A Magnetically Switchable Ferrite Radome for Printed Antennas

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***Abstract*—A ferrite superstrate or radome layer can be used to 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. By properly choosing the bias field, the effective permeability of an extraordinary plane wave propagation in the ferrite region can be made to be zero or negative over a certain frequency range, resulting in an evanescent wave behavior in the ferrite layer, and a large attenuation of the wave transmitted through the layer. Similarly, the radar cross section of the antenna will be reduced by twice this attenuation factor. A simple model capable of predicting the gross behavior of the ferrite radome layer is presented, and experimental data is shown to validate the concept.**

I. Introduction

Because ferrite materials have a permeability tensor whose elements can be controlled by the direction and strength of a dc magnetic bias field, their application to microstrip antennas and arrays can lead to a variety of new and useful phenomenon that cannot be achieved with ordinary dielectric materials. These include the ability to tune the operating frequency of a microstrip antenna [1], the generation of circular polarization with a single feed point [2], [3], the dynamic wide angle impedance matching of a phased array [3], and the reduction of microstrip antenna RCS using a normally biased ferrite substrate [4]. In this letter we describe 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 plane wave propagating in a ferrite region [5], [6]. 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 is not a new one; related work on ferrite-loaded waveguide switches was reported several decades ago [6]–[8], and the cutoff characteristics of propagation through a ferrite slab is also well known [6]. But the application to RCS reduction, especially in the context of conformal or planar antennas, has apparently been unrealized.

II. Theory of Operation

Consider a plane wave propagating in the z-direction in an infinite ferrite region with a magnetic bias field applied in the x-direction. As discussed in [5]–[6], if the plane wave is polarized in the y-direction (so that the RF magnetic field is parallel to the dc bias field), there will be no interaction with the magnetic properties of the ferrite; this case is referred to as the ordinary wave. When the plane wave is x-polarized (RF magnetic field orthogonal to the bias field), there is an interaction with the magnetic properties of the ferrite, and this case is referred to as the extraordinary wave. The complex propagation constant for an extraordinary plane wave is given as,

$$\gamma_e = \alpha_e + j\beta_e = j\omega\sqrt{\mu_{\text{eff}}\epsilon}, \tag{1}$$

where μ_{eff} is the effective permeability,

$$\mu_{\text{eff}} = \left(\mu^2 - \kappa^2\right)/\mu\,, \tag{2}$$

and μ and κ are elements of the ferrite permeability tensor,

$$\mu = \mu_o\left[1 + \omega_o\omega_m/\left(\omega_o^2 - \omega^2\right)\right] \tag{3a}$$

$$\kappa = \mu_o\omega\omega_m/\left(\omega_o^2 - \omega^2\right) \tag{3b}$$

with $\omega_o = \mu_o\gamma H_o$, $\omega_m = \mu_o\gamma M_s$, $\gamma = 1.759 \times 10^{11}$ C/Kg. M_s is the saturation magnetization of the ferrite, and H_o is the internal bias field. If necessary, both magnetic and dielectric loss can be included in these results.

In the absence of loss, γ_e is pure imaginary when $\mu_{\text{eff}} > 0$ and pure real when $\mu_{\text{eff}} < 0$; the former case corresponds to a propagating plane wave, while the latter corresponds to a nonpropagating evanescent plane wave in the ferrite region. Using (2)–(3), it can be shown that μ_{eff} will be negative whenever the following condition is satisfied:

$$\sqrt{\omega_o(\omega_o + \omega_m)} < \omega < \omega_o + \omega_m\,. \tag{4}$$

If it is assumed that the ferrite layer does not perturb the near field of the antenna, and multiple reflections between the antenna and the ferrite are ignored, the one-way attenuation of a wave through the ferrite layer can be approximated as

$$\exp\left(\alpha_e d\right), \tag{5}$$

where d is the thickness of the ferrite layer.

Thus, as illustrated in Fig. 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. When the ferrite is unbiased, or biased to a state where $\mu_{\text{eff}} > 0$, the antenna will transmit and receive as normal. When the ferrite is biased to the cutoff state where $\mu_{\text{eff}} < 0$, however, an incident wave will be largely reflected. Because of the finite value of α_e, and the finite thickness of the

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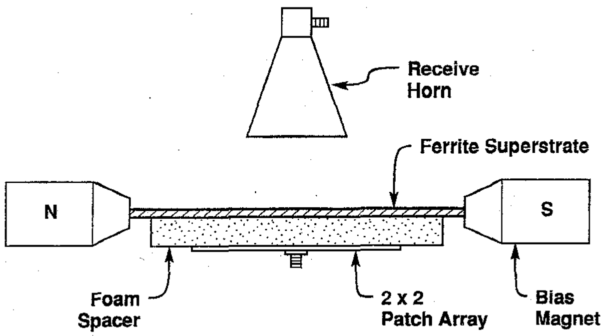

Fig. 1. Setup for the measurement of transmission loss through a magnetically biased ferrite superstrate layer. Ferrite was 1.27-mm thick, with a saturation magnetization of $4\pi M_s = 780$ G and $\epsilon_r = 11.25$. Operating frequency was 9.04 GHz.

ferrite layer, the wave will not be totally reflected; much like a beyond-cutoff waveguide attenuator, some power will leak through the layer. As indicated in (5), the amount of attenuation can be increased by operating the ferrite in a bias state to maximize α_e, or by increasing the thickness of the ferrite layer. 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). Because scattering from the antenna involves a two-way path through the ferrite layer, the RCS of the antenna will be reduced by the square of the value given in (5) (twice the attenuation in dB). When biased to cutoff, the ferrite radome will reflect an incident plane wave specularly, but the antenna element itself will not contribute to the scattered field.

