Advanced Packaging for 5G in RF and Analog Mixed Signal

IEEE HIR 5G mm-waves TWG Chair
Tim Lee (The Boeing Company)

February 2023

Boeing Technical Fellow, BR&T
2022 IEEE Board of Directors
2022 IEEE Region 6 Director
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Past President, IEEE MTT-S

Timothy Lee, currently a Boeing Technical Fellow, is responsible for the development of RF and digital electronics for advanced communications networks and sensor systems. In the IEEE, Tim is promoting the use of technology to benefit humanity.

Technology Roadmaps to Enable the 5G Ecosystem

- Microwave / millimeter-wave RF-Front Modules needed for emerging 5G User Equipment (UE) and Base-stations (BS)
- Roadmaps for Hardware and Advanced Packaging to guide us to areas of research for millimeter-wave RF Front-Ends for 5G and Beyond
- Time horizons: 3-, 5- and 10-years
- Addressing Semiconductors and Advanced Packaging technical trades
- Devices, materials, processes and substrates needed to support the goal of low-cost high performance 5G New Radio (NR) hardware
- Initial look at beyond 5G for technology needs between 100 GHz to 1 THz (6G)

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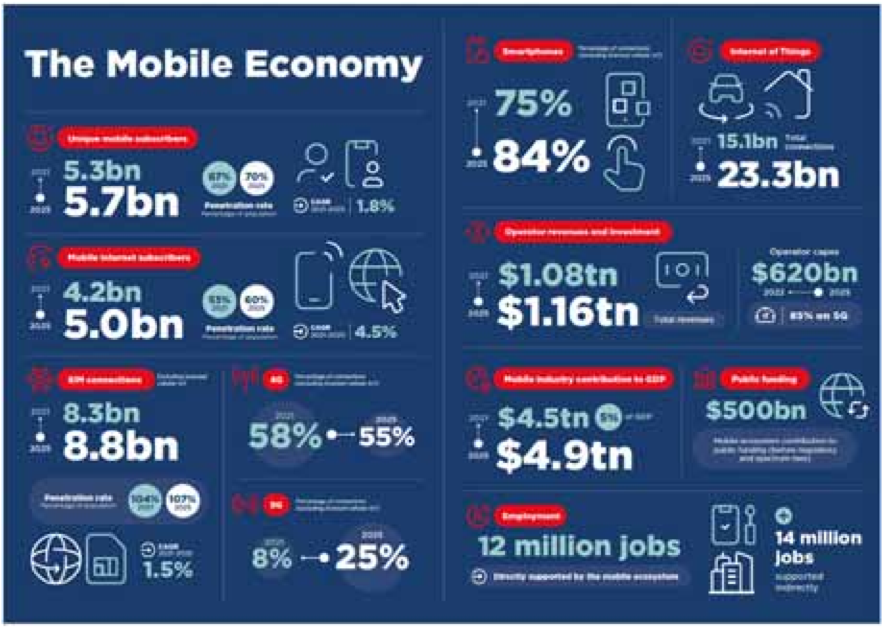

https://www.gsma.com/mobileeconomy/

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Status of 5G Deployments in 2022 (GSMA Report)

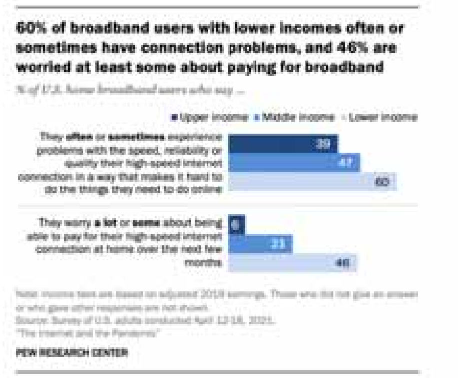
The 5G Era has begun and gaining momentum!

