Addressing the Design Challenges of RF/ Millimeter Wave Semiconductor Packaging

Craig Vieira – RF Designer

Content Overview

• Company Overview
  – What we do
  – Markets served
  – RF/ high frequency interconnect experience

• What’s new in 2016
  – RF Design, Test & Measurement capabilities
  – Portfolio additions & innovative technology

• Design Challenges in high speed Interconnects
  – Think like a wavelength & remember waveguide theory
  – Managing bandwidth, loss, and signal fidelity
Ametek Electronic Packaging Overview

- Ametek, Inc.
  - $4B sales, 15k employees worldwide
- Electronic Packaging Division specializes in Hermetic microelectronic package design & manufacturing
  - Glass-to-metal seals
  - Ceramic-to-metal seals
  - Ceramic packages
- Who we are
  - Aegis
  - Glassseal Products
  - SCP

www.ametek-ecp.com
Ametek Electronic Packaging Overview

• Markets served
  – Defense
  – Industrial
  – Aerospace
  – Optical Communications
**I/O Types**

- **SMA**  
  - DC- 26GHz
- **K, V, W**  
  - 40, 67, 110GHz
- **SMP**  
  - Equivalent to GPO  
  - 26GHz
- **SMPM**  
  - Equivalent to GPPO  
  - 40GHz
- **SMPS**  
  - Equivalent to G3PO  
  - 65GHz

**Applications**

- Hermetic coaxial connectors standalone
- Optical modulators
- Defense

[www.ametek-ecp.com](http://www.ametek-ecp.com)
Personal Introduction

• Application & Design Experience
  – ATE, semiconductor test
    • Packaged & wafer
      – DC – 80GHz
      – Passive & Active RF/ mm Wave design
  – Joined Ametek in June 2015
What’s New for 2016

• SMPx series
  – In house design, specification & datasheet
  – Test & evaluation boards
  – Customization options

• HTCC R&D Continues
  – S-Bend
    • Alpha design showing performance to 35GHz
    • Beta design intends to meet 50GHz
  – High speed flat solutions
    • Several variations
    • Feasibility study underway

www.ametek-ecp.com
Design Challenges of RF & Millimeter Wave

- Passive circuitry tradeoffs
  - Bandwidth
  - Insertion Loss
  - Size
  - Crosstalk/ signal fidelity
  - Cost
Think Like a Wavelength

• At lower frequencies, wavelength (λ) is not normally a concern
• Commercial RF market bulk spectrum is <6GHz
• Optical market example 40GHz+

\[\text{λ Comparison}\]

<table>
<thead>
<tr>
<th>Medium</th>
<th>Dk</th>
<th>6GHz</th>
<th>40GHz</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>1</td>
<td>2”</td>
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<tr>
<td>High Quality PCB</td>
<td>3.5</td>
<td>1.05”</td>
<td>0.16”</td>
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<td>Ceramic</td>
<td>9.5</td>
<td>0.64”</td>
<td>0.1”</td>
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</table>
# Keep Thinking Like a Wavelength

## $\lambda/2$ Comparison

<table>
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Observe as frequency increases, wavelength decreases.

## $\lambda/4$ Comparison

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<tr>
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<td>0.5”</td>
<td>0.075”</td>
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<tr>
<td>High Quality PCB</td>
<td>3.5</td>
<td>0.275”</td>
<td>0.04”</td>
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<tr>
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<td>9.5</td>
<td>0.16”</td>
<td>0.025”</td>
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Observe as Dk increases, wavelength decreases.
Now Remember Waveguide Theory

- **Circular Waveguide**
  \[ \lambda_{c,mn} = \frac{2 \cdot \pi \cdot r}{p_{mn}} [m] \]

- **Rectangular Waveguide**
  \[ (f_c)_{mn} = \frac{1}{2 \cdot \pi \cdot \sqrt{\mu \varepsilon}} \sqrt{\left(\frac{m \cdot \pi}{a}\right)^2 + \left(\frac{n \cdot \pi}{b}\right)^2} [Hz] \]
  \[ (\lambda_c)_{mn} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}} [m] \]

- ↑BW  ↓λc
- ↓λc  ↓r
- ↑BW  ↓λc
- ↓λc  ↓a
Circular Waveguide – Real World Coax

- Example hermetic male shroud SMPM connector
- Fc limited by conventional glass bead diameter

