION

On applying a DC magnetic bias field to LiTi ferrite substrate magnetostatic surface wave and partially (less in height or not layered) volume wave excited. Due to the metal patches and non layered structure, surface wave excited dominantly rather than volume magnetostatic wave.

In order to study non-reciprocal behavior of ferrite, the dispersion relation has been obtained which relates the propagation constant variation with respect to external magnetic field [9, 10].

$$k = \omega \left[(\varepsilon\mu_o) \times \frac{((\omega_r + \omega_m)^2 + \omega^2)}{(\omega_r^2 + \omega_m\omega_r - \omega^2)} \right]^{1/2} \quad (7)$$

where

$$\omega_o = \gamma H_o,\ \ \omega_m = \gamma 4\pi M_s\ ,\ \ \ \omega = 2\,\pi f$$

$$\omega_r = \ \omega_o + \ \omega_{ex}\, a^2\, k_o^2$$

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 (10^8). The rest part of curve represents MSW and Spin wave excitation. Spin wave excitation is the result of exchange forces between atoms. 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. Keeping all these points in view antenna structure has been arranged such that it can absorb all unwanted frequencies or noises. The absorbing limit of antenna`s substrate cover all the frequencies of noises which improve the S/N ratio. Here obtained results are simulated and are in close agreement with results available in the literature. Few decibel noise spikes signals of differ-differ wave form (sine, cosine and tangent) has been incorporated in incident signals which has reduced after applying external dc magnetic field. The suppressed noise frequency belongs to the band frequency of dispersion curve of MSW for the LiTi ferrite. After suppression the overall power of signal also decreased but very well within the affordable range in respect of noise suppression.

A comparison of parameters for unbiased and biased case is presented in table 2. Field patterns of array geometry for the values $f = 10\,GHz$, $\varepsilon_r = 17.5$, $h = 0.2\,cm$ are computed and plotted under unbiased and biased condition of LiTi ferrite substrate which are shown in fig 3 and 4 respectively. From these figures it can be observed that after applying magnetic field, noise as well as desired signal suppressed but the suppression of noise (low power) is considerable rather than desired signal (high power).

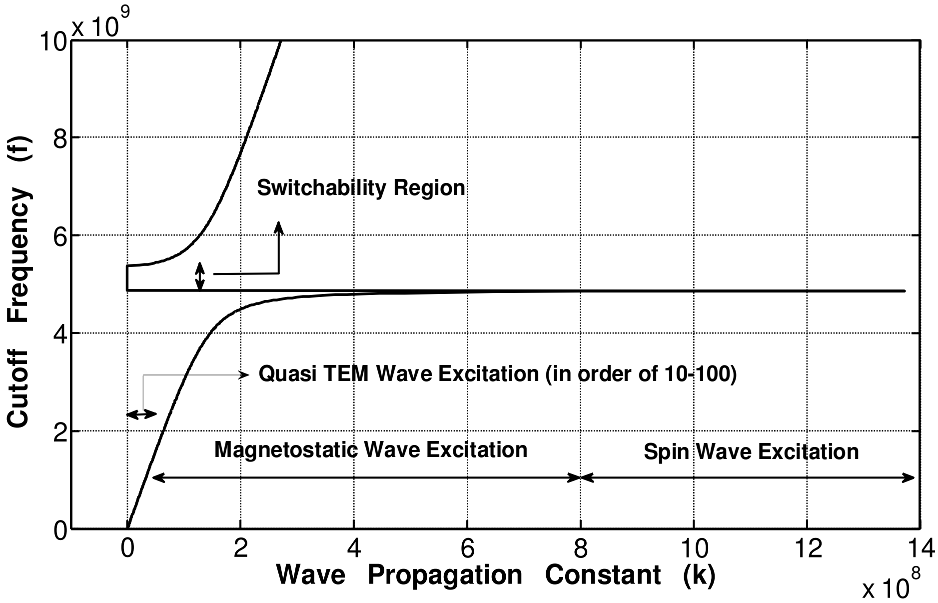

Fig. 2: Dispersion curve (f vs. k) of MSW in LiTi for incident plane wave perpendicular to the biased substrate by 750 Oe. magnetic field.

Table 2**:** Comparison of antenna parameters for unbiased and biased case

Parameters	Values (Unbiased)	Values (Biased)
Total Impedance (Z_{in})	124.93 ohms	76.35 ohms
Quality Factor (Q)	~12 %	~12 %
Bandwidth (BW)	~2 dB	~2 dB
Directive Gain (D_g)	5.7	3.4
Radiated Power (P_r)	2 mW	3.3 mW
H-Plane Beamwidth	166°	161°
E-Plane Beamwidth	178°	180°

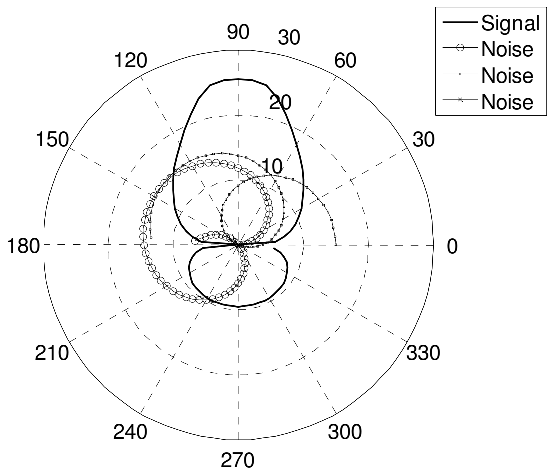

Fig. 3 Radiation pattern of array antenna with noise

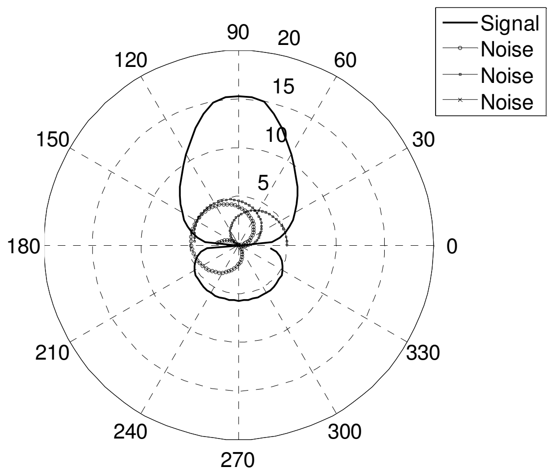

Fig. 4 Radiation pattern of array antenna with noise suppression

V. CONCLUSION

In the present communication, an important salient feature i.e. S/N enhancing characteristic of 16 elements array antenna have been described. Apart from this S/N enhancer, this array structure may also be useful as tunable antenna within the X band. Further this type of antenna configuration may be useful in high quality communication systems like cellular, satellite, scanning radar, etc. where noise suppression is one of the foremost requirements.

VI. REFERENCES

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