- C-Band: 3.7GHz to 3.98GHz turned on in US

AT&T 5G+ SpeedTest at CES 2022 in Las Vegas Convention Center (**mm-waves**)

https://www.gsma.com/mobileeconomy/

The Pandemic has Exposed the Digital Divide



The World Bank:
Connectivity is a Public Good During COVID-19 Pandemic

- One and a half billion. That's the number of children who need online schooling due to the coronavirus pandemic (COVID-19).
- In the battle against COVID-19, digital technologies are front and center.
- What will it take to achieve universal, affordable, and good-quality broadband?
- This crisis painfully shows that the benefits and opportunities of technology are not equally distributed

5G WILL PLAY A MAJOR ROLE TO BUILDING A RESILIENT AND INCLUSIVE RECOVERY

https://www.pewresearch.org/internet/2021/09/01/the-internet-and-the-pandemic/

https://blogs.worldbank.org/voices/covid-19-reinforces-need-connectivity

ITU: The State of Broadband: Accelerating broadband for new realities

- While Internet use grew during the COVID-19 pandemic, a new Broadband Commission report reveals the urgent need for broadband connectivity that is fit for purpose in terms of affordability and accessibility.
- According to the latest ITU data, 66 per cent of the global population – some 5.3 billion people – used the Internet in 2022, up from 54 per cent in 2019.
- Broadband played a central role in this uptake after the pandemic shifted much of daily life online, from remote work and learning to online shopping and banking and even medical consultations using e-health applications.
- At the same time, COVID-19 brought the digital divide into sharp relief. Today, 2.7 billion people have yet to access the Internet, causing them to miss out on digital public services and other opportunities unlocked by broadband connectivity.

