Addressing the Design Challenges of RF/ Millimeter Wave Semiconductor Packaging

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IMAPS New England - May 3, 2016

www.ametek-ecp.com

Content Overview

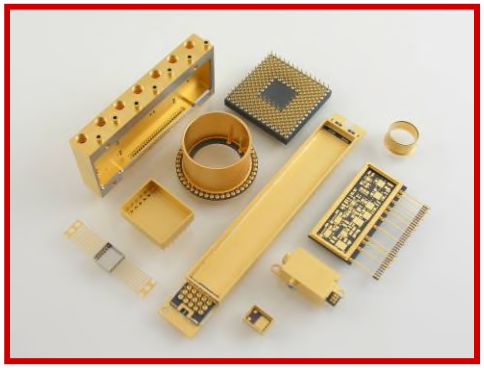
- Company Overview
  - What we do
  - Markets served
  - RF/ high frequency interconnect experience

- 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

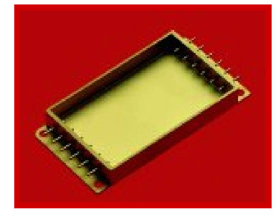
Ametek Electronic Packaging Overview

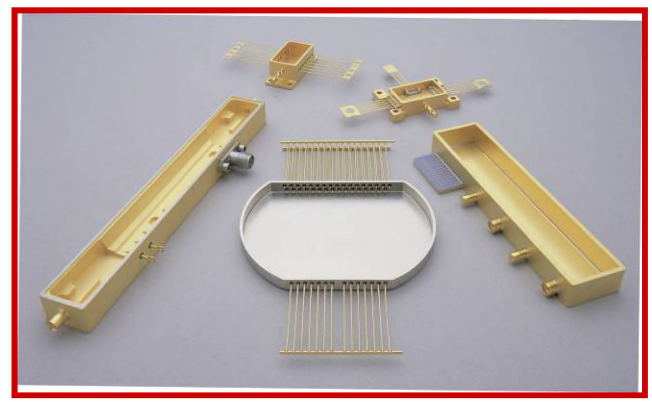
- Ametek, Inc.
  - $4B sales, 15k employees worldwide
- Electronic Packaging Division specializes in Hermetic microelectronic package design & manufacturing
  - Glass-to-metal seals
  - Ceramic-to-metal seals
  - Ceramic packages
- Who we are
  - Aegis
  - Glasseal Products
  - SCP

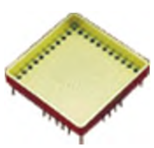


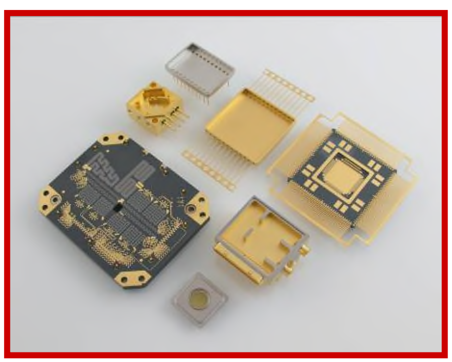
Ametek Electronic Packaging Overview

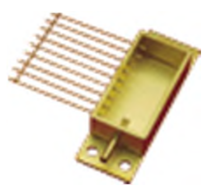
- Markets served
  - Defense
  - Industrial
  - Aerospace
  - Optical Communications











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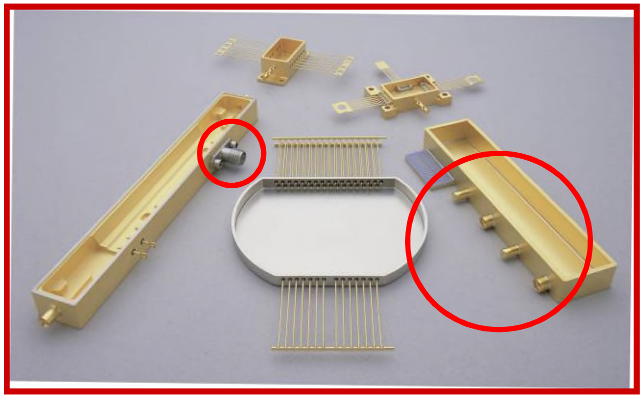
RF Interconnect & Package Experience

