# Analysis of Sonnet and Electronic Modeling of a Thick Metal Microstrip

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**Abstract**

Expanding the voltage equation pertaining to a transmission line and collecting certain terms, we have equations of transmission and reflection. Computational analysis of the electronic program, Sonnet, is based on this approximation principle. Application of Sonnet on a thick metal microstrip provides information on energy loss and current density.

## 1 INTRODUCTION

Transmission lines are a type of waveguide, which guide waves of any frequency from one point to another. It is desired that the energy be conveyed with maximum efficiency and losses in heat or radiation to be as small as possible. In addition, they only can accommodate transverse electromagnetic modes (TEM modes). If we assume the propagation of the wave is in the **z** direction, then there are no longitudinal fields ($H_z$ and $D_z$ are zero). One of the characteristics of this type of conductive waveguide is that it must have guiding walls that consist at least of two isolated pieces, e.g. a coaxial-cylinder or two parallel plates. The integral form of the curl **H** Maxwell equation,

$$\oint_C d\vec{l}\cdot\vec{H}=\int_S d\vec{S}\cdot(\vec{J}+\frac{\partial\vec{D}}{\partial T})=0 \qquad (1)$$

supports this property. We shall prove by contradiction. Suppose we have a single-conductor waveguide such as a rectangular or cylindrical waveguide. We take the closed contour C lying perpendicular to the **z** direction to be completely inside the waveguide. Hence, **J**=0 and
d$\overrightarrow{S}\cdot\partial\overrightarrow{D}/\partial$z=dS$\partial$D$_z/\partial$z=0.[1] Let the contour encompass the magnetic field. Then **H** is parallel to d**l** and this integral is not zero. Thus, this contradiction rules out the existence of a TEM mode.

In this paper, we study the expansion series of the voltage equation pertaining to a transmission line based on the above characteristics of a TEM mode. Then we do a computational simulation of a thick microstrip with certain parameters to obtain energy loss and current density graphs.

# 2 FORMALISM

In the lossy transmission line consisting of two parallel plates of length z=0 to z=l, we assume the propagation of the wave is in the **z** direction, so

$$\overrightarrow{E}(\overrightarrow{r})=-\mathrm{E}_{i0}\overrightarrow{y}(\mathrm{e}^{-i\beta z}-\Re\mathrm{e}^{i\beta z}),$$
$$\overrightarrow{H}(\overrightarrow{r})=\frac{1}{\eta_0}\mathrm{E}_{i0}\overrightarrow{x}(\mathrm{e}^{-i\beta z}-\Re\mathrm{e}^{i\beta z}), \tag{2}$$

where $\Re=(\eta_0-\eta_1)/(\eta_0+\eta_1)$. In addition,

$$\mathrm{V(z)}=\frac{I_L}{2}(\mathrm{Z}_L+\mathrm{Z}_0)[\mathrm{e}^{\gamma(l-z)}+\mathrm{e}^{-\gamma(l-z)}],$$
$$\mathrm{I(z)}=\frac{I_L}{2Z_0}(\mathrm{Z}_L+\mathrm{Z}_0)[\mathrm{e}^{\gamma(l-z)}+\mathrm{e}^{-\gamma(l-z)}], \tag{3}$$

where $\Gamma=(\mathrm{Z}_L-\mathrm{Z}_0)/(\mathrm{Z}_L+\mathrm{Z}_0)$ is the output reflection coefficient and
$\gamma=\alpha+i\beta=\sqrt{(r+i\omega L)(G+i\omega C)}$.
Also, $\Gamma_S=(\mathrm{Z}_S-\mathrm{Z}_0)/(\mathrm{Z}_S+\mathrm{Z}_0)$is the input reflection coefficient. Note that the subscript 0 denotes vacuum, 1 denotes dielectric medium, i denotes initial, L denotes load, and S denotes source. Applying boundary conditions and Kirchhoff's voltage equation, we obtain

$$\mathrm{V(z)}=\mathrm{V}_S\mathrm{e}^{-\gamma z}\frac{1+\Gamma e^{-2\gamma(l-z)}}{1-\Gamma_S\Gamma e^{-2\gamma l}}, \tag{4}$$

where $\mathrm{V}_S=\mathrm{Z}_0\mathrm{V}_S/(\mathrm{Z}_S+\mathrm{Z}_0)$. By expanding the denominator (assuming $|1-\Gamma_S\Gamma e^{-2\gamma l}|<1$), we find

