Glass Packaging for G-Band Applications

Madhavan Swaminathan, Penn State Univ.

www.chimes.psu.edu

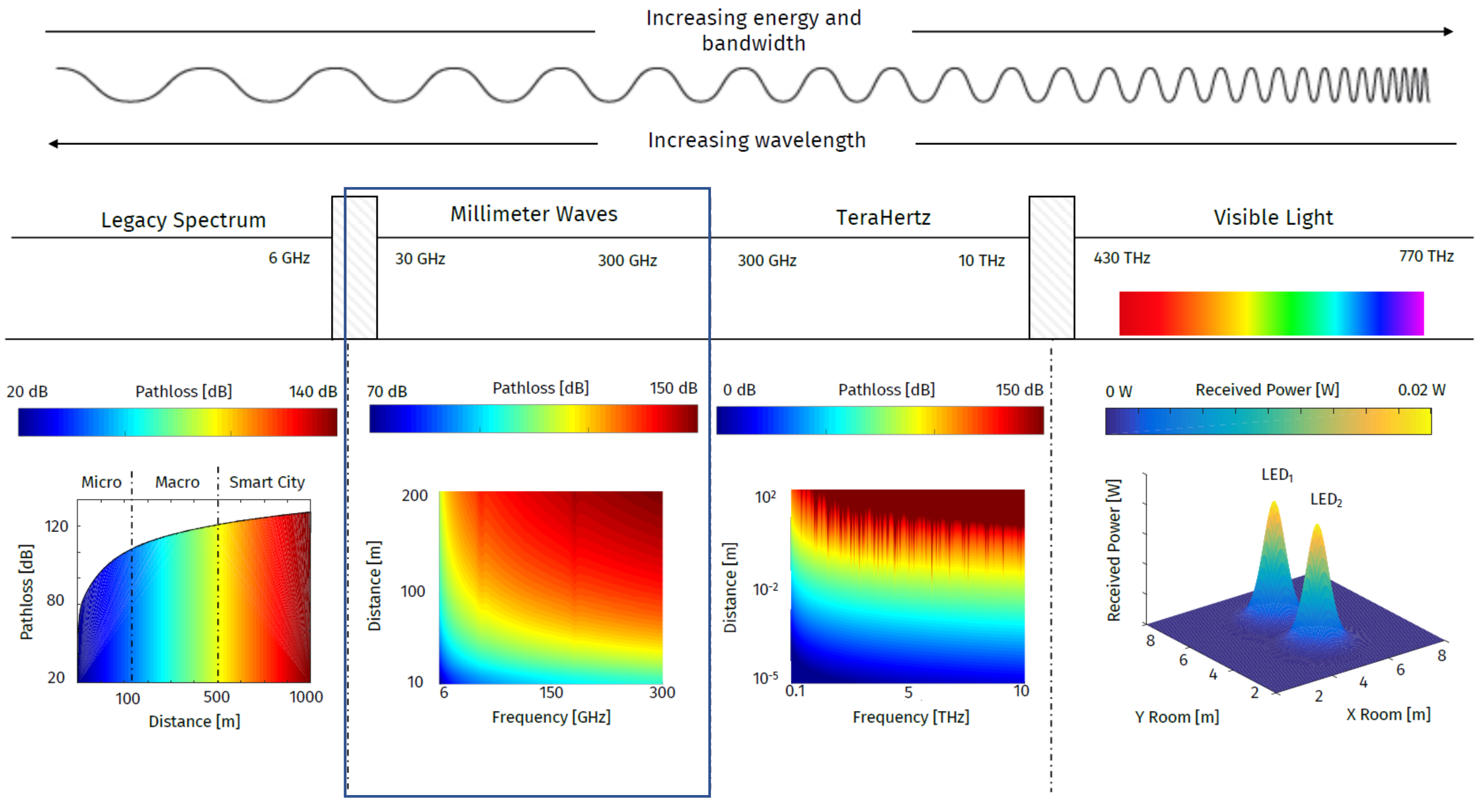
PennState College of Engineering | ELECTRICAL ENGINEERING AND COMPUTER SCIENCE

ECTC Panel May 28, 2024

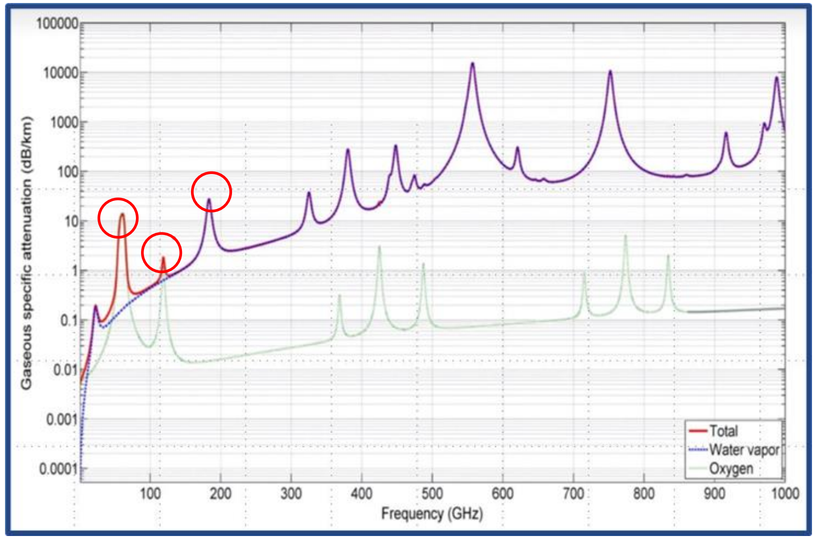
CHIMES Center for Heterogeneous Integration of Micro Electronic Systems

SRC

Electromagnetic Spectrum & Path Loss



Marco Giordani, Michele Polese, Marco Mezzavilla, Sundeep Rangan, and Michele Zorzi, "Towards 6G Networks: Use Cases and Technologies", IEEE Communications Magazine 2020

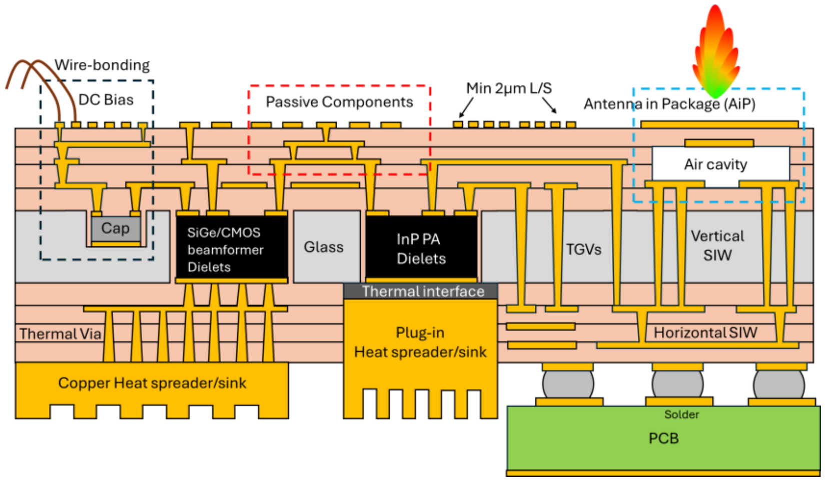


Courtesy: IEEE AP Magazine, Vol. 57, No. 1, Feb. 2015

❑ Path Loss, absorption loss, …. need to be compensated using antenna & RF circuitry!

