Design and Demonstration of High-Performance and Ultra-Thin Antenna-Integrated 3D Glass-based mm-wave Packages

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Masahiro Karakawa (Ajinomoto)
Dan Okamoto (Taiyo Inc.)
Raj Parmar (Corning),
Christian Hoffman (Qualcomm)

Outline

- ☐ Goals & Objectives
- ☐ Prior Work
- ☐ Technical Approach
- ☐ Results & Key Accomplishments
- ☐ Comparison with Prior Art
- ☐ Schedule
- ☐ Summary

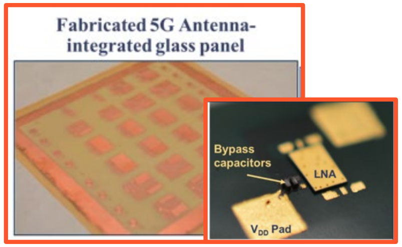
5G D&D Technologies and Team

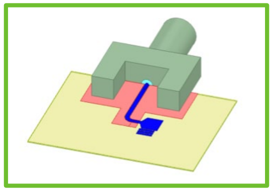
5G Antenna Test Vehicles (D&D)

GT Team	Atom Watanabe (Lead), Muhammad Ali, Tong-Hon Lin, Yiteng Wang
Industry partners	Qualcomm, Samsung, Nagase, JSR, Taiyo, AGC, Ajinomoto, NXP

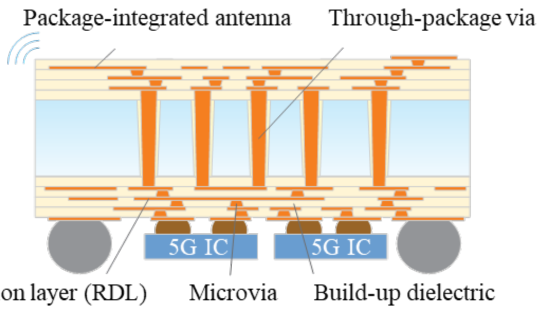
High-performance passive components

GT Team	Ali Muhammad (Lead), Tong-Hong Lin, Atom Watanabe
Industry partners	Qualcomm, Taiyo, JSR, AGC, Corning, Ajinomoto

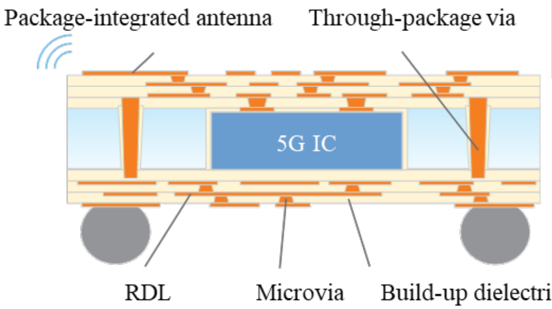


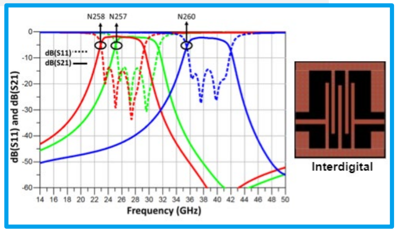


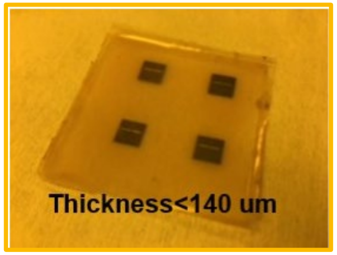
Chip-last Glass-based 5G Packages



Chip-first Glass-based 5G Packages







Miniaturized Antenna in Package

GT Team	Tong-Hong Lin (Lead), Atom Watanabe, Muhammad Ali, Prof. Manos Tentzeris
Industry partners	Qualcomm, Samsung, JSR, Taiyo, AGC, Corning

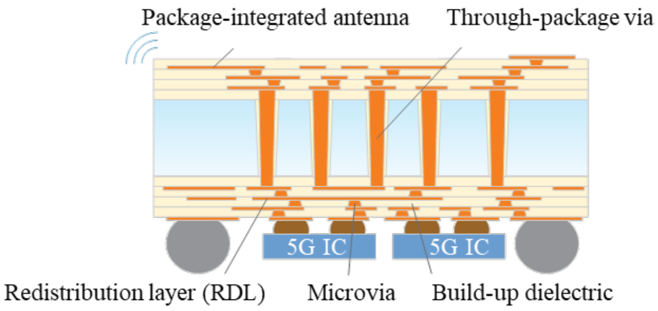
High-performance passive components

GT Team	Tailong Shi
Industry partners	Nagase

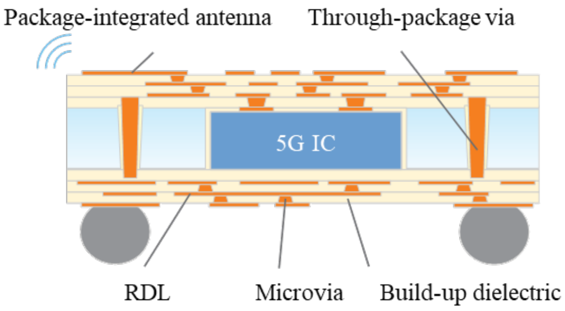
Goals and Objectives

- ❑ Model, design, and demonstrate high-performance ultra-thin antenna-integrated 3D glass-based mm-wave modules on 100-200 µm thick glass substrates for 5G packages.

