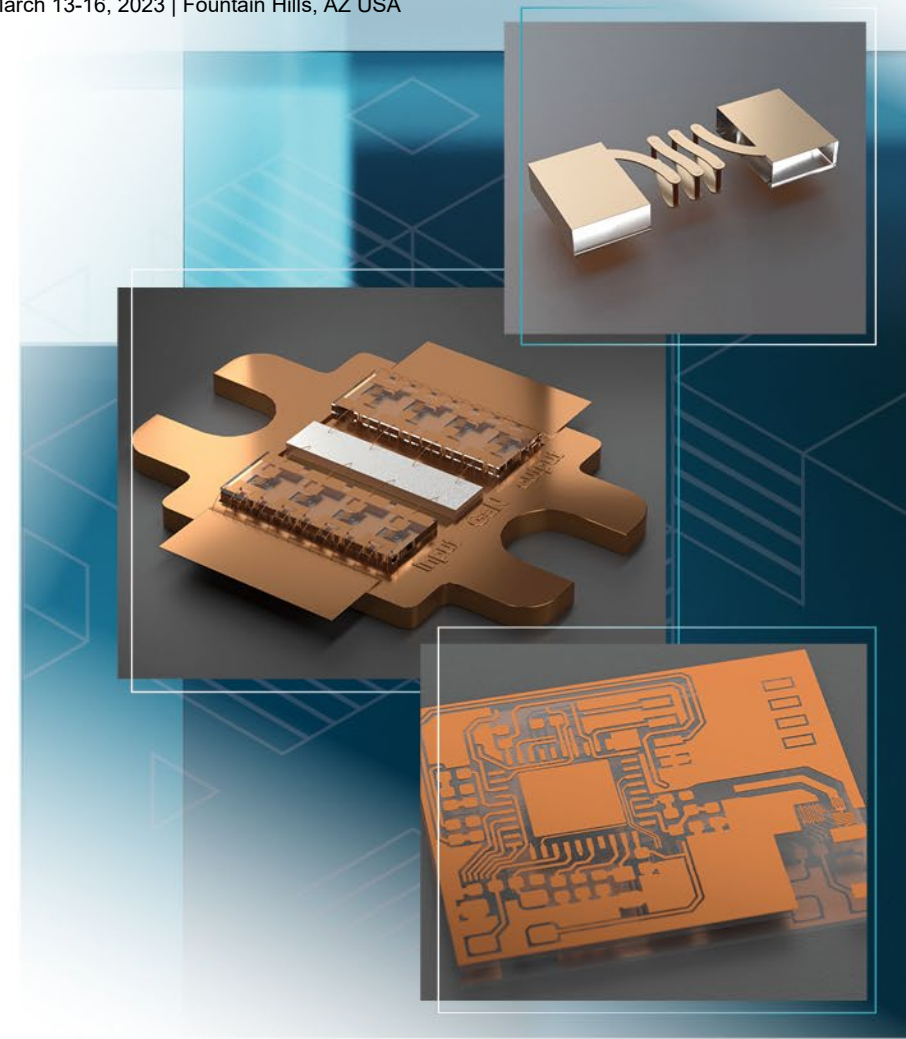
3DGS™

A New Dimension for Electronics

Glass Devices for Next-Generation Packaging and RF Signal Conditioning



Presented by Jeb H. Flemming

Founder, CTO

Company Overview

- Pure Play Glass Foundry
- Design → Production under one roof
- Fully integrated EDA for rapid device design
- Work with all types of glass
- Heavy focus on Photosensitive Glass Ceramic (PSG)
- Other portfolio glasses: HPFS, Eagle XG, and others...
- Headquartered in Albuquerque, NM USA
- 100% US Built:
- Foundational IP on glass-based devices
  - >70 patents granted and >70 pending
- Air & space legacy, ISO:AS9100 qualified

Commercial View @3DGS

Commercial adoption is now

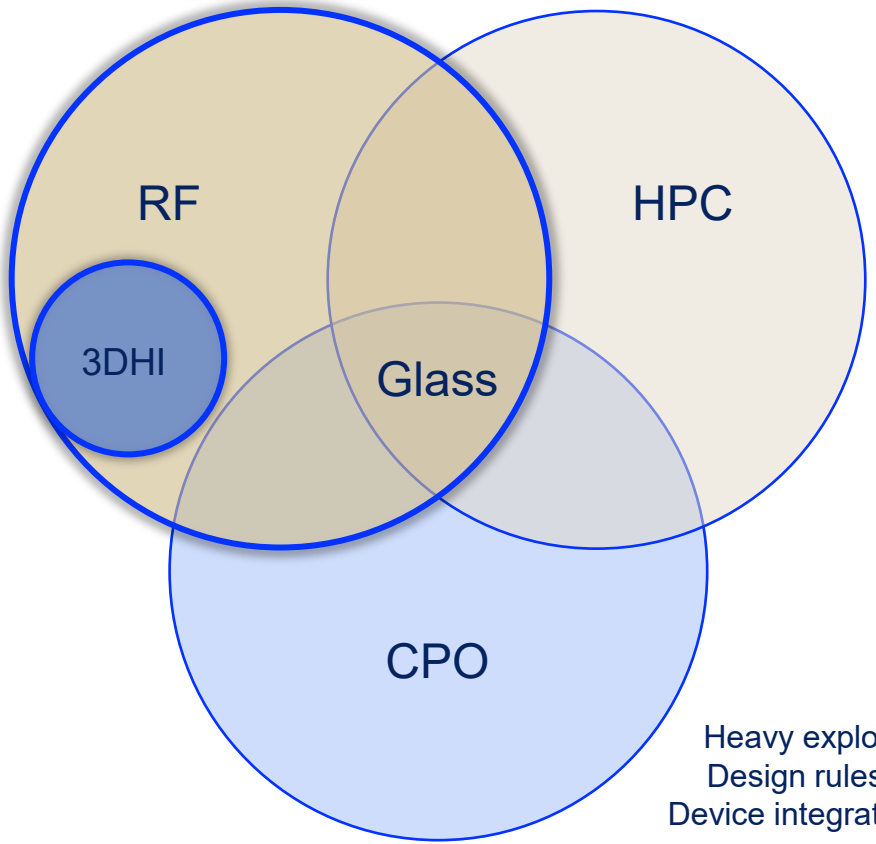
- ✔ Design rules
- ✔ EDA
- ✔ Known-good mfg. process

- ✔ Scalability
- ✔ Repeatability (Cpk)
- ✔ Reliability
- ✔ Low cost

Product requirements

Low loss
Low loss
Low loss

Thick metal
High CTE
Solid filled vias
200V



Heavy exploration
Trajectory in favor of adoption
Design rules in progress

Known-good mfg. process
being established

Heavy exploration
Design rules TBD
Device integration TBD

RF Market Challenge

Low cost, precise, repeatable, and scalable solution next generation wireless applications

The Market Need

- Affordable RF Front Ends (RFFEs) for 5G/6G, operating at new higher frequencies bands (Gigahertz)
- More functions in small form factor for high frequency bands—need greater integration
- Solutions to overcome conventional electronic materials not well suited for high GHz applications—high loss and limited bandwidth

