LiTiZn - Ferrite Radome for Satellite Communication

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Abstract: The magnetically switchable LiTiZn-Ferrite Radome's dispersion characteristics is presented for the satellite communication. A thin layer of LiTiZn-ferrite is used as superstrate or radome layer which control the radiation, reception, and scattering from a printed antenna or array by applying a dc magnetic bias field in the plane of the ferrite, orthogonal to the RF magnetic field. In this analysis absorbing and transmission power coefficient is calculated to obtain the power loss in radome layer and transmitted power through respectively. The absorbing power coefficient verifies the switching behavior of radome for certain range of applied external magnetic field (H_o) which depends on the resonance width parameter (ΔH) of ferrite material. By properly choosing the bias field, quasi TEM wave propagation in the ferrite layer can be made to be zero or negative over a certain frequency range, results a switching behavior in the ferrite layer. [Nature and Science 2009;7(11):9-14]. (ISSN: 1545-0740).

Key words: Substituted Li-ferrite superstrate layer, absorbing and transmission power coefficient, quasi-TEM and magnetostatic wave.

List of Symbols

f_r	=	resonant frequency
δ	=	thickness of radome layer
α	=	attenuation constant
β	=	phase constant
β_o	=	propagation constant in vacuum
ε_r	=	dielectric constant
μ_{eff}	=	effective permeability
μ, k	=	permeability tensor components of μ_{eff}
K_d	=	ordinary propagation constant
K_e	=	extraordinary propagation constant
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
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
Υ	=	gyromagnetic ratio (2.8 MHz / Oe.)

1. Introduction

Ferrite materials have a permeability tensor, whose elements can be controlled by the direction and strength of a dc magnetic bias field. A certain frequency range, results an evanescent wave behavior in the ferrite layer, and a large attenuation of the wave transmitted through the layer due to the generation of quasi-TEM modes and higher-order modes of the magnetostatic surface wave mode which propagates transversely to the quasi-TEM mode. This reciprocal behavior include the ability to tune the operating frequency of a microstrip antenna, the generation of circular polarization with a single feed point, the dynamic wide angle impedance matching of a phased array , and the reduction of microstrip antenna RCS using a normally biased ferrite substrate. In this work we describe the dispersion characteristics of radome layer by evaluating the absorbing and transmission power coefficients (Pozar et al., 1993, 1992, 1988; Fukusako et al., 1998).

With the help of proposed analysis we can also conclude, how a ferrite radome or superstrate layer can be used in conjunction with a printed antenna as a bulk effect "switch," whereby the antenna can be turned "on" or "off' by applying an appropriate magnetic bias field. This effect makes use of the negative permeability state of an extraordinary quasi TEM plane wave, propagating in a ferrite region. Applications include radar cross section reduction, EMP protection, and possibly a switchable polarizer. The idea of using the negative permeability effect of a ferrite for switching radome is not a new one (Dixit et al., 2000; Batchelor et al., 1997; Ufimtsev et al., 2000; Horsfield et al., 2000); but here a different approach is applying with new ferrite material LiTiZn-ferrite which is synthesized by Solid State Reaction Technique at Solid State Physics Laboratory, Timarpur, Delhi.

2. Synthesis of Radome Layer

LiTiZn ferrite synthesized from the basic components of lithium ferrites In this work a typical composition of LiTiZn ferrite having room temperature magnetization (4πMs) of 2200 gauss (± 5%) & Curie temperature (Tc) of 500 ^{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 (Uitert et al., 1956; Kishan et al, 1985). In order to avoid Lithia at high temperatures of sintering, Bi_2O_3 (0.25 wt %) was added as sintering aid (Randhawa et al, 2007). 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.

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)	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

The presintering of the mixed powder has been carried out at ~ 750^{o}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^{o}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.

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 $\times$ 6mm$\times$ 3mm were used. The dielectric measurements were conducted from 1 to 20 MHz. by a HP 4192 A impedance analyzer. The value of the real part of dielectric constant (ε') of the ferrite samples was calculated using formula $\varepsilon' = Ct/(\varepsilon_o A)$, (where ε_0 is the permittivity of free space = 8.854 $\times$ 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 LiTiZn 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 LiTiZn ferrite substrate is experimentally calculated are presented in table 1.