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



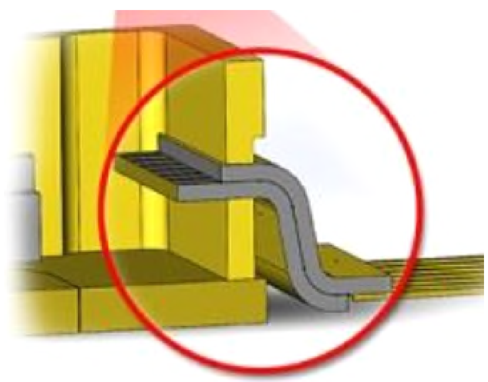
Personal Introduction

- 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



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+

λ Comparison

Medium	Dk	6GHz	40GHz
Air	1	2”	0.3”
High Quality PCB	3.5	1.05”	0.16”
Ceramic	9.5	0.64”	0.1”

Keep Thinking Like a Wavelength

λ/2 Comparison

Medium	Dk	6GHz	40GHz
Air	1	1”	0.15”
High Quality PCB	3.5	0.55”	0.08”
Ceramic	9.5	0.32”	0.05”

Observe as frequency increases, wavelength decreases

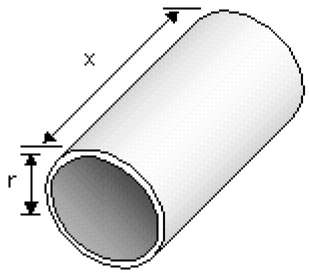
λ/4 Comparison

Observe as Dk increases, wavelength decreases

Medium	Dk	6GHz	40GHz
Air	1	0.5”	0.075”
High Quality PCB	3.5	0.275”	0.04”
Ceramic	9.5	0.16”	0.025”

Now Remember Waveguide Theory

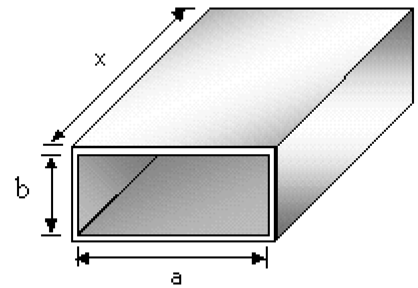
- Circular Waveguide



$$\lambda_{c,mn} = \frac{2 \cdot \pi \cdot r}{p'_{mn}} \quad [\![m]\!]$$

- ↑BW ↓λc
- ↓λc ↓r

- Rectangular Waveguide



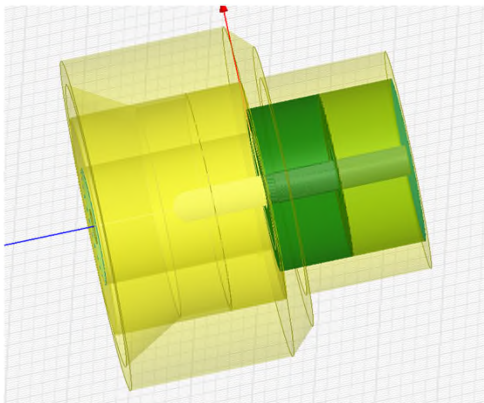
$$(f_c)_{mn} = \frac{1}{2 \cdot \pi \cdot \sqrt{\mu \varepsilon}} \sqrt{\left(\frac{m \cdot \pi}{a}\right)^2 + \left(\frac{n \cdot \pi}{b}\right)^2} \quad [\![Hz]\!]$$

$$(\lambda_c)_{mn} = \frac{2}{\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2}} \quad [\![m]\!]$$