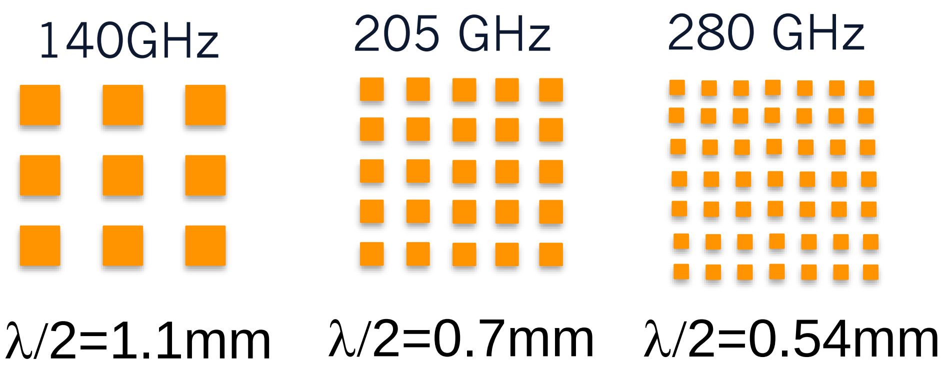
Available Technologies

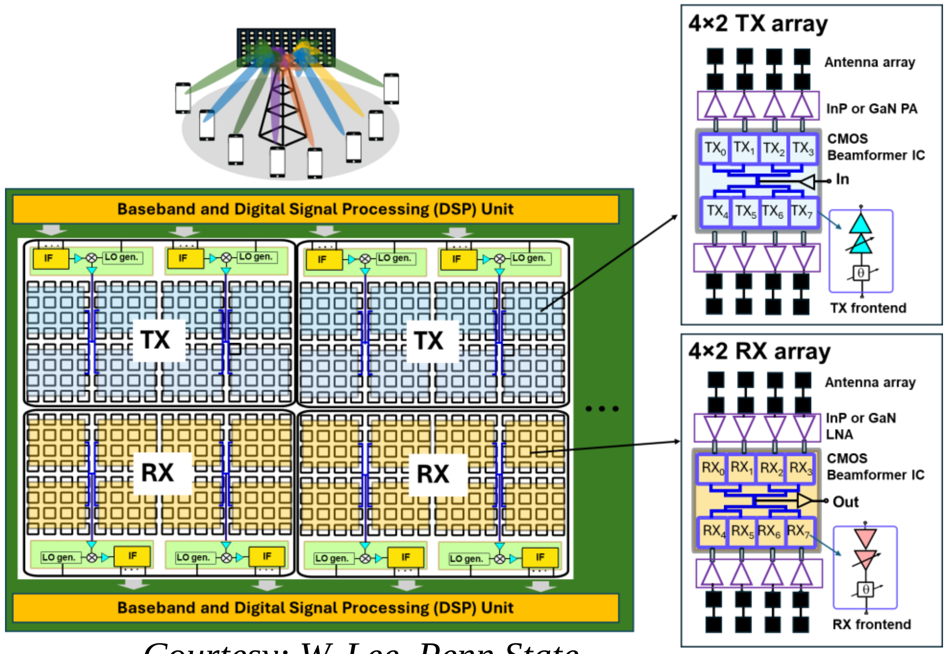
Key Parameter	LTCC	Laminate (LCP)	Si Interposer	Glass
Dk (ϵ_r)	7.3 - 9.8	3.17	11.7	3.7 - 21
Df ($\tan(\delta)$)	0.0007	0.006 @ 140 GHz	0.004 @ 35 GHz	0.008 @ 100 GHz
Surface Roughness (nm)	120	350	<60	<10
CTE (ppm/K)	6.7	18(x & y) 200 (z)	2.3-3.3	3 - 12
Young's Modulus (GPa)	90-150	3.4 -4.0	168.9	50 - 90
Moisture absorption	0	0.04%	0	0
Thermal Conductivity (W/mK)	> 3	0.9	148	1.1
Large Panel Processing	No	Yes	No	Yes
Cost	Very high	Low	High	Moderate
Min. Feature Size (μm)	100	10	1	1
Component Density	Low	Medium	Very high	Very high