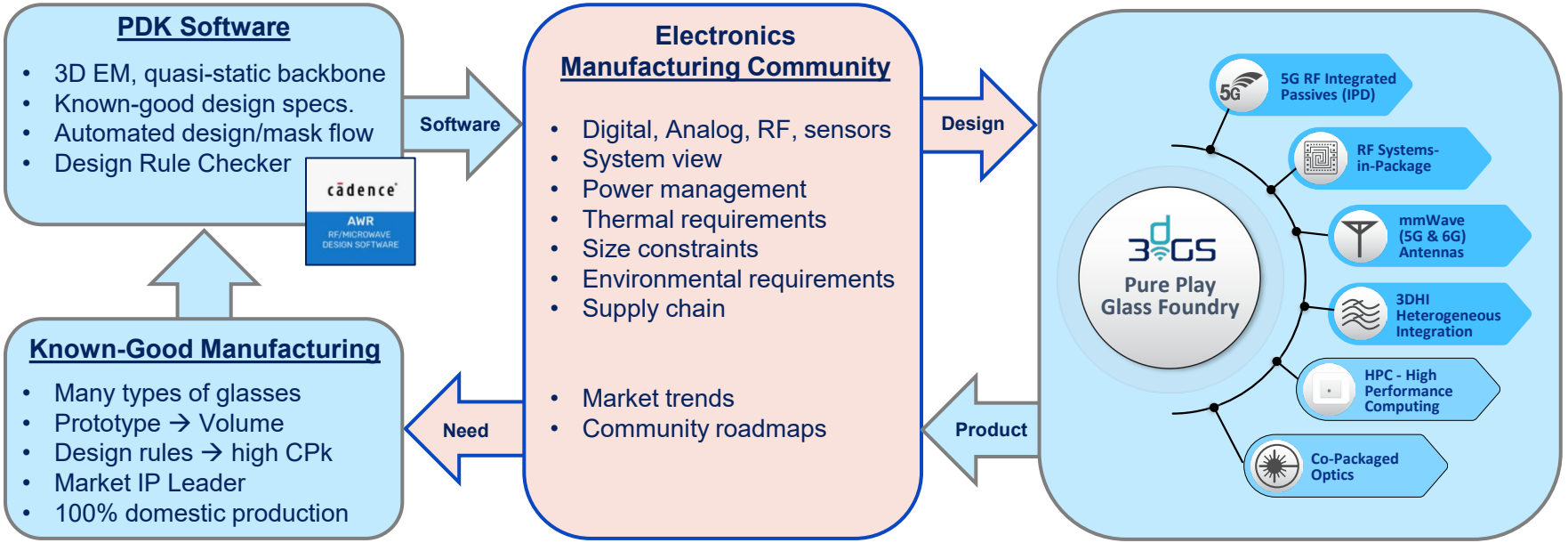
New materials sets are needed for high performance applications

The 3DGS Solution

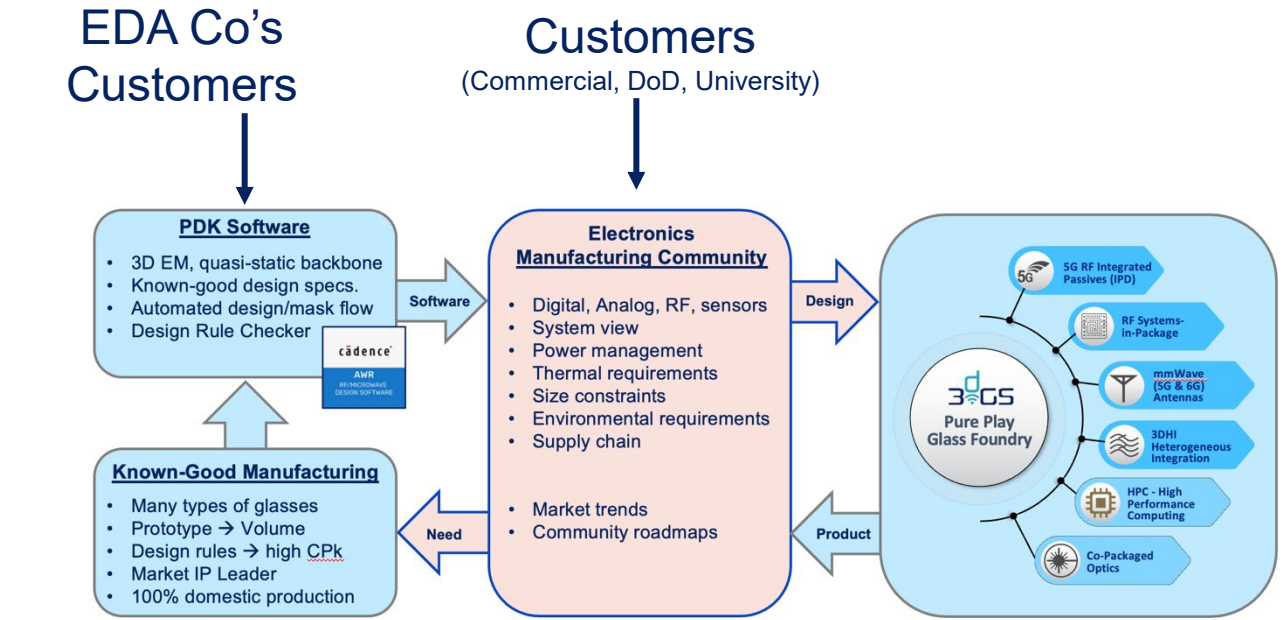
- Low loss components based on 3DGS novel APEX® Glass-Ceramic material
- Glass enables lower power usage and greater bandwidth---ideal for higher data rates in LTE, 5G, and above
- Integrate industry leading RF filtering with advanced packaging to meet next generation electronics—maintain cost

Utilize the ideal high frequency properties of Glass-Ceramic with Si fab-low cost & scalable manufacturing

Pure Play Market Approach



Why the IMAPS community is Important to USA/IC Resilience



Different Glasses for Different Products

Reliability

Material	Structuring Costs	Heterogeneous Integration	Conductor undercut	Cavity Formation	Dk	Loss Tangent	CTE	Etch Singulation vs. Dicing	Thick Metal RDL for RF
3DGS' APEX® Glass Photosensitive Glass (PSG)	$	Yes, full ability	Yes	Yes	1.5-6.4	0.000001 - 0.014	8.53ppm/C	Etch Singulation +30% Die per wafer	Up to 40µm
EAGLE XG® Glass	$$$	Limited	No	Limited	~5.5	~0.001	3.0ppm/C	Dice Only	Up to 10µm
HPFS® Glass	$$$	No	No	Limited	3.79	0.00002	0.5ppm/C	Dice Only	Up to 2µm

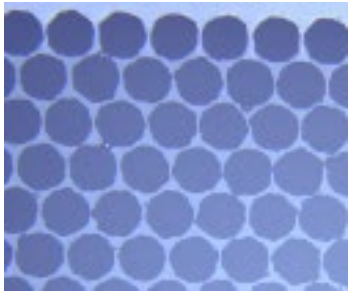
Lower Device Cost

5G/6G

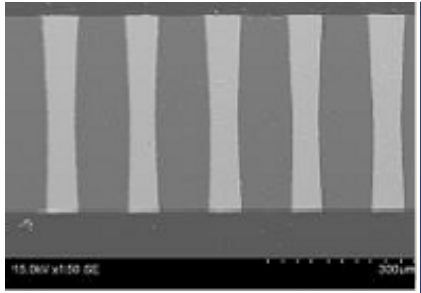
Color coding based upon RF product evaluation

