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The RCS of a Microstrip Antenna on an In-Plane Biased Ferrite Substrate

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***Abstract*—The numerical solutions for the RCS of a microstrip patch on an in-plane biased ferrite substrate are presented. The peaks in the RCS can be moved with respect to frequency by changing the magnetic bias field. We consider a monostatic RCS with various incident angles and examine all four elements of the cross-section matrix. For the case of an unmagnetized ferrite substrate the cross-polarized RCS components are zero. When the ferrite is magnetized, the cross-polarized RCS components become as significant as do the copolarized RCS components. It is also shown that a loaded patch has the effect of significantly reducing RCS at resonances. The analysis used is based on a full-wave moment method with the exact spectral-domain Green's function.**

I. Introduction

THE nonreciprocal property of ferrite materials has been used in microwave components for many years. More recently, the bias dependent property of ferrite materials has been used to control printed circuits and antennas [1]–[4]. The bias field can be in different directions. It has been demonstrated experimentally that the resonant frequency of a microstrip antenna printed on a ferrite substrate can be tuned over a 40% frequency range for an in-plane bias by adjusting the applied magnetic bias strength [5], and that the polarization can be changed with bias field also [6]. In [7]–[8], the RCS of a microstrip antenna on a ferrite substrate biased normally was discussed. In [9], one element of the RCS matrix of a microstrip patch on an arbitrarily biased ferrite substrate was presented. In practice, an in-plane bias would be easier to achieve than a normal bias because an in-plane bias allows two pole pieces of the magnet to be in close contact with the substrate [5]. Also, the in-plane external bias is equal to the internal bias for the case of an infinite substrate. The same is not true for the normal bias components since a normal external bias must oppose the internal magnetization of the substrate. Since the in-plane bias case seems to be of most practical interest, the monostatic RCS of a microstrip antenna on an in-plane biased ferrite substrate is considered in the present work. In this case, it is interesting to consider cross polarization of the scattered field since the polarization can change significantly with applied bias field as discussed in [6]. Thus, this work considers the full cross-section matrix.

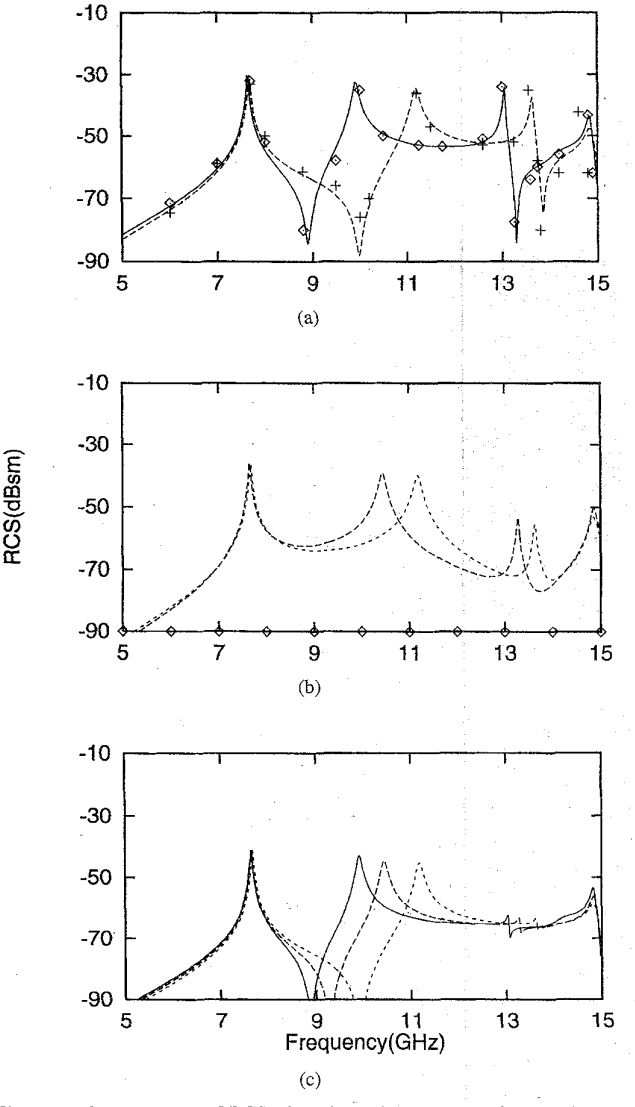

Fig. 1. All components of RCS of a microstrip patch on a ferrite substrate for different bias conditions with incident angle, $\theta = 60°$, $\phi = 45°$. (a) $\sigma_{\theta\theta}$: Unmagnetized: ——, ◇◇◇◇ in [9]; $H_0 = 360$ G: ------, $+ + + +$ in [9] (b) $\sigma_{\phi\theta}$: Unmagnetized: ◇◇◇◇; Latched: ----; $H_0 = 360$ G: ------ (c) $\sigma_{\phi\phi}$: Unmagnetized: ——; Latched: ----; $H_0 = 360$ G: ------.

