FULL-WAVE ANALYSIS OF HIGH-Tc SUPERCONDUCTOR PATCH ANTENNA ON LOSSY BI-ANISOTROPIC SUBSTRATES

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I. INTRODUCTION

Many practical substrates have a significant amount of anisotropy that can either degrade the performance of printed circuits and antennas or have a beneficial effect once it is fully included in the design procedure [1]. In order to further improve the radiation efficiency of patch antennas, it has been proposed to replace the conventional patch structures by superconductors [2]. Although the characteristics of patch antennas on anisotropic media have been studied, e.g. [3]-[4], the effects of finite conductor thickness for either conventional or superconductors built on lossy bi-anisotropic media have not yet been taken into account for the analysis of printed circuit antennas.

Therefore, this paper focuses on a general analysis technique for the high-Tc superconductor patch antenna on lossy bi-anisotropic substrates (Fig.1a). The extended spectral domain immittance approach (SDIA) is combined with the concept of imperfect conductors imbedded in layered anisotropic media [4]. A new decoupling procedure for the electric and magnetic field is developed which makes it possible to arrive at closed form impedance dyadic Green's functions in the spectral domain for bi-anisotropic cases. The results presented achieve excellent agreement with previously published data and, moreover, demonstrate the feasibility of the method.

II. THEORY

The geometry of a patch resonator with an imperfect conductor on bi-anisotropic tensor substrate is shown in Fig. 1a. Without losing generality, we restrict the demonstration of the procedure to the tensor cases

$$<\vec{\varepsilon}>=\varepsilon_o\begin{pmatrix}\varepsilon_x & 0 & 0\\ 0 & \varepsilon_y & 0\\ 0 & 0 & \varepsilon_x\end{pmatrix} \qquad <\vec{\mu}>=\mu_o\begin{pmatrix}\mu & 0 & j\kappa\\ 0 & \mu_y & 0\\ -j\kappa & 0 & \mu\end{pmatrix} \tag{1}$$

where μ, μ_y, κ and ε_x, ε_y are complex quantities to account for the losses in the material. By using the concept of SDIA [6], the six-component electromagnetic field considered in the coordinate system (x,y,z) can be decomposed into TM-to-y and TE-to-y waves in the (u,x,y) system (Fig.1b). Applying Maxwell's equations in the transformed coordinate system yields the wave immittances of TE and TM waves.

$$Y_{TM}=\frac{j\omega\varepsilon_o\varepsilon_x}{\gamma_h} \qquad Y_{TE}=\frac{\gamma_e}{j\omega\mu_o(\mu^2-\kappa^2)/\mu} \tag{2}$$

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$$\gamma_h^2 = \frac{\varepsilon_x}{\varepsilon_y}\left[\alpha^2 + \beta^2 - \omega_o^2 \varepsilon_o \mu_o \varepsilon_y (\mu^2 - \kappa^2)/\mu\right] \tag{3}$$

$$\gamma_e^2 = \frac{\mu}{\mu_y}\left[\alpha^2 + \beta^2 - \omega_o^2 \varepsilon_o \mu_o \varepsilon_x \mu_y\right] \tag{4}$$

α and β are the propagation constants in x and z directions, respectively. In order to take the finite conductor thickness into account, the complex resistive boundary condition[4] is used which can model either conventional metal or superconductors. For a thin superconductor of finite complex conductivity σ and thickness t, the surface impedance can be expressed as $Zs=1/(\sigma t)$ [4]. After applying Galerkin's procedure and expanding the tangential current density in a set of Bessel functions which take the edge singularities into consideration [5], the complex resonant frequency $\omega_c=\omega_r+j\omega_i$ is given by the roots of the characteristics equation which is evaluated using the numerical integration technique [3]. The Q-factor of the patch antenna is defined as the ratio $\omega r/\omega i$.

III. RESULTS

The dependence of the resonant frequency on the anisotropic ratio is shown in Fig. 2. Excellent agreement is obtained with Itoh [6] for the isotropic case ($\varepsilon x/\varepsilon y=1$) and with Nelson [5] for the anisotropic cases. Note that the resonant frequencies decrease with increasing anisotropic ratio.

In order to demonstrate the effect of dielectric losses, the Q-factor of a superconductor patch is plotted versus the substrate thickness for different loss tangents in Fig. 3. The conductor material is chosen to be YBCO at 77^oK. For most practical applications, a loss tangent of 10^{-4} or less appears to be sufficient since a further reduction in $\tan\delta$ has a rather small effect on the Q-factor.