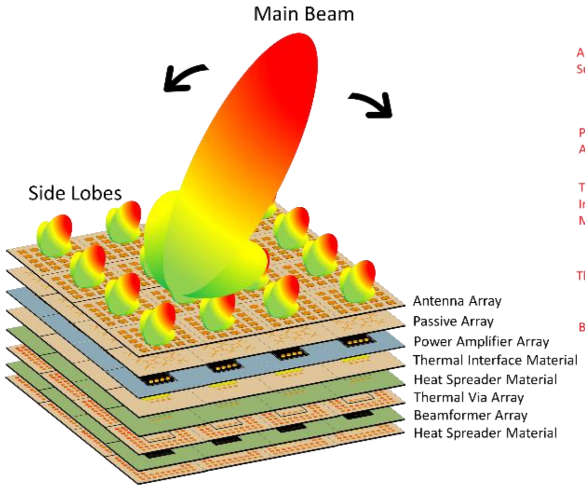
Design Challenges

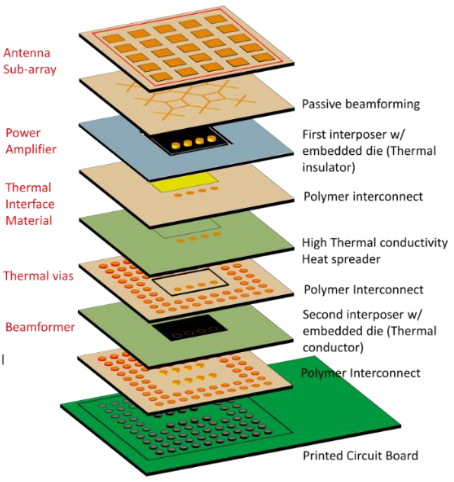
Scalable Antenna Array

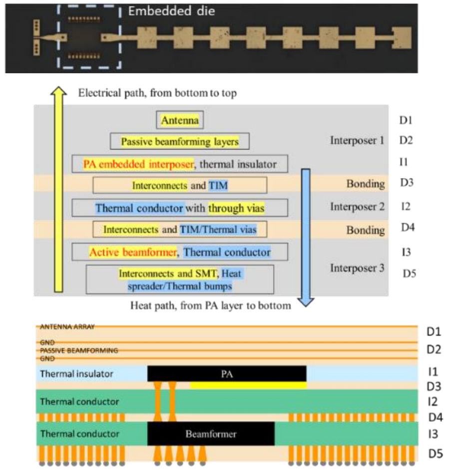




Courtesy: W. Lee, Penn State



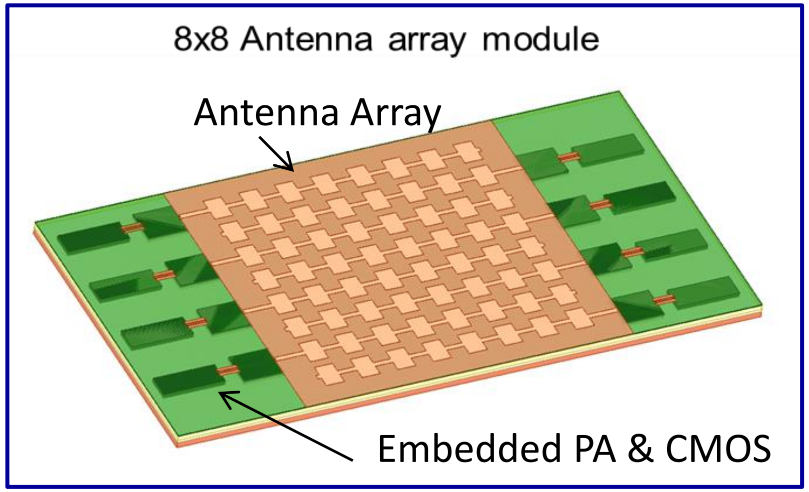


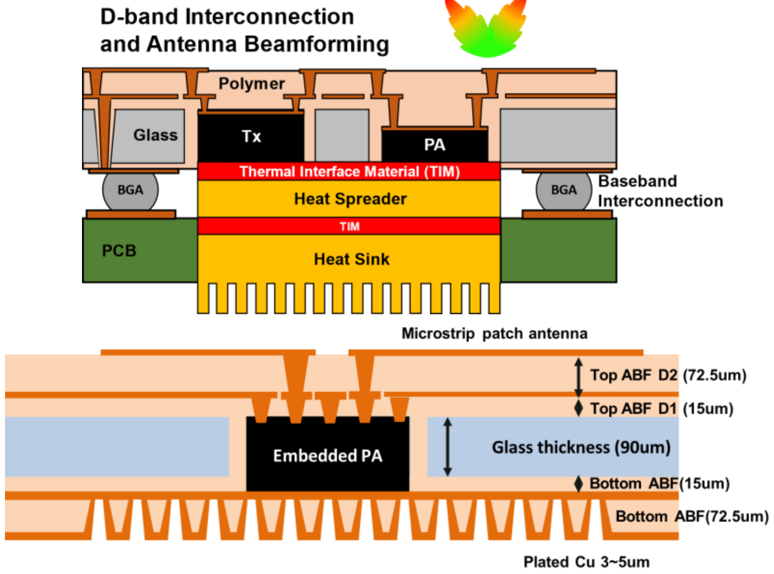


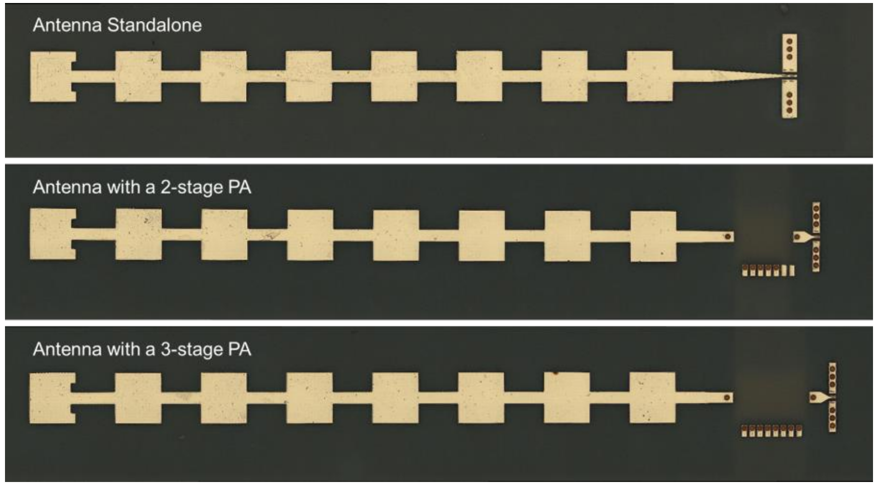
- ❑ Area of an antenna-in-package (AiP) scales down with λ^2 due to fixed half-wavelength antenna spacing.
- ❑ Resulting small AiP dimensions make it difficult
  - (1) to fit RFICs into the available space.
  - (2) to remove the large heat fluxes.
  - (3) to route the signal, control, and DC lines to all the ICs.
  - (4) Silicon-based RFICs cannot generate high power.
  - (5) Gain above 200 GHz limited due to limited fmax and breakdown voltage, which necessitates cointegration with high-performance InP front-end ICs.
  - (6) ICs need to be vertically integrated underneath the antenna array

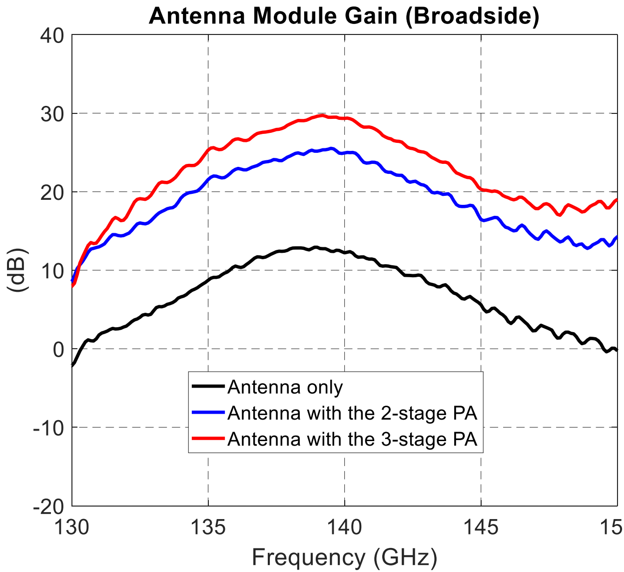
Emerging Solution – Glass Packaging

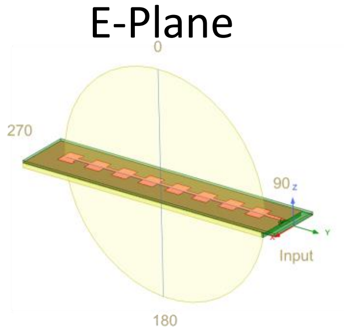
ComSenTer COMMUNICATIONS SENSING TERAHERTZ

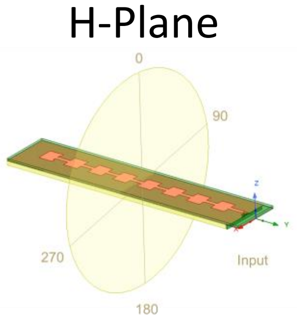


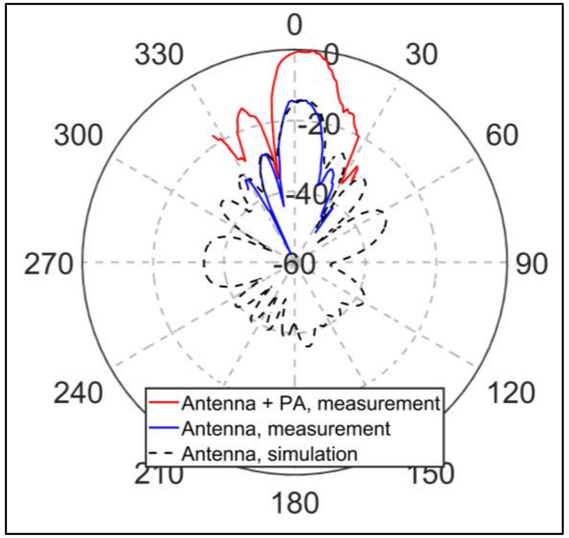












RF Packaging for Communication and Sensing Applications above 100 GHz – Technologies, Design Challenges and Emerging Solutions

RF Packages with Integrated Antennas above 100 GHz

Uwe Maaß

Outline

Motivation - Challenges for 100GHz+ Packaging

State of the Art for D-band Antenna-in-Package (AiP) Solutions

Fraunhofer IZM Embedding-based AiP Solutions

Example: Fraunhofer IZM’s Embedding-based AiP Solution using FoWLP for 6G

100GHz+ Packaging Design Challenges

Challenges

THz signals suffer from very high free space path loss

Frequency	3.5 GHz (n78)	39 GHz (n260)	140 GHz	300 GHz
Free Space Path Loss (300 m)	93 dB	114 dB (+ 21 dB)	125 dB (+ 32 dB)	132 dB (+ 39 dB)

Additional losses due to a) atmospheric effects (e.g., rain) and b) blockage (e.g., from buildings)

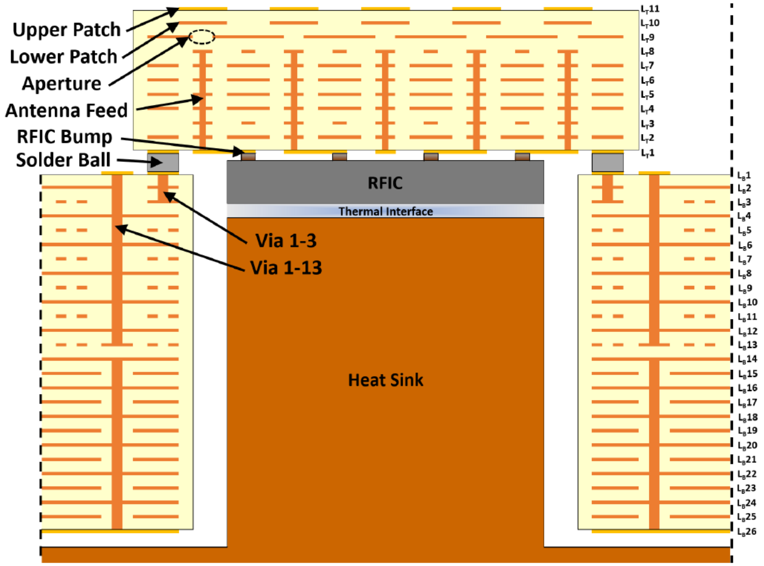
Possible Solutions

Sub-THz + (massive) MIMO = Sub-THz (massive) MIMO

Antenna-in-Package (AiP) solutions required for hardware implementation of Sub-THz (massive) MIMO

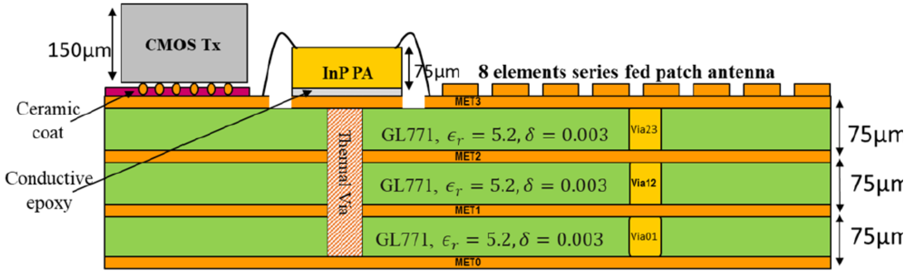
D-Band AiP Solutions – 1/2

PCB-based Flip Chip AiP



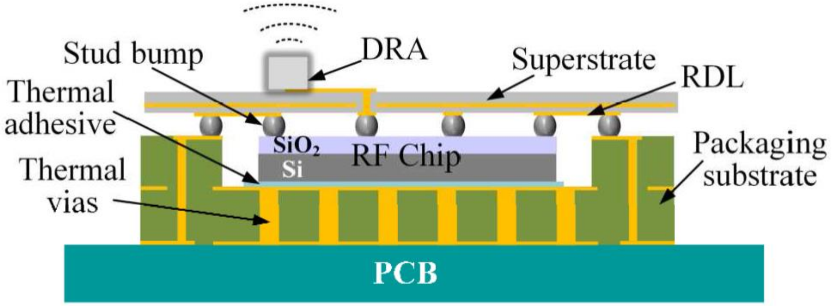
S. Shahramian, M. J. Holyoak, A. Singh and Y. Baeyens, "A Fully Integrated 384-Element, 16-Tile, W -Band Phased Array With Self-Alignment and Self-Test," in IEEE Journal of Solid-State Circuits, vol. 54, no. 9, Sept. 2019