$$\mathrm{V(z)}=\textstyle\sum_{n=0}^{\infty}\mathrm{V}_n\mathrm{(z)}$$
$$\mathrm{V}_1\mathrm{(z)}=\mathrm{V}_S\mathrm{e}^{-\gamma z},$$
$$\mathrm{V}_2\mathrm{(z)}=\mathrm{V}_S\Gamma\mathrm{e}^{-\gamma(2l-z)}=\mathrm{V}_S\mathrm{e}^{-\gamma l}\Gamma\mathrm{e}^{-\gamma(l-z)}, \tag{5}$$
$$\mathrm{V}_3\mathrm{(z)}=\mathrm{V}_S\Gamma\Gamma_S\mathrm{e}^{-2\gamma l-\gamma z}=\mathrm{V}_S\mathrm{e}^{-\gamma l}\Gamma\mathrm{e}^{-\gamma l}\Gamma_S\mathrm{e}^{-\gamma z},$$
$$\mathrm{V}_4\mathrm{(z)}=\mathrm{V}_S\Gamma^2\Gamma_S\mathrm{e}^{-2\gamma l}\mathrm{e}^{-2\gamma(l-z)}=\mathrm{V}_S\mathrm{e}^{-\gamma l}\Gamma\mathrm{e}^{-\gamma l}\Gamma_S\mathrm{e}^{-\gamma l}\Gamma\mathrm{e}^{-\gamma(l-z)},$$

etc. Interestingly, the odd terms pertain to forward propagation while the even terms pertain to reflection. For instance, the $V_3$(z) term has two forward propagations and one reflection. Namely, the $V_3$(z) term indicates a change in $V_S$ by means of propagation over the entire length z=l of the transmission line (i.e. the factor $e^{-\gamma l}$), then reflection off the load, characterized by the factor Γ . Then propagation all the way back to the source (another factor $e^{-\gamma l}$) and reflection off the generator (the factor $\Gamma_S$), and finally forward proagation to z=l (the factor $e^{-\gamma z}$ ).

More specifically, pertaining to a lossless parallel plate transmission line, we have $\gamma \rightarrow i\beta = i\omega\sqrt{LC}$

$$\Gamma \rightarrow (Z_L\text{-}R_0)/(Z_L+R_0).^2 \tag{6}$$

Therefore the absolute values of voltage and current are

$$|V(z)|=|\widetilde{V}|\sqrt{(1-|\Gamma|)^2+4|\Gamma|cos^2[\tfrac{1}{2}\phi(z)]},$$
$$|I(z)|=|\widetilde{I}|\sqrt{(1-|\Gamma|)^2+4|\Gamma|sin^2[\tfrac{1}{2}\phi(z)]}, \tag{7}$$

where $\widetilde{V}=\frac{I_L}{2}(Z_L+Z_0)$ and $\widetilde{I}=\widetilde{V}/Z_0$.
In addition, $\phi$(z)=$\theta - 2i\beta$(l-z) and $\theta$ is the phase angle of the reflection coefficient. Summing up all the odd V(z) terms, we can obtain $P_{incident}$, and similarly, summing up all the even V(z) terms, we can obtain $P_{reflection}$.

# 3 RESULTS

By using the high frequency simulation software, Sonnet, we can analyze a transmission line with certain parameters based on the above principles. In this model, we investigate the properties of a thick metal microstrip or two parallel plates with unequal widths. The top layer is a conductor with thickness of 1000 mm, while the bottom layer is a dielectric ($\varepsilon$ = 9.8, porcelain has $\varepsilon = 6 - 8$) with thickness of 25 mm. Also, a 3 mm layer of air is placed between the two layers. Identical ports are placed on the left and right walls.

