LOSS REDUCTION IN SUPERCONDUCTING MICROSTRIP-LIKE TRANSMISSION LINES

Brian Young* and Tatsuo Itoh

Dept. of Electrical and Computer Engineering
University of Texas
Austin, Tx 78712

abstract - A mode-matching analysis is applied to microstrip-like transmission lines to determine the dielectric and conductor loss. In microstrip using normal metals and typical low-loss dielectrics, the conductor loss dominates the dielectric loss. For microstrip employing superconductors, the dielectric loss is shown to be dominant. Further reductions in overall loss must come in the dielectric loss. Superconducting suspended substrate and ridged microstrip are analyzed to determine the dielectric loss reduction available and the effect of the reductions on the conductor loss.

INTRODUCTION

Losses in waveguides are generated from three sources: conductor loss, dielectric loss, and radiation. Typical strip-type transmission lines used in microwave/millimeter-wave circuits use low-loss dielectrics, so the dominant loss mechanism is the conductor loss. Past efforts to reduce the overall loss in these waveguides have focussed on the conductor loss [1-5]. The recent surge in high T_c (critical temperature) superconductors raises the possibility of dramatically reducing the conductor loss, thereby making the dielectric loss the dominant loss mechanism.

Recent work [6] on reducing the dielectric loss in microstrip-like transmission lines does not address the effect on the conductor loss of the structure modifications used to reduce the dielectric loss. The possibility exists that the efforts to reduce the dielectric loss may increase the conductor loss and defeat any advantages gained. This work investigates both the dielectric and conductor losses to determine the overall loss reductions available from several microstrip-like structures. The effects of the structure modification on the radiation loss are not considered.

ANALYSIS

The structure under consideration is shown in Fig. 1. The mode-matching method (see, for example [7]) is used to calculate the propagation constant, characteristic impedance using the voltage-current definition, perturbational dielectric loss, and perturbational conductor loss on the ground plane and side wall. The incremental inductance rule [8] is used to calculate the conductor loss on the strip.

The conductors consist either of copper at 295 K with σ=5.786×10^7 Ω^{-1}m^{-1}, copper at 77 K with σ=5.208×10^8 Ω^{-1}m^{-1}, or YBaCuO at 77 K with T_c=92.5 K, ρ_n=200 $\mu\Omega$•cm, $\lambda_L(0)$=1400 Å [9]. The two-fluid model [10] is used to calculate the conductivity of the superconductor. The model is accurate for frequencies much below the gap frequency [11]. For this work, frequencies are limited to 100 GHz, which is far below the ~ 6.8 THz gap frequency of YBaCuO. Assuming conductor thicknesses greater than a few penetration depths, then the surface resistance in all cases is given by

$$R_s = \mathrm{Re}\, Z_s = \mathrm{Re}\left(\frac{j\omega\mu_o}{\sigma}\right)^{\frac{1}{2}}$$

The effect of the imaginary part of Z_s on the propagation constant all cases is found to be negligible. The strip conductor thickness is 5 μm. The dielectrics are alumina with ε_r=9.3 and tanδ=2.1×10^{-4}. The results can be scaled for other values of loss tangent.

Analysis of microstrip, with $\varepsilon_1 = \varepsilon_2 = \varepsilon_5$ and $\varepsilon_3 = \varepsilon_4 = 1$, demonstrates the advantages of using superconductors. The losses in microstrip for constant 50 Ω lines are plotted in Fig. 2 as a function of frequency. The room-temperature results for Cu show that the conductor losses in the frequency range from 1-100 GHz are one to two orders of magnitude greater than the dielectric losses. Replacing the Cu with superconducting YBaCuO reduces the conductor losses so that the dielectric losses exceed the conductor losses by one to three orders of magnitude. The dielectric loss is not adjusted to 77 K from 295 K because of the lack of data on loss tangents at low temperatures. Since alumina is a good insulator, dropping the temperature should not significantly affect the loss tangent.

The microstrip results show that for superconducting microstrip-like lines, there exists the possibility of reducing the overall loss by at least an order of magnitude by reducing the dielectric loss. Many interesting structures can be investigated based on the structure in Fig. 1. Results are presented here for suspended-substrate microstrip, where $\varepsilon_1 = \varepsilon_3 = \varepsilon_4 = 1$ and $\varepsilon_2 = \varepsilon_5 = 9.3$, and for ridged microstrip, where $\varepsilon_1 = \varepsilon_2$ and $\varepsilon_3 = \varepsilon_4 = \varepsilon_5 = 1$. Dielectric loss reduction is expected in suspended substrate microstrip because significant amounts of dielectric material are removed from beneath the strip, where the field is strong. The strip to ground-plane distance, d, is fixed at 0.254 mm. The dielectric substrate thickness, d-c, is then varied to determine the effect of the thickness on the overall loss. The results for constant 50 Ω lines at 1, 10, and 100 GHz are shown in Fig. 3. Almost an order of magnitude reduction of dielectric loss is available for thin substrates. Note that the conductor loss actually decreases with thinning substrate: there

* Now at Texas A&M University, Dept. of Electrical Engineering, College Station, TX 77843.

