LOSS ANALYSIS FOR THE RADIATION CHARACTERISTICS OF RECTANGULAR MICROSTRIP ELEMENTS

Zhenglian Cai* and **Jens Bornemann**
Laboratory for Lightwave Electronics, Microwaves and Communications
(LLiMiC)
Department of Electrical and Computer Engineering
University of Victoria, Victoria B.C. Canada V8W 3P6

I. INTRODUCTION

With the increasing utilization of microstrip radiators in monolithic microwave integrated circuits and, at the same time, applications in the millimeter-wave frequency range, more and more interest is focused on the development of rigorous numerical models to calculate the effects of losses on the performance of integrated circuits and antenna systems. Particularly with the introduction of high-Tc superconductors for low-loss and low-dispersion applications of microstrip radiators, e.g. [1], the need for rigorous techniques to analyze the influences of different kinds of lossy conductors and substrates on the radiation pattern became apparent. However, the few investigations published so far are only concerned with the effects of substrate losses, e.g. [2]. Rigorous models to include the losses of superconductors, conventional conductors such as copper and, if necessary, of ground metallizations are still in demand.

Therefore, this work focuses on a loss analysis for the radiation pattern calculation of rectangular patch elements. The theoretical model includes the effects of the following parameters: a lossy ground plane, lossy conducting patches, which can be either conventional or high-Tc superconductors, and lossy substrates. By normalizing the calculated patterns to the maximum values obtained for a lossless analysis, the reduction in antenna efficiency due to the influences of different materials can immediately be obtained.

II. THEORY

The geometry of a rectangular patch resonator with imperfect conducting patch on a lossy substrate and lossy ground metallization is depicted in Fig. 1. The spectral-domain immittance approach [3] is modified to include the conductivity and thickness of the ground plane and the properties of conventional or high-Tc superconducting patches and lossy substrates. The reader is referred to [4] for further details.

In order to obtain the radiation pattern of the structure, the complex resonance frequency of the resonator is determined by applying Galerkin's procedure [5]. The far field radiation pattern is given from $\tilde{E}_x$ and $\tilde{E}_z$ as the Fourier transforms of the electric fields.

$$E_\theta(\phi,\theta) \propto \sin\phi \tilde{E}_x(\alpha,\beta) + \cos\phi \tilde{E}_z(\alpha,\beta) \tag{1}$$

0-7803-1246-5/93/$3.00 © 1993 IEEE.

$$E_\phi(\phi,\theta) \propto \cos\phi\cos\theta\tilde{E}_x(\alpha,\beta) - \cos\theta\sin\phi\tilde{E}_z(\alpha,\beta) \tag{2}$$

with $$\alpha = \kappa\sin\phi\sin\theta \qquad \beta = \kappa\cos\phi\sin\theta \tag{3}$$

κ is the free space wavenumber, and α, β are transformed coordinates. $\tilde{E}_x$ and $\tilde{E}_z$ are given by:

$$\tilde{E}_x(\alpha,\beta,0) = (\tilde{Z}_{11}(\alpha,\beta) - Z_s)\tilde{J}_x(\alpha,\beta) + \tilde{Z}_{12}(\alpha,\beta)\tilde{J}_z(\alpha,\beta) \tag{4}$$

$$\tilde{E}_z(\alpha,\beta,0) = \tilde{Z}_{21}(\alpha,\beta)\tilde{J}_x(\alpha,\beta) + (\tilde{Z}_{22}(\alpha,\beta) - Z_s)\tilde{J}_z(\alpha,\beta) \tag{5}$$

where $\tilde{J}_x$, $\tilde{J}_z$ are Fourier transforms of current distributions J_x and J_z, $\tilde{Z}_{mn}$ are the elements of the impedance Green's function, and Z_s is the surface impedance of the conducting patch. The E- and H-plane radiation patterns correspond to $\phi=0$, and $\phi=\pi/2$, respectively.

III. RESULTS

The set of Fig. 2 shows the effects of different kind of losses on the radiation pattern of the patch. In order to better distinguish between the individual influences, the patterns are plotted on a linear amplitude scale. The normalization values are the maxima calculated in the lossless case for which the resonance frequency is 8.16 GHz. As is well known from conventional and monolithic microwave integrated circuits, the consideration of losses also influences the real part of the propagation constant and, consequently, the resonance frequency of the radiating structure. This is demonstrated in Fig. 2a where the pattern obtained with only dielectric losses is displayed. The shift in resonance frequency is -30 MHz, and the loss with respect to the radiated field amounts to approximately eight percent. In comparison, the combined effects of conventional conductor and ground metallizations (σ=40S/μm) are lower. Only a shift of -20 MHz and losses of approximately three percent are observed as shown in Fig. 2b. Fig. 2c shows the almost ideal results obtained for a high-Tc superconducting patch on ideal substrate and ground metallization. The resonance frequency is only 10 MHz below that of the lossless case.

Finally, Fig. 2d shows the combined loss effects of the substrate, a conventional patch and the ground metallization. A resonance frequency of only 8.12 GHz is obtained, and the radiated field is below 90 percent of the lossless case, hence resulting in almost 1dB degradation in efficiency. Since the dielectric losses are the main contributor in this example, the performance can be improved by selecting a high-quality substrate.

IV. CONCLUSION

A modified and extended spectral domain immittance approach to rigorously analyze the resonance frequency and radiation pattern of rectangular patches is presented. The theoretical model includes the effects of a lossy ground plane, lossy conventional or high-Tc superconductor patches as well as those of lossy substrates. It is demonstrated that material losses can contribute more than ten percent to the efficiency degradation of a microstrip radiator. Therefore, it is necessary to include loss analyses in CAD packages for modern integrated-circuit antenna applications.