3. Theory of Operation

Consider a plane wave propagating in the perpendicular direction of radome layer with a magnetic bias field applied longitudinally. On the basis of magnetic field directions following waves are generated in the radome layer.

3.1 Magnetostatic mode of wave

MSW are generated when external magnetic field applied to the perpendicular direction of the magnetic vector of EM waves. MSW are two types **(1)** Surface MSW **(2)** Volume MSW. MSW will propagate perpendicularly on both sides to the EM wave's propagation [Lax et at, 1962].

Vol. MSW:

$$\mu_o \gamma H \le \omega \le \mu_o \gamma \sqrt{H(H+M_o)} \qquad (1)$$

Sur. MSW:

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

The absorption and transmission coefficients due to the generation of MSW in the ferrite slab are:

$$P = \frac{2\beta_o \varepsilon_r(\alpha \sin 2\beta\delta + \beta \sinh(2\alpha\delta))}{\left[\begin{array}{c} \beta_o^2\, \varepsilon_r^2\left((\cos\beta\delta)^2 + (\sinh(\alpha\delta))^2\right) \\ +(\alpha^2+\beta^2)\left((\sin\beta\delta)^2 + (\sinh(\alpha\delta))^2\right) \\ +\beta_o \varepsilon_r(\alpha \sin 2\beta\delta + \beta \sinh(2\alpha\delta)) \end{array}\right]} \qquad (3)$$

$$T = \frac{8(\alpha^2+\beta^2)\,\beta_o^2 \varepsilon_r}{\left[\begin{array}{c} [4\beta^2\beta_o^2\varepsilon_r^2 + (\alpha^2+\beta^2+\beta_o^2\varepsilon_r^2)^2]\cosh(2\alpha\delta) \\ +4\beta\beta_o\varepsilon_r(\alpha^2+\beta^2+\beta_o^2\varepsilon_r^2)\sinh(2\alpha\delta) \\ -[4\beta^2\beta_o^2\varepsilon_r^2 + (\alpha^2+\beta^2-\beta_o^2\varepsilon_r^2)]\cosh(2\beta\delta) \\ +4\alpha\beta_o\varepsilon_r(\alpha^2+\beta^2-\beta_o^2\varepsilon_r^2)\sin(2\beta\delta) \end{array}\right]} \qquad (4)$$

where

$$\alpha = \beta_o \sqrt{\left(\frac{\varepsilon_r}{2}\right)} \sqrt{\left[\sqrt{(\mu'^2 + \mu''^2)} - \mu'\right]}$$

$$\beta = \beta_o \sqrt{\left(\frac{\varepsilon_r}{2}\right)} \sqrt{\left[\sqrt{(\mu'^2 + \mu''^2)} + \mu'\right]}$$

and

$$\mu' = 1 + \chi'$$

$$\mu'' = \chi''$$

where

$$\chi' = \frac{\omega_m\, T\,(\omega_o + \omega)}{(\omega_o - \omega)^2 T^2 + 1}$$

$$\chi'' = \frac{\omega_m\, T}{(\omega_o - \omega)^2\, T^2 + 1}$$

with

$$T = \frac{2}{\sqrt{\times}\,\Delta H} \quad and \quad \beta_o = \frac{\omega}{c}$$

3.2 Quasi TEM mode of wave

As discussed in (Lax et al, 1962; Kabos et al, 1994; Sodha et al, 1981), 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 K_e. In the case of extraordinary mode, the propagation constant dependence on the basic parameters is given as

$$\gamma_e = \alpha_e + j\beta_e = j\omega\sqrt{\mu_{eff}\,\varepsilon_r} \qquad (5)$$

where μ_{eff} is the effective permeability

$$\mu_{eff} = \frac{\mu^2 - k^2}{\mu}$$

$$\mu = 1 + \frac{\omega_o \omega_m}{\omega_o^2 - \omega^2}$$

$$k = \frac{\omega \omega_m}{\omega_o^2 - \omega^2}$$

where $\omega_o = \gamma H_o$, $\omega_m = \gamma 4\pi M_s$, 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 wave mode, the propagation constant dependence on the basic parameters is given as

$$\left(\frac{K_e}{K_d}\right)^2 = \frac{(\omega_o + \omega_m)^2 - \omega^2}{\omega_o(\omega_o + \omega_m) - \omega^2} \qquad (6)$$

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

$$[\omega_o(\omega_o+\omega_m)]^{1/2} < \omega < (\omega_o+\omega_m) \qquad (7)$$

The frequency limits define the approximate range within and around which the ferrite exhibit interesting microwave characteristics.