Chip-last Glass-based 5G Packages



Chip-first Glass-based 5G Packages



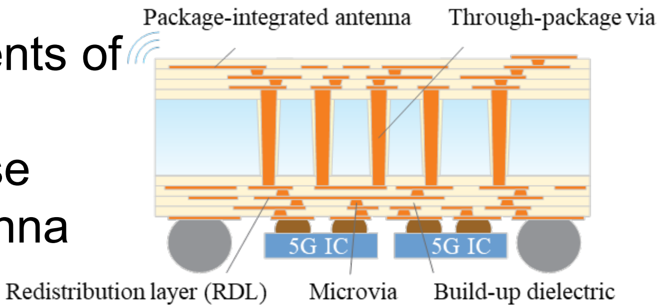
Topics	Metrics	Objectives	Prior Art	Challenges
Chip-to-Antenna Interconnects	Performance	• System interconnects IL < 1 dB • Precision < 2% with 50 µm	• System interconnects IL = 3 – 5 dB • Precision: 6 – 10 % with 80 µm	• Conductor and dielectric losses at 28 or 39 GHz. • Impedance discontinuity in vias. • Ultra-thin low loss materials • Process variations
	Miniaturization	• RDL thickness: 15 – 20 µm • Signal routing density: 2X	• RDL thickness: > 50 µm • Signal routing density: X	
3D Antenna-integrated mm-wave Modules	Performance	• System interconnects: IL < 1 dB • Antenna bandwidth 24.25 – 29.5 GHz	• System interconnects IL = 3 – 5 dB • Antenna bandwidth 26.5 – 29.5 GHz	• Low-loss thin-film dielectric • Antenna efficiency with low thickness • Heterogeneous integration of components
	Miniaturization	• Total module thickness < 400 µm • Number of metal layers < 6	• Total thickness > 800 µm • Number of metal layers > 10	

Prior Work

Designed and demonstrated chip-last 3D glass-based panel-level package with antenna-in-package.

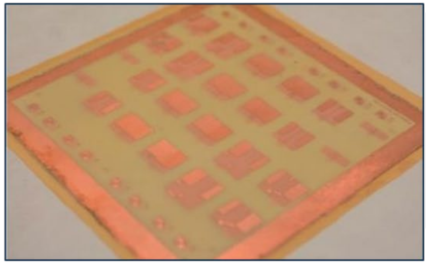
- 21.1% of FBW was achieved in the measurements of antenna.
- Good model-to-hardware correlation with precise fabrication of transmission lines, TPVs, and antenna

Chip-last Glass-based 5G Package

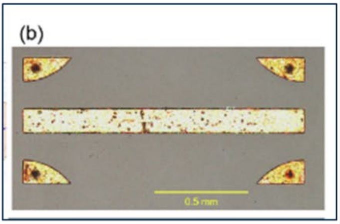


Microstrip line & TPV

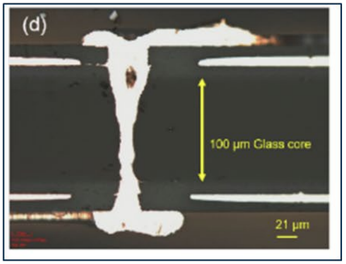
Fabricated 5G Antenna-integrated glass panel



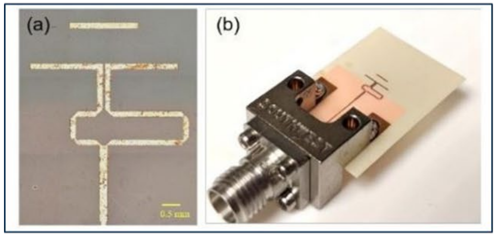
Microstrip line on RDL



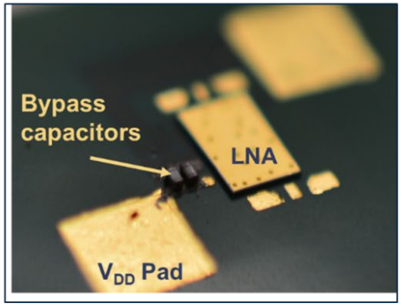
Through-package via



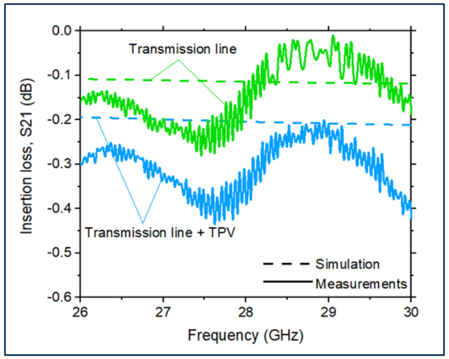
Package-integrated antenna



Active & passive components assembled



☐ Simulation and characterization results of the glass-package interconnects.

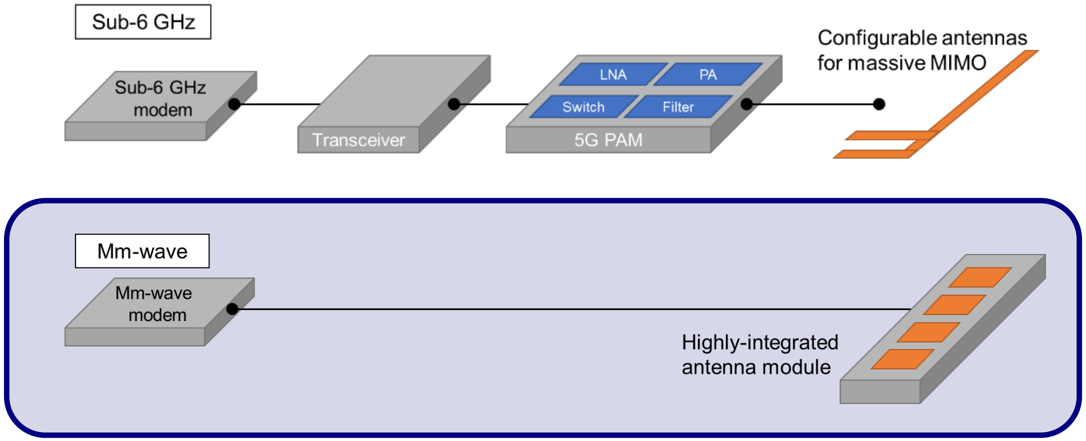


		Simulation	Measurement
Microstrip line	dB	0.114	0.162
	db/mm	0.076	0.108
TPV	dB	0.090	0.191
	db/TPV	0.045	0.095

A. Watanabe, T. Lin, Muhammad Ali, T. Ogawa, P. M. Raj, M. Tentzeris, R. Tummala, M. Swaminathan, “3D Glass-Based Panel-Level Package with Antenna and Low-Loss Interconnects for Millimeter-Wave 5G Applications,” Proc. *IEEE IMC-5G*, August 2019.