PCB-based Wirebond AiP



A. A. Farid, A. S. H. Ahmed, A. Dhananjay and M. J. W. Rodwell, "A Fully Packaged 135-GHz Multiuser MIMO Transmitter Array Tile for Wireless Communications," in IEEE Transactions on Microwave Theory and Techniques, vol. 70, no. 7, July 2022

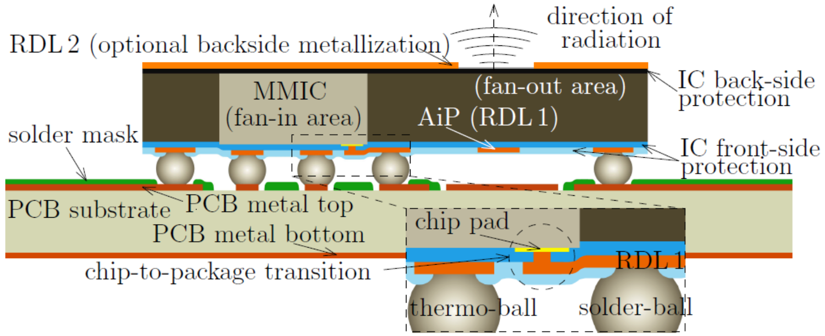
HDI PCB-based AiP



T. Li, K. Schneider, A. Haag, A. Visweswaran, A. Bhutani and T. Zwick, "Design of Wideband Dielectric Resonator Antenna for D-Band Applications," 2021 International Symposium on Antennas and Propagation (ISAP), 2021

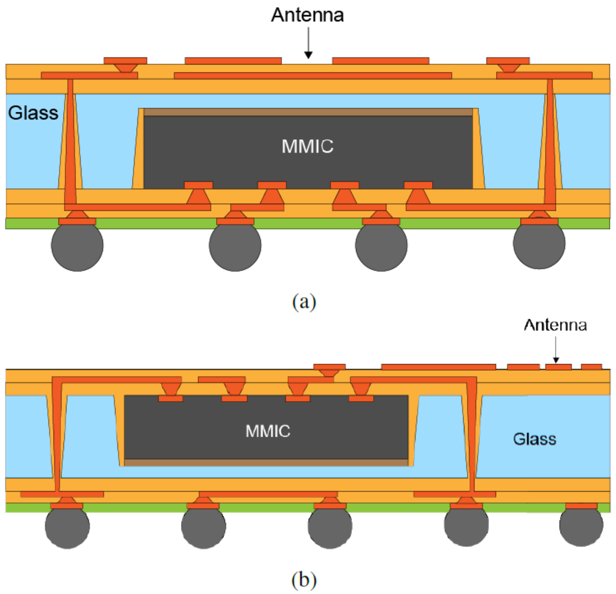
D-Band AiP Solutions – 2/2

Mold-Embedding based AiP



F. Ahmed, M. Furqan and A. Stelzer, "120-GHz and 240-GHz Broadband Bow-Tie Antennas in eWLB Package for High Resolution Radar Applications," 2018 48th European Microwave Conference (EuMC), 2018

Glass Panel Embedding based AiP



(a)

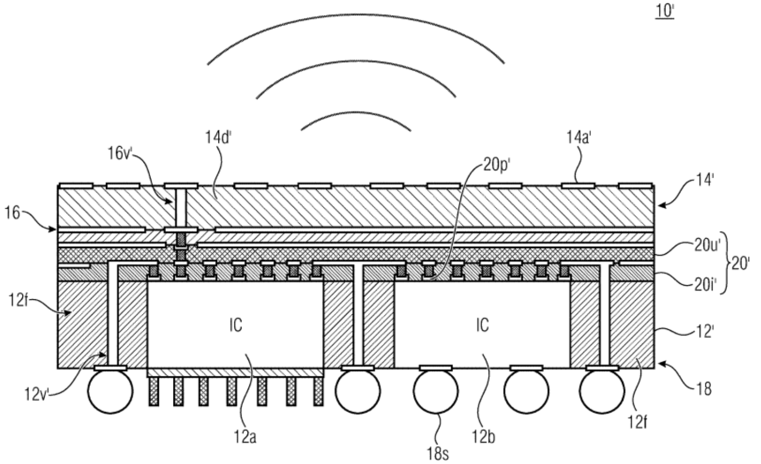
(b)

S. Erdogan, S. Ravichandran, X. Jia and M. Swaminathan, "Characterization of Chip-to-Package Interconnects for Glass Panel Embedding (GPE) for Sub-THz Wireless Communications," 2021 IEEE 71st Electronic Components and Technology Conference (ECTC), 2021

Fraunhofer IZM Embedding based AiP Solutions for Applications above 100 GHz

Embedding based AiP using Mold (FoWLP) and PCB Technologies

Embedding-based AiP using Mold



6GKom

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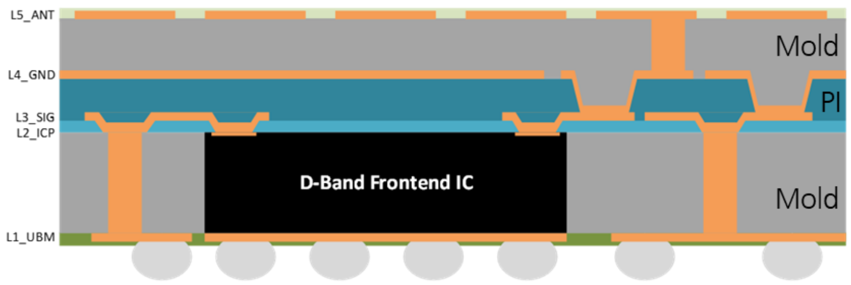
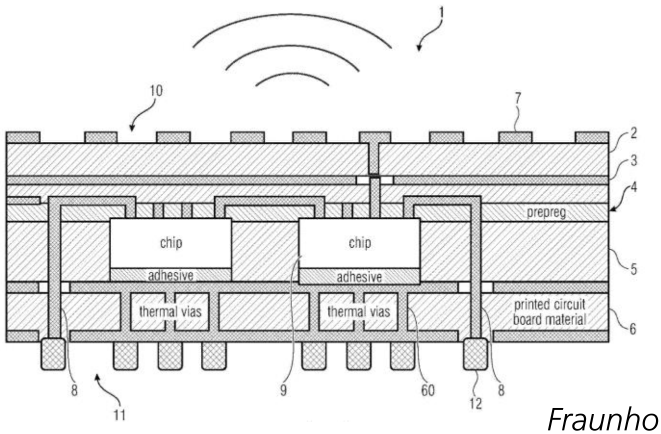


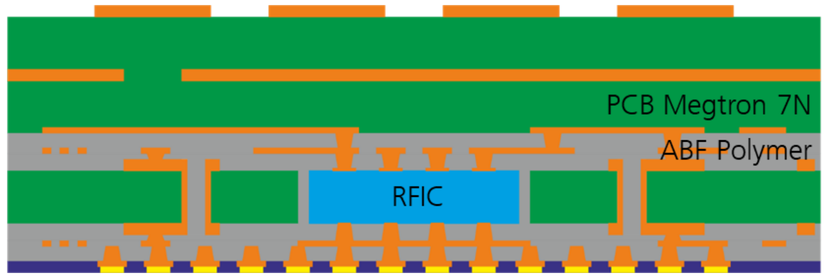
Fraunhofer IZM's IP (US Patent Nr. US 10 978 778 B2; German Patent Nr. DE 10 2017 200 122 B4)

