FULL–WAVE ANALYSIS OF TUNABLE MICROSTRIP FILTERS FABRICATED ON MAGNETIZED FERRITES [1]

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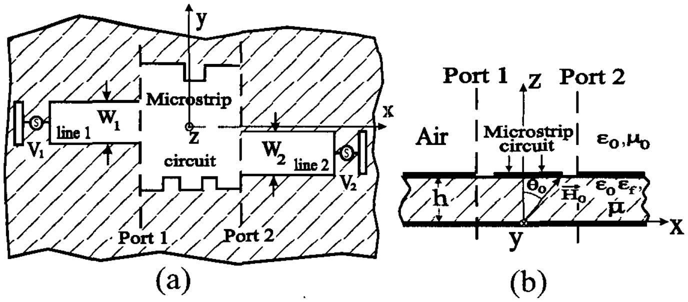
1 Introduction

Numerical and experimental results [1–3] have shown that the resonant frequencies of microstrip patch resonators fabricated on magnetized ferrites can be adjusted over a wide range by varying the magnitude or/and the orientation of the bias magnetic field. Based on this fact, Pozar et al. have fabricated a microstrip patch antenna on a ferrite substrate which can be tuned over a 40% frequency range [4]. Also, tunable ferrite bandpass filters containing microstrip resonators have been fabricated and measured [5,6].



(a) (b)

Figure 1: Side (a) and top (b) views of two–port microstrip circuit fabricated on a magnetized ferrite. The direction of the bias magnetic field inside the ferrite is contained within the x–z plane and makes and angle θ_0 with the x axis.

Although the tuning capabilities of microstrip antennas and circuits on magnetized ferrite substrates have been experimentally demonstrated, the rigorous numerical characterization of this type of structures has been limited to very simple cases such as the rectangular microstrip antenna [7] and the open–end microstrip discontinuity [8]. In the current paper the authors extend the previous work of [7] and [8], and apply the method of moments (MoM) in the spectral domain to the determination of the frequency–dependent scattering parameters of two–port microstrip circuits fabricated on magnetized ferrite substrates. The results presented show that it is possible to fabricate bandpass filters on magnetized ferrites that can be tuned by varying either the magnitude or the orientation

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of the bias magnetic field, which is in agreement with the experimental results published in [5] and [6].

2 Outline of the numerical procedure

Fig. 1 shows the side and top views of the generic two–port microstrip circuit analyzed in this paper. The circuit is fed by two microstrip lines and the axes of the two feeding lines are assumed to be parallel to the x axis as shown in Fig. 1.a. The metallizations of the circuit and the feeding lines are considered to be perfect electric conductors (PEC) of negligible thickness. The circuit is fabricated on a magnetized ferrite. The ferrite substrate is assumed to be lossless (ΔH=0), and the DC bias magnetic field inside the ferrite substrate is assumed to have no component along the y axis. This restriction on the orientation of the bias magnetic field ensures that the two feeding microstrip lines are bidirectional [9,10], which makes it possible to use standard circuit theory in the determination of the scattering parameters of the two–port circuit. The permeability tensor of the ferrite is obtained in terms of the gyromagnetic ratio $\gamma = 1.759 \cdot 10^{11}$ C/Kg, the saturation magnetization of the ferrite material, M_s, the magnitude of the internal bias magnetic field, H_0, and the angle between the bias field and the x axis, θ_0, as explained in [11]. In order to obtain the scattering parameters of the two–port circuit of Fig. 1, the feeding microstrip lines are excited by delta–gap generators [12]. Then, an electric field integral equation (EFIE) for the current density on the circuit and the feeding lines is obtained by imposing the PEC condition for the tangential electric field on the metallizations. The Galerkin's version of the MoM is applied to the solution of the EFIE. Rooftop basis functions are used in the approximation of the current density [12]. Since the determination of the dyadic Green's function of the ferrite substrate is rather cumbersome in the spatial domain and relatively straightforward in the spectral domain [3], the entries of the Galerkin's matrix are computed in the spectral domain [3]. Special asymptotic extraction techniques developed by the authors are used for accelerating the computation of these entries, which consist of double integrals with infinite limits [3]. Once the currents on the feeding lines are known for two independent excitations, the matrix of pencil technique is used to de–embed the scattering parameters from the currents as explained in [12]. In order to reduce the computational expense involved in the determination of the scattering parameters in a wide range of frequencies, the entries of Galerkin's matrix are interpolated as a function of frequency and the interpolation is subsequently used at every frequency. In all the results presented in next section the authors deliberately avoid the range of frequencies in which magnetostatic wave propagation along the ferrite substrate is allowed [11]. This is because magnetostatic waves are often undesirable in the performance of circuits fabricated on ferrite substrates since these waves may prevent resonators from resonating [3] and transmission lines from propagating.