We also study the RCS properties of a loaded rectangular patch on a biased ferrite substrate. The present work uses an idealized-probe-feed model. This model should be adequate for an electrically thin substrate.

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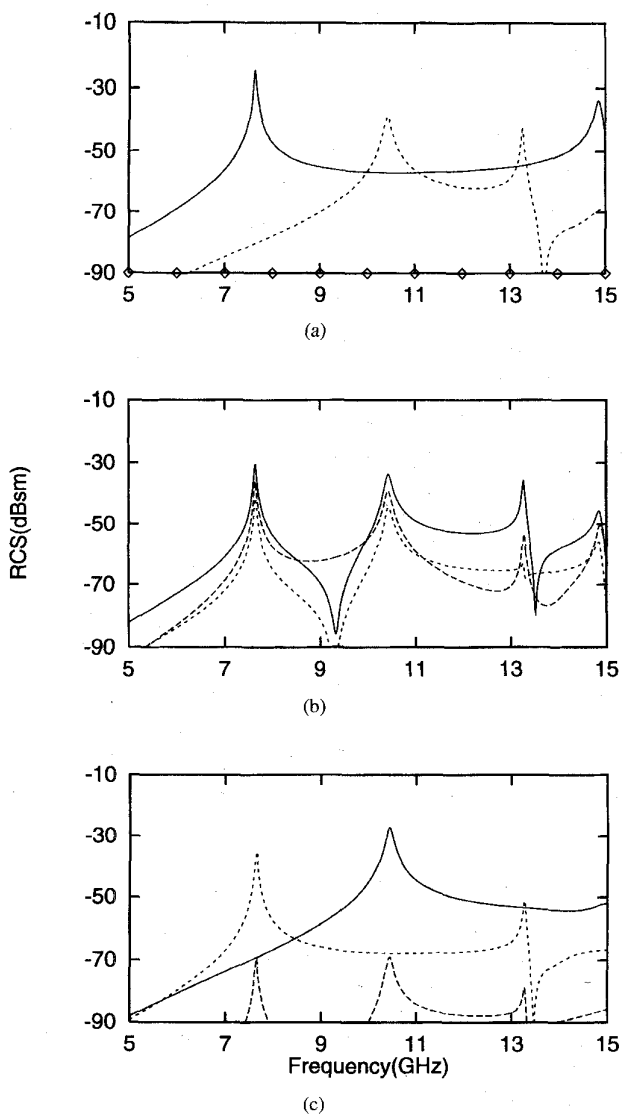

Fig. 2. All components of RCS of a microstrip patch on a latched ferrite substrate with various incident angles. ——: $\sigma_{\theta\theta}$, – – –: ($\diamond\diamond\diamond$): $\sigma_{\phi\theta}$, – – – –: $\sigma_{\phi\phi}$ (a) $\theta = 60°$, $\phi = 0°$, (b) $\theta = 60°$, $\phi = 45°$, and (c) $\theta = 60°$, $\phi = 90°$.