Embedding-based AiP using PCB



6G SENTINEL
100 Gb/s
1Tb/s

Fraunhofer Society 6G Lighthouse Project

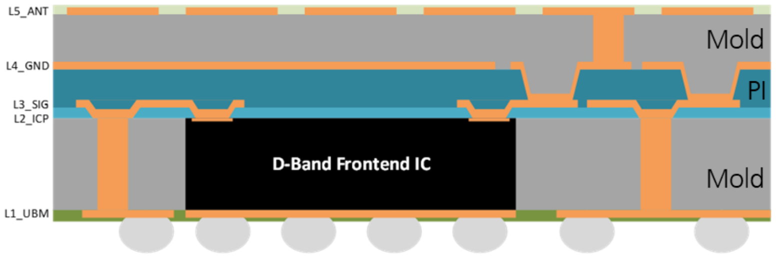


Fraunhofer IZM's IP (US Patent Nr. US 11 394 109 B2; EU Patent Nr. EP 33 465 48 B1)

Example: 6G Sub-THz Module using IZM's Mold-Embedding based AiP – 1/4

BMBF Project *6GKOM*

- Investigation and development of an ultra-broadband, miniaturized, massive MIMO D-band hardware module with integrated beamforming for 6G
- Application of Fraunhofer IZM's mold embedding-based AiP for development of front-end module with integrated antennas



Technische Universität Berlin	TECHNISCHE UNIVERSITÄT DRESDEN		ihp	Fraunhofer IZM
Prof. Dr. G. Caire	Prof. Dr. G. Fettweis	Prof. Dr. D. Kissinger	Prof. Dr. E. Grass	Prof. Dr. Dr. I. Ndip
Competences and Focus				
Information theory and signal processing for mobile communication systems	**Signal processing and hardware** development for mobile communication systems	**Frontend chip design** for mmWave and THz systems	Localization, **chip development and manufacturing** for mmWave and THz systems	**Advanced packaging and system integration**, reliability, RF system design, **signal integrity** and **antenna design** for mmWave and THz systems

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6GKom Industry Advisory Board (16 German Companies)

ni, TE, vodafone, XILINX, CREONIC, ERICSSON, JOHN DEERE, Infineon
Heraeus, ROHDE&SCHWARZ, AIRBUS, SCHOTT glass made of ideas, contag, alcan, isola, GLOBALFOUNDRIES, Continental The Future in Motion

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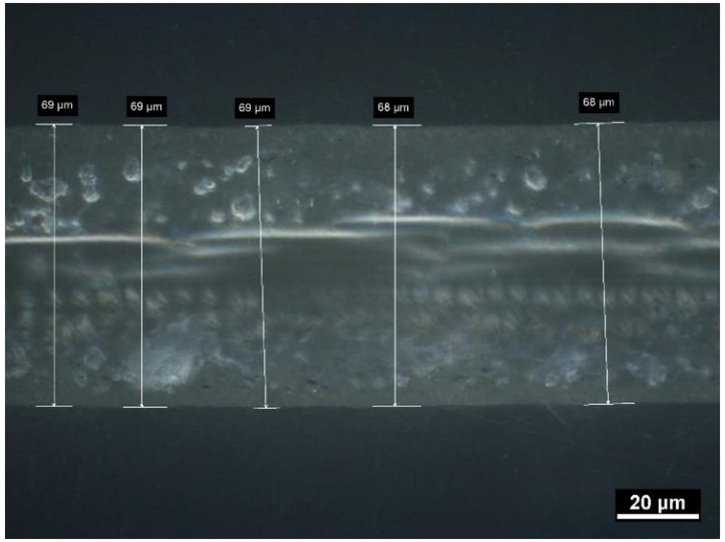
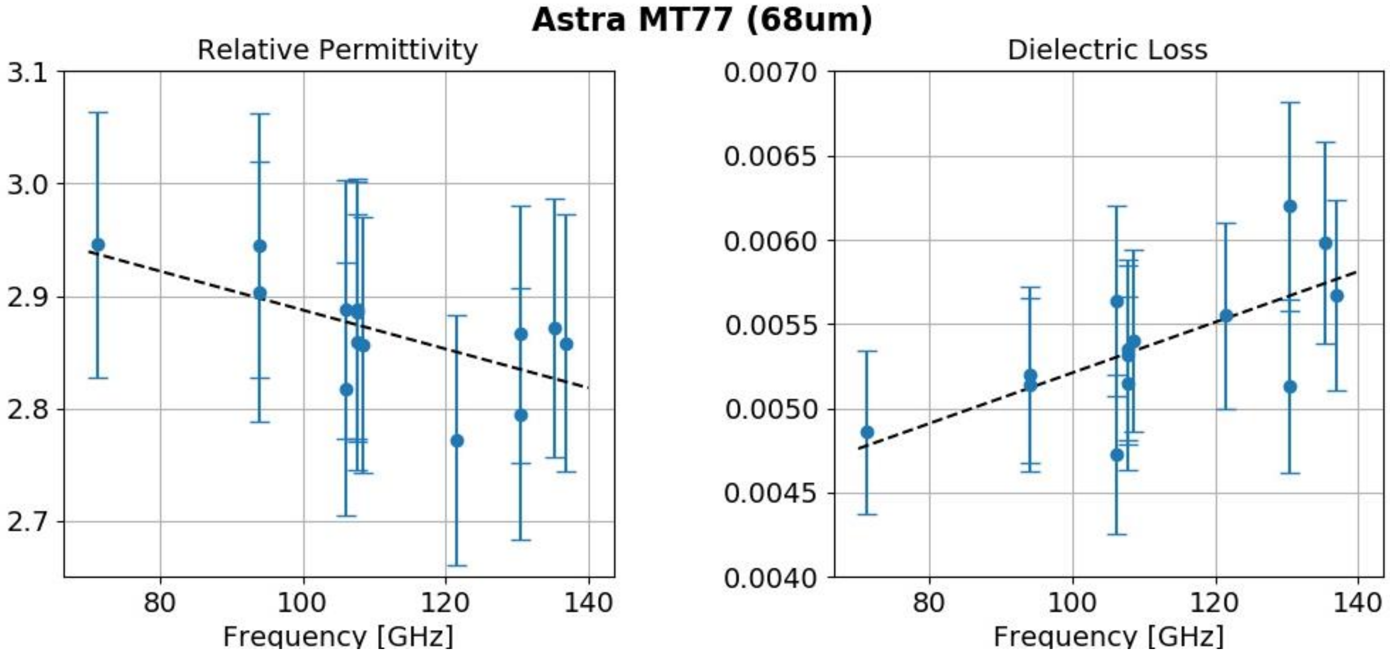
Example: 6G Sub-THz Module using IZM's Mold-Embedding based AiP – 2/4

BMBF Project *6GKOM:* RF Measurement and Characterization of Packaging Materials

Example: ISOLA ASTRA MT77





Frequency (GHz)	70	80	90	100	110	120	130	140
DK	2.94	2.92	2.90	2.89	2.87	2.85	2.84	2.82
DF (10^{-3})	4.8	4.9	5.1	5.2	5.4	5.5	5.7	5.8

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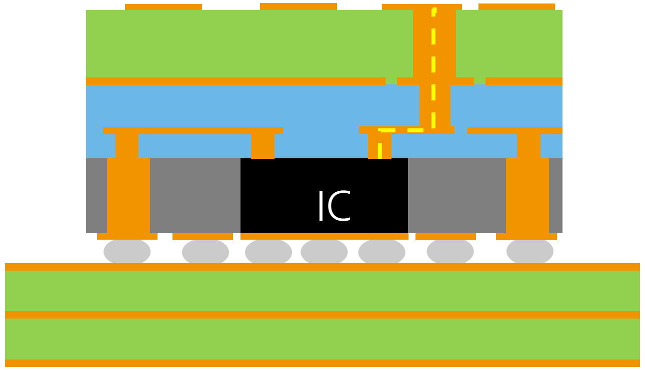
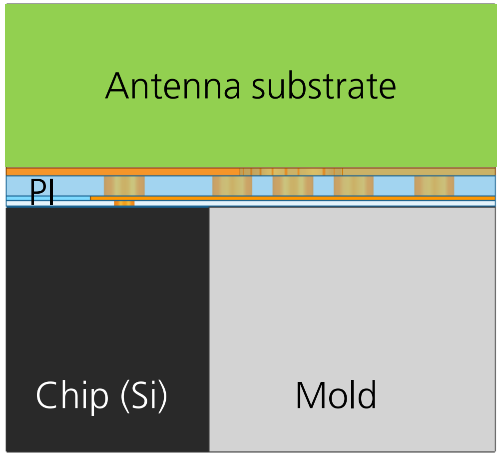
Example: 6G Sub-THz Module using IZM's Mold-Embedding based AiP – 3/4