- ↑BW ↓λc
- ↓λc ↓a

Circular Waveguide – Real World Coax

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

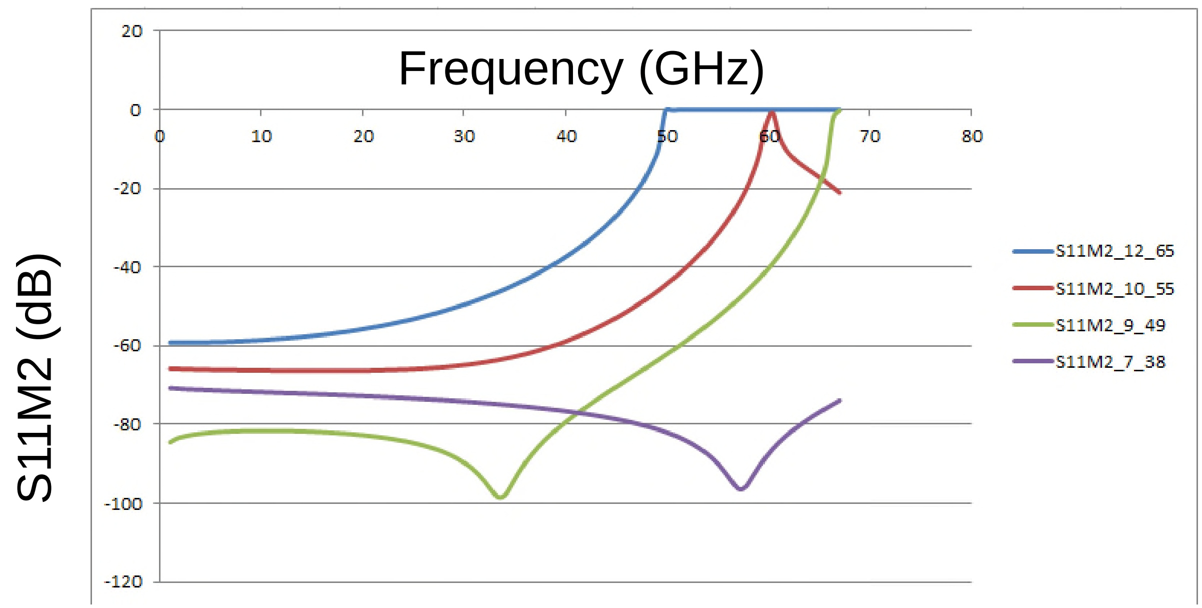


Dielectric	Application	Er	Zo(Ω)	d (mils)	D (mils)	Fc (GHz)
Air	Ideal world	1	50	12	28	187.8
PTFE	F/F SMPM bullet	2.1	50	14	47	85
Glass Orig	Existing designs	4.1	50	12	65	48

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

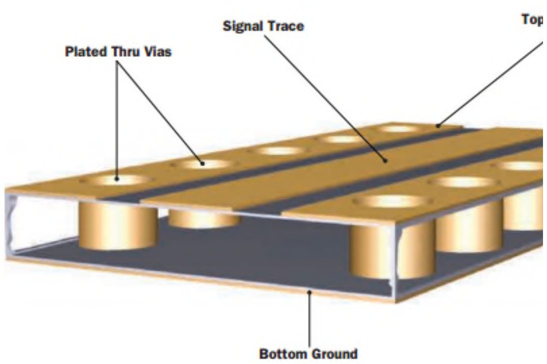


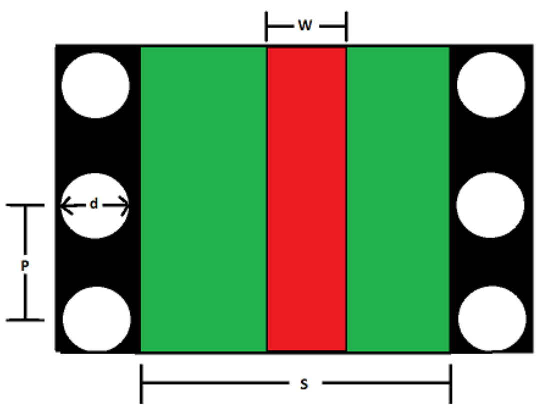
AMETEK ELECTRONIC PACKAGING

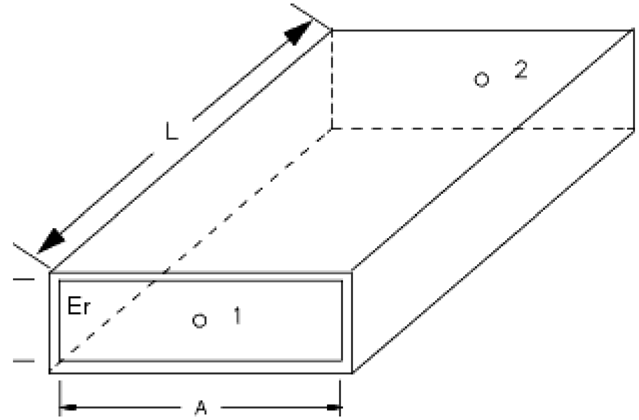
AEGIS GENERAL CERAMICS GLASSEAL PRODUCTS

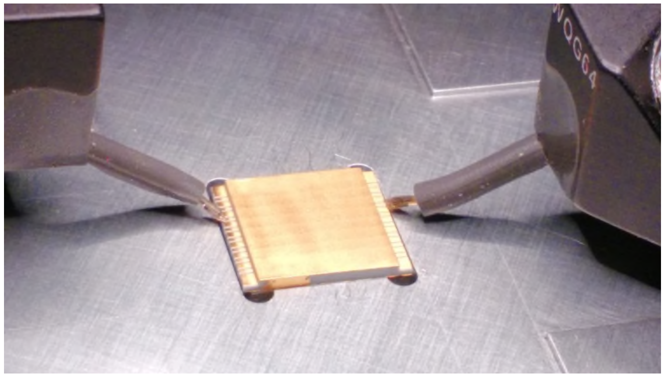
Rectangular Waveguide Theory – HTCC

- What factors limit the transmission line BW?