4. Setup

Figure 1 shows the arrangement of an experimental setup for the validation of the switchable ferrite radome effect.

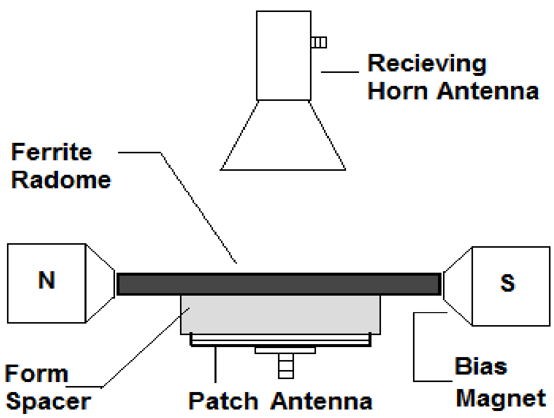

Figure 1. Setup for the measurement of radome power coefficients. Ferrite is 2 mm thick with 2200 Gauss saturation magnetization, '16' dielectric constant and 1800 Oe magnetic resonance width.

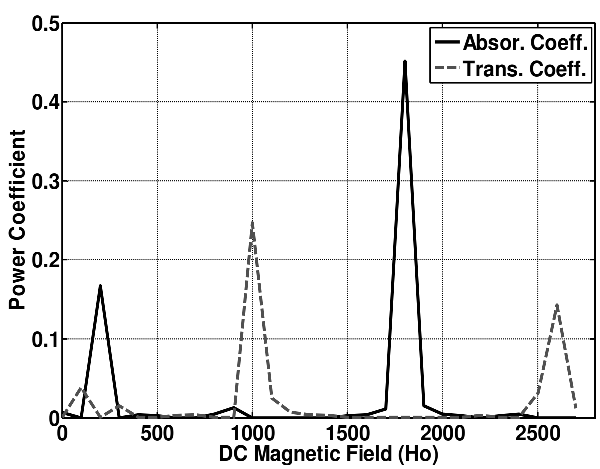

Figure 2: Comparison of transmission (T) and absorption (P) power coefficient with the varying DC magnetic field (H_o)

A 2 x 2 circular microstrip patch array was fabricated on a RT-duroid substrate, and operated at 10 GHz. A 1-cm foam spacer separated the array face from the ferrite radome. The ferrite layer was 44mm diameter, and was mounted between the poles of a laboratory electromagnet. An X-band waveguide-to-coax adapter was used as a receiving antenna, and was spaced about 5 cm above the ferrite layer.

As illustrated in Figure 1, a ferrite superstrate or radome layer can be placed above a microstrip antenna or array (Or any type of antenna, for that matter), and used as a switch. In practice such a ferrite layer could be spaced a small distance above the antenna, or placed directly over the antenna as a superstrate layer. Spacing the ferrite above the antenna may be preferable for ease of biasing, and also to minimize the direct interaction of the ferrite with the antenna elements (Bahl et al, 1980; Balanis et al, 1982).

5. Results

When the ferrite layer is unbiased, or biased to a state where $K_e > 0$, the antenna will transmit and receive as normal. When the ferrite is biased to the cutoff state where $K_e < 0$, however, an incident wave will be transformed to quasi-TEM and magnetostatic waves, which largely absorb and attenuate the incident RF waves.

From the graph figure 2 we can see, the absorbing power is max between 1700 Oe and 1850 Oe which is in good agreement of dispersion graph figure 3 plotted for LiTiZn-ferrite radome layer.