The Uniqueness of PSG

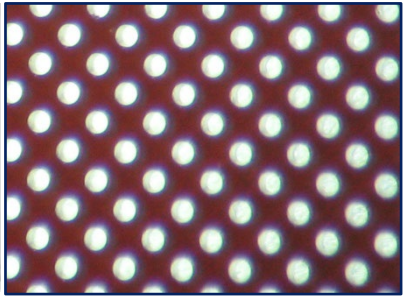
TGVs



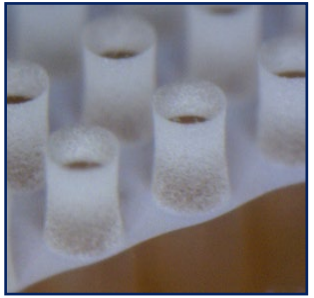
Solid Cu Fill



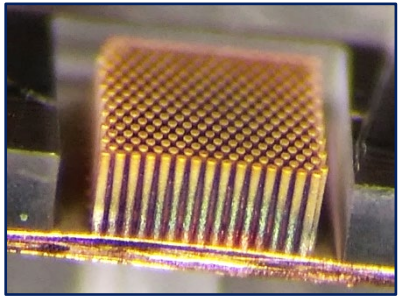
Ceramic



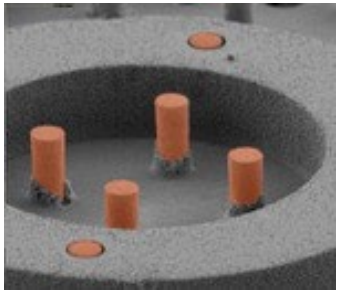
Glass Pillars



Cu Pillars

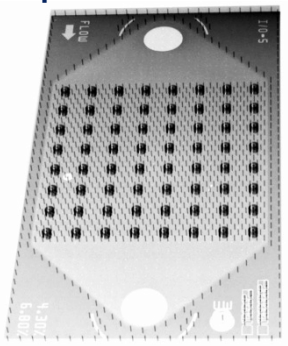


Cavities

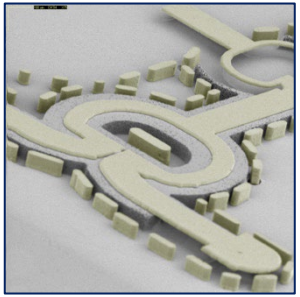


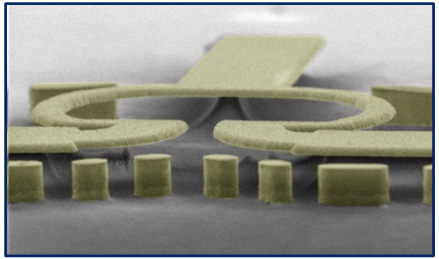
Antenna

µFluidics

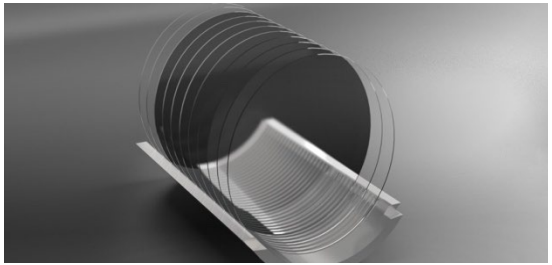


Conductor undercut



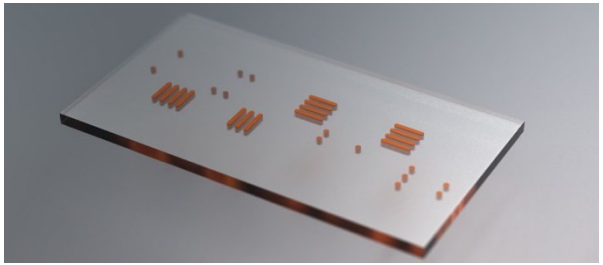


PSG Device Manufacturing Process

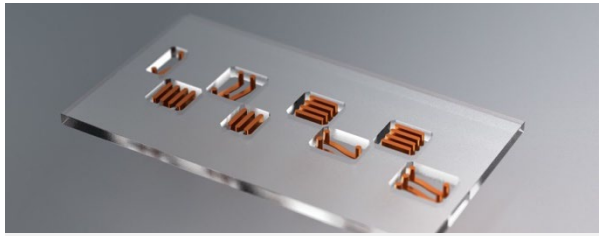


1. Start with blank APEX® Glass
   Expose and pattern

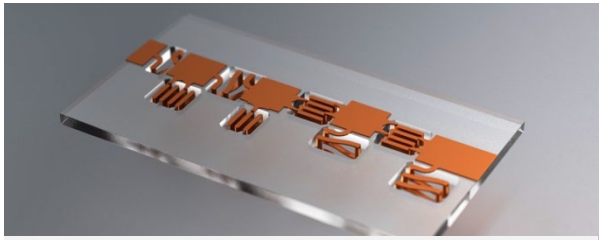
2. Bake. Convert exposed regions into ceramic
3. Wet etch to remove ceramic
4. Can repeat multiple times (add cavity, etc.)



5. Plate open 3D vias with solid pure Cu



6. Backside metallization of RDL

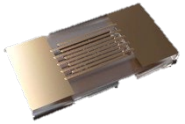


7. Topside metallization of RDL

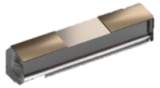
8. Create IPD by Metal Sputtering, PECVD SiNx, TaN, ALD Al2O3, HFO, etc.

Sub-10GHz Foundry Capabilities Outline

World's best High Q Inductor (SMD)
Q=145 @1GHz, 1nH, 0603mm

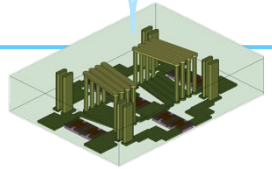


High Q Capacitor (SMD)
Q>350 @1GHz, 3.7pF, 200V

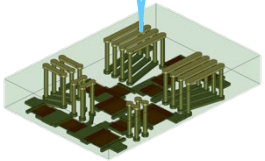


Thin Film Resistor
10 & 30Ω□

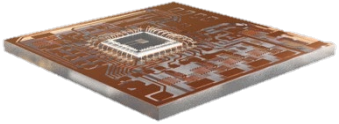
Micromachining
Multiple glass types, vias & cavities



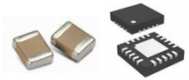
LC-IPD
BPF, HPF, LPF, Baluns, couplers, diplexers, matching networks, LCR filters



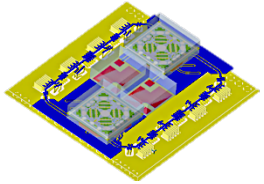
LCR-IPD
GaN/LDMOS matching networks
LCR filters



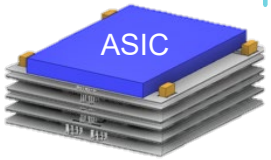
Glass Interposer
FOWLP



Commercial SMT Devices
Caps, QFN, BAW, SAW, etc.

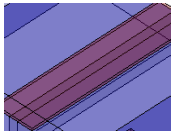


System in Package
Switch bank filters
Matching networks
BAW/SAW BW expansion

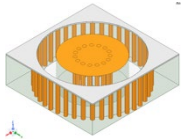


Heterogeneous Integration
Transceivers
Beam forming
Tunable filters

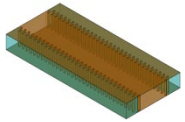
mmWave Foundry Capabilities Outline



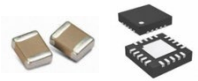
Suspended Stripline
Q=150 at 30GHz



Coax Cavity
10-30GHz, Q=540 @10GHz

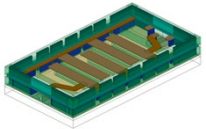


Air filled SIW
0.25dB/cm @140GHz

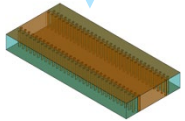


Commercial SMT Devices
Caps, QFN, BAW, SAW, etc.

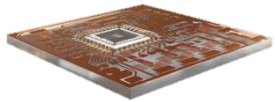
High Gain Antennas
Patch, sinuous, dipole



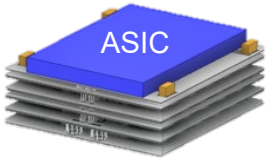
Filters and Passives
BPF, splitters, combiners, etc.



