Printed Antennas Tuned by Transversely Magnetized Ferrite Operating at a Novel Resonant Mode

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Abstract— The excitation of a novel single mode in the negative $\mu_{\text{eff}}$ area is studied for rectangular patch antenna printed on magnetized ferrite substrates or tuned by a ferrite inclusion. In all cases the DC magnetic field is considered perpendicular to the substrate plane. The ferrite inclusion-post shape is considered either cylindrical or rectangular. Numerical simulation results reveal the existence of this novel resonating mode inside the negative $\mu_{\text{eff}}$ area for both the rectangular microstrip patch printed on ferrite substrate or tuned by a rectangular ferrite post. Also, the input impedance characteristics of these patch antennas are studied.

1. INTRODUCTION

A number of published works (e.g., Pozar [1]) show that in the case of patch antennas printed on transversely magnetized ferrite substrates, there is a cutoff frequency range where there is not any propagating mode in the substrate below the radiator. In this range the effective permeability $\mu_{\text{eff}}$ of the ferrite is negative, so the corresponding wavenumber becomes imaginary leading to an evanescent mode. The resonant frequency of circular and ring patch antennas printed on transversely magnetized ferrite substrate was analytically studied in our previous works [2, 3]. The analysis was performed using the perfect magnetic walls approximation and the ferrite losses were also taken into account. Closed form expressions were given for all the geometries studied. By including ferrite losses in our analysis and with the proper mathematical handling of the involved Bessel functions, the solution of the characteristic equation in the negative $\mu_{\text{eff}}$ area became possible revealing a novel single propagating mode. There is only one similar work published in the literature reporting on this mode as propagating in a grounded ferrite substrate [4]. Baccarelli et al. [4] have also considered a lossy ferrite substrate, but biased with an $H_{\text{DC}}$ parallel to the ground plane. Assuming propagation along the substrate, but in a direction transverse to the $H_{\text{DC}}$, they indeed found a single mode denoted as $TE_{1+}$ in the region of negative $\mu_{\text{eff}}$.

Our previous studies on axially symmetric patches proved that the novel mode exists in the negative $\mu_{\text{eff}}$ range independent of the specific patch shape or the tuning ferrite inclusion. This observation motivated us to study the rectangular patch printed on transversely magnetized ferrite substrate and the same patch tuned by a circular or rectangular ferrite post. Thus, the aim of the present work is to identify the existence of any resonant mode in the negative $\mu_{\text{eff}}$ range, for rectangular patch radiators.

2. RECTANGULAR PATCH ANTENNA

The first geometry studied is the rectangular patch antenna printed on a ferrite substrate transversely magnetized at saturation, as shown in Fig. 1. The YIG Al doped type “GA-65” of Ferrite Domen is used for the ferrite substrate with $4\pi M_s = 650$ Gauss, $\varepsilon_r F = 14.2$ and $\Delta H = 45$ Oersted. The whole geometry is inside a DC magnetic field perpendicular to the ferrite substrate plane. The existence of the resonant mode inside the negative $\mu_{\text{eff}}$ region is investigated using the Ansoft HFSS [5] software, which employs the finite element method to analyze random three dimensional geometries. The main reason for choosing this software is that ferrite losses can be taken into account.

The coaxial probe was preferred for the antenna feeding, because it has the least effect on the printed patch geometry. Moreover, the complex input impedance of the antenna can be easily matched by changing the feeding position. Fig. 1 also shows the position of the coaxial connector which feeds the microstrip patch.

The graph of Fig. 2 shows the resonant frequency of the rectangular patch antenna printed on a ferrite substrate versus the DC magnetic bias. Both sides of the microstrip patch are 10.6 mm...
Figure 1: Geometry of rectangular patch antenna printed on transversely magnetized ferrite substrate.

and it was designed to cover the 800, 900 and 1800 MHz frequency bands. This can be achieved by switching the antenna resonant frequency through the DC magnetic bias. The shaded area of Fig. 2 represents the negative effective permeability $\mu_{\text{eff}}$. It is clear from the graph that the second resonating mode, does not vanish when it reaches the negative $\mu_{\text{eff}}$ boundary, but it continues to propagate inside the negative $\mu_{\text{eff}}$ region. This behaviour is exactly the same as for the case of the circular microstrip patch antenna printed on a transversely magnetized ferrite, which was studied in our previous work [2, 3]. Since ferrite losses are taken into account, revealing the existence of this novel mode is exactly what we expected. The justification of this mode based on the assumption of [2, 3] that the field below the radiator can be expressed as a superposition of right and left hand circularly polarized modes, falls outside the scope of the present work. However this can be an interesting subject for a future investigation.