REFERENCES

[1] H. Chaloupka, N. Klein, M. Peiniger, H. Piel, A. Pischke and G. Splitt, "Miniaturized high-temperature superconductor microstrip patch antenna", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-39, pp. 1513-1521, Sep. 1991.

[2] D. M. Pozar, "Radiation and scattering from a microstrip patch on a uniaxial substrate", *IEEE Trans. Antennas Propagat.*, vol. AP-35, pp. 613-621, June 1987.

[3] T. Itoh, "Spectral-domain immittance approach for dispersion characteristics of generalized printed transmission lines", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, pp 733-736, July 1980.

[4] Z. Cai and J. Bornemann, "Generalized spectral-domain analysis for multilayered complex media and high-Tc superconductor applications", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-40, Dec. 1992.

[5] Z. Cai and J. Bornemann, "Full-wave analysis of high-Tc superconductor patch antenna on lossy bi-anisotropic substrates", in *1992 IEEE-APS Intl. Symp. Dig.*, pp 983-986.

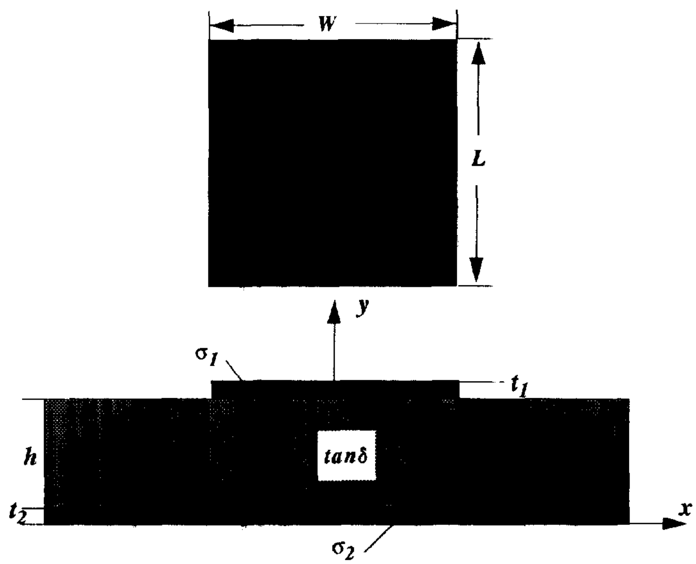

Fig. 1 Geometry of microstrip radiator.

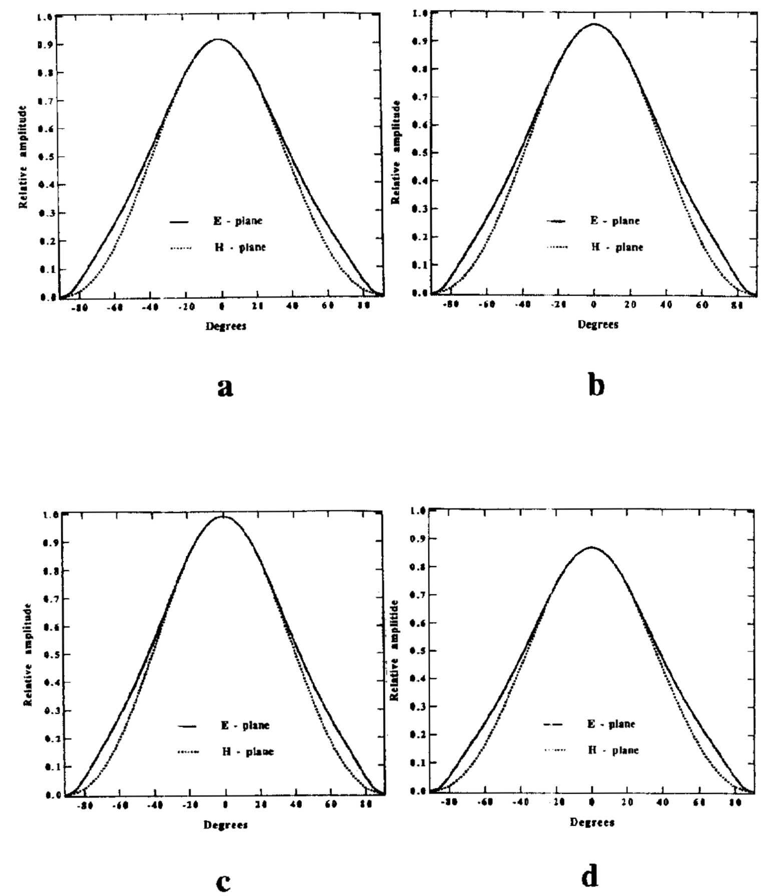

Fig. 2 Radiation pattern of rectangular patch with parameters W=1.0cm, L=1.2cm, h=3.15mm, ε_r=2.3 (amplitude normalized to lossless case: f_r=8.16GHz).
(a) substrate losses only, tanδ=0.03, f_r=8.13GHz; **(b)** conductor and ground plane losses only, t_1=0.2mm, t_2=0.3mm, $\sigma_1=\sigma_2$=40S/μm, f_r=8.14 GHz; **(c)** lossy superconductor only, t_1=0.3μm, σ_n=200S/mm, T/T_c=0.5, λ_{eff}=1500Å, f_r=8.15GHz; **(d)** conductor, ground plane and substrate losses. t_1=0.2mm, t_2=0.3mm, $\sigma_1=\sigma_2$=40S/μm, tanδ=0.03, f_r=8.12GHz.