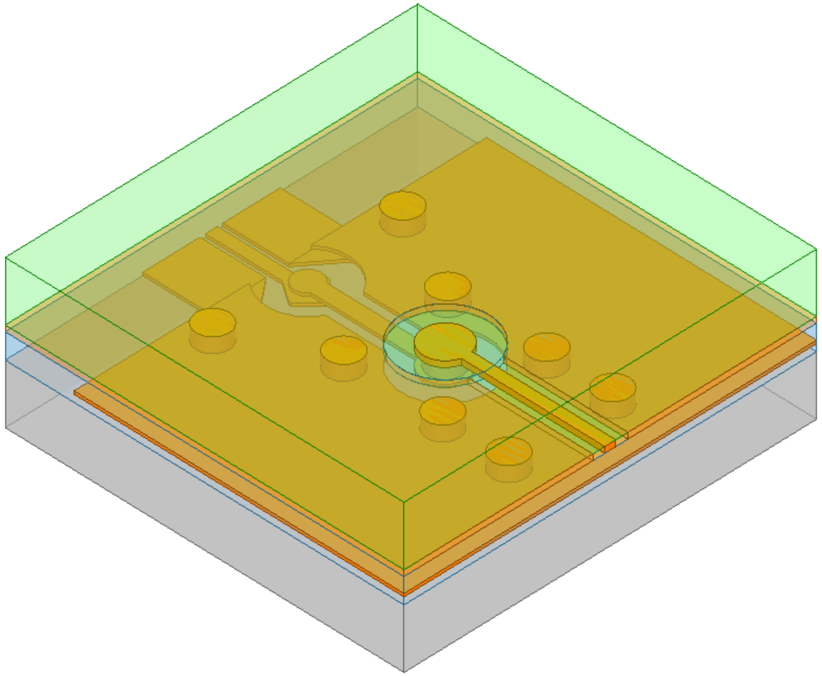
BMBF Project *6GKOM:* Design of Critical Signal Paths, Chip to Antenna



Entire Module with System Board

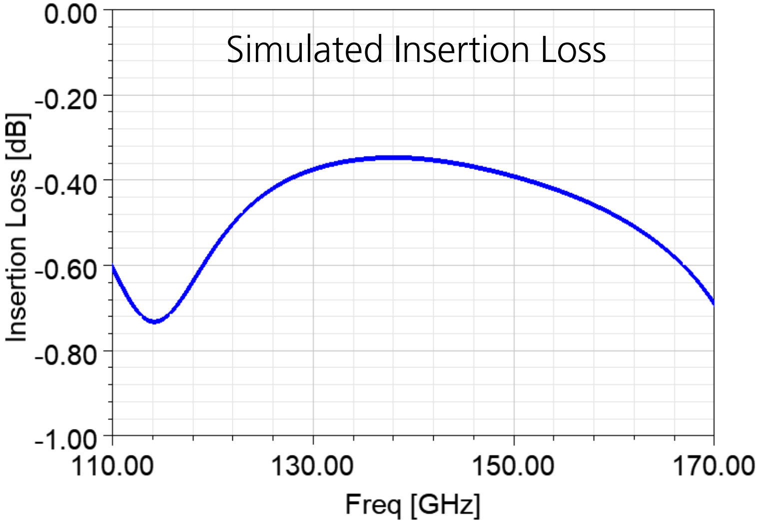


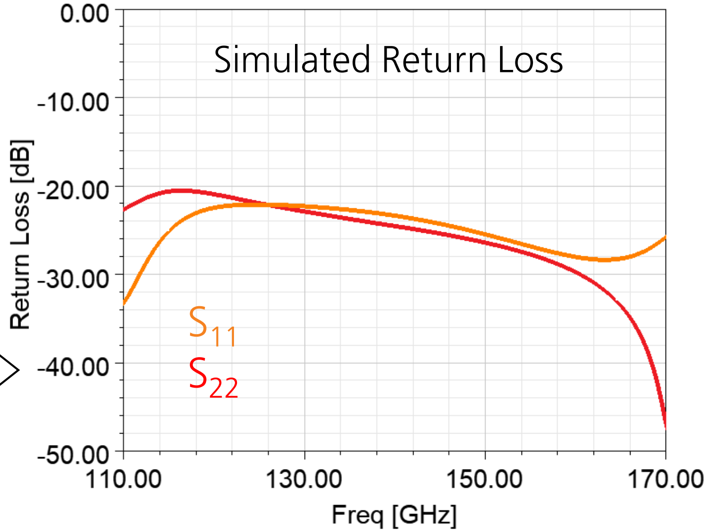
Details of cross section



- Chip Microstrip
- Chip-Package RDL Via
- GCPW on PI
- RDL via PI to PI
- GCPW on PI-Antenna Interface

Signal path elements with material effects





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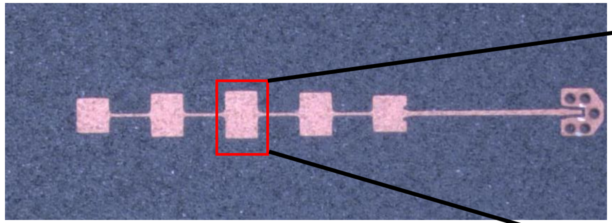
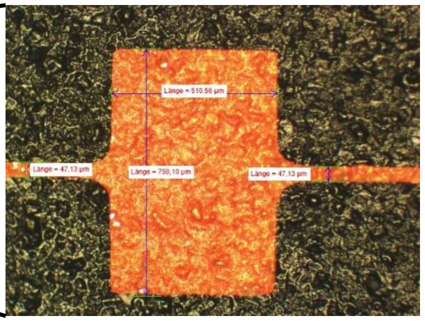
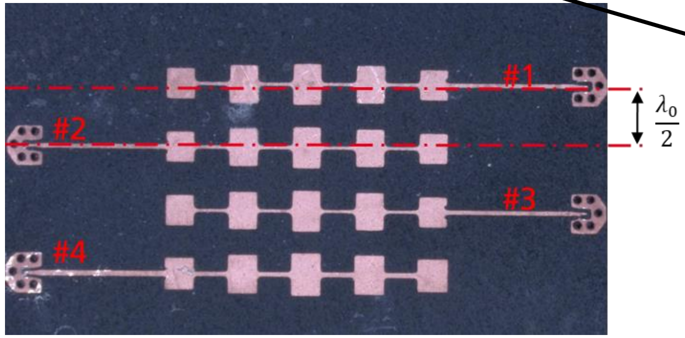
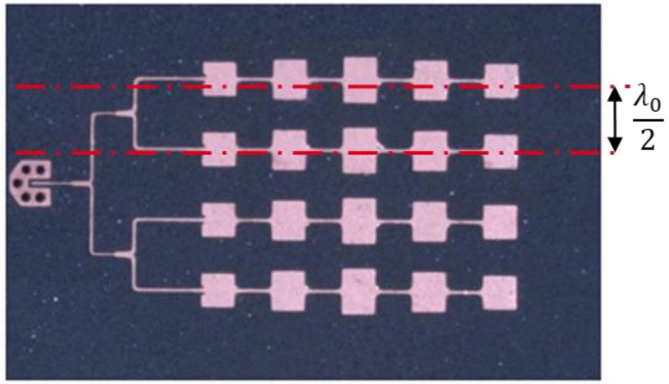
Example: 6G Sub-THz Module using IZM's Mold-Embedding based AiP – 4/4

