Evaluation of Transmission Line Modeling Using Different De-embedding Methods

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Outline

• Background
• About de-embedding
• Different de-embedding methods
  – Open-short method
  – Thru-only method
  – L-2L method
• Comparison of measured transmission line data
• Performance comparison of the PAs using different TL models
• Conclusion
Background

Advantage of 60GHz

Enable communication distance is short.
Be resistant to interfere

Suitable for short range wireless Communications

IEEE 802.15.3c
- QPSK
  ☑ 3.5Gbps/ch
- 16QAM
  ☑ 7.0Gbps/ch

Gbps Wireless Communication

Wireless Transmission of uncompressed HDTV
Transmission Line

TL is used for considering the circuit by distributed constant.

PDK are only guaranteed to 20 GHz.

The accurate models for 60 GHz are required.

The structure of TL.
What is De-Embedding?

- Measurement data include parasitic components.
- Parasitic components are not ignorable at 60GHz.

These are required to be removed.

- Open-short method
- Thru-only method
- L-2L method
Open-short and thru-only method

**Open-short**

Ideal short pattern cannot be achieved.

$$Z_P = Z_{open}$$

**Thru-only**

Affected by the thru length and probe coupling.

$$Z_P = \frac{1}{Y_{11} + Y_{12}}$$

$$Z_S = \frac{Z_{open} \times Z_{short}}{Z_{open} - Z_{short}}$$

$$Z_S = -\frac{1}{2Y_{12}}$$

L-2L De-embedding method

\[ T_{\text{L}} \quad T_{2L^{-1}} \quad T_{\text{L}} \]

\[ \begin{pmatrix} 1 & Z \end{pmatrix} \]

\[ T_S = \begin{pmatrix} 1 & Z \end{pmatrix} \]

\[ T_P = \begin{pmatrix} 1 & 0 \\ Y_P & 1 \end{pmatrix} \]

😊 Realize ideal thru pattern.
😊 Good isolation between probes.

Parameters of TL ($\alpha$, $\beta$, $Q$, $Z_0$)

\[ \frac{dV(z)}{dz} = (R + j\omega L)I(z) \]
\[ \frac{-dI(z)}{dz} = (G + j\omega C)V(z) \]

\[ \gamma = \sqrt{(R + j\omega L)(G + j\omega C)} = \alpha + j\beta \]
\[ \alpha \approx \frac{1}{2} \left( \frac{R}{Z_0} + GZ_0 \right) \]
\[ \beta \approx \omega \sqrt{LC} \]

\[ Q = \frac{\beta}{2\alpha} \]
\[ Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}} \]

$\alpha$: attenuation constant
$\beta$: phase constant
$Q$: quality factor
$Z_0$: characteristic impedance
Evaluation

- open-short
- thru-only
- L-2L

Compare the parameter $\alpha, \beta, Q,$ and $Z_0$ per unit length.

These parameters must be the same regardless of the length of TLs.

Make the models of TL using measurement result of different de-embedding methods.
Simulate the effect of different models by applying to a 4-stage PA.

Circuit schematic of 4-stage PA for simulation

- common source topology
- MIM capacitor is used for decoupling
- 1.2V supply, 65nm CMOS

The evaluation is focused on the accuracy of transmission line models, so the same models are used for transistor, MIM capacitor, etc.
Measurement results using open-short method

Open-short method cannot be used for modeling.
**Measurement results using thru-only method**

Z₀ has 3 Ω difference at 60 GHz.
Measurement results using L-2L method

$Z_0$ has 0.9 $\Omega$ difference at 60 GHz.
De-embedding error at 60GHz

This table shows the difference of transmission line parameters between different length of TLs.

<table>
<thead>
<tr>
<th></th>
<th>Open-short</th>
<th>Thru-only</th>
<th>L-2L</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\Delta \alpha [%]$</td>
<td>20.4</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>$\Delta \beta [%]$</td>
<td>32.7</td>
<td>5.7</td>
<td>0.1</td>
</tr>
<tr>
<td>$\Delta Q [%]$</td>
<td>21</td>
<td>1.5</td>
<td></td>
</tr>
<tr>
<td>$\Delta Z_0 [%]$</td>
<td>15.3</td>
<td>6.1</td>
<td>1.7</td>
</tr>
</tbody>
</table>

L-2L method can obtain the smallest error of transmission line parameters.
The effect of different de-embedding methods

Simulation result

<table>
<thead>
<tr>
<th></th>
<th>Thru-only</th>
<th>L-2L</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Freq. [GHz]</strong></td>
<td>61.4</td>
<td>58.8</td>
</tr>
<tr>
<td><strong>Gain [dB]</strong></td>
<td>19.8</td>
<td>21.3</td>
</tr>
<tr>
<td><strong>P_{1dB} [dBm]</strong></td>
<td>7.41</td>
<td>8.78</td>
</tr>
<tr>
<td><strong>P_{sat} [dBm]</strong></td>
<td>11.0</td>
<td>11.4</td>
</tr>
<tr>
<td><strong>Peak PAE [%]</strong></td>
<td>6.51</td>
<td>7.45</td>
</tr>
<tr>
<td><strong>Power [mW]</strong></td>
<td>169</td>
<td>170</td>
</tr>
</tbody>
</table>

There are 1.5-dB gain error and 2.6-GHz frequency shift. Sim. error heavily depends on the de-embedding method.
Conclusion

• This presentation shows an evaluation of de-embedding methods for mmW transceiver design.

• The L-2L de-embedding method is the most accurate for transmission-line characterization.

• The frequency shift with 4-stage PA using different de-embedding methods is 2.6 GHz which is over a channel of IEEE802.15.3c.

• The effect of different de-embedding method cannot be negligible.