<table>
<thead>
<tr>
<th>Dielectric</th>
<th>Application</th>
<th>Er</th>
<th>Zo(Ω)</th>
<th>d (mils)</th>
<th>D (mils)</th>
<th>Fc (GHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>Ideal world</td>
<td>1</td>
<td>50</td>
<td>12</td>
<td>28</td>
<td>187.8</td>
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<tr>
<td>PTFE</td>
<td>F/F SMPM bullet</td>
<td>2.1</td>
<td>50</td>
<td>14</td>
<td>47</td>
<td>85</td>
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<tr>
<td>Glass Orig</td>
<td>Existing designs</td>
<td>4.1</td>
<td>50</td>
<td>12</td>
<td>65</td>
<td>48</td>
</tr>
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Circular Waveguide – Real World Coax

- Push the SMPM bandwidth by making the TE11 mode propagate higher in frequency
- How?

TE11 S11 v. Frequency & Connector Geometry

![Graph showing TE11 S11 vs Frequency & Connector Geometry](chart.png)
Rectangular Waveguide Theory – HTCC

• What factors limit the transmission line BW?
Fc Limitations in HTCC

- Substrate Thickness – TE1 mode
  - Parallel plate waveguide / Surface waves
  - To be kept < $\lambda/4$, simulation suggests $\lambda/5$

**$\lambda/4$ Comparison**

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- Thinner material is better for higher frequencies
  - But worse for handling, insertion loss, heat, etc.
Fc Limitations in HTCC continued

- Ground spacing
- Consider CPWG
  - \( s < \lambda/2 \) (ground separation)
  - Actual limitation is based on via fence location
  - ‘s’ is like broad wall dimension ‘a’ of rectangular waveguide
**λ/2 in HTCC**

- Via spacing must be < 0.050” for 40GHz mode-free operation

### λ/2 Comparison

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S-Bend Concept

• Ametek patented the S-Bend concept for HTCC feedthroughs

• Provides a smooth RF signal path with no abrupt transitions nor signal vias
S-Bend Baseline Analysis

- 3D EM Simulation performed on flat HTCC to provide a baseline for results
- Does waveguide theory apply?
S-Bend Baseline Broad Wall Vias

**Via Spacing Comparison**

<table>
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<tr>
<th>Via Spacing</th>
<th>Fc Theory</th>
<th>Fc Simulated</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.030”</td>
<td>65GHz</td>
<td>54GHz</td>
</tr>
<tr>
<td>0.050”</td>
<td>38GHz</td>
<td>38GHz</td>
</tr>
<tr>
<td>0.070”</td>
<td>27GHz</td>
<td>29GHz</td>
</tr>
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</table>

Why the difference?
Fc Limitations in HTCC continued

- Via ground fence – pitch
- Vias parallel to CPWG signal trace must be spaced $< \lambda/4$ ('p' – 'd')
# S-Bend Baseline Via to Via Fence Spacing

<table>
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<th>P-d</th>
<th>Fc Theory</th>
<th>Fc Simulated</th>
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</thead>
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<tr>
<td>0.015”</td>
<td>0.011”</td>
<td>87GHz</td>
<td>54GHz</td>
</tr>
<tr>
<td>0.020”</td>
<td>0.016”</td>
<td>64GHz</td>
<td>52GHz</td>
</tr>
<tr>
<td>0.025”</td>
<td>0.021”</td>
<td>45GHz</td>
<td>41GHz</td>
</tr>
<tr>
<td>0.030”</td>
<td>0.026”</td>
<td>37GHz</td>
<td>34GHz</td>
</tr>
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![Graphs showing S21 and S11 vs. Via to Via Pitch](image-url)
S-Bend Baseline Via to Via Fence Pitch

- Another way to look at it, view the results with respect to the TE10 mode

![Graph showing TE10 Mode vs. Via to Via Pitch with frequencies 36GHz, 45GHz, and 52GHz marked]
Rectangular Waveguide Theory – Real World

• Where can we go, and how do we get there?
  – Increase bandwidth, decrease thickness
  – Decrease thickness, decrease line widths to maintain 50Ω
  – Decreasing signal widths, increased insertion loss
  – Decreased size, increased crosstalk

• Managing Tradeoffs – design for maximum frequency and not much more
Today & Tomorrow

• More bandwidth!
  – IOT (Internet of Things)
  – Smartphones, tablets, PCs, etc.
  – Smart TV’s, streaming entertainment

• Markets are driven to push bandwidth, enabling faster communication networks

• 100G & 400G Ethernet need high speed I/O
Q & A

- Thank you for your time, any questions or comments?

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