3 Results

In order to check the validity of the algorithm described in the previous section, our numerical results for microstrip filters fabricated on ferrites have been compared in the nonmagnetic limit ($M_s \rightarrow 0$) with numerical results provided by the simulator "Ensemble". Good agreement has been found between the two sets of results. In Figs. 2 and

3 results are presented for the return and insertion losses of standard coupled line microstrip bandpass filters fabricated on ferrite substrates. The filter of Fig. 2 is printed on a normally biased ferrite. This filter can be tuned by about 30% as the magnitude of the bias magnetic field is varied from $\mu_0 H_0 = 0.02$ T to $\mu_0 H_0 = 0.1$ T. However, the tuning is carried out at the expense of a bandwidth reduction. In fact, the 3 dB bandwidth of the filter is about 7.5% when $\mu_0 H_0 = 0.02$ T, and about 2.5% when $\mu_0 H_0 = 0.1$ T. Results obtained for the resonant frequencies and quality factors of the two coupled resonators of the filter [3] show that the bandwidth reduction is mainly due to a reduction of the coupling between the two resonators as $\mu_0 H_0$ increases.

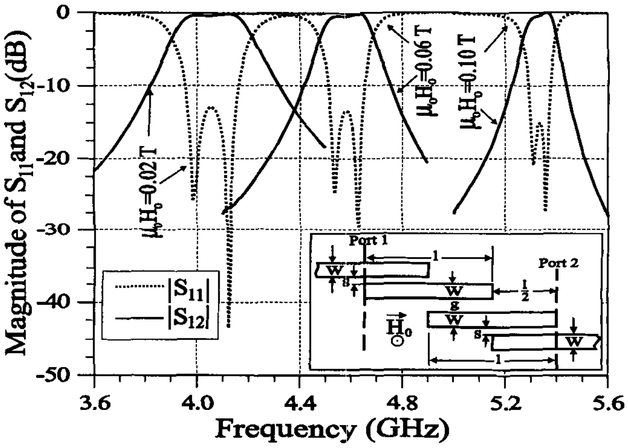

Figure 2: Return and insertion losses for coupled line filter printed on a normally biased ferrite ($\epsilon_f = 15$, $\mu_0 M_s = 0.178$ T, $\theta_0 = 0°$, $h = 0.635$ mm, $w = 0.43$ mm, $s = 0.215$ mm, $g = 0.86$ mm, $l = 12.5$ mm). Results are presented for different values of the magnitude of the bias magnetic field H_0.

In Fig. 3 the coupled line filter of Fig. 2 is analyzed in the case where the ferrite substrate is longitudinally biased. A comparison between Figs. 2 and 3 shows that the coupled line filter on ferrite substrate can be tuned over 50% by rotating the bias magnetic field from normal to longitudinal direction. Also, Fig. 3 shows that the filter on longitudinally biased substrate can be tuned within 30% as $\mu_0 H_0$ is varied from 0.02 T to 0.1 T, which is a tunability range similar to that observed for the filter of Fig. 2. However, the bandwidth reduction noticed in Fig. 3 is more drastic than that noticed in Fig. 2. In fact, the 3 dB bandwidth of the filter analyzed in Fig. 3 is about 2% when $\mu_0 H_0 = 0.02$ T, and is reduced to 0.25% when $\mu_0 H_0 = 0.1$ T. There are two combined effects that contribute to this important bandwidth reduction. In one hand, the coupling between the resonators of the filter of Fig. 3 decreases as $\mu_0 H_0$ increases, as it happens with the filter of Fig. 2. On the other hand, the resonances of the coupled resonators of the filter of Fig. 3 have been found to have very high quality factors that increase with increasing $\mu_0 H_0$.

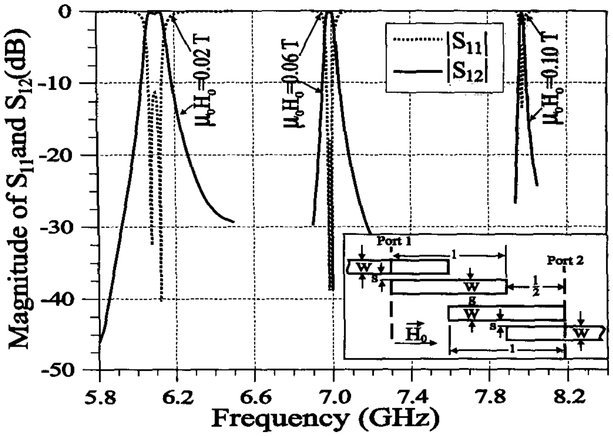

Figure 3: Return and insertion losses for coupled–line filter printed on a longitudinally biased ferrite ($\epsilon_f = 15$, $\mu_0 M_s = 0.178$ T, $\theta_0 = 90°$, $h = 0.635$ mm, $w = 0.43$ mm, $s = 0.215$ mm, $g = 0.645$ mm, $l = 12.5$ mm). Results are presented for different values of the magnitude of the bias magnetic field H_0.

4 Conclusions

The method of moments in the spectral domain has been employed in the rigorous full–wave numerical determination of the scattering parameters of two–port microstrip circuits fabricated on magnetized ferrite substrates. The numerical algorithm developed has been applied to the analysis of microstrip bandpass filters fabricated on ferrites. The results obtained show that the center frequency of the filters can be tuned over a wide range as the magnitude and/or the orientation of the bias magnetic field are varied. However, tunability is achieved at the expense of bandwidth reduction.

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