Technical Approach

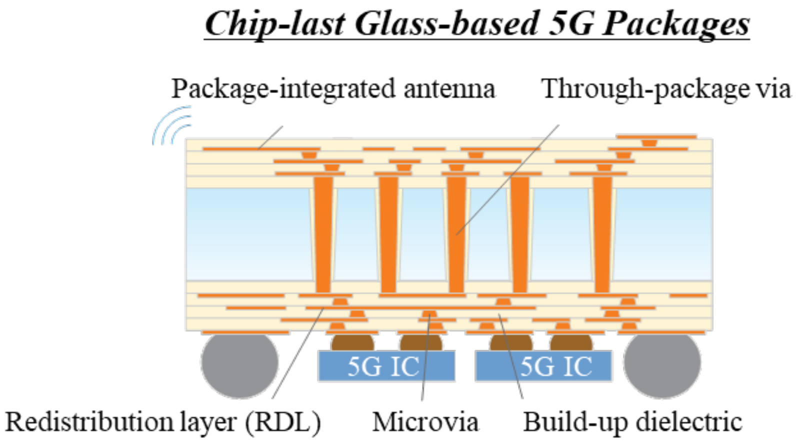
System Architectures for 5G communications

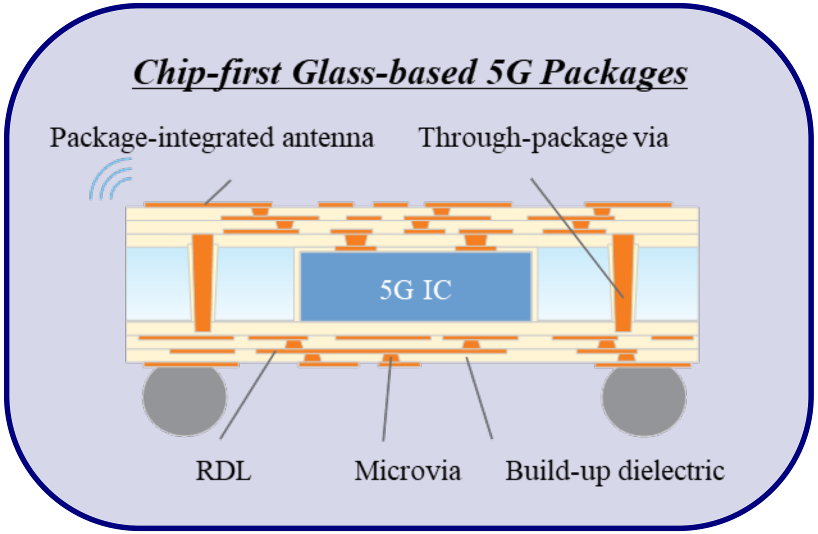


Heterogeneous Integration

1. Glass-panel embedding
2. LNA embedding
3. Dual-pol patch antenna array
4. Bandpass filters
5. Impedance-matched ultra-short interconnects

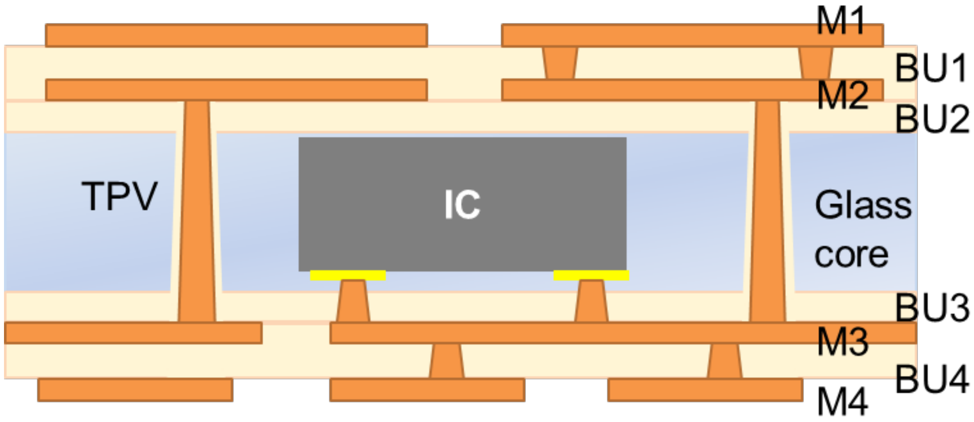
Glass-based mm-wave packaging structures





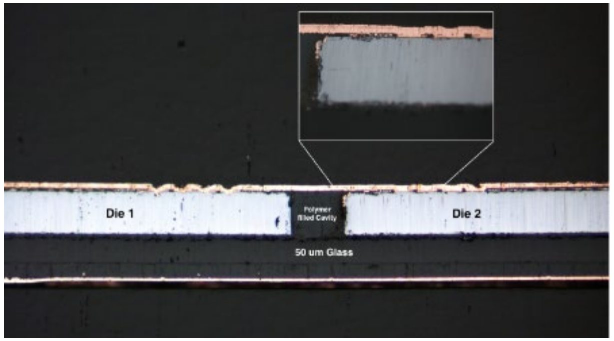
1. Glass-Panel Embedding for mm-wave Antenna-Integrated Packages

