RCS Reduction for a Microstrip Antenna Using a Normally Biased Ferrite Substrate

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Abstract—**It is shown that the radar cross section of a microstrip antenna can be significantly reduced over a broad frequency range by using a ferrite substrate biased to a cutoff state. When unbiased, the antenna operates in its usual fashion, with relatively large RCS peaks at frequencies corresponding to the resonances of the patch element. When the ferrite substrate is properly biased, the antenna element becomes effectively short-circuited, resulting in the elimination of the resonant behavior of the scattering response of the patch, and a reduction of 20–40 dB in its RCS. This mechanism allows the implementation of a microstrip antenna or array system that can be switched to an "off" state, where it will be much less visible to an interrogating radar. Calculated results are obtained from a full-wave moment method solution for the RCS of a microstrip antenna on a normally biased ferrite substrate.**

I. Introduction

Ferrite materials have been used for many years in microwave components, but only recently have they begun to be considered for use with planar antenna systems. The main advantage in this application is that ferrites provide material parameters that can easily be controlled by adjusting an externally applied dc magnetic bias field, thus enabling control of various radiation and scattering characteristics of the antenna. Previously, it has been shown that the resonant frequency of a microstrip antenna can be magnetically tuned in this manner [1], and that this tuning effect can also be used to frequency tune the RCS peaks of a microstrip antenna. Here we show that biasing the ferrite substrate to a cutoff state can eliminate the peaks in the RCS of a microstrip antenna.

Results are obtained from a full-wave moment method solution for a probe-fed microstrip antenna [3], using the exact Green's function for the normally biased ferrite substrate. As shown in [3], the RCS of a typical microstrip antenna is characterized by relatively large peaks on the order of −20 dBsm at frequencies where the dominant mode, as well as higher order modes, become resonant. The type of load connected to the patch also affects its RCS; generally an open-circuited element has the highest RCS, while a resistive load tends to reduce the peak RCS. Depending on the incidence angle, the aspect ratio of the patch, and the modes of the patch that are excited, the scattered field may be cross-polarized from the incident field.

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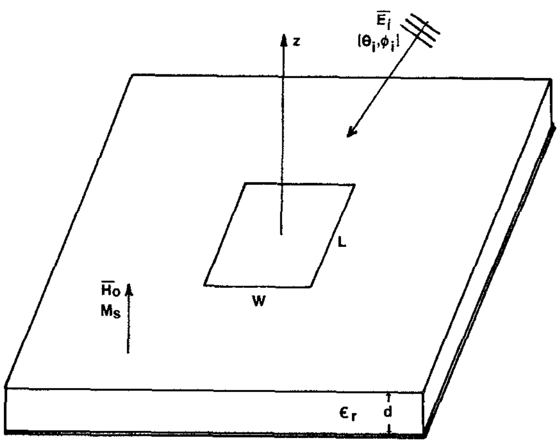

Fig. 1. Geometry relevant to the radar cross section of a microstrip antenna on a normally biased ferrite substrate.

II. Results

The microstrip antenna RCS geometry is shown in Fig. 1; the ferrite has a saturation magnetization M_s, and an internal bias field strength of H_o. Note that, due to the demagnetization factor for this geometry, the relation between the external applied field, H_e, and the internal field is $H_o = H_e - 4\pi M_s$ (in CGS units). The permeability tensor, assuming a z-directed bias field, is given by [4],

$$[\mu] = \begin{bmatrix} \mu & j\kappa & 0 \\ -j\kappa & \mu & 0 \\ 0 & 0 & \mu_o \end{bmatrix} \tag{1}$$

with elements given by,

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

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

where $\omega_o = \mu_o\gamma H_o$ and $\omega_m = \mu_o\gamma M_s$. Thus, the internal field, H_o, may be zero while the ferrite is biased and saturated, with a nonzero value of κ.

We consider a monostatic radar with incidence angles θ_i, φ_i, and examine all four components of the cross section: $\sigma_{\theta\theta}$, $\sigma_{\theta\varphi}$, $\sigma_{\varphi\theta}$, and $\sigma_{\varphi\varphi}$. Bistatic cross section could be easily treated, but the radiation pattern of the patch is fairly broad, so there are no rapid variations with angle, at least for frequencies near the lowest order resonances of the patch. It is especially important in this case to consider cross-polarization of the scattered field because the ferrite can cause a significant