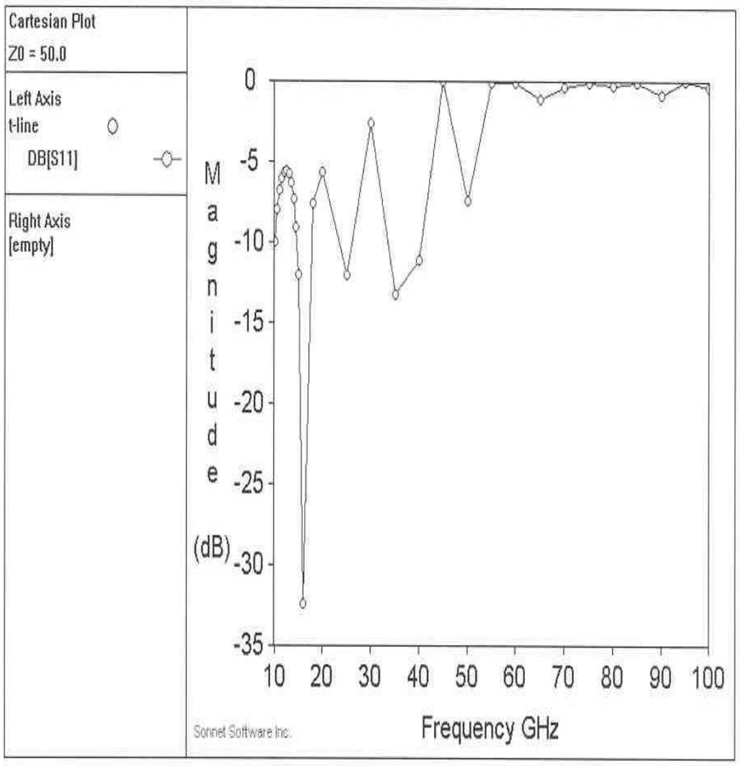


FIG. 1. The energy loss in dB is the ratio of $P_{reflection}/P_{incident}$ with logarithm based 10. The minimum energy loss in this domain is 16 GHz.

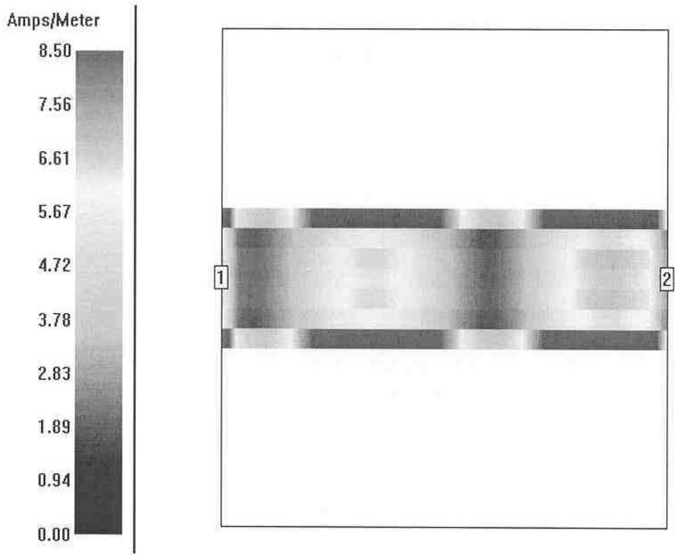


FIG. 2a. Current density graph at 16 GHz. Shown here is the top layer of the microstrip. Current density is non-uniform.

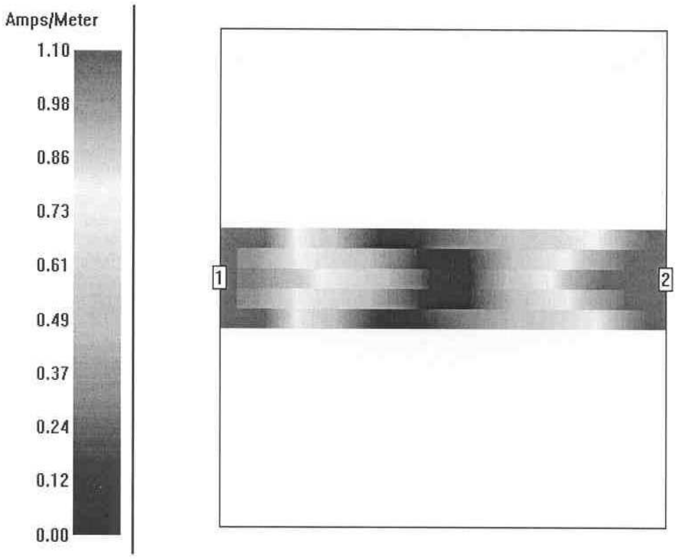


FIG. 2b. Bottom layer of the microstrip. Notice it's narrower than the top layer. Lowest current density is concentrated in the center and highest in the left and right walls.

# 4 CONCLUSION

We have performed a response and a current density simulation of a thick metal microstrip. Using Sonnet, we can determine the frequency that is most suitable for an efficient transmission line. Then we can view the current density of the geometry and establish its application in circuitry.

## References


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