Cross-section of GPE for mm-wave antenna-integrated packages



Layer	Stack-up	Thickness
M1	Antenna	8 µm
BU1	Taiyo Zaristo	15 µm
M2	Antenna	8 µm
BU2	Taiyo Zaristo	**15-71** µm
Core-Glass	AGC Glass core with TGVs & Cavity	200 µm
BU3	Taiyo Zaristo	**15** µm
M3	GND, Antipads	8 µm
BU4	Taiyo Zaristo	71 µm
M4	Routing, Filters	8 µm

GPE Demonstration by Siddharth



Feature	Dimensions (µm)
Min. L/S	20/20
TGV Dia.	150
Via-in-Via Dia.	120

Ravichandran, S., et al. (2019). Low-Cost Non-TSV Based 3D Packaging Using Glass Panel Embedding (GPE) for Power-Efficient, High-Bandwidth Heterogeneous Integration. 2019 IEEE 69th Electronic Components and Technology Conference (ECTC).

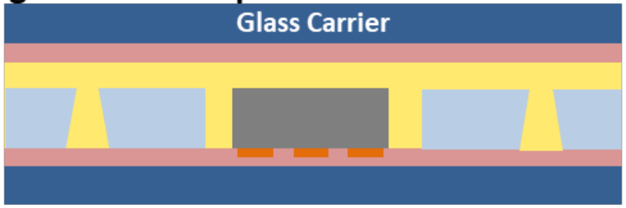
1. Glass-Panel Embedding for mm-wave Antenna-Integrated Packages

1, Attach cavity and TGV drilled glass substrates on temporary carrier glass

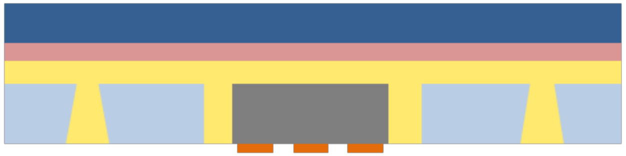
2, Mount IC

3, Laminate low-loss polymer and cure

4, Attach temporary adhesive and carrier glass on the top side



5, Remove the bottom carrier

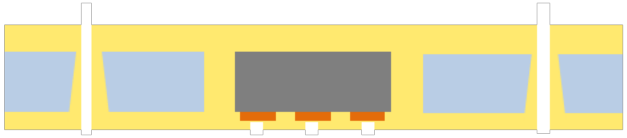


6, Via drilling with UV laser

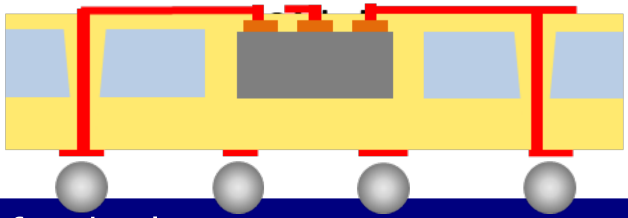
7, Laminate low-loss dielectric material and cure

8, Remove carrier and planarize the laminated low-loss polymer

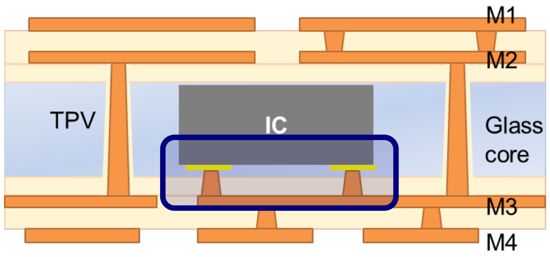
9, Via-in-via process: Laser drill into low-loss dielectric



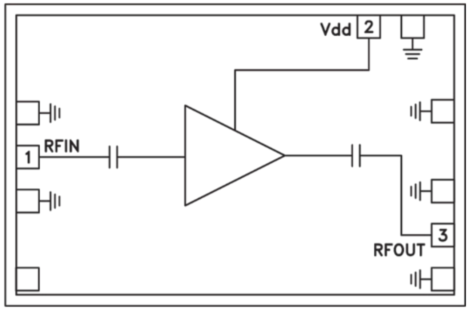
10, Metallization of double sides RDLs



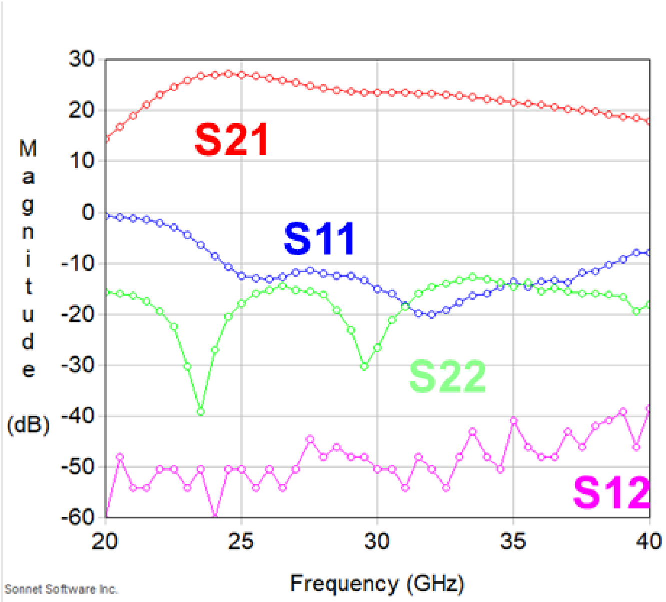
2. LNA Embedding into Glass-Core Substrate