https://www.itu.int/hub/2022/11/state-of-broadband-commission-report/

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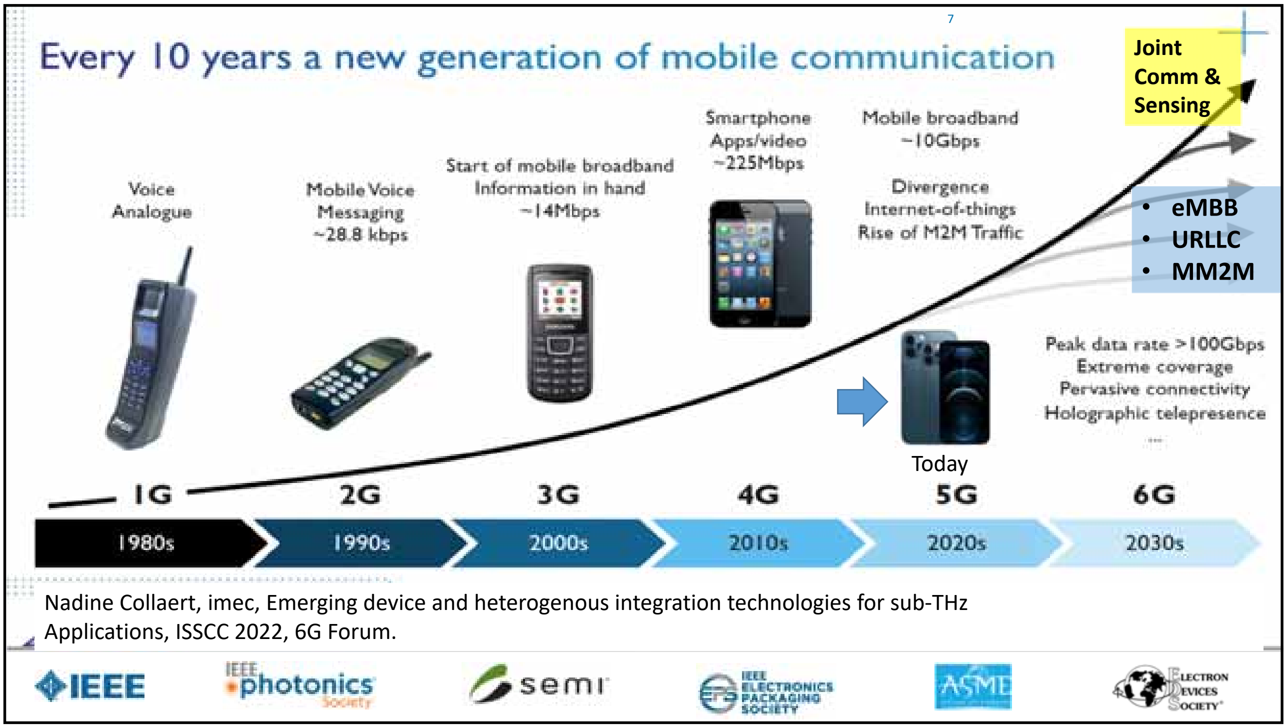
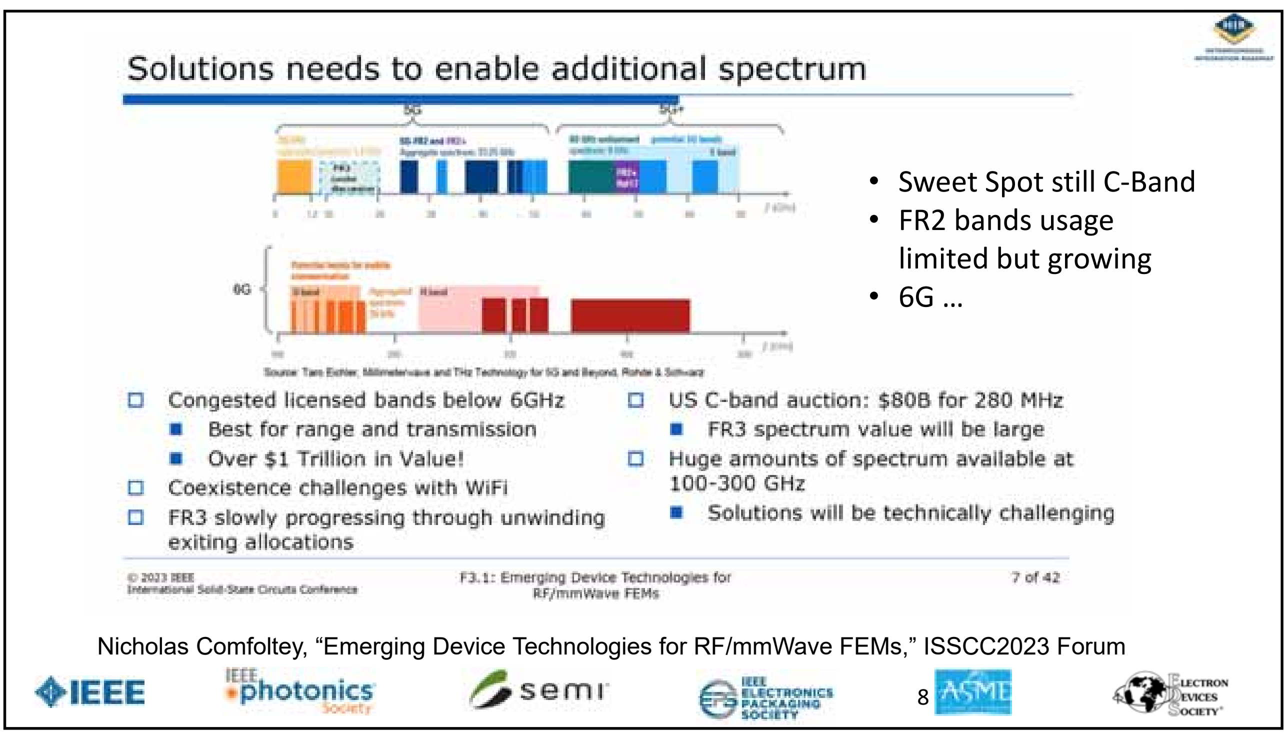