BMBF Project *6GKOM:* Design and Test of Antennas



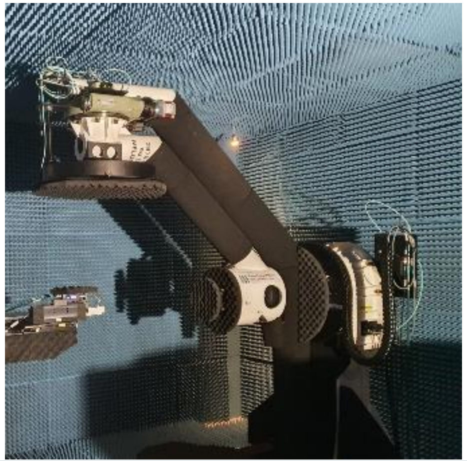


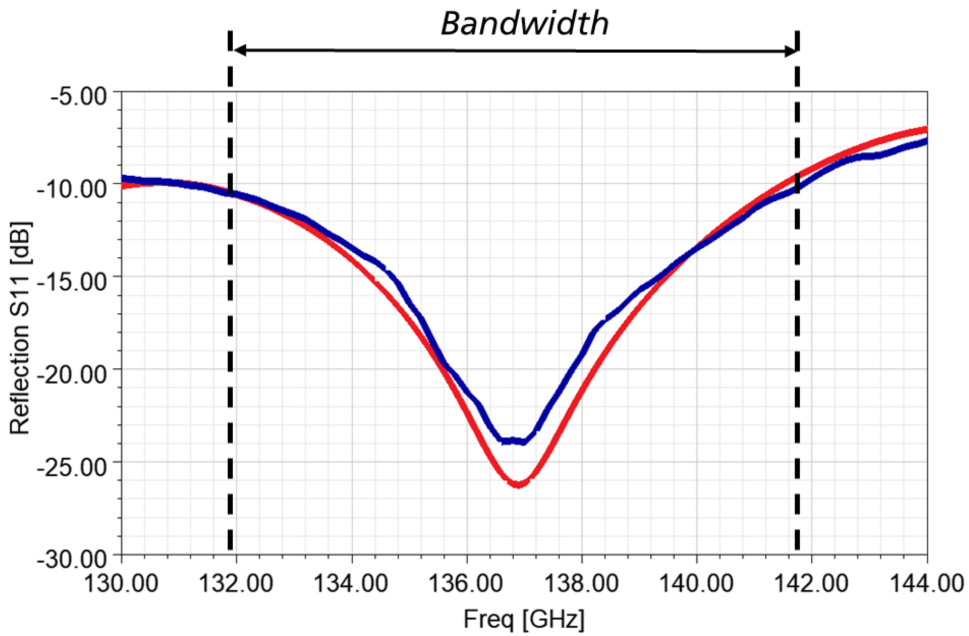




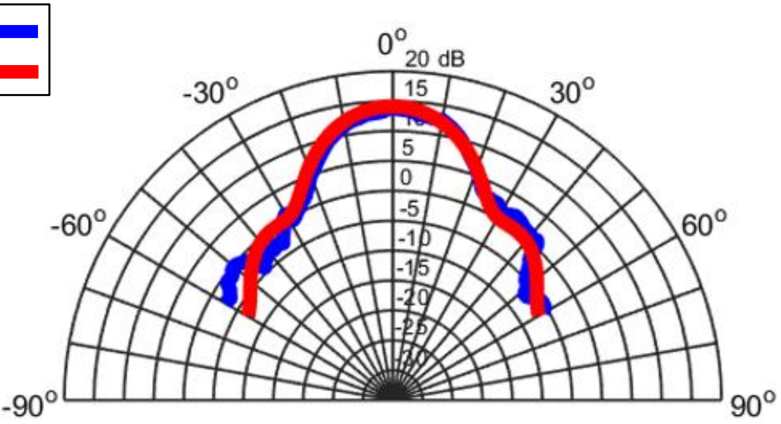
	Simulation model	Manufactured structure	Deviation
Patch length	**489,2 µm**	**510,7 µm**	**4,3 %**

	Simulated	Measured
Peak Gain	**15.7 dBi**	**15.5 dBi**





Measurement 🟦
Simulation 🟥



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Fraunhofer Institute for Reliability and Microintegration IZM

Uwe Maaß
Dept. RF & Smart Sensor Systems
Email: uwe.maass@izm.fraunhofer.de

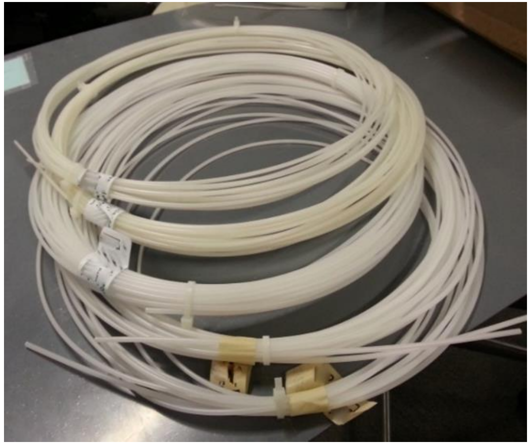
Fraunhofer IZM Berlin
Gustav-Meyer-Allee 25
13355 Berlin
Germany
+49 30 46403-100

Fraunhofer IZM-ASSID
Ringstraße 12
01468 Dresden-Moritzburg
Germany
+49 351 795572-12

Fraunhofer IZM Außenstelle Cottbus
Karl-Marx-Straße 69
03044 Cottbus
Germany
+49 355 383 770-12

A sub-THz CMOS Transceiver IC and system for Medium-Reach Guided Wave and Short-Reach Wireless Communication Links

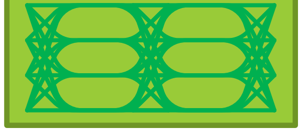
Gerd Schuppener, Juan Herbsommer, Bradley Kramer[1], Hassan Ali, Robert Payne, Nirmal Warke[2], Carole Rush, Baher Haroun, and Swami Sankaran



[1]Retired, [2]Formerly with Texas Instruments

sub-THz/mmWave Interconnect Vision

Power efficient Baseband Backend



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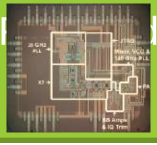
Sub-THz/mmW CMOS



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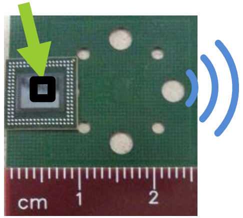
On-package Antenna/Launch



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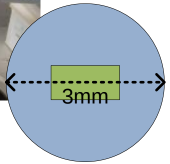


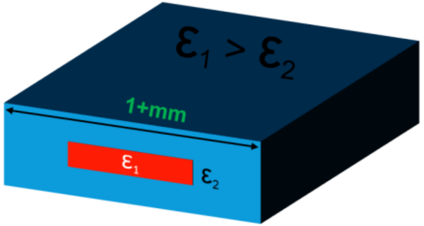
Flexible, Low-Loss, Low-cost Plastic Waveguides

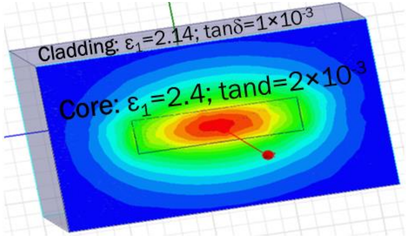
Characteristic		Characteristic	
Baud Rate Targets	20+Gbaud	**Technology**	Standard CMOS (≤65nm)
Carrier	100+GHz	**λ (in waveguide)**	~1-1.3mm
Distance	1-10m, in-expensive waveguides 5cm, Over-the-Air (OTA)	**Waveguide Dimensions**	1.3x0.65mm core, 3mm diameter
Waveguide Loss **Dispersion/GDV**	3-15dB/m ?	**Alignment tolerances**	100s of µm (~10% λ)
Modulation	BPSK (20+Gbps)/QPSK (40+Gbps) 16QAM (80+Gbps)	**Power efficiency @ Full-Rate**	<10pJ/bit; (65nm CMOS)

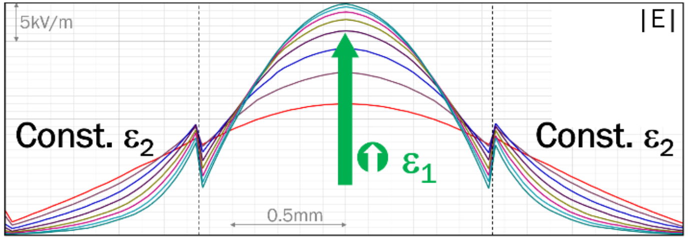
sub-THz Interconnect Tradeoffs

- Sub-THz/mmW TX, RX co-packaged or co-integrated with Baseband
- Guided-Wave Launch/OTA Antenna array embedded in package substrate
- RF carrier frequency selection – Trade-off between:
  - Net bandwidth (for given % occupancy) and IC process f_{MAX} limit
  - Cost/Packaged chip size – λ Determines Launch, Antenna dimensions
  - DWG diameter – Critical in conduit area/Gbps constrained applications