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Fc Limitations in HTCC

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

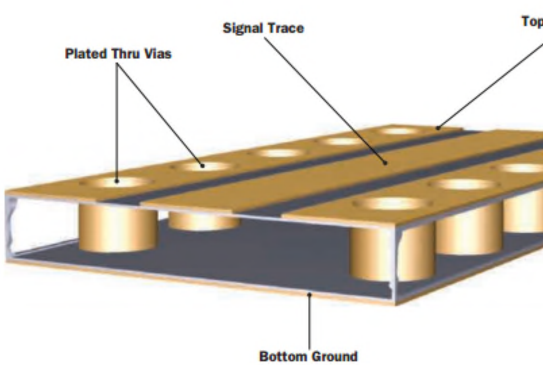
λ/4 Comparison

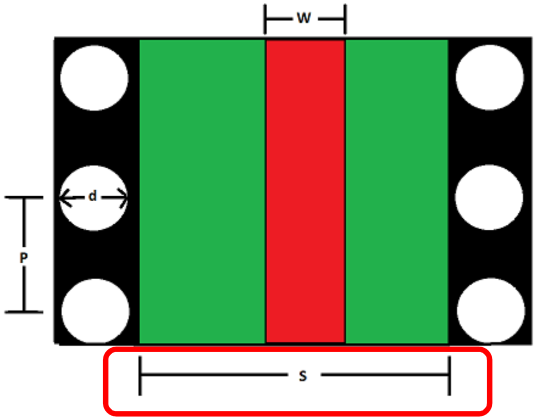
Medium	Dk	6GHz	40GHz
Air	1	0.5”	0.075”
High Quality PCB	3.5	0.275”	0.04”
Ceramic	9.5	0.16”	0.025”

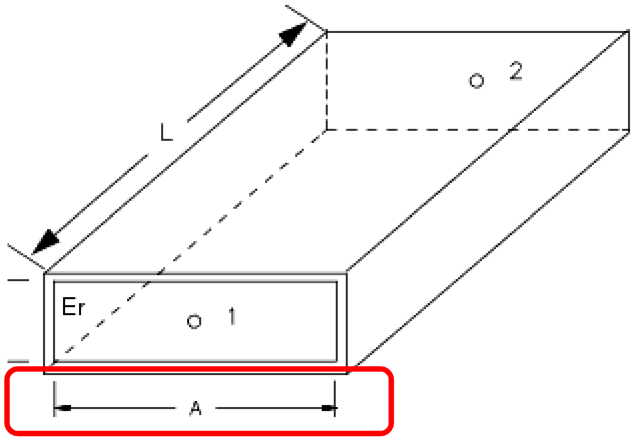
- Thinner material is better for higher frequencies
  - But worse for handling, insertion loss, heat, etc.

Fc Limitations in HTCC continued

- Ground spacing
- Consider CPWG
  - s < λ/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

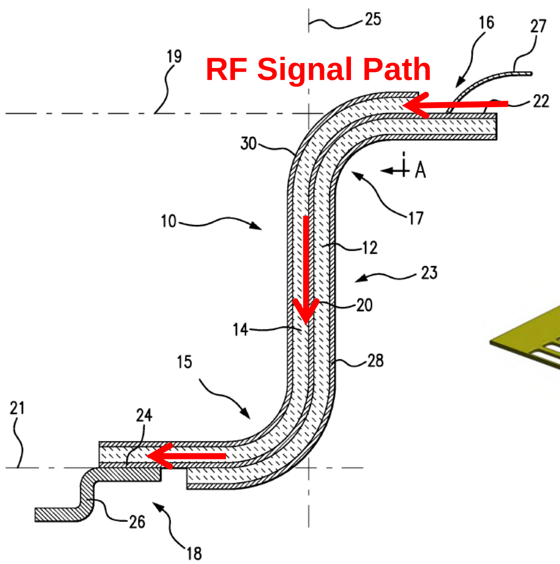
- Via spacing must be < 0.050” for 40GHz mode-free operation