Every 10 years a new generation of mobile communication
Joint Comm & Sensing
Voice
Analogue
Mobile Voice
Messaging
~28.8 kbps
Start of mobile broadband
Information in hand
~14Mbps
Smartphone
Apps/video
~225Mbps
Mobile broadband
~10Gbps
Divergence
Internet-of-things
Rise of M2M Traffic
• eMBB
• URLLC
• MM2M
Peak data rate >100Gbps
Extreme coverage
Pervasive connectivity
Holographic telepresence
...
Today
1G
2G
3G
4G
5G
6G
1980s
1990s
2000s
2010s
2020s
2030s
Nadine Collaert, imec, Emerging device and heterogenous integration technologies for sub-THz Applications, ISSCC 2022, 6G Forum.
IEEE
IEEE photonics Society
semi
IEEE ELECTRONICS PACKAGING SOCIETY
ASME
Electron Devices Society


Solutions needs to enable additional spectrum
5G
5G+
6G
Source: Taro Eichler, Millimeterwave and THz Technology for 5G and Beyond, Rohde & Schwarz
• Sweet Spot still C-Band
• FR2 bands usage limited but growing
• 6G …
Congested licensed bands below 6GHz
Best for range and transmission
Over $1 Trillion in Value!
Coexistence challenges with WiFi
FR3 slowly progressing through unwinding exiting allocations
US C-band auction: $80B for 280 MHz
FR3 spectrum value will be large
Huge amounts of spectrum available at 100-300 GHz
Solutions will be technically challenging
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F3.1: Emerging Device Technologies for RF/mmWave FEMs
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Nicholas Comfoltey, "Emerging Device Technologies for RF/mmWave FEMs," ISSCC2023 Forum
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Why mmWave?

Shannon-Hartley Theorem:

$$C = B\log_2\left(1+\overbrace{\frac{\bar{P}}{N_o B}}^{\text{SNR}}\right)$$

C: Channel capacity
B: Channel Bandwidth [Hz]
N_o: Noise Power Spectral Density [W/Hz]
P: Average Received Power [W]

High SNR: Capacity is linear in bandwidth, logarithmic in power.

Low SNR: Capacity is insensitive to bandwidth, linear in power.

Carrier Frequency	Modulation	Available Bandwidth[GHz]	Max Data Rate [Gb/s]
Sub-6GHz	4096-QAM	0.15	1.35
28GHz	256-QAM	0.85	5.1
60GHz	64-QAM	8.64	38.9
70GHz	64-QAM	5	22.5

~30x increase in data rate!

Operation at mmWave frequencies enables wide bandwidth designs → Potential for higher data rates

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RF Front-Ends Play a Critical Role to the Deployment of 5G Ecosystem (RFICs, Antennas and Advanced Packaging)

According to the Fact & Figures research report, the global 5G Smart Antenna Market in 2019 was approximately USD 260 million. The market is expected to grow at a CAGR of 57% and is anticipated to reach around USD 6,325 million by 2026.

5G RF Front-End Modules faces many design challenges

- ***UE is highly SWaP-C constrained***
  - ***Battery Life***
  - ***Mm-wave propagation losses***
- ***BS Challenges***
  - ***Signal Blockage***
  - ***Output Power & PAE***
  - ***Thermal***
  - ***Yield & Affordability***
- ***Key Technologies:***
  - ***Advanced node CMOS, FD-SOI***
  - ***2.5D/3D packaging***
  - ***Low-loss substrates***

AiP / AoP Modules (Amkor)

https://www.everythingrf.com/news/details/12962-amkor-develops-advanced-packaging-technology-for-5g-rf-front-end-modules

Si/SiGe Beamformers (GF)

https://www.globalfoundries.com/sites/default/files/rf_soi_can_save_billions_in_5g_mmwave_network_costs_with_efficient_pas_2020-04-06_microwave_journal.pdf

https://unitedlex.com/insights/apple-iphone-13-pro-max-teardown-report

Mm-wave BS Phased Array – Beamformer Technologies using III-V and SiGe (Fujikura)