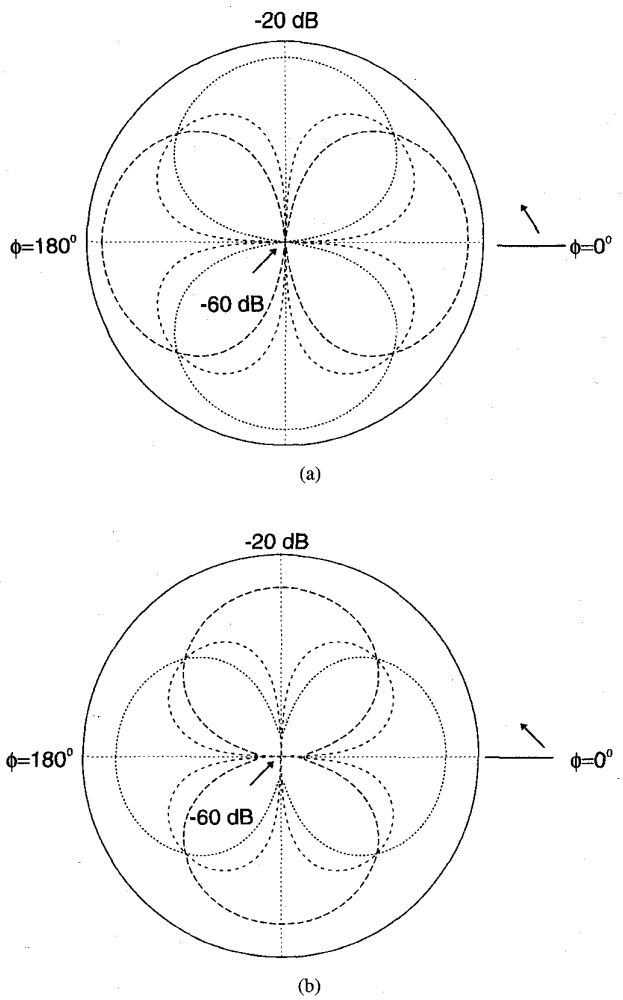

Fig. 3. RCS patterns of a latched ferrite patch antenna with incident angle, $\theta = 60°$. (a) $f = 7.65$ GHz and (b) $f = 10.44$ GHz ——— $\sigma_{\theta\theta}$ (dBsm), – – – – – $\sigma_{\phi\theta}$ (dBsm), ------ $\sigma_{\phi\phi}$ (dBsm).

II. Numerical Result and Discussion

To validate our results, numerical values of the RCS are compared against those in [9] and [10] for various bias conditions. In a limiting case, when the bias field H_0 and $4\pi M_s$ are both set to zero, the numerical Green's function and the RCS results are almost identical to those in [10] on a dielectric substrate and show a good agreement with that in [9]. Also in a magnetized state, the copolarized RCS component ($\sigma_{\theta\theta}$) show an excellent agreement with that in [9], as shown Fig. 1(a). The numerical integrations carried out to evaluate the impedance and voltage matrix use the complex integration path deformation technique to avoid surface wave poles as in [10]. Since most of the computational effort occurs in evaluating these integrals, interpolation of the elements between frequency points is used to save CPU time as in [10]. All numerical results were made by computing the impedance matrix every 0.1 GHz, and then using quadratic interpolation to approximate the impedance matrix at intervals of 0.01 GHz.

Here, we show the RCS response of a microstrip patch on an in-plane biased ferrite substrate, and show that the RCS peaks shift in frequency and are almost unchanged in amplitude by changing the magnetic bias field. The parameters used for the analysis of RCS of a patch on a ferrite substrate are $H_0 =$ 0 G, 360 G; $4\pi M_s = 1780$ G; $4\pi M_r = 1277$ G, $\varepsilon_r =$ 12.8; $\tan\delta = 0.0002$; $\Delta H = 45$; $Z_L = 50\Omega$; and $d =$ 0.6 mm. The microstrip patch has length $L = 0.55$ cm and width $W = 0.4$ cm. Fig. 1(a), (b), and (c) show all four elements of RCS matrix of a microstrip patch on a biased ferrite substrate with different bias conditions. The microstrip patch has two types of modes: one is the mode with its $\overline{H}$ perpendicular to the bias ($\perp$), and two is the mode with its $\overline{H}$ parallel to the bias ($||$). When the magnetic bias field becomes strong, the RCS peaks of $\perp$ modes shift to higher frequencies.