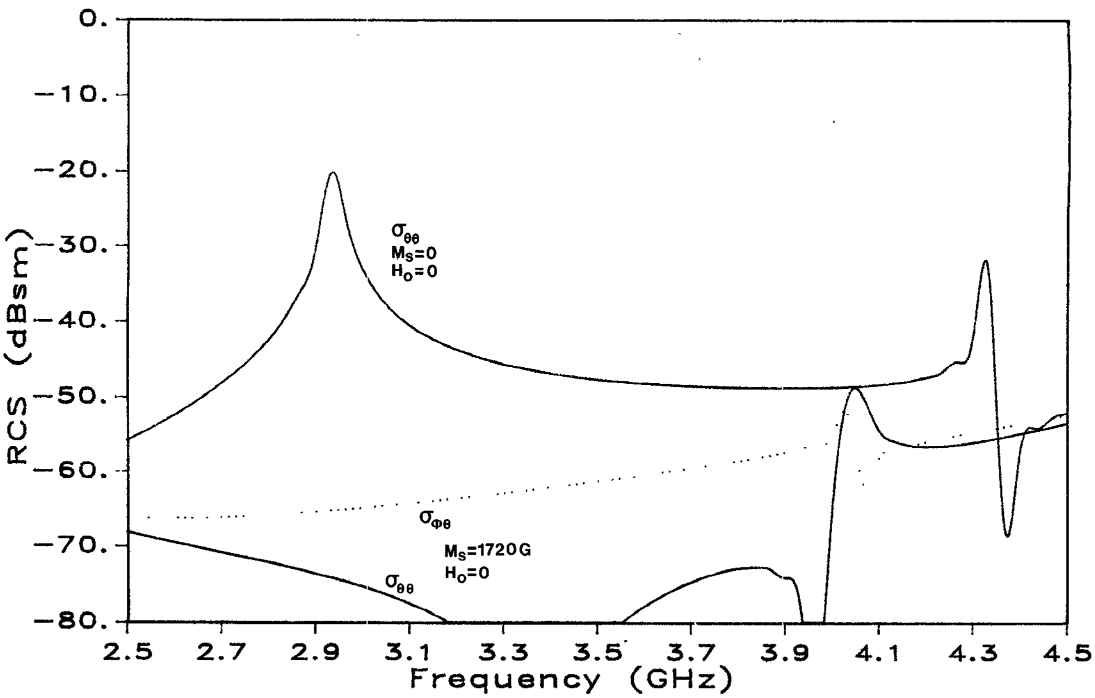

Fig. 2. Radar cross section versus frequency for a square microstrip antenna on a normally biased ferrite substrate. $L = W = 1.3$ cm, $d = 0.13$ cm, $\epsilon_r = 15$, $4\pi M_s = 1720$ G, $\theta_i = \varphi_i = 45°$, no load on patch.

amount of depolarization. Finally, we note that the scattered fields considered here include only the fields radiated by the patch, and do not include the specularly reflected field from the substrate or ground plane. This is because the pattern of a plane wave reflected from an infinite substrate has a zero beamwidth, and thus, can only affect the monostatic RCS in the broadside direction

Fig. 2 shows the calculated RCS of a square microstrip patch antenna on a ferrite substrate for an unmagnetized state ($M_s = H_o = 0$), and for a magnetized state ($M_s = 1720$ G, $H_o = 0$). The response for the unmagnetized case shows a large peak at about 2.9 GHz, which corresponds to the dominant mode of the patch antenna. The cross-polarized scattering response for this case is zero. When the ferrite is magnetized to saturation, the resonant peak at 2.9 GHz is completely eliminated, leaving a residual cross section of about -65 to -75 dBsm. Also note that the cross-polarized scattering component, $\sigma_{\theta\varphi}$, is actually greater than the co-polarized component. Although the cross section for the magnetized state is as high as -50 dBsm at some frequencies, it is always at least 20 dB below the worst-case peaks of the unmagnetized case (this remains true over the frequency range of at least 1 to 5 GHz).

Fig. 3 shows the input impedance versus frequency for this antenna with the substrate in both the unmagnetized and magnetized states. For the unmagnetized state we see the typical resonance locus and large resistance that characterizes the input impedance of a microstrip antenna. When the substrate is magnetized, however, the antenna no longer resonates, and the impedance is characterized by a small locus near the zero impedance point of the chart.

Although these results were obtained using a rigorous full-wave solution, it is easier to get an intuitive understanding of

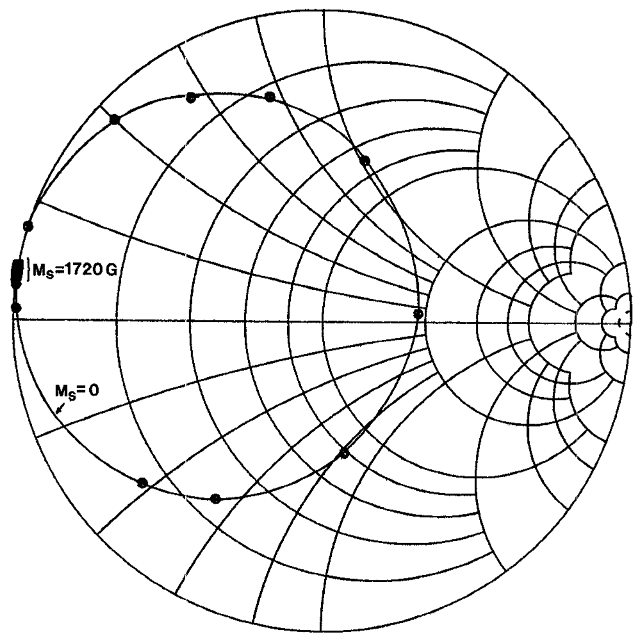

Fig. 3. Smith chart plot of the input impedance versus frequency for the patch antenna of Fig. 2, for both the magnetized and the unmagnetized states. Probe feed is located 0.5 cm from an edge.

these results from a simple cavity model for the patch antenna on a ferrite substrate. Such a model has been developed, and shows that the fields under the patch antenna are similar to those of an extraordinary plane wave propagating in a biased ferrite medium [4], having a cutoff region when $\mu_{\text{eff}} < 0$, where,

$$\mu_{\text{eff}} = \left(\mu^2 - \kappa^2\right)\mu, \tag{3}$$

and μ and κ are given in (2). The relation $\mu_{\text{eff}} < 0$ thus defines the combination of frequency and bias field where the antenna will be cutoff. For the example considered here, $\mu_{\text{eff}} < 0$ for the magnetized state for $f < 5$GHz.

III. Conclusion

A technique for reducing the RCS of a printed antenna by 20 to 40 dB through the use of a biased ferrite substrate has been proposed. The resulting RCS reduction occurs over a broad frequency range, and requires only moderate values of bias field. The same technique should also be applicable to arrays of printed antennas. Work is underway to see if the same effect can be achieved with a magnetic bias applied in the plane of the ferrite substrate; in practice, an in-plane bias would be easier to achieve than the normal bias condition used here, and would allow the substrate to be used in a "latched" mode of operation.

References

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