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is no tradeoff between reduced dielectric loss and conductor loss. The reduced conductor loss follows from the wider strips necessary to obtain the 50 Ω lines on the thinner substrates. The 100 GHz results do not extend to c/d=0.9 because of numerical instabilities.

Dielectric loss reduction is expected in ridged microstrip because dielectric material is removed from the vicinity of the strip edge where the fields are strongest. Once again, the strip to ground-plane distance, d, is fixed at 0.254 mm. The ridge height is varied by reducing c to determine the effect on the overall loss. This type of structure could be fabricated by wet etching or ion milling. The results for constant 50 Ω lines at 1, 10, and 100 GHz are shown in Fig. 4. Surprisingly, no significant dielectric loss reduction is available from this type of modification. The reason is that as more material is removed to try to reduce the dielectric loss, the line must become wider to achieve 50 Ω impedance, which introduces more dielectric material with the associated increase in dielectric loss.

CONCLUSION

A mode-matching analysis is used to analyze microstrip, suspended substrate microstrip, and ridged microstrip for the dielectric and conductor loss to investigate the possibility of overall loss reductions when using superconductors. Dielectric losses exceed conductor losses in superconducting microstrip by more than an order of magnitude. Suspended substrate microstrip reduces the dielectric loss while also reducing the conductor loss. Total loss reductions of nearly an order of magnitude compared to microstrip are possible using suspended-substrate microstrip. Compared to Cu microstrip at 77 K, overall loss reductions of two orders of magnitude are possible at 10 GHz for superconducting suspended substrate microstrip. Ridged microstrip offers no significant dielectric loss reductions.

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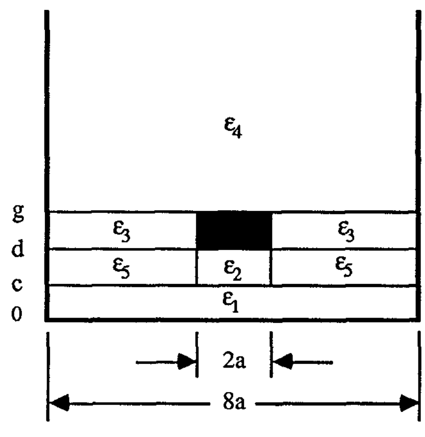

Fig. 1. Microstrip-like transmission line for mode-matching analysis.

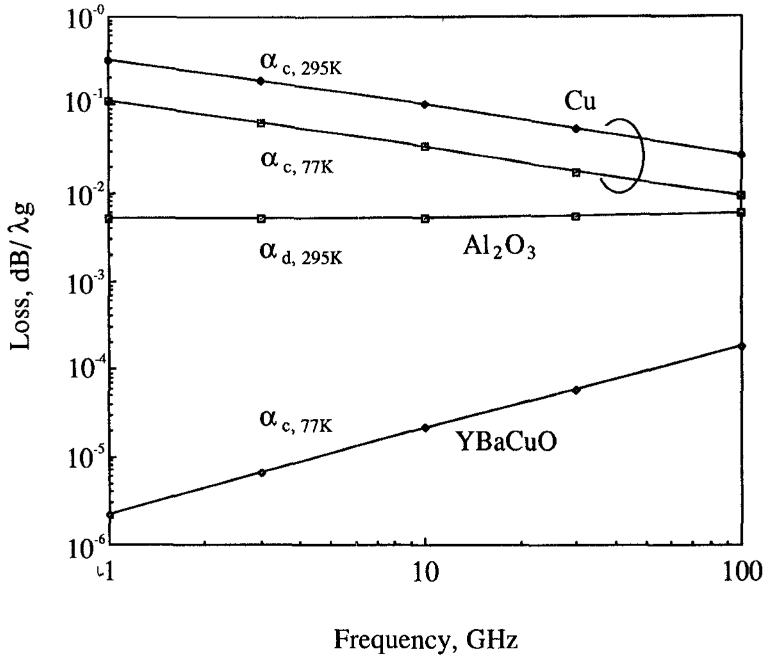

Fig.2. Microstrip analysis results for the dielectric (α_c) and conductor (α_d) attenuation constants. $\varepsilon_1 = \varepsilon_2 = \varepsilon_5 = 9.3$, $\varepsilon_3 = \varepsilon_4 = 1$, d=0.254 mm, g-d=5μm, and a varies to achieve 50 Ω lines.