“Plastic” Dielectric Wave-Guide







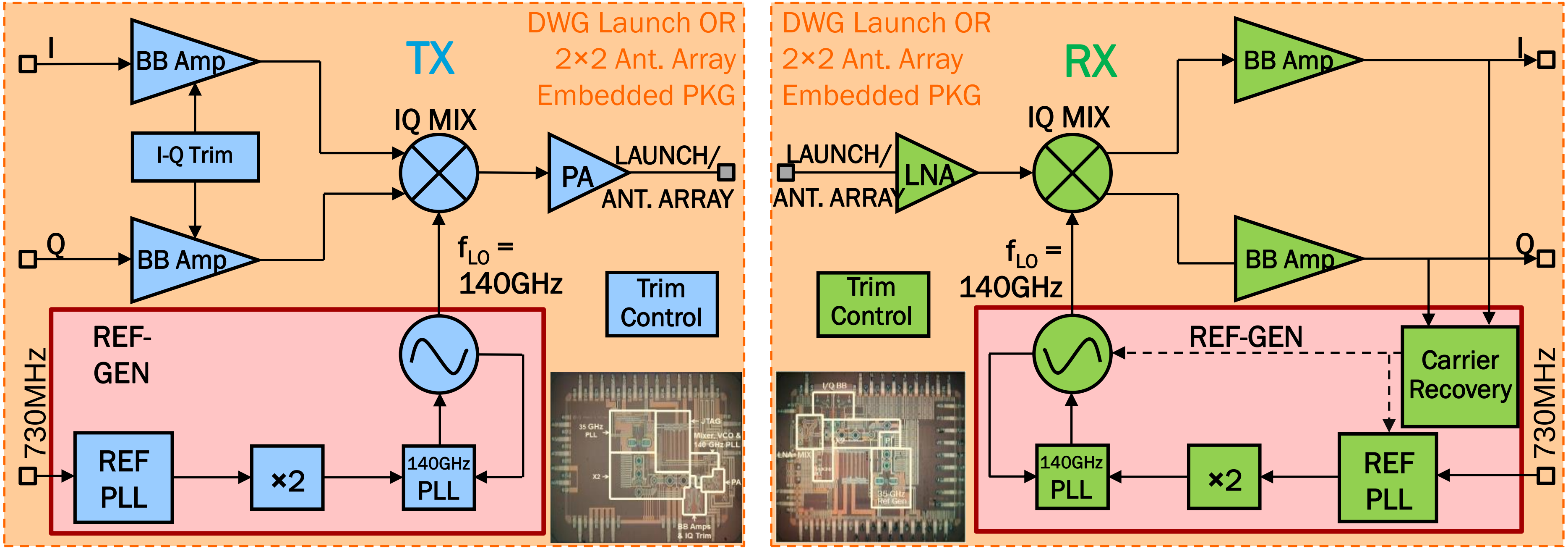
- Works on “Total-Internal-Reflection” (TIR) principle, similar to optical fibers
- ↑ Core-to-Cladding contrast enhances confinement but trades off with dB/m loss
- Material (Plastic) + Use of standard extrusion → Potential for Low-cost
- Material composition → Mechanically flexible

Measured Loss (WR5 - 140GHz)

Core	Cladding	∅ (mm)	α (dB/mm)
PE	PP	3	6.7
PE	PP	1	3.7
COMPOSITE-A	PP	3	9.3
	PP	2	4.7
COMPOSITE-B	PP	3	17.5
	PP	2	8.46

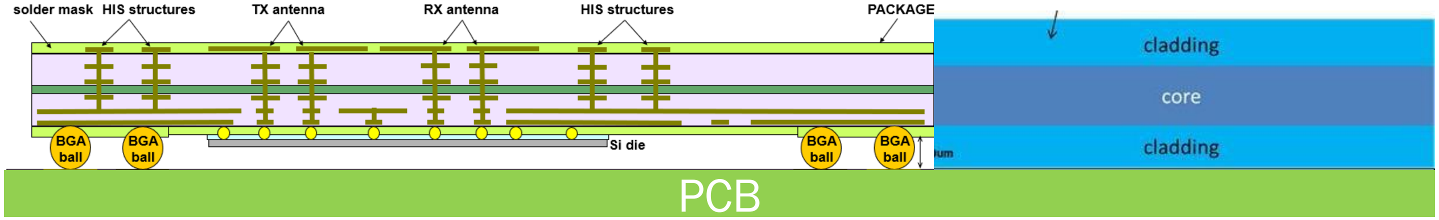
Texas Instruments

140-GHz System Block Diagram

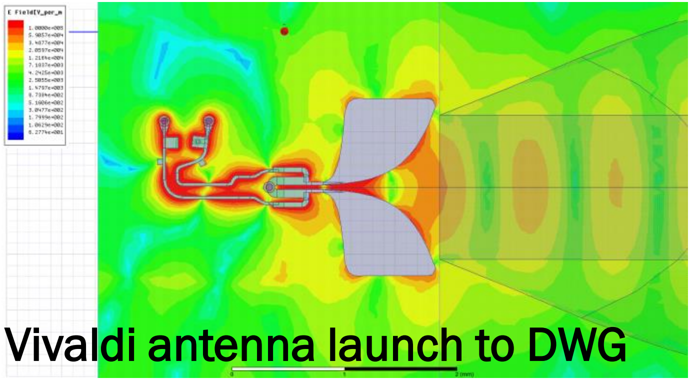


- ICs: 65-nm CMOS, ~6mm^2; Package: 6L, FCCSP
- High-Speed I/Q interface: Ground-referenced LVDS

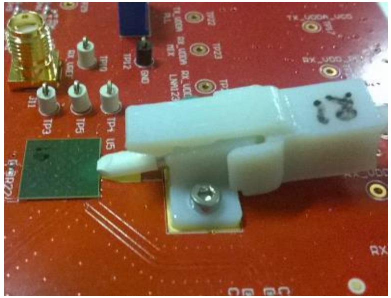
Package-embedded Launch/2×2 Antenna Array



10mm x 10mm Flip-chip Chip-Scale Package (FCCSP)

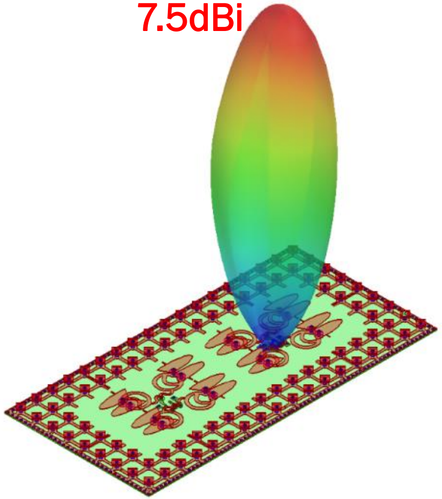


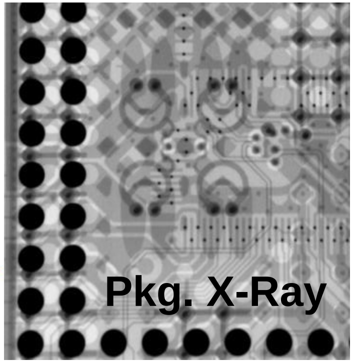
Vivaldi antenna launch to DWG



- Insertion Loss ~2.8dB (per side)
- -10dB RL bandwidth > 20GHz

Over-the-Air: 2x2 Antenna Array

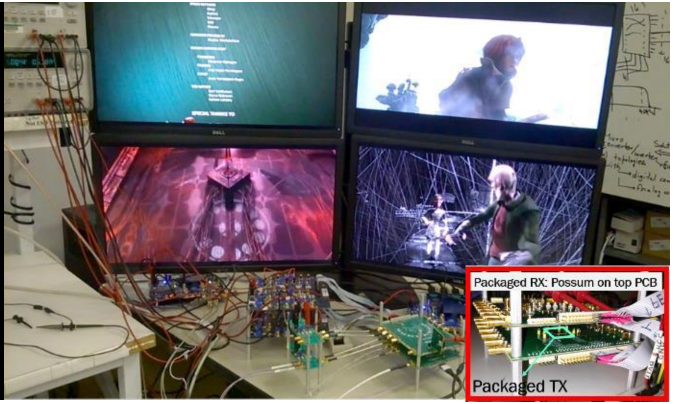




Wireless (OTA), Guided-Wave demonstration

Interface	Data-Rate	BER	Distance	DWG
OTA	10.8Gbps	$<1.6\times10^{-11}$	25.4mm	--
DWG	10.8Gbps	2.1×10^{-15}	1m	TI
	16Gbps	9.3×10^{-12}	1m	
	10.3Gbps	$<1\times10^{-14}$	4m	External
$f_{carrier}$ = 140GHz; P_{DC}=700mW; **Energy η (@ 4m): 17pJ/bit/m**				

Wireless



DWG