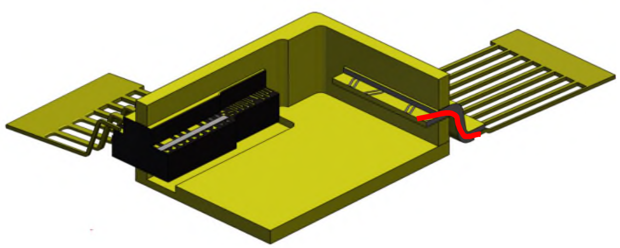
λ/2 Comparison

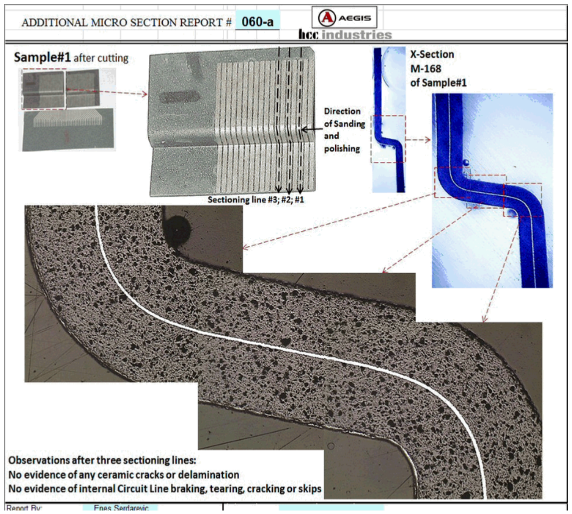
Medium	Dk	6GHz	40GHz
Air	1	1”	0.15”
High Quality PCB	3.5	0.55”	0.08”
Ceramic	9.5	0.32”	0.05”

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

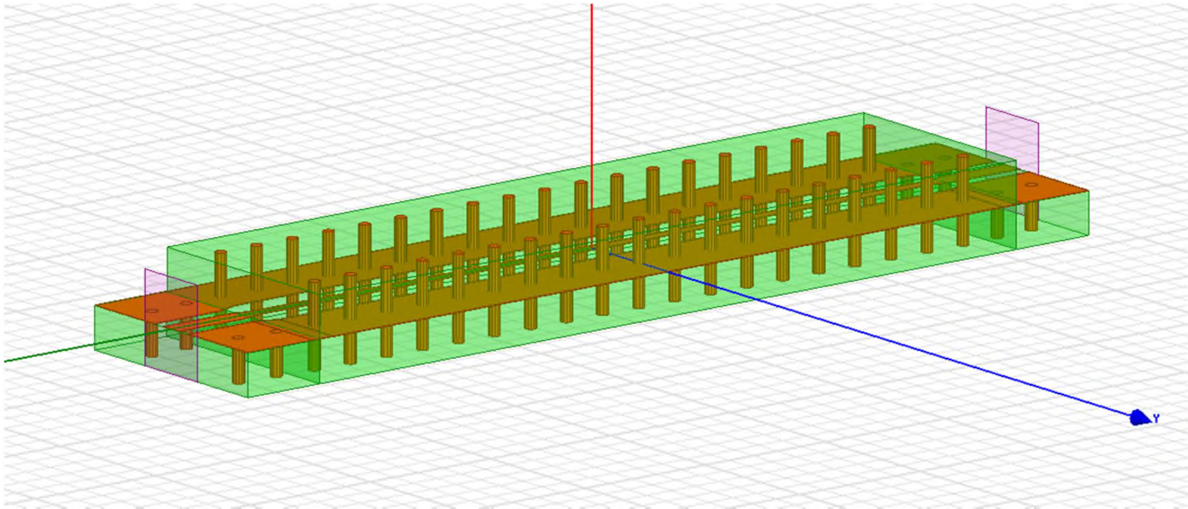


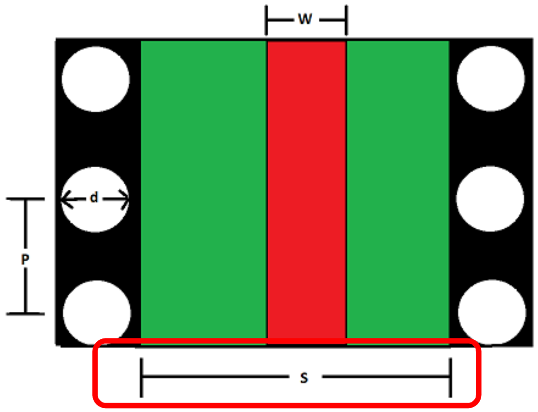




S-Bend Baseline Analysis

- 3D EM Simulation performed on flat HTCC to provide a baseline for results
- Does waveguide theory apply?