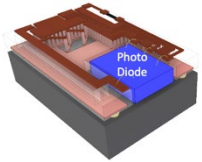
Air Filled SIW
Splitters, filters, MN, antenna
RFIC to WG transitions



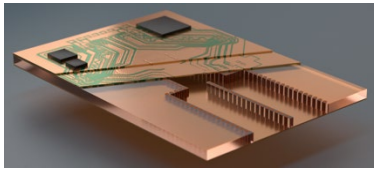
Glass Interposer
FOWLP



Heterogeneous Integration
Transceivers
Beam forming
Broadband Bias-T
Photonics TOSA/ROSA

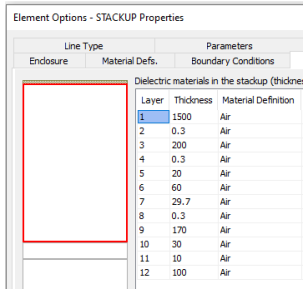


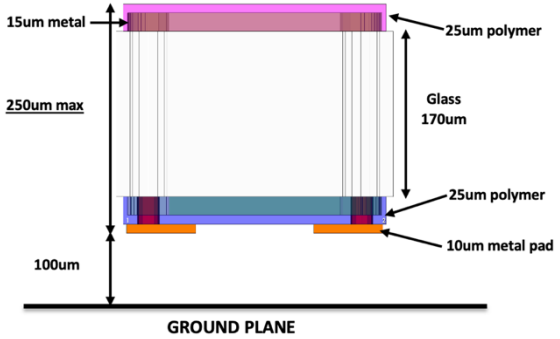
Radio-on-Glass
(70 – 500GHz+ applications)
W, D, E Band Backhaul
Automotive Radar
Phased Array Systems



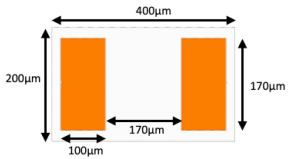
0402 Metric Inductor – Simulation vs. Measurement

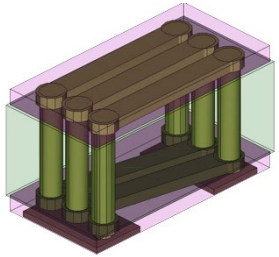
- Accurately modeling an inductor is very challenging due to its high sensitivity of minute design differentials and measurement of Quality Factor (substantial environmental influences)
- The test vehicle demonstrates a good match between performance and simulation for inductance, SRF, and Quality Factor
- Test vehicle demonstrates a high confidence in EM and production ability for an individual inductor

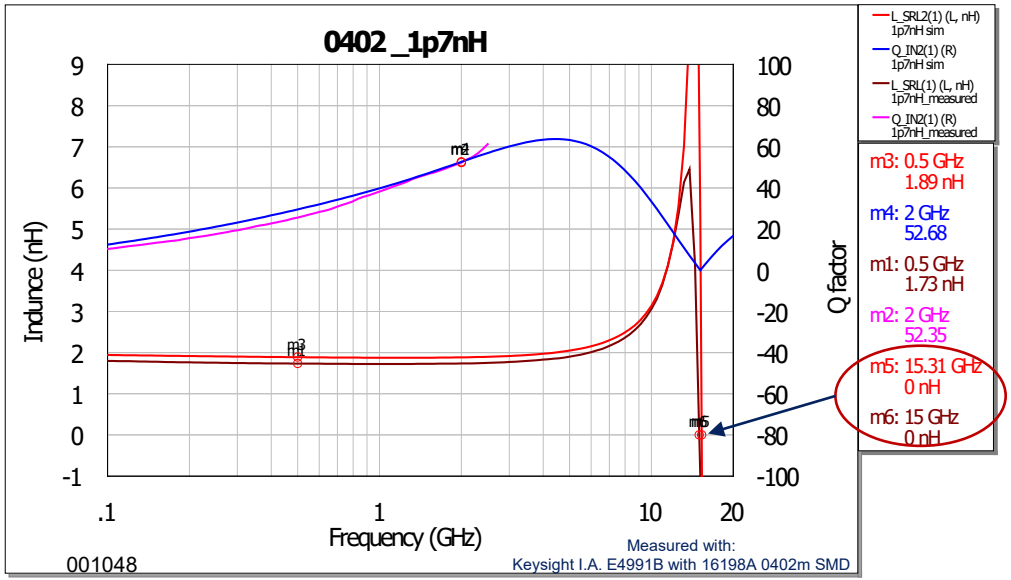




Footprint



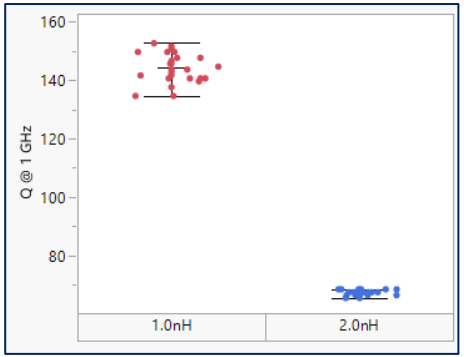




High-Q Inductors – A Solid Foundation for IPDs

- High SRF (>15GHz) makes lower values ideal for 3-8GHz applications
- Similar performance is expected in IPD format (with usual integration losses)

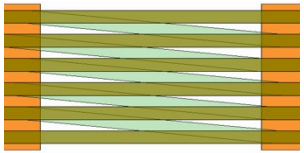
0603 Metric Size



Inductance (0603 mm)	Murata Q @ 1Ghz	3DGS Q @ 1GHz	Q Gain
1.0nH	65	145	**123%**
2.0nH	45	68	**53%**

0402 Metric Size

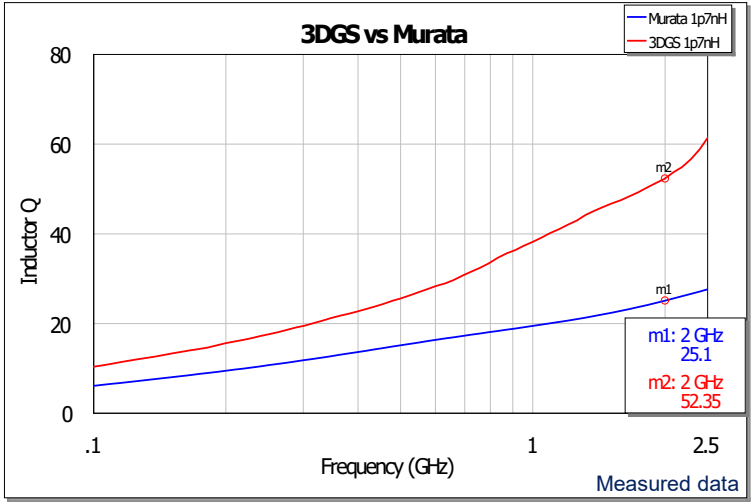
8.0nH Design



- 400µm x 200µm
- 240µm thick
- 20µm TGV
- 13µm L/S
- 20µm thick Cu

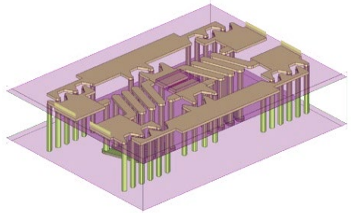
3DGS 1.7nH Inductor

vs. 1.7nH LQP02TQ_ from Murata

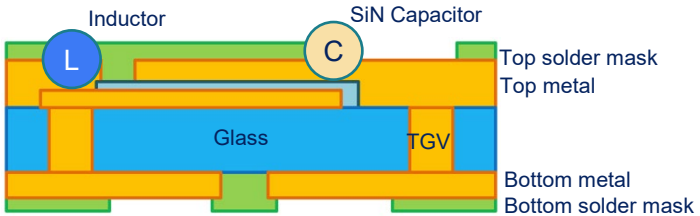


Integrated Passive Devices (IPD)