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. Placing the ferrite directly on the antenna elements may, however, allow this interaction to be used to further advantage, although modeling such a configuration will probably require full-wave techniques [2]. In any case, the cutoff effect previously described only works when the RF magnetic field is orthogonal to the dc bias field. This should not be a problem for linearly polarized antennas, but there will be difficulty with dual or circularly polarized antennas. It may also be possible to utilize the birefringent effect of the ferrite layer to produce a switchable polarizer, or the cutoff effect with a circularly polarized antenna to switch between circular and linear polarization.

The dc bias field is applied in the plane of the ferrite layer, which is convenient because there are no demagnetization factors in this case, and because a closed magnetic circuit can be arranged without perturbing the radiating aperture of the antenna. This is contrast to the normal bias condition required in [4]. In addition, the existence of a closed magnetic circuit may allow the ferrite to be latched in a biased state, which would greatly reduce the necessary size of the bias electromagnet and associated power supply.

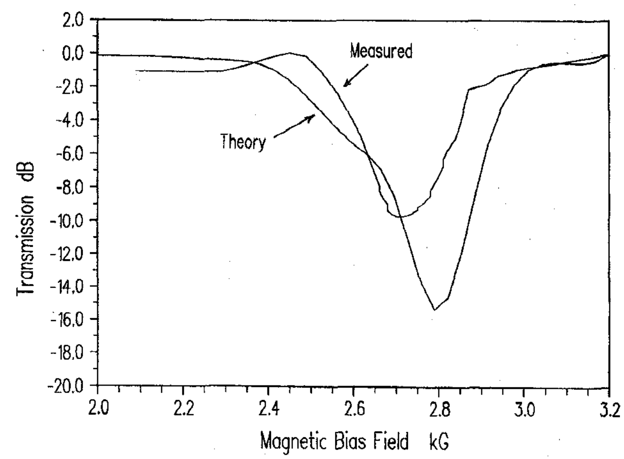

Fig. 2. Measured relative transmission loss versus bias field strength for the arrangement of Fig. 1. Calculations are based on (5), and include a samll magnetic loss factor.

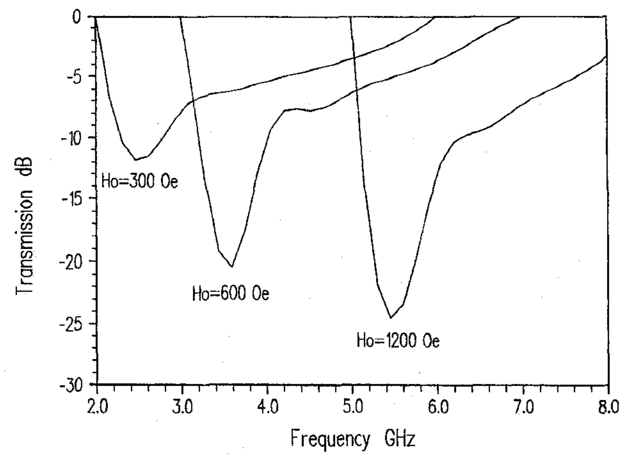

Fig. 3. Calculated transmission loss versus frequency for three different bias fields. Ferrite has $4\pi M_s = 1780$ G, $\epsilon_r = 15$, and $d = 1.5$ mm. Loss is not included.

III. Results

Fig. 1 shows the arrangement of a laboratory setup for the experimental validation of the switchable ferrite radome effect. A 2×2 microstrip patch array was fabricated on a PTFE substrate, and operated at 9.04 GHz. A 1-cm foam spacer separated the array face from the ferrite radome. The ferrite layer was 3-in square, 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. The received power was measured as the bias field was adjusted, with the results shown in Figure 2; these results are normalized to the maximum received power.

For this ferrite material and frequency, μ_{eff} is negative for a bias field between 2400 and 2800 Gauss, which roughly corresponds to the measured cutoff range in Fig. 2. It is seen that a maximum transmission loss of about 10 dB is achieved with a bias field of about 2700 G. Fig. 2 also shows calculated data obtained from (5), with the inclusion of magnetic loss. As discussed above, this is a very simple model 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 prediction 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.

Fig. 3 shows additional data calculated using this model, in this case for a ferrite with no loss and $4\pi M_s = 1780$ G. The transmission loss is plotted versus frequency for three different bias fields. 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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