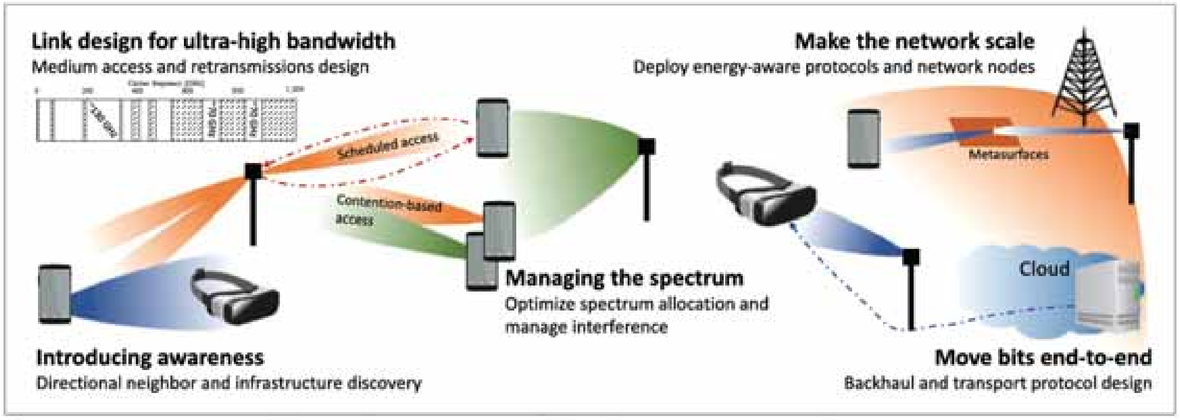
https://mmwavetech.fujikura.jp/5g/?gclid=EAIaIQobChMI4qWzsLLs8wIVGmxvBB0EhwfOEAAYAyAAEgJ96_D_BwE

Intelligent Reflective Surfaces for 6G (ETSI)

https://www.5gtechnologyworld.com/etsi-launches-intelligent-surfaces-effort/

Resilient 5G

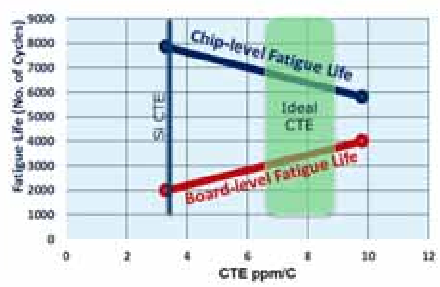
Main Design Challenges for End-to-End, Full-Stack THz Networks



M. Polese, "Toward End-to-End, Full-Stack 6G Terahertz Networks," IEEE Communications Magazine, Nov 2020. (Northeastern University)

Heterogeneous Integration Platform

Substrate Core	Silicon	Organic		Glass
		Laminates	Fanout (Epoxy Mold Compound)	
Material properties				
Surface roughness (nm)	<10	400-600	> 1000	<10
CTE (ppm/K)	2.9-4	3-17	16-30	3-9
Young's modulus (GPa)	165	10-40	22	50-90
Moisture absorption	0	0.04%	1-2.5%	0
Thermal conductivity (W/m.K)	148	0.9	0.5-0.75	1.1
Physical Dimensions				
Package size (mm)	35x35	70x70	50x50	100x100
Panel/Wafer size	300 mm	710 mm²	300 mm / 510 mm²	710 mm²



- ❑ Materials with Silicon like properties that maximize chip and board level reliability and support larger body sizes required!
- ❑ CTE in the range of 7-9 ppm/C with low surface roughness, Young's Modulus and zero moisture absorption required.
- ❑ Glass Interposer is a good candidate!