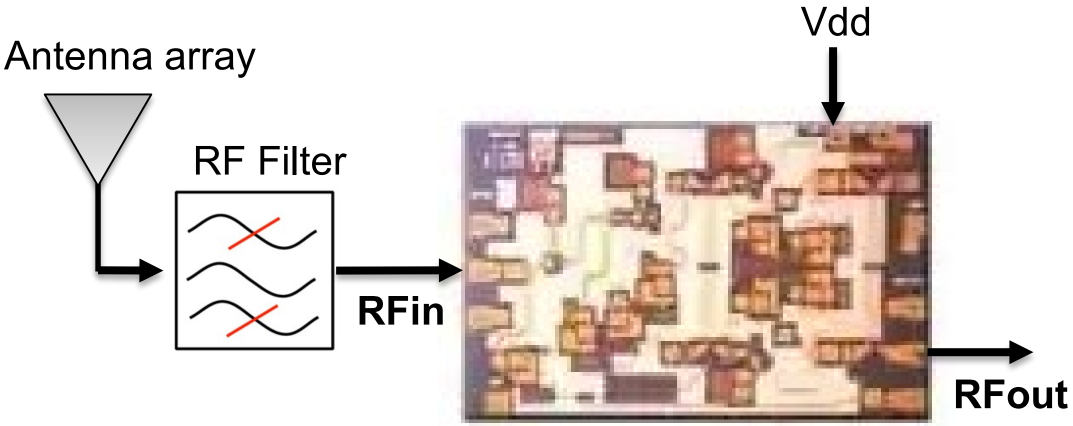


- Excellent Noise Figure: 2.0 dB
- Gain: 22 dB
- P1dB Output Power: +11 dBm
- Supply Voltage: +5V @ 66 mA
- Die Size: 2.10 x 1.37 x 0.1 mm