Fig. 4 shows the Q-factor and resonant frequency for different conductors. As expected, the Q-factor of the YBCO superconductor comes close to the ideal case while that of the conventional copper cladding is significantly lower. However, the resonant frequency, which decreases with the substrate thickness, is influenced only marginally by the conductor material. The results for the three cases investigated fall within the plotting accuracy.

Fig. 5 shows the anisotropic effect on the resonant frequency versus the patch length for a bi-anisotropic structure with a magnetic bias in y-direction. As expected, the resonant frequency decreases with increasing patch length. However, the effect of the anisotropic ratio is significant and illustrates that all tensor parameters need to be rigorously taken into account when evaluating the performance of printed circuit antennas.

IV. CONCLUSIONS

A method for the analysis of patch antennas with finite-thickness conductors and lossy bi-anisotropic media is presented. Conductor losses are taken into account which allows patches with either conventional or superconducting material to be evaluated. The procedure can easily be extended to the analysis of structures with multilayered anisotropic stubstrates. The numerical results show that the Q-factor of patch antennas can be significantly improved by replacing the conventional conductor with high-Tc superconducting material whereas this has negligible influence on the resonant frequency.

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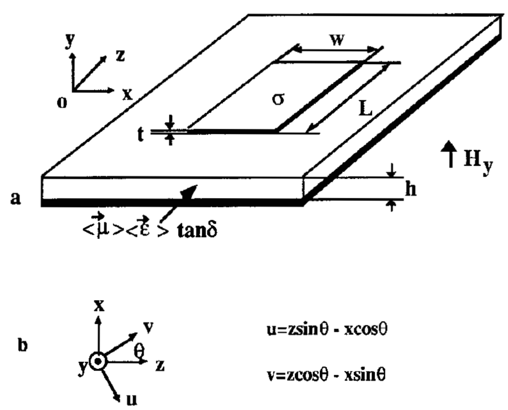

Fig. 1 Geometry of patch antenna (a) and transformation system for SDIA (b).

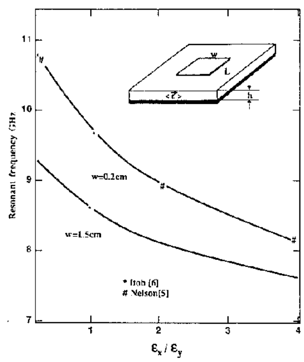

Fig.2 Resonant frequency versus anisotropic ratio; ε_y=2.35, κ=0, u=u_y=1, L=1.0cm, h=1.58mm.

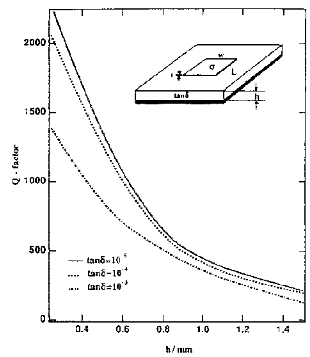

Fig.3 Q-factor versus substrate thickness with dielectric loss tangent as parameter; ε_x=ε_y=25, u=u_y=1, κ=0, L=6mm, w=1.5mm, superconductor: σ=2S/μm, T/Tc=77/92.5, λ=1500A°, t=.5mm.

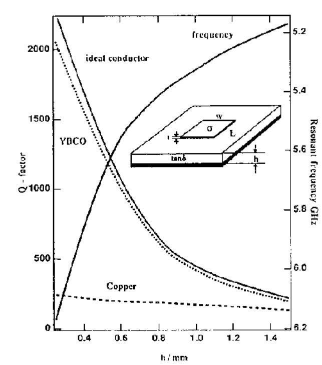

Fig.4 Q-factor and resonant frequency versus substrate thickness with conductor material as parameter; ε_x=ε_y=25, u=u_y=1, κ=0, L=6mm, w=1.5mm, superconductor: σ=2S/μm, T/Tc=77/92.5, λ=1500A°, t=0.5mm.

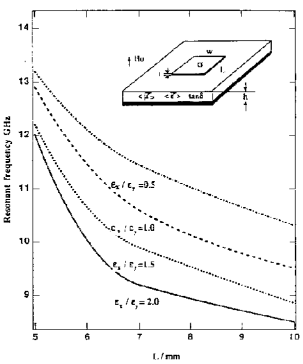

Fig. 5 Resonant frequency of a patch on bi-anisotropic substrate; ε_x=9.6, H_0=0.14T, H_s= 0.15T, u_y=1.0, h=1mm, w=2mm, $\tan\delta=10^{-5}$, copper: σ=40S/mm, t=1mm.