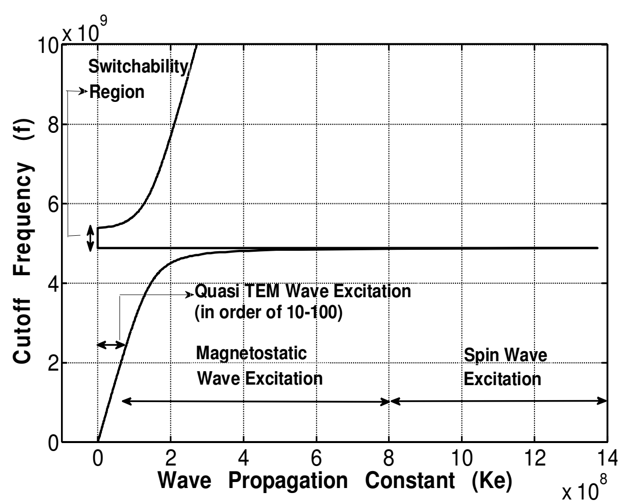

Figure 3: Dispersion curve (f vs. K_e) for incident plane wave perpendicular to biased radome layer

Dispersion graph depicts the switch off state of radome layer for cutoff frequency (f) around 5 to 5.5 GHz. From the figure 2, we can also observe the transmitted power coefficient variation with varying external DC magnetic field.

The amount of absorption and attenuation can be increased by operating the ferrite in a bias state to maximize power loss or by increasing the thickness of the ferrite layer (figure 4 and 5). If desired, dielectric matching layers could be placed on either side of the ferrite layer to reduce reflections. Magnetic and dielectric losses will have the effect of increasing the amount of attenuation; as compared to the lossless state (although at the point of maximum cutoff the attenuation may actually decrease slightly with the addition of magnetic losses).

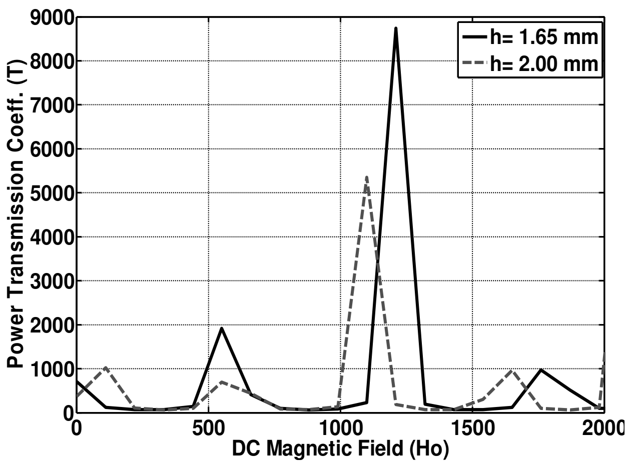

Figure 4: Transmission (T) power coefficient with the varying DC magnetic field (H_o)

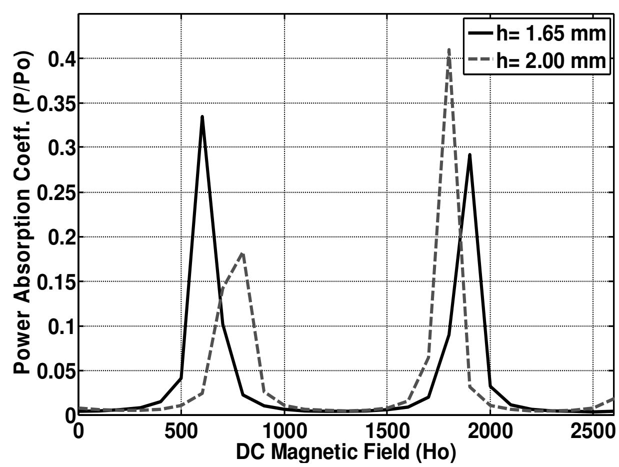

Figure 5: Absorption (P) power coefficient with the varying DC magnetic field (H_o)

Conclusion

The Dispersion Characteristics of thin layer radome of LiTiZn-ferrite under external DC-magnetic is presented. Resulted absorbing power coefficients graph, verifies the dispersion relation graph obtained by quasi-TEM cutoff frequency range. As discussed, this is a very simple approach which ignores reflections at the ferrite-air interfaces, as well as multiple reflections between the ferrite and antenna layers, but it is found to give a reasonable justification of the attenuation through the radome layer. More sophisticated (e.g., full-wave) analysis may be necessary if the ferrite layer is in direct contact with the antenna or array. It is seen that the frequency where maximum attenuation occurs can be tuned by adjusting the bias field. Also note that the attenuation is greater for higher frequencies, primarily because the ferrite layer looks electrically thicker.

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