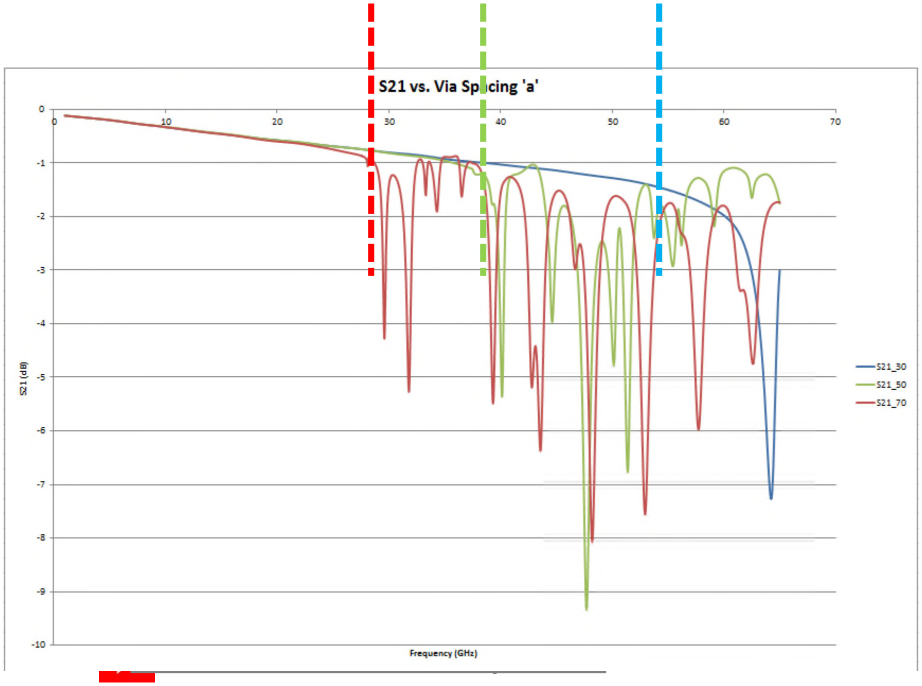


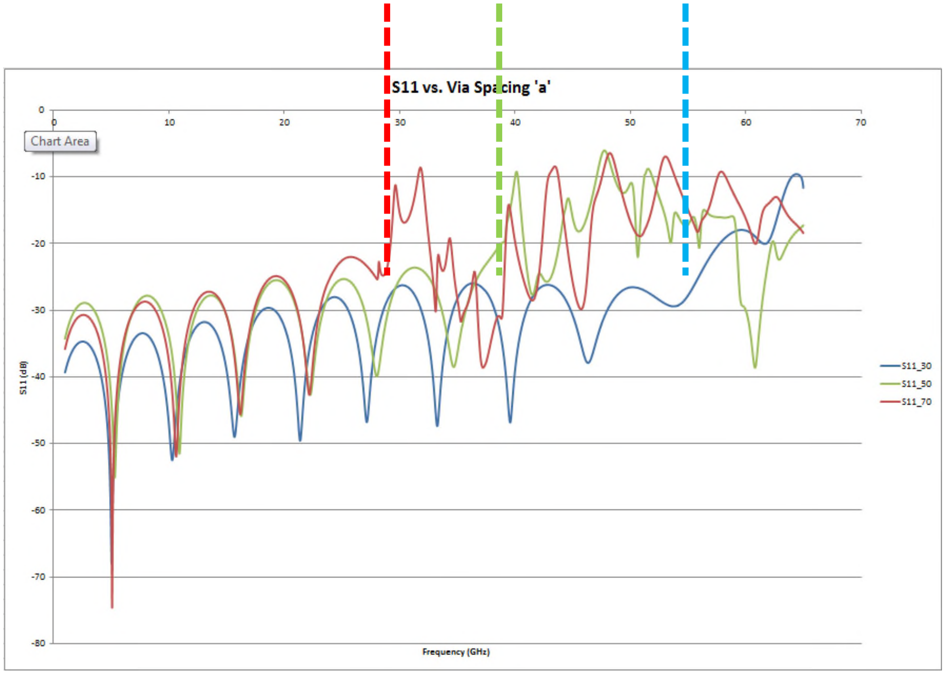
S-Bend Baseline Broad Wall Vias

Via Spacing Comparison

Via Spacing	Fc Theory	Fc Simulated
0.030”	65GHz	54GHz
0.050”	38GHz	38GHz
0.070”	27GHz	29GHz