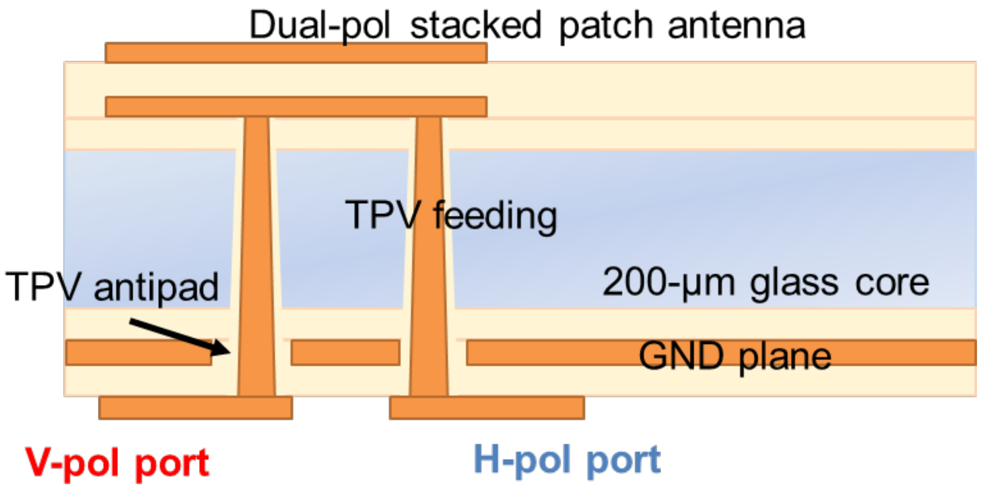


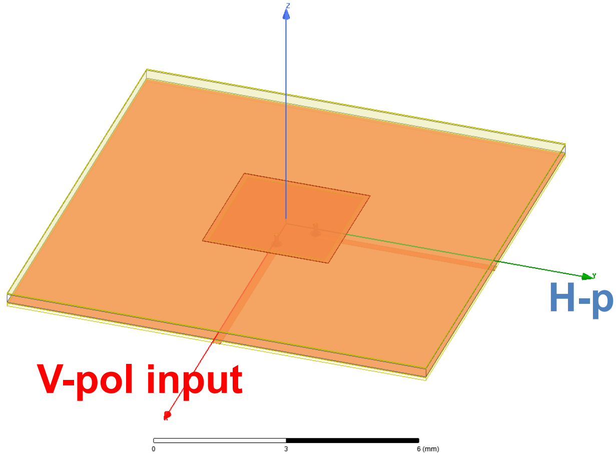
S parameters

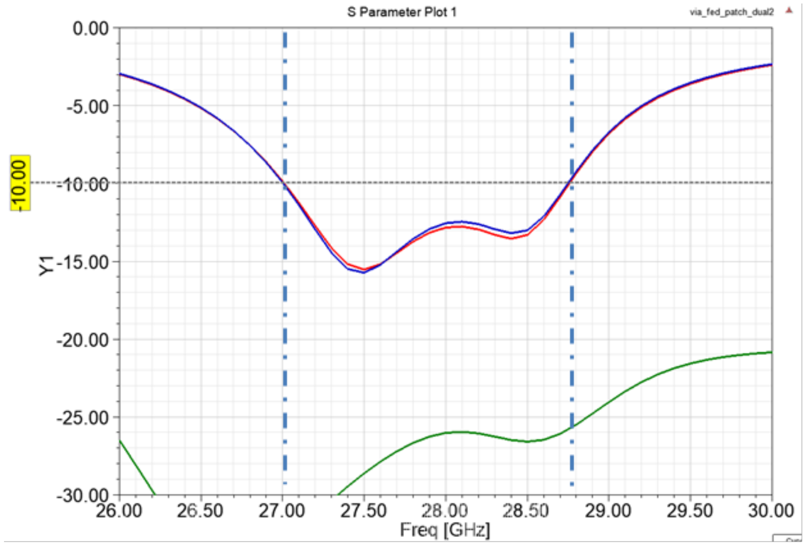




3. Dual-pol patch antenna array







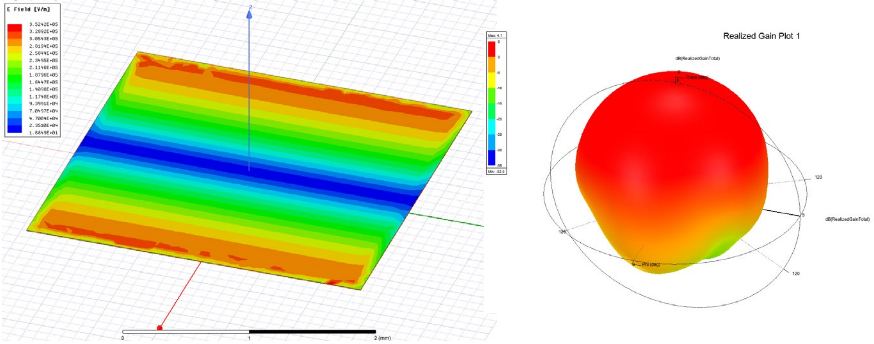
Return loss (V-pol) **Return loss (H-pol)**

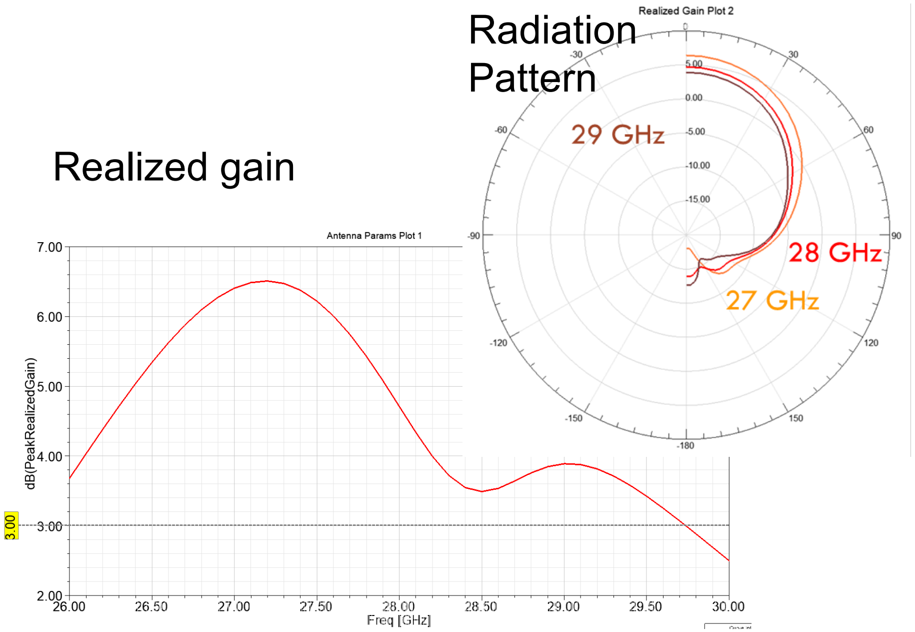
Isolation of the two polarizations

- **TPV-fed stacked patch antenna**
  - ✓ Dimensions: 3 mm x 3 mm
  - ✓ BW: 27.0 – 28.8 GHz
  - ✓ Dual-polarized antenna
  - ✓ Insertion loss |S11| < -10 dB
  - ✓ Isolation between polarizations |S21| < -20 dB