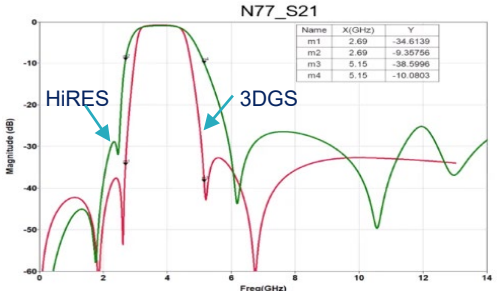
- Leverages 3DGS' market-leading High-Q inductor for low loss performance
- Custom design and fabrication of Sub-10 GHz IPDs to meet the most stringent performance needs.
  - Solves challenging co-existence challenges
  - Advanced Packaging + Superior Performance in a small footprint
- Lower cost of ownership by minimizing assembly costs
- Reduce device size by 25%, higher power handling
  - ~30% reduction in size vs. "planar" inductors (HiRES Si)
  - Use up to 10W demonstrated



N46 Hybrid Coupler
(2.0mm x 1.5mm)



3DGS Glass IPD vs. HiRES Si IPD



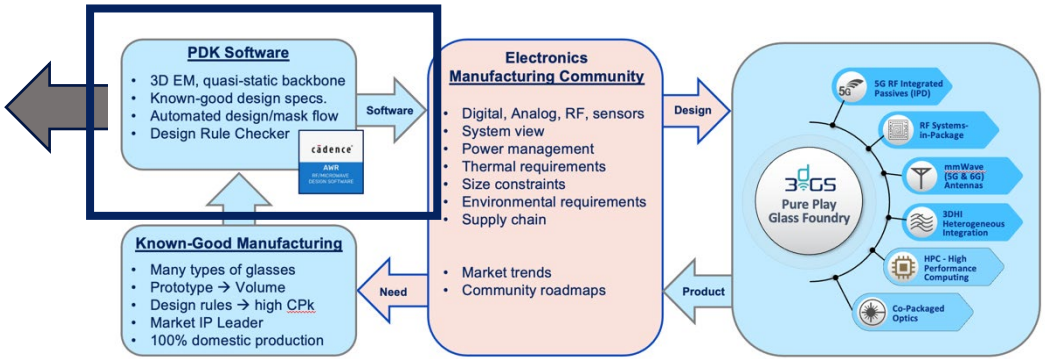
Common Applications

- Wireless handheld and infrastructure devices
- Internet infrastructure components
- Interposers, inductor networks
- BAW/SAW bandwidth widening
- Bandpass filters, baluns
- LC and LCR filters
- Bias Ts, couplers
- PA matching networks

PDK: Putting the Design in Customers Hands

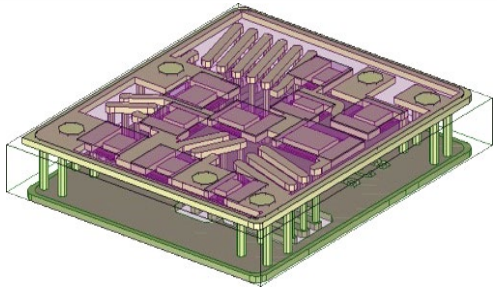
Quasi-Static → Full 3D EM → Product

- Simple, intuitive
- EDA support
- Fast schematic to 3D conversion
- Quick ”ballpark” RF performance
- Accurate 3D EM
- Agreement with device test

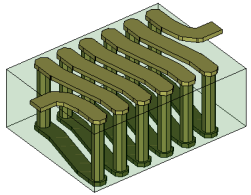


APEX® Glass Device Building blocks

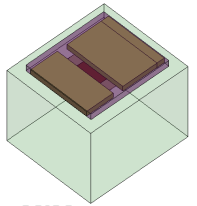
- p-Cells
  - High Q inductor
  - Capacitor
  - Coupled inductors
  - Resistors (Q4)
- Via fence for isolation
- Vias for I/O s
- Vias for thermal vias
- L/S, thick copper



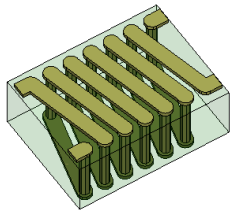
n77 BPF: 1.2mm x1.0mm
- **Compact size, low profile**
- **Low loss**
- **Good stopband rejection**



3D Inductor:
- **Compact size**
- **Precise & repeatable**
- **Qs up to 100+**
- **SRFs into >15 GHz**
- **Useful for filters, diplexers, matching networks**



MIM cap:
- **Series & Shunt**
- **Qs in the 200s**
- **Suitable up to 10 GHz**

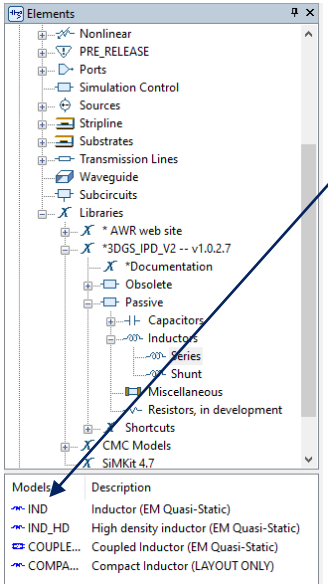


Coupled Inductors:
- **Tight coupling -3dB**
- **Applicable for matching transformers, baluns up to 10GHz**

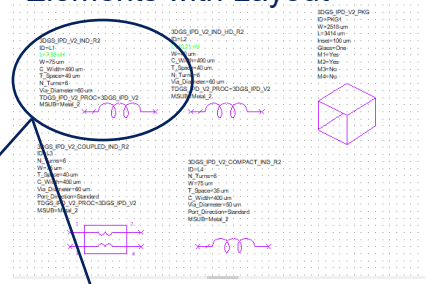
- Design Flow:
  - Start with the IPD-PDK to create and optimize circuit, attach ports to the layout (created automatically)
  - Perform full 3D EM simulations using Analyst (Frequency Domain) or Clarity (Transient Domain)
  - p-cell parameters can be swept to optimize the performance iteratively
  - Alternatively, port tuning can be used for co-simulation between Microwave Office & Analyst

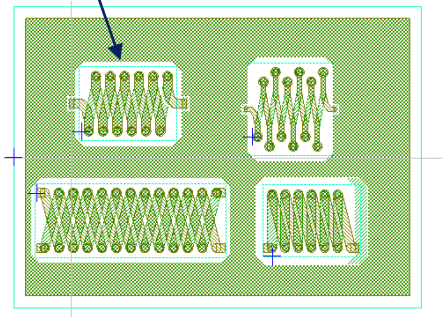
IPD PDK Design Flow

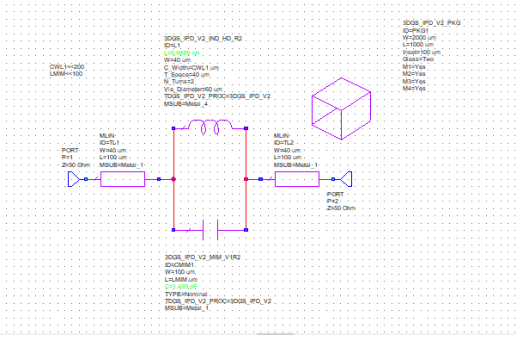
- AWR/Cadence PDK for EM Based FEM Circuit Based Modeling



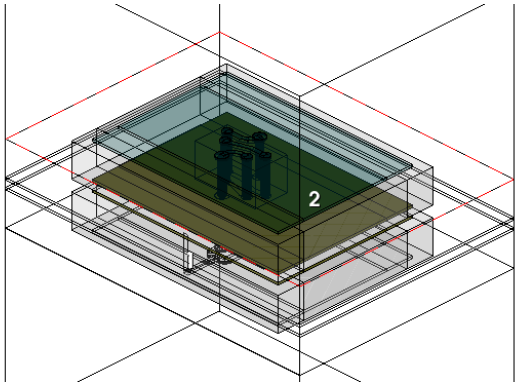
Fully Parameterized PDK Elements with Layout