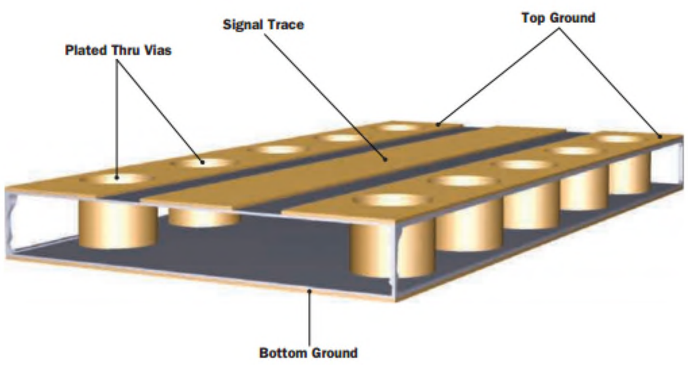
Why the difference?

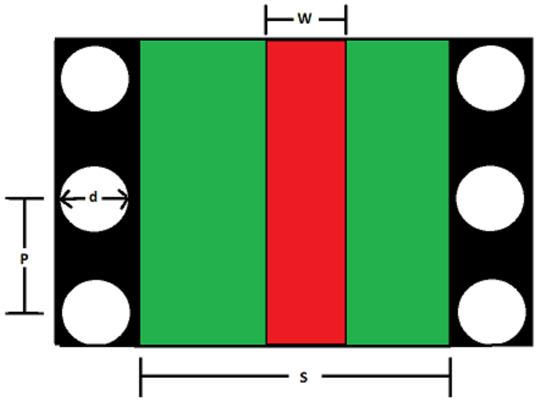




Fc Limitations in HTCC continued

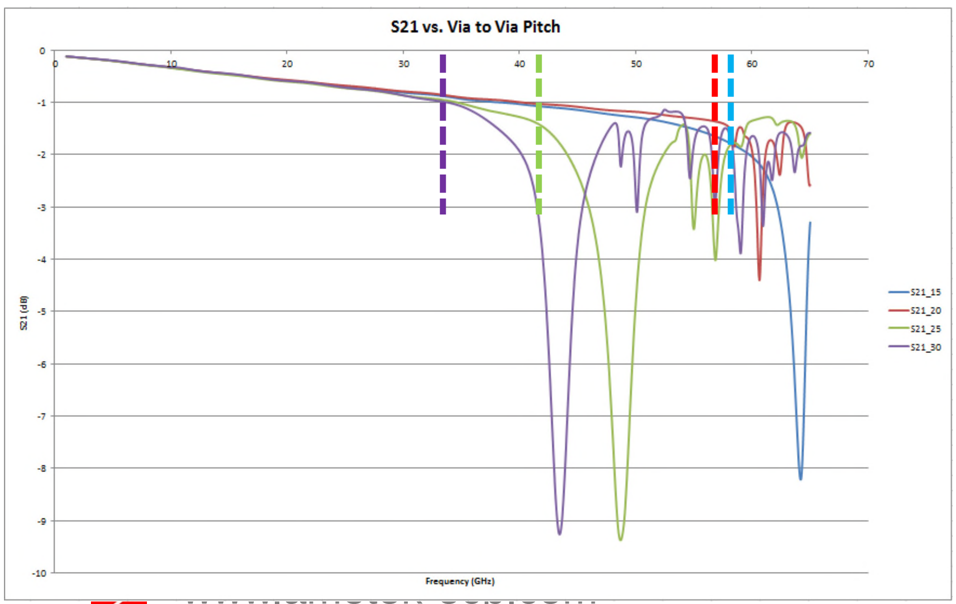
- Via ground fence – pitch
- Vias parallel to CPWG signal trace must be spaced < λ/4 (‘p’ – ‘d’)