3. Dual-pol patch antenna array

V-polarization

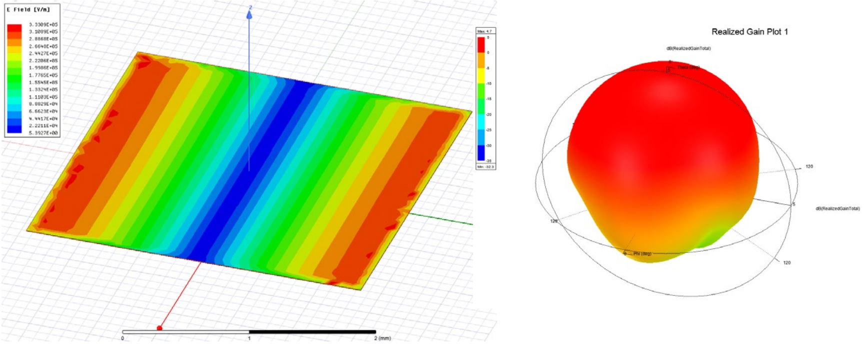


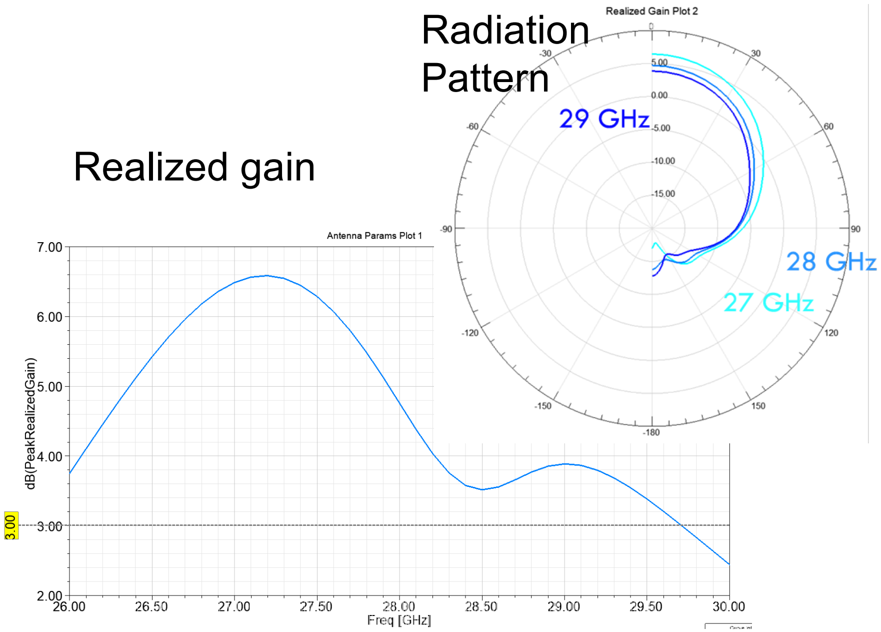


Radiation Pattern

Realized gain

H-polarization





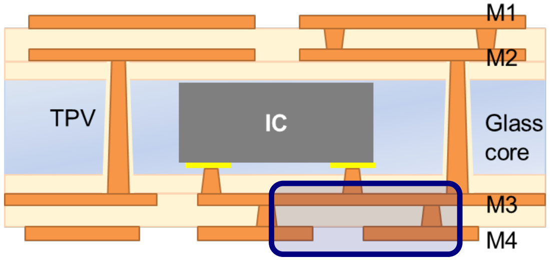
Radiation Pattern

Realized gain

4. Compact Bandpass Filters

Bandpass filters

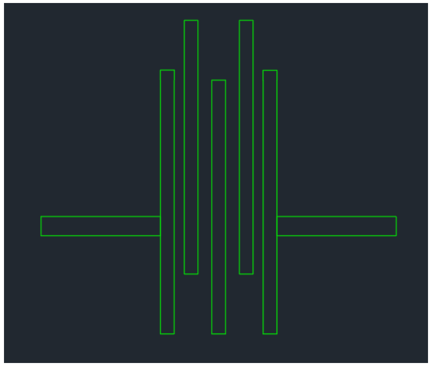
- Package-level miniaturized bandpass filters
- Incorporated into M3 & M4.
- Isolated from Antennas
- Minimum features: 40 μm

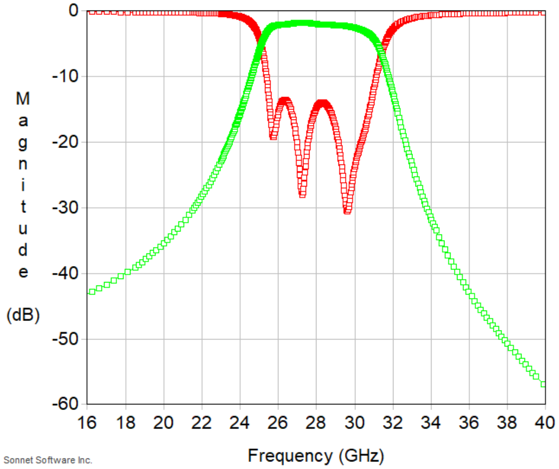


Courtesy: Muhammad Ali

5th order Interdigital BPF

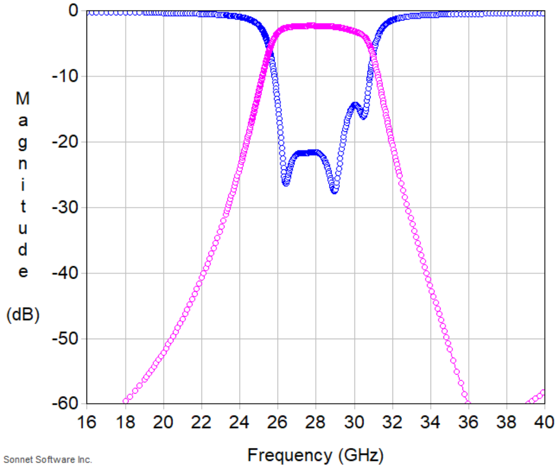
Physical Dimensions (mm^3)	Electrical Dimensions (λ_0)^3
3.06×2.25×0.1885	0.29×0.21×0.018





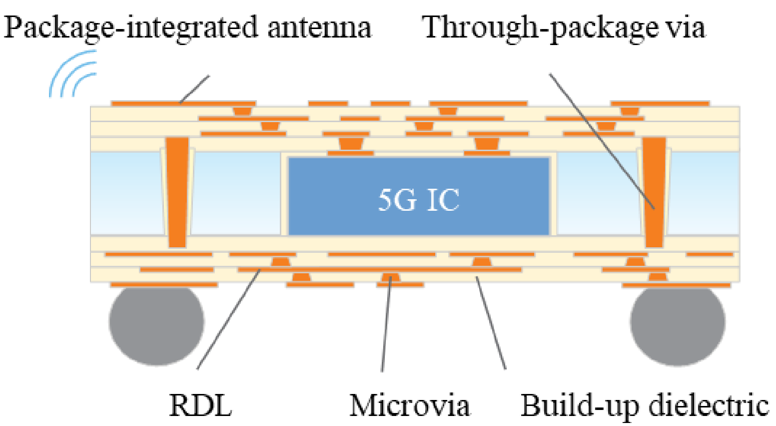
5th order Hairpin BPF

Physical Dimensions (mm^3)	Electrical Dimensions (λ_0)^3
4.65×2.12×0.1885	0.43×0.19×0.018