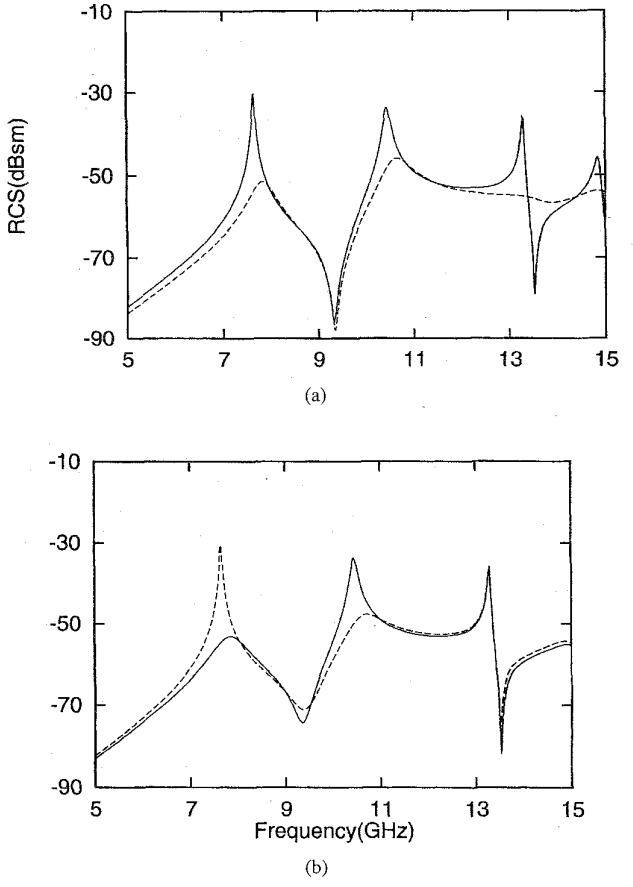

Fig. 4. RCS ($\sigma_{\theta\theta}$) of a microstrip patch on a latched ferrite substrate with matched load at incident angle, $\theta = 60°$, $\phi = 45°$. (a) Probe position $= (-L/6, -W/6)$ ——— (Load impedance, $Z_L = \infty$), – – – (Load impedance, $Z_L = 50\,\Omega$) and (b) ———: Probe position $= (-L/6, 0)$, - - - - -: Probe position $= (0, -L/6)$.

A great frequency shift can be obtained by increasing the magnetic bias strength. But the RCS peaks of || modes are almost unaffected by the bias field. Fig. 1(b) shows the cross-polarized RCS component. In the unmagnetized state, the cross-polarized RCS component has zero response. It is in a biased ferrite that cross-polarized scattering response is dramatically changed with respect to that of an unmagnetized state: the cross-polarized component $\sigma_{\theta\phi}$ is actually as high as the copolarized component level at the lower resonances. Fig. 2(a), (b), and (c) show all four components of the RCS of a microstrip patch on a latched ferrite substrate with different incident angles. The resonant peaks of $\sigma_{\theta\phi}$ are similar in amplitude to those of the copolarized components at $(\theta, \phi) = (60°, 45°)$ but very weak at $(\theta, \phi) = (60°, 0°)$ and $(60°, 90°)$. Since the cross-polarized RCS components do vary rapidly with angle ϕ, Fig. 3 shows the scattering pattern of a ferrite patch antenna. Fig. 3(a) and (b) show the monostatic RCS patterns of a latched ferrite patch antenna for the lowest || mode at $f = 7.65$ GHz and the lowest $\perp$ mode at $f = 10.44$ GHz, respectively. In the || mode, $\sigma_{\theta\theta}, \sigma_{\theta\phi}$, and $\sigma_{\phi\phi}$ are maximum at angles $\phi = 0°$ and 180°, at angles $\phi = 45°$, 135°, 225°, and 315°, and at angles $\phi = 90°$, and 270°, respectively. In the $\perp$ mode, $\sigma_{\theta\theta}, \sigma_{\theta\phi}$, and $\sigma_{\phi\phi}$ are maximum at angles $\phi = 90°$ and 270°, at angles $\phi = 45°$, 135°, 225°, and 315°, and at angles $\phi = 0°$ and 180°, respectively. In the previous cases, the RCS components were calculated with an open-circuit load, but in Fig. 4(a) and (b), $\sigma_{\theta\theta}$ is evaluated with a 50 Ω load. We observe that the load has the effect of reducing the level of the peaks in the RCS. In Fig. 4(a), the probe position is near a corner of the patch, so that the feed would influence virtually all of the modes. Fig. 4(b) shows the RCS of the microstrip patch on a biased ferrite for different probe positions. If the feed is located on the axis perpendicular to the bias, it would not couple to many of the $\perp$ modes, and thus not affect the peak RCS of those modes.

III. Conclusion

In this analysis, the full RCS matrices of loaded and unloaded microstrip patch antennas on in-plane biased ferrite substrates were analyzed for different bias conditions and incident angles. It was found that the $\perp$ mode's RCS peaks can be moved with respect to frequency and cannot be changed with respect to amplitude by changing the strength of the bias field. But the RCS peaks of || modes are almost unchanged by the bias field. It was also noticed that the cross-polarized RCS component can be significantly affected by bias field and incident angle. It was also observed that the load has the effect of reducing the peaks of the RCS. This work may be extended to analyze the RCS of arrays of printed antennas and multilayer ferrites and dielectrics. Bistatic RCS can be calculated by the same method as well.

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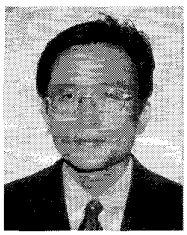

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