Micromachined Coaxial Transmission Lines for Integrated Millimeterwave Communication Antennas

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Why 3D Transmission Lines?

Traditional IC processes and micromachining are not three dimensional

Resulting in the use of planar transmission lines such as microstrip and coplanar waveguides
Problems with Planar T-Lines

**Microstrip**

- Quasi TEM
  - Dispersive
- Fields in air and substrate
  - Line width is proportional to substrate thickness
  - Loss tied to substrate material
  - Cross talk to neighboring lines and devices
- Requires backside metalization
- Ground connection requires a via
- Crossing signal lines is difficult

**Coplanar Waveguide**

- Quasi TEM
  - Dispersive
- Fields in air and substrate
  - Line width and gap are related to substrate properties
  - Loss tied to substrate material
  - Cross talk to neighboring lines and devices
- Moding is a major design issue
- Crossing signal lines is difficult
3D Micro-fabrication
T-Line Comparison

Recta-Coax

- TEM Transmission line
- Substrate independent
- Fields confined to enclosed region
- Ground and signal available
- Crossovers and bends are readily implemented
Rectangular Coaxial Transmission Lines

Modeled and simulated characteristic impedance for lines that can be realized in EFAB
(All dimensions in micrometers)

<table>
<thead>
<tr>
<th>Line</th>
<th>t (µm)</th>
<th>t_g (µm)</th>
<th>w_g (µm)</th>
<th>w_{50} (Ω)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>28</td>
<td>24</td>
<td>50</td>
<td>47</td>
</tr>
<tr>
<td>B</td>
<td>30</td>
<td>32</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>C</td>
<td>28</td>
<td>122</td>
<td>150</td>
<td>309</td>
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</tbody>
</table>
### Loss Comparison (dB/cm)

#### 50Ω Transmission Lines

<table>
<thead>
<tr>
<th>Line Dimensions (Micrometers)</th>
</tr>
</thead>
</table>

#### Recta-Coax

<table>
<thead>
<tr>
<th>Line</th>
<th>t</th>
<th>t_g</th>
<th>w_g</th>
<th>w_{50}</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC B (Ni)</td>
<td>30</td>
<td>32</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>RC B (Au)</td>
<td>30</td>
<td>32</td>
<td>50</td>
<td>65</td>
</tr>
<tr>
<td>RC B (Cu)</td>
<td>30</td>
<td>32</td>
<td>50</td>
<td>65</td>
</tr>
</tbody>
</table>

#### Microstrip

<table>
<thead>
<tr>
<th>Line</th>
<th>w</th>
<th>d</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS (Au)</td>
<td>35</td>
<td>50</td>
<td>GaAs</td>
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</table>

#### Coplanar Waveguide

<table>
<thead>
<tr>
<th>Line</th>
<th>w</th>
<th>g</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPW (Au)</td>
<td>80</td>
<td>40</td>
<td>Sapphire</td>
</tr>
</tbody>
</table>
Loss Comparison (Quality Factor)

50Ω Transmission Lines

Line Dimensions
(Micrometers)

<table>
<thead>
<tr>
<th>Line</th>
<th>t</th>
<th>t_g</th>
<th>w_g</th>
<th>w_{50}</th>
</tr>
</thead>
<tbody>
<tr>
<td>RC C (Ni)</td>
<td>28</td>
<td>122</td>
<td>150</td>
<td>309</td>
</tr>
<tr>
<td>RC C (Au)</td>
<td>28</td>
<td>122</td>
<td>150</td>
<td>309</td>
</tr>
<tr>
<td>RC C (Cu)</td>
<td>28</td>
<td>122</td>
<td>150</td>
<td>309</td>
</tr>
</tbody>
</table>

Recta-Coax

<table>
<thead>
<tr>
<th>Line</th>
<th>w</th>
<th>d</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>MS (Au)</td>
<td>??</td>
<td>150</td>
<td>Quartz</td>
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Microstrip

<table>
<thead>
<tr>
<th>Line</th>
<th>w</th>
<th>g</th>
<th>Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPW (Au)</td>
<td>80</td>
<td>40</td>
<td>Sapphire</td>
</tr>
</tbody>
</table>
Fabricated Resonators
Fabricated Resonators

![Graph showing quality factor Q vs. frequency (GHz) for different models and designs.](image)

- **Model - Small Line**
- **Model - Large Line**
- **Simulation - Design #3**
- **Simulation - Design #4**
- **Test - Design #4**

<table>
<thead>
<tr>
<th>Design</th>
<th>$Z_0$</th>
<th>$f_0$</th>
<th>Length (mm)</th>
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</thead>
<tbody>
<tr>
<td>RC A (Ni)</td>
<td>50</td>
<td>44</td>
<td>1.60</td>
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<tr>
<td>RC B (Ni)</td>
<td>50</td>
<td>60</td>
<td>1.15</td>
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</tbody>
</table>
Lines and Bends

Measured Insertion Loss

1 - 1.2 mm Line
2 - 3.2 mm Lines
2 - 3.2 mm Lines with Bends

Frequency (GHz)

Insertion Loss (dB)
# 60 GHz Branch Line Coupler

**Table I. Design Parameters for the 60 GHz Coupler. All dimensions are in millimeters.**

<table>
<thead>
<tr>
<th>Line</th>
<th>$t$</th>
<th>$t_g$</th>
<th>$w$</th>
<th>$w_g$</th>
<th>Length</th>
<th>$Z_0(\Omega)$</th>
</tr>
</thead>
<tbody>
<tr>
<td>L1</td>
<td>0.028</td>
<td>0.024</td>
<td>0.086</td>
<td>0.05</td>
<td>1.26</td>
<td>35.6</td>
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<tr>
<td>L2</td>
<td>0.028</td>
<td>0.024</td>
<td>0.046</td>
<td>0.05</td>
<td>1.26</td>
<td>51.4</td>
</tr>
</tbody>
</table>
60 GHz Branch Line Coupler

**Graph: Frequency Response**

- **Frequency (GHz)**: 30.00 to 70.00
- **dB( |S_{ij}| )**: Range from 0.00 to -50.00

- **Ports**: Port 1, Port 2, Port 3, Port 4
- **S Parameters**:
  - $S_{11}$
  - $S_{12}$
  - $S_{13}$
  - $S_{14}$

- **20% BW** indicated at the frequency range.

**Diagram Details**:
- Arrows indicating the behavior of $S_{12}$ and $S_{13}$
- Graph showing the dB values for each S parameter across the frequency range.
Summary

• New micromachining processes enable the realization of enclosed TEM transmission lines

• These Recta Coax Lines offer significant advantages
  – Substrate independent
  – Complex routing, including cross-overs and bends
  – Isolation from surrounding devices
  – 1st Pass success shows potential for dramatically reducing design costs
Microfabrica’s EFAB

Layer Cycle

<table>
<thead>
<tr>
<th>Layer #</th>
<th>Thickness</th>
<th>Line</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
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<td></td>
</tr>
<tr>
<td>11</td>
<td>8</td>
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<td></td>
</tr>
<tr>
<td>1</td>
<td>8</td>
<td></td>
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</tbody>
</table>

EFAB Process
1. Begin with planar metal surface
2. Deposit a patterned layer
3. Deposit a blanket layer
4. Planarize
5. Repeat 1-4 for the desired number of layers
6. Sacrificially remove one of the two materials