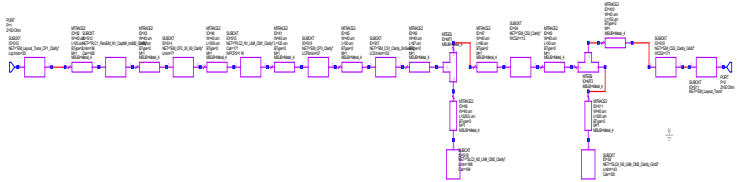
EM Schematic for Parameterized EM Based Modeling



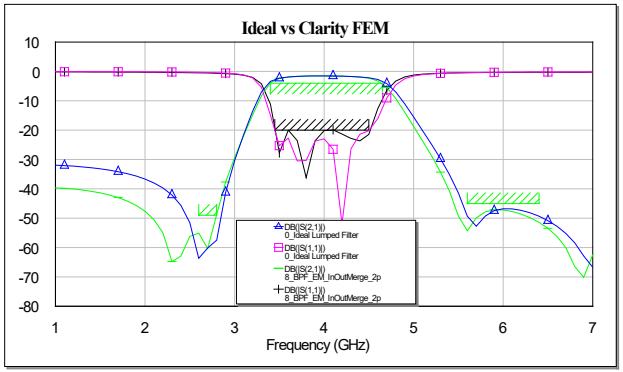
3D Layout of EM Structure from EM Schematic

IPD PDK Design Flow

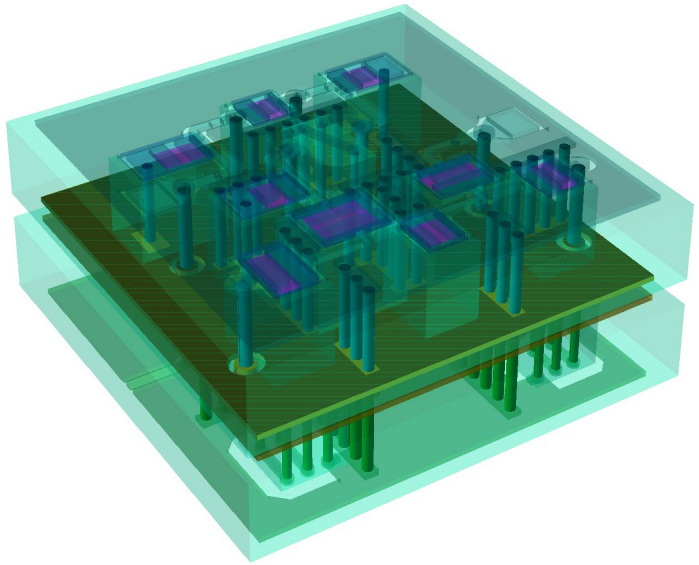
- AWR/Cadence EM Based Circuit Based Modeling Design



EM Based Modeling Schematic



Final 3D EM vs. Quasi-Static Modeling

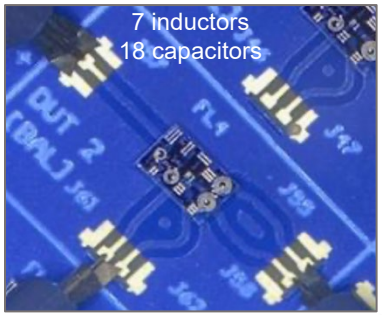


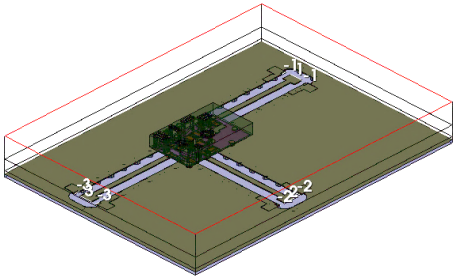
Final Layout of Clarity FEM Structure

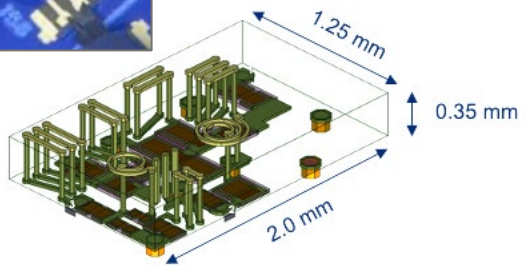
Wi-Fi Diplexer: Simulation vs. Measurement

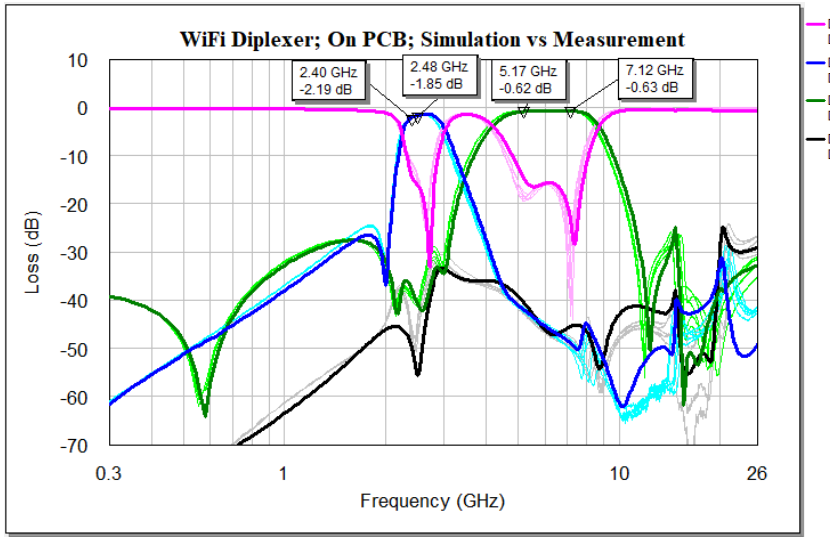
- Accurately modeling complex IPD designs in a known good environment is very important to a timely product launch
- 3DGS has explored a variety of 3D EM environments and has found that Clarity provides excellent match between simulation and performance
  - Shown at both the die level and when soldered to evaluation PCB

DUT







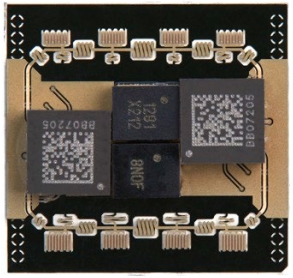


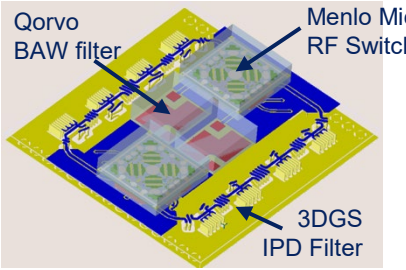
Lighter traces are measurement data.
Good correlation between simulation and measurement across the band.