Comparison with Prior Art

Chip-first Glass-based 5G Packages

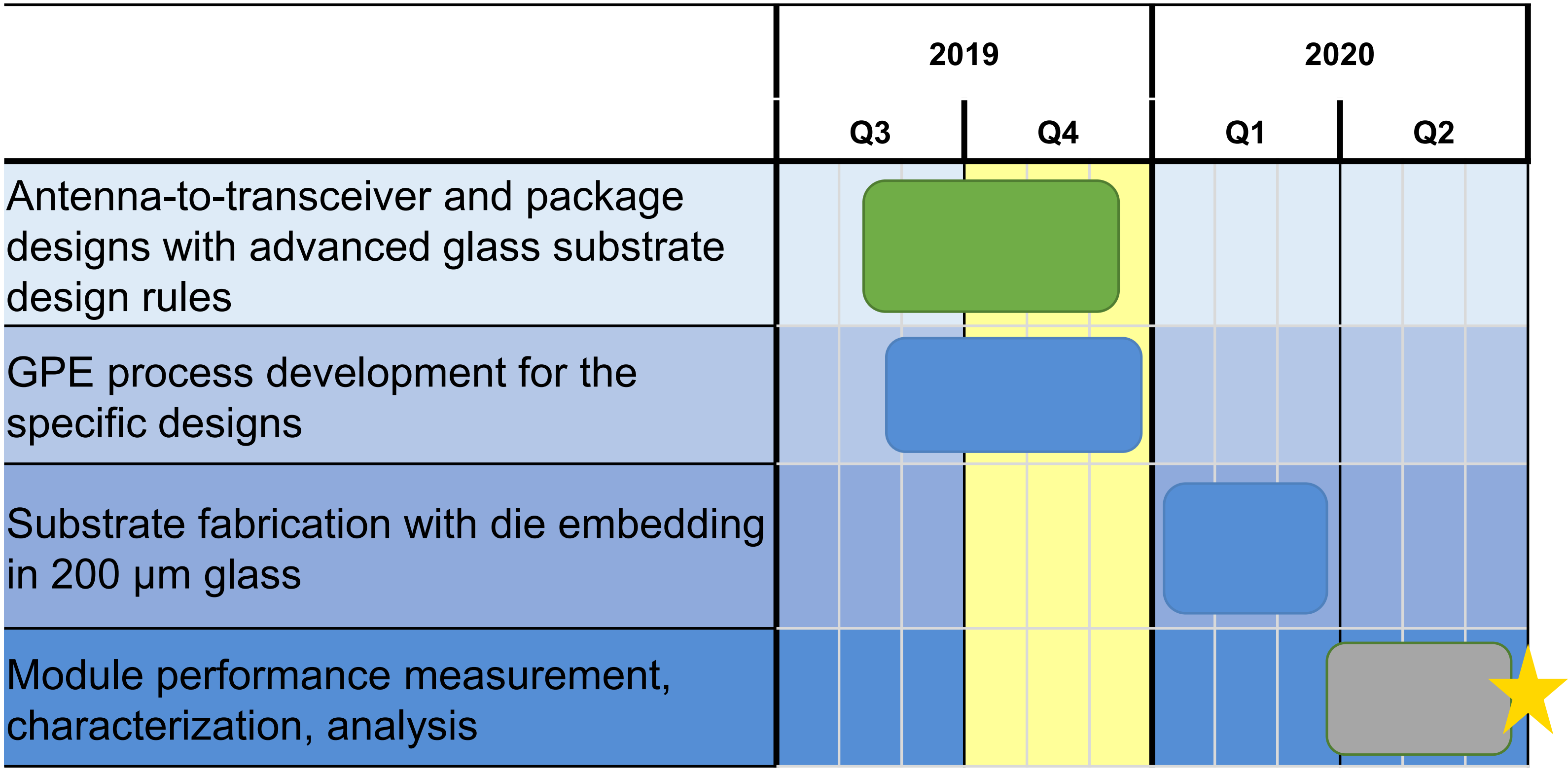


Heterogeneous Integration

1. Glass-panel embedding
2. LNA embedding
3. Dual-pol patch antenna array
4. Bandpass filters
5. Impedance-matched ultra-short interconnects

Topic	Metrics	Objectives	Prior Art
3D Antenna-integrated mm-wave Modules	Performance	• System interconnects: IL < 1 dB • Antenna bandwidth 24.25 – 29.5 GHz • Precision < 2% with 50 μm	• System interconnects IL = 3 – 5 dB • Antenna bandwidth 26.5 – 29.5 GHz • Precision: 6 – 10 % with 80 μm
	Miniaturization	• Total module thickness < 400 μm • Number of metal layers < 6	• Total thickness > 800 μm • Number of metal layers > 10

Schedule



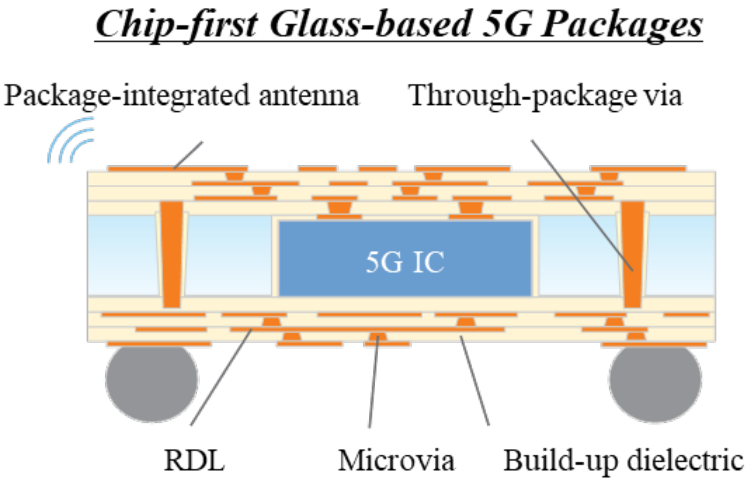
		2019		2020	
		Q3	Q4	Q1	Q2
Done	Antenna-to-transceiver and package designs with advanced glass substrate design rules	🟩	🟩		
In Progress	GPE process development for the specific designs	🟦	🟦		
	Substrate fabrication with die embedding in 200 μm glass			🟦	
	Module performance measurement, characterization, analysis				⬜ ★

Light Yellow: Current time window

🟩 Electrical Design and Optimization
🟦 Fabrication
⬜ Characterization and Correlation
★ Graduation

Summary

- Low-loss interconnects with through-package vias in low-loss dielectric polymer thin-films, and package-integrated dual-pol patch antenna structures were modeled and designed around 28 GHz on 200 μm thick glass substrate.
- Fabrication of the GPE structures and the characterization of the whole RF chain will be completed by May IAB 2020.



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