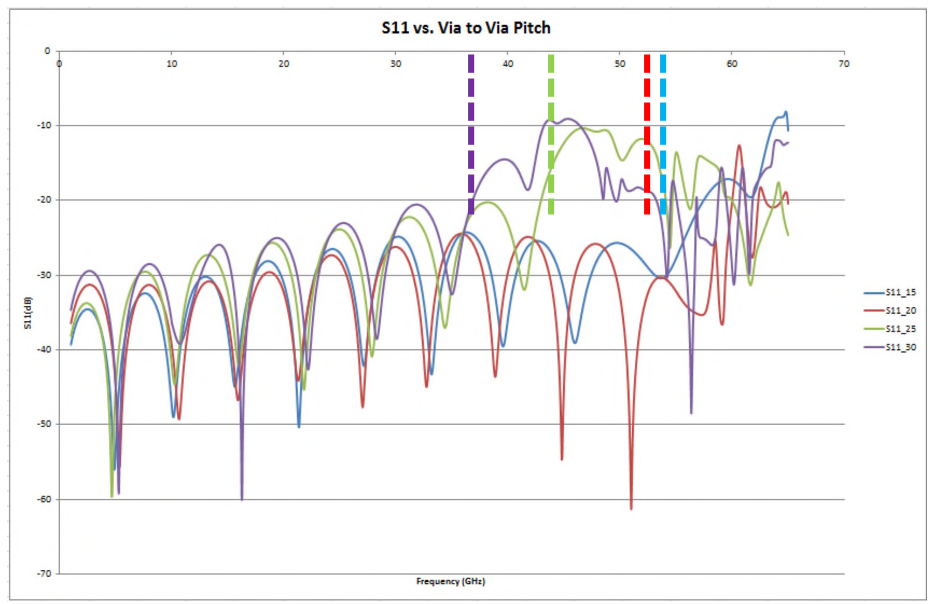




S-Bend Baseline Via to Via Fence Spacing

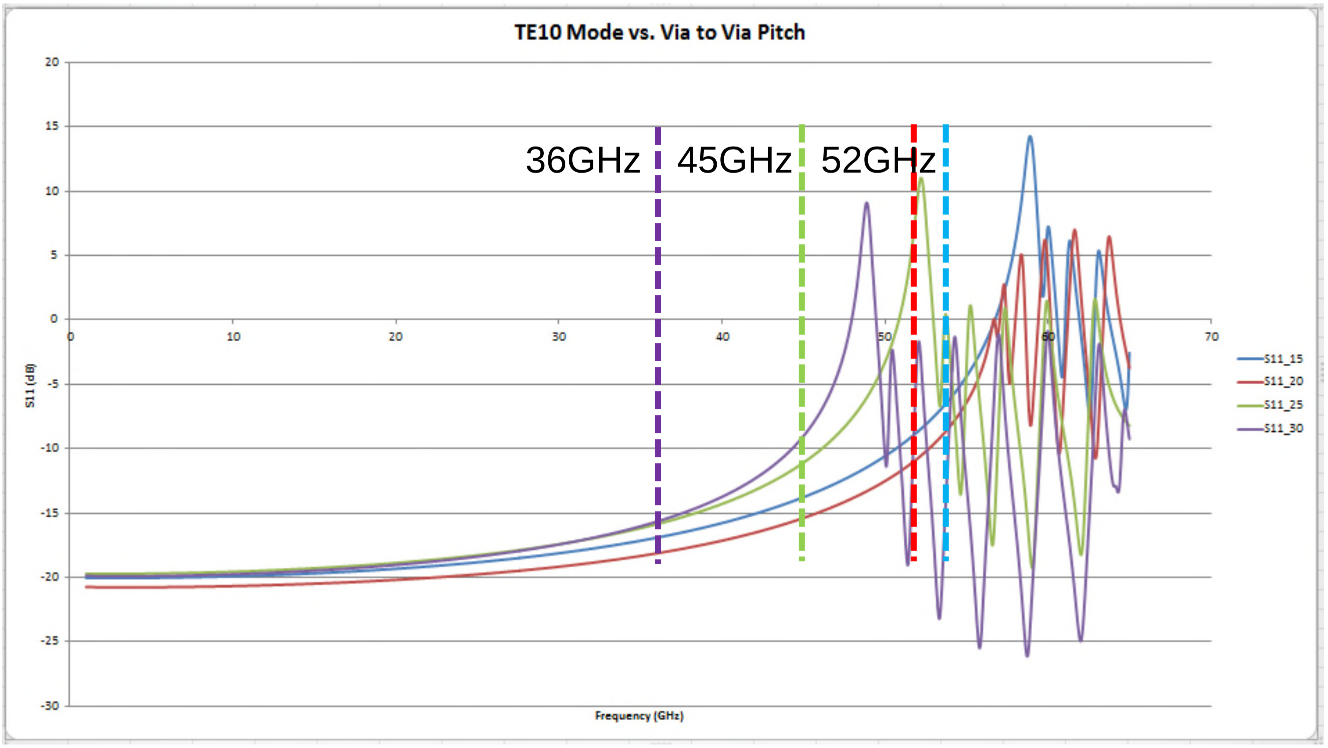
Via Spacing	P-d	Fc Theory	Fc Simulated
0.015”	0.011”	87GHz	54GHz
0.020”	0.016”	64GHz	52GHz
0.025”	0.021”	45GHz	41GHz
0.030”	0.026”	37GHz	34GHz





S-Bend Baseline Via to Via Fence Pitch

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



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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