Accurate Modelling of Thin-Film Resistor upto 40 GHz


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Motivation

- Accurate TFR model required for μwave and mm-wave circuits
- μwave and mm-wave circuits used for many applications

Detection of O₂ absorption in atmosphere

Emerging mobile wide-band cellular systems

Wireless LANs, wireless vehicle & traffic information systems

Outline

- Description of Thin-Film Resistor (TFR) Model
- Step Discontinuity in Microstrip Width
- Parameter Extraction of Lossy Microstrip Line
- Thin-Film Resistor Model in ABCD Form
- Conclusions
Background of TFR model

TFR model in HP-ADS circuit simulator considers the parasitic series L and shunt C to be the same as the lossless microstrip case.

\[ \text{HP-ADS model does not provide good results when the width of resistor is much smaller than substrate thickness.} \]

Demurie [2] introduced self-capacitance in the TFR

This model places C between the two ports of the TFR. It has large errors when predicting the HF characteristics of TFR.

Resistor Model

\[ R \cdot \Delta l \quad L \cdot \Delta l \quad C \cdot \Delta l \]
Step Discontinuity in Microstrip Width \[2\]

Electrical scattering fields

\[ C_p = \frac{1}{2} \left( \frac{\sqrt{\varepsilon_{eff1}} - \varepsilon_0 \varepsilon_r W_1}{c_0 Z_{01}} \right) \cdot (W_1 - W_2) \]

\[ L_s = \left[ a \left( \frac{W_1}{W_2} - 1 \right) - b \log \left( \left( \frac{W_1}{W_2} \right) + c \left( \frac{W_1}{W_2} - 1 \right)^2 \right) \right] h \]

Parameter Extraction of Lossy μstrip Line

Transfer Momentum simulation S-parameters to ABCD parameters

\[ Z_0 = B / \left[ \sinh(\text{acosh}(A)) \right] \]
\[ \gamma = \text{acosh}(A) / l \]
\[ Z = Z_0 \cdot \gamma \]
\[ Y = \gamma / Z_0 \]
\[ R = \text{Re}(Z) \]
\[ L = \text{Im}(Z) / \omega \]
\[ C = \text{Im}(Y) / \omega \]
Normalized Resistance per Unit Length

Substrate: 15mil (381µm) Alumina
Sheet Resistance of Resistor Layer: 50Ω/□

Table 1: Parameters of simulated microstrips

<table>
<thead>
<tr>
<th>Input Parameter</th>
<th>Minimum Value</th>
<th>Maximum Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>1GHz</td>
<td>40 GHz</td>
</tr>
<tr>
<td>Width</td>
<td>100 µm</td>
<td>500 µm</td>
</tr>
<tr>
<td>Length</td>
<td></td>
<td>500 µm</td>
</tr>
</tbody>
</table>
Capacitance per Unit Length

[Image of 3D graphs showing capacitance as a function of frequency and width for both lossy and lossless microstrip lines.]

Inductance per Unit Length

Lossy Microstrip Line

Lossy

Lossless

Step

Lossy Microstrip Line

Step
Self-Capacitance Effect \[1\]

Model of series impedance per unit length

\[
R_{\text{eff}} = R \left[ 1 - \frac{(\omega R C_s / 2)^2}{1 + (\omega R C_s / 2)^2} \right] \Omega/m
\]

\[
L_{\text{eff}} = L - \frac{R^2 C_s / 4}{1 + (\omega R C_s / 2)^2} H/m
\]

\[
C_s = 1.58 \times 10^{-3} \left( \frac{W}{h} + 1.26 \right) fF
\]
Thin-Film Resistor Model in ABCD Form

\[
\begin{bmatrix}
A & B \\
C & D
\end{bmatrix} = \begin{bmatrix}
1 - \omega^2 L_s C_p & j\omega L_s \\
j\omega C_p & 1
\end{bmatrix} \begin{bmatrix}
\cosh(\gamma l) & Z_0 \sinh(\gamma l) \\
\frac{\sinh(\gamma l)}{Z_0} & \cosh(\gamma l)
\end{bmatrix} \begin{bmatrix}
1 & j\omega L_s \\
j\omega C_p & 1 - \omega^2 L_s C_p
\end{bmatrix}
\]

\[Z_0 = \sqrt{\frac{Z}{Y}} \text{ and } \gamma = \sqrt{Z \cdot Y}\]

\[Y = j\omega C\]

\[Z = R_{\text{eff}} + j\omega L_{\text{eff}}\]
S-parameter Comparisons

Table 2:

<table>
<thead>
<tr>
<th>W(µm)</th>
<th>L(µm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>52.4Ω</td>
<td>270</td>
</tr>
<tr>
<td>104.2Ω</td>
<td>530</td>
</tr>
</tbody>
</table>

Lossy Microstrip Line
Conclusions

- An accurate scalable model for thin-film resistors has been represented in ABCD matrix form.

- A self-capacitance is used to get better fitting of the model.

- The proposed model is very fast computationally compared to the full-wave momentum simulator.

- Good agreement between simulations with the proposed model and measurements has been obtained up to 40 GHz.