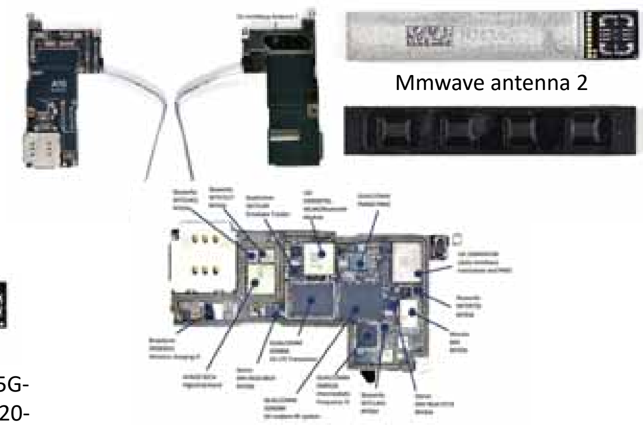
Madhavan Swaminathan, "Packaging for mmWave Communications," March 2021, INEMI Webinar

Mm-wave Phased Arrays: a Common Feature in your Phone!

5G Antenna Modules in Samsung S20 Ultra

https://omdia.tech.informa.com/OM006104/Criticality-of-5G-Modem-to-RF-Integration-A-look-inside-Samsung-Galaxy-S20-Ultra

Iphone 13 Pro mm-wave modules / antenna and 5G Modem



https://unitedlex.com/insights/apple-iphone-13-pro-max-teardown-report/

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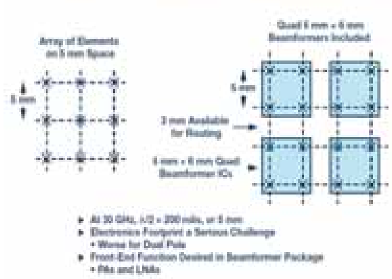
Technology/Capability Gaps and Showstoppers

Challenge 1: Tight Integration is Needed for mm-wave Phased Arrays



Frequency	Element Spacing	Dual Pole I/O Spacing
3 GHz	50 mm, 2 inches	25 mm, 1 inch
10 GHz	15 mm, 600 mils	7.5 mm, 300 mils
30 GHz	5 mm, 200 mils	2.5 mm, 100 mils

6G → 140 GHz 1mm

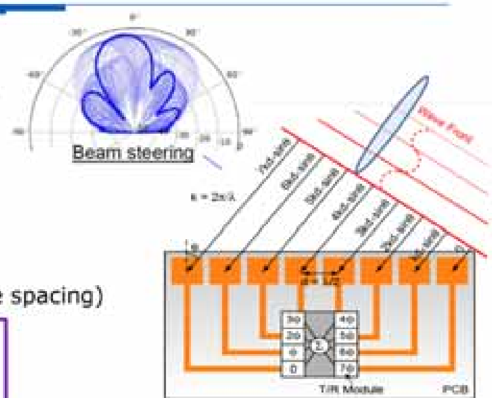
5G Front-End architecture (number of elements, EIRP, Si vs III-V, and Packaging) need to be tailored for each use case

Phased Arrays are a key enabler for mmWave

- Link budget improves 30*log*10(N)
- For a phased array of N elements
  - Tx array: focused Tx radiation energy
    - TRP increases by $10\log_{10}(N)$
    - EIRP increases by $20\log_{10}(N)$
  - Rx array: enhanced Rx sensitivity
    - S/N increases $10\log_{10}(N)$
    - NF decreases by $10\log_{10}(N)$
- Beam width narrows ~ $2*\sin^{-1}(2/N)$
- Array area decreases $(l/2)^2$ (l/2 lattice spacing)

Lower Tx power per Power Amplifier and Antenna element

mmWave FEM requirements can be addressed by Silicon technologies



Gabriel Rebeiz, "Si RF Technologies Enabling 5G Millimeter Wave Applications," October 2018.

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Nicholas Comfoltey, "Emerging Device Technologies for RF/mmWave FEMs," ISSCC2023 Forum

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Key Antenna Package Requirements

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