Glass System-In-Package with IPD

- Wafer level production and assembly
- Fusion of leading RF filter performance and advanced electronic packaging
- Assembly compatible with SMT, flip chip, and wire bonding
- Removes cost associated with QFN, decreases BOM by using IPDs
- Multi layer RDL enables high performance and simple PCB attach during board assembly
- High density through glass vias provide high isolation (>40dB) in tight spaces

4 channel switch bank filter

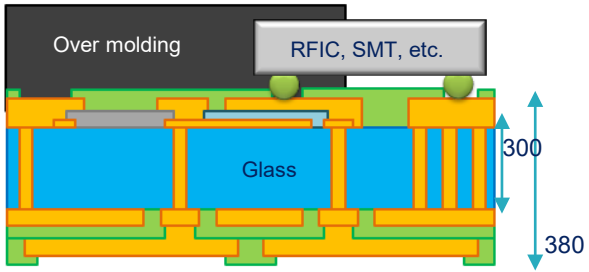


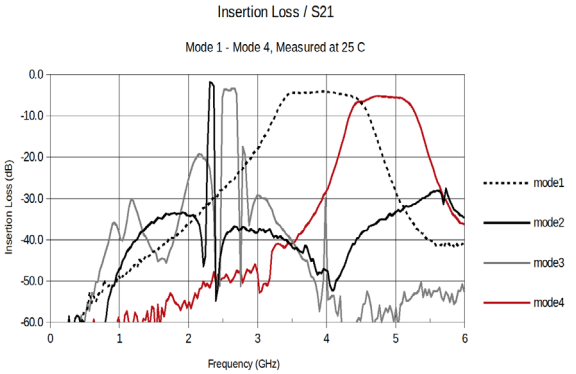


Common Applications

- RF sub-system packages
- BAW/SAW coexistence packages
- Switch filter matrices
- Power amplifiers packages

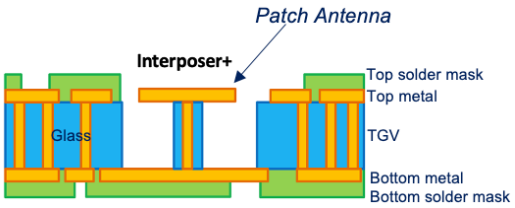
Glass System-in-Package





Multiple Solutions for Multiple Markets

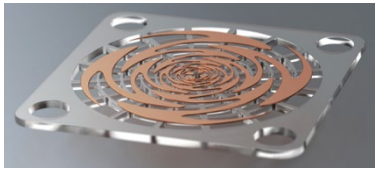
25-100 GHz (suspended stripline)



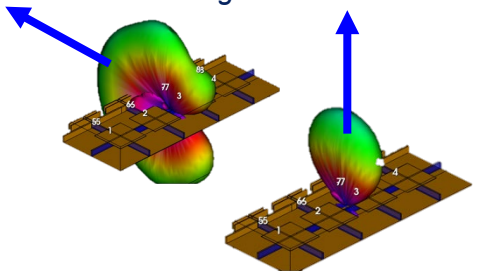
Common Applications

- Cell phone
- Cellular infrastructure
- WiGig

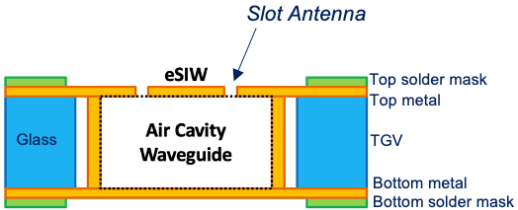
4-Port Sinuous Antenna



28GHz Patch Array Antenna with Boresight & End Launch



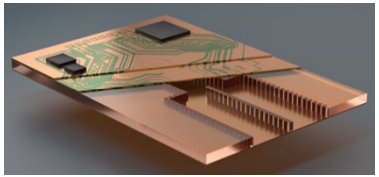
60-500GHz (substrate integrated waveguide)



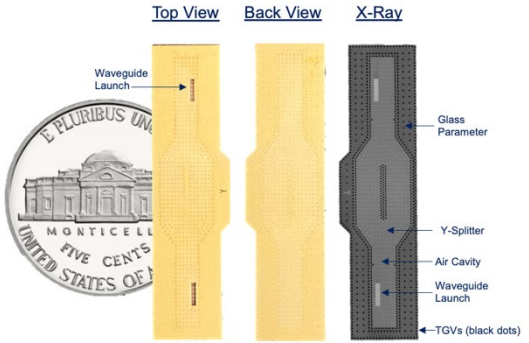
Common Applications

- Automotive Radar
- 5G & 6G Backhaul
- Board-to-board communications

150GHz Antenna-in-Package

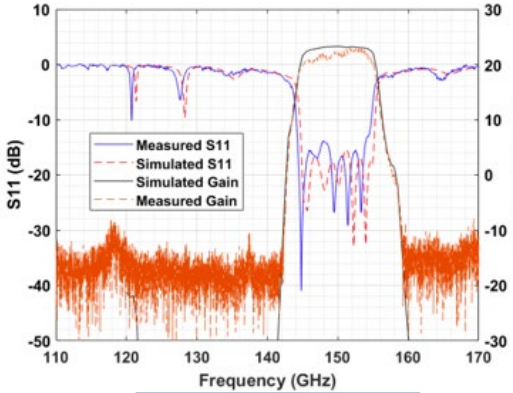


90GHz Reference Design

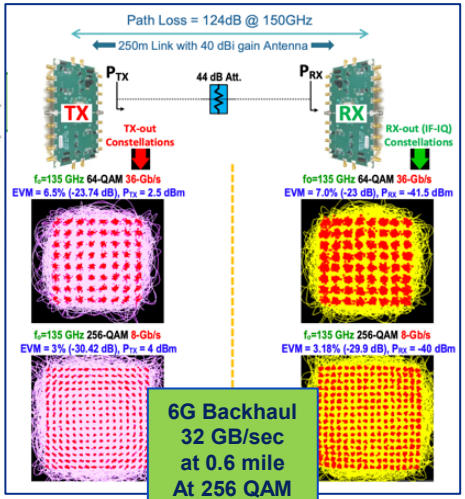


mmWave Antenna

- Strategically design-in air cavities to maximize performance and reduce loss (eff. Dk from 1.0 – 6.4)
- Ideal for mmWave applications 80 – 525GHz
- Simplifies system-level packaging for antenna-in-package (AiP) applications
- 0.18dB loss per cm at 140GHz
- RFIC-to-antenna in <1dB @150GHz demonstrated
- High degree of design flexibility allows a variety of performance configurations (transceiver, end launch, RFIC to waveguide transition, etc.)

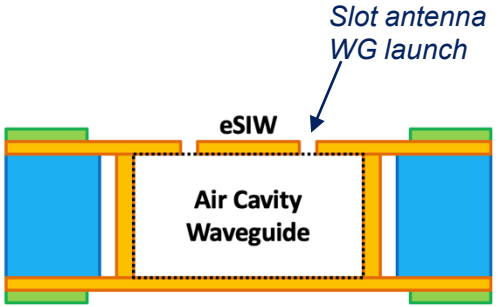


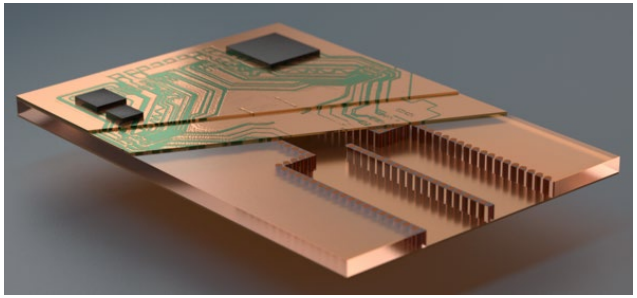
Excellent Simulation to Measurement Agreement