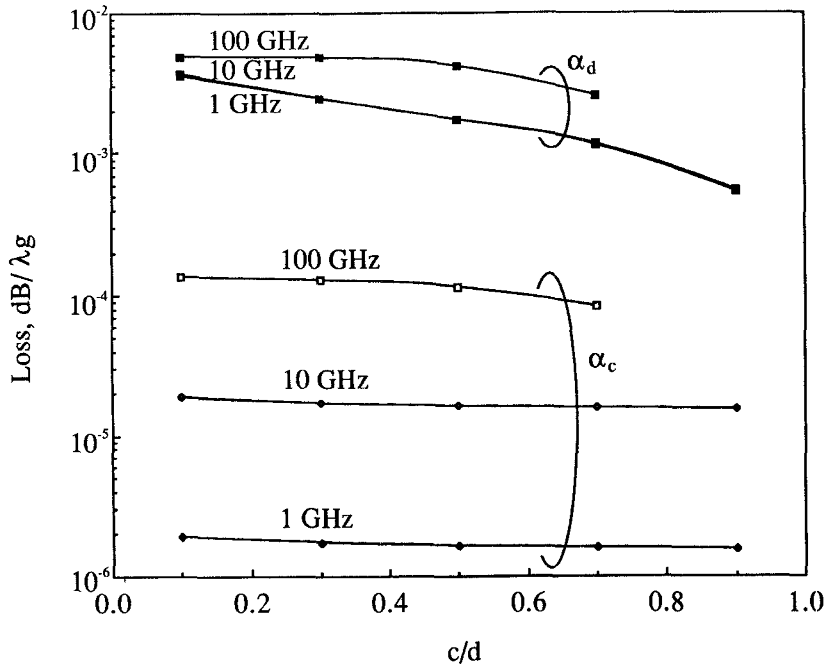

Fig.3. Suspended substrate microstrip analysis results for the dielectric (α_c) and conductor (α_d) attenuation constants. $\varepsilon_1 = \varepsilon_3 = \varepsilon_4 = 1$, $\varepsilon_2 = \varepsilon_3 = 9.3$, d=0.254 mm, g-d=5μm, and a varies to achieve 50 Ω lines.

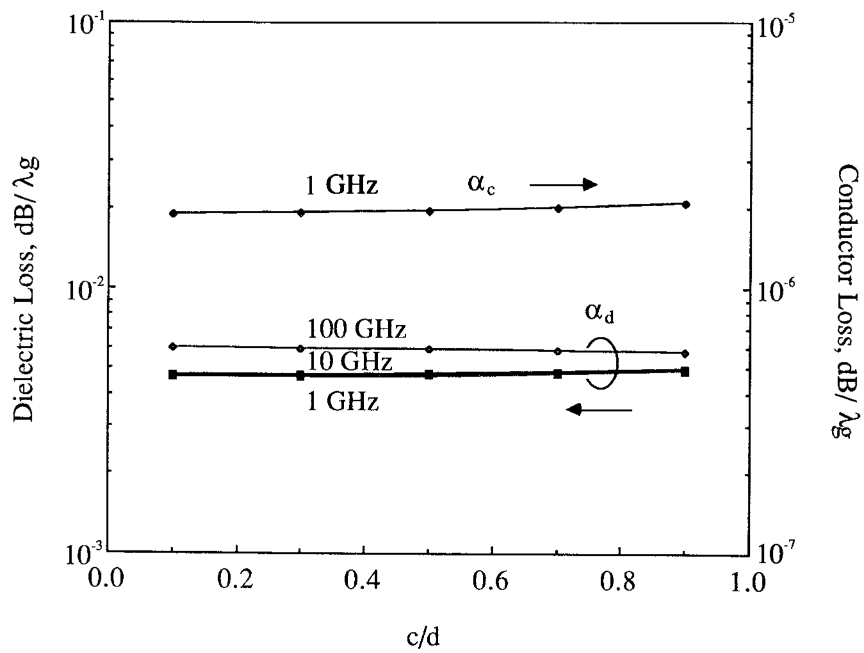

Fig.4. Ridged microstrip analysis results for the dielectric (α_c) and conductor (α_d) attenuation constants. $\varepsilon_3= \varepsilon_4= \varepsilon_5=1$, $\varepsilon_1= \varepsilon_2=9.3$, d=0.254 mm, g-d=5μm, and a varies to achieve 50 Ω lines.