The input impedance is a very important characteristic since it defines the antenna bandwidth. In order to further investigate the resonating mode inside the negative $\mu_{\text{eff}}$ range, the input impedance of the antenna at such a resonant frequency is studied. The graph of the rectangular microstrip patch antenna input impedance versus frequency is shown in Fig. 3. The geometry is the same as that of Fig. 1. The center of the coaxial feed inner conductor is placed 1.1 mm from the patch edge. This position of the coaxial connector yields a 50 Ohm maximum input resistance for the second resonating mode, inside the negative $\mu_{\text{eff}}$ area and for $H_0 = 800$ Oe. The resonant frequency of the antenna is 3.61 GHz, while the 3 dB bandwidth of the antenna is 1.52 percent. The input reactance at resonance is $-12$ Ohm. The above characteristics imply that the behaviour of the mode resonating inside the negative $\mu_{\text{eff}}$ area is similar to any other resonating mode of a rectangular microstrip patch printed on a transversely magnetized ferrite substrate.

3. RECTANGULAR MICROSTRIP PATCH ANTENNA TUNED BY A RECTANGULAR FERRITE POST

The main idea here is to design an antenna that retains the benefits from the use of ferrite substrate, like the control of the resonant frequency, offering at the same time less weight and losses. To accomplish this, the geometry of the rectangular patch printed on a dielectric substrate is used, only a part of the dielectric at the centre, underneath the patch, is substituted by a ferrite post. The shape of the ferrite post can be either rectangular, circular or ring shaped. In the design example presented here, the ferrite post is considered rectangular, similar to the shape of the patch. The antenna of Fig. 1 covering the 800, 900 and 1800 MHz frequency bands, is designed again using a 0.5 ratio of ferrite to patch dimensions. The ferrite post is embedded in a dielectric substrate, which for the studied patch antenna is the Rogers type TMM-10, with $\epsilon_r = 9.2$ and $\tan \delta = 0.0022$.

The resonant frequency of the rectangular ferrite post tuned antenna versus the DC magnetic bias is shown in Fig. 4. First, it is clear that the second resonating mode still enters the negative $\mu_{\text{eff}}$ area. Second, the control of the resonant frequency through the DC magnetic field is preserved, at least for the first resonating mode, even though the ferrite material volume is reduced to the 25 percent compared to the case of the antenna printed on a purely ferrite substrate. The curve of the second resonating mode shows that the resonant frequency is almost unchanged with the dc
magnetic field. However, the same phenomenon was observed in the study of circular patches [2, 3] and it was clearly proved that the resonance control-sensitivity can be greatly improved if a dielectric with lower dielectric constant is used. An identical behaviour is expected for the rectangular patch radiator.

Finally, another important advantage of the ferrite post tuned antennas is that the coaxial connector position can be shifted outside the ferrite. Since ferrites are hard to drill, it is very convenient if the feeding position is located in the dielectric part of the substrate.
Figure 4: Resonant frequency of rectangular patch tuned by a transversely magnetized rectangular ferrite inclusion.

4. CONCLUSION

The resonating mode inside the negative $\mu_{eff}$ area was investigated for the rectangular microstrip patch antenna printed on a transversely magnetized ferrite substrate. Numerical simulations were performed using the Ansoft HFSS software, which provides the ability to include ferrite losses in the analysis. All the numerical results presented here were expected according to the analysis of the circular microstrip patch antenna printed on a transversely magnetized ferrite substrate which was thoroughly studied in our previous work [2, 3]. Results for all the cases studied, show that the investigated mode is excited even when small ferrite losses are considered. Besides the resonant frequency, a study of the input impedance versus feeding position is also presented. A theoretical explanation of the observed novel mode constitutes a challenging future research task.

REFERENCES