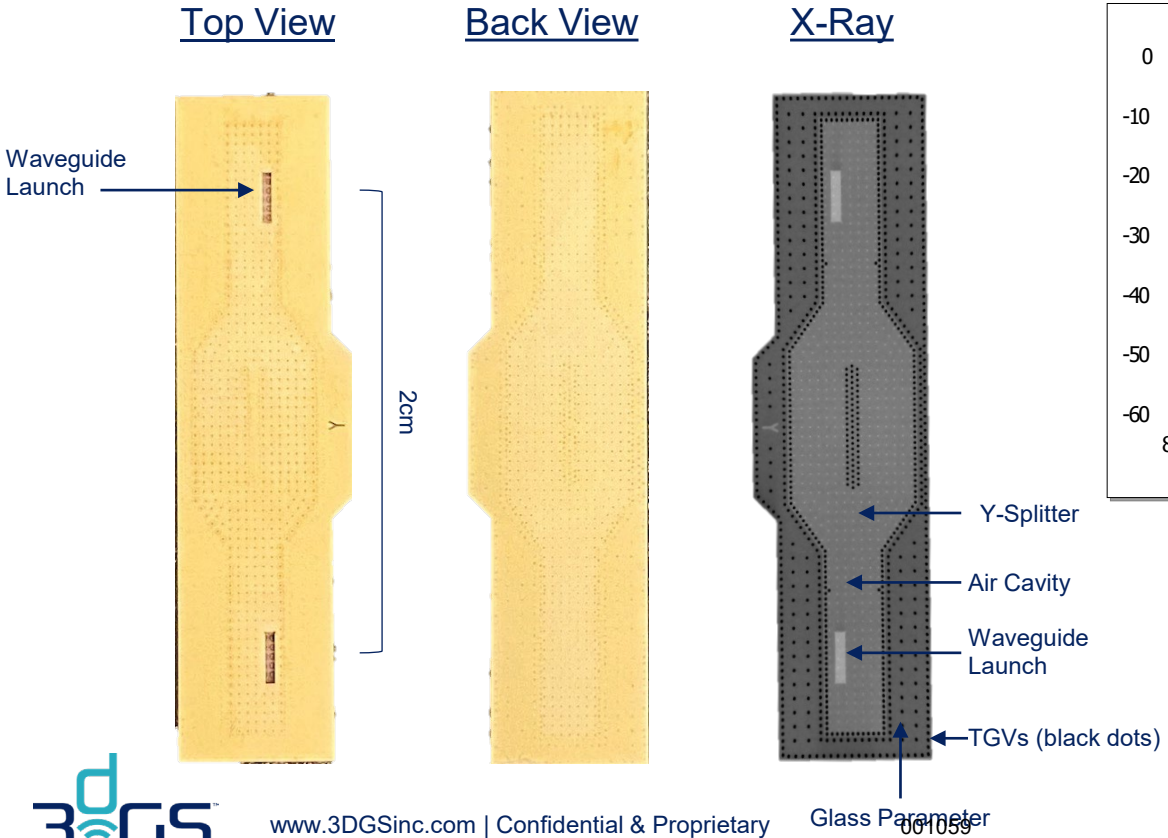
Common Applications

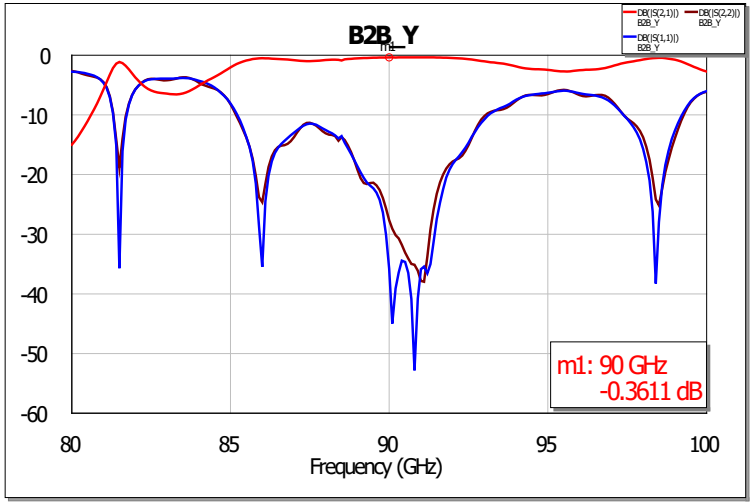
- Wireless handheld and infrastructure devices
- Automotive Radar
- 5G & 6G Backhaul
- Board-to-board communications





90GHz Reference Design (Back to Back Test)



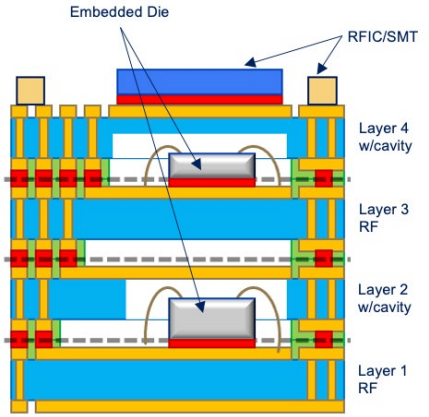


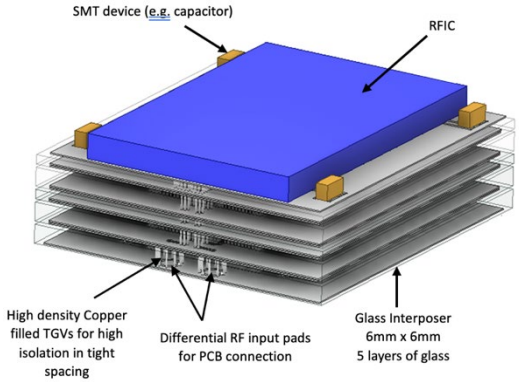
	SIM (dB)	MEAS.(dB)
Full B2B-Y	0.209	0.361
eSIW-WR10 (ea.)	0.093	0.110
B2B-Y	0.023	0.140

Testing and Test Data provided in collaboration with Rogers Corporation

3D Heterogeneous Integration

- Integrate 3DGS' LCR components, cavities for embedded die, and stacked glass layers for improved RFFE SWAP
  - Simple 2 layer PA Matching Networks
  - Beam formers
  - RFFE
- APEX® Glass' intermediate CTE (9ppm/K) is ideal for integration of GaAs, GaN, InP, Si, SiGe, and copper RDL
- Flexible assembly of actives and passives
  - Flip chip, SMT, wire bonding
- TGVs:
  - 80W/mK Copper thermal vias
  - >100dB isolation between layers/cavities
  - Coaxial layer-to-layer interconnects for controlled impedances
- 4-8 glass-layer assembly
- Ideal for applications from 1-50GHz

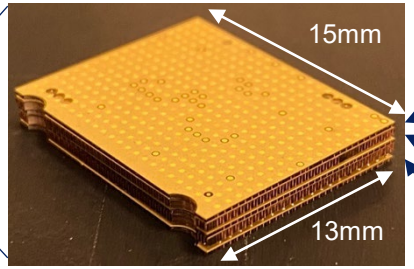




3D Heterogeneous Integration

Traditional PCB (71mm x 131mm)

3DGS 3D-HI System

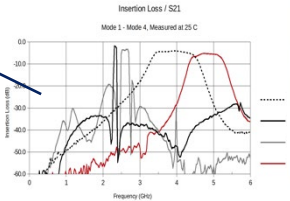


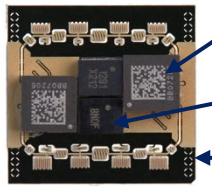
Proof of concept: 7 Glass Layers

GaAs, GaN, InP
SMT, Wire bond
Integration
On Glass 3DHI

7 Layer Glass Stack Up

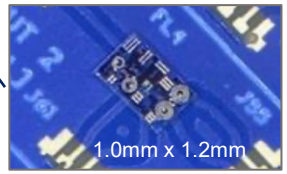
Glass SiP: RF - HI Assembly

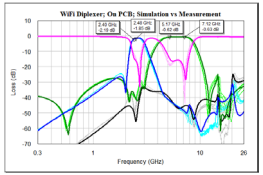




Example: 4 Filter Switched Matrix

Advanced RF Filtering





Example: WiFi Diplexer

3DHI Packaging proof-of-concept

- 3DGS has demonstrated the substantial reduction of an L-Band transceiver reference design
- Demonstrated:
  - 4 layer (2 RF)
  - >98% reduction in size
  - >90% weight reduction
  - Early design rules

3DGS – Delivering Next Generation Solutions with Glass

3DGS is a Pure Play glass foundry with a variety of IP blocks that can be leveraged by the broader RF and electronics packaging community to build custom high-performance product

Your Design – 3DGS Manufacturing – Your Product

3DGS™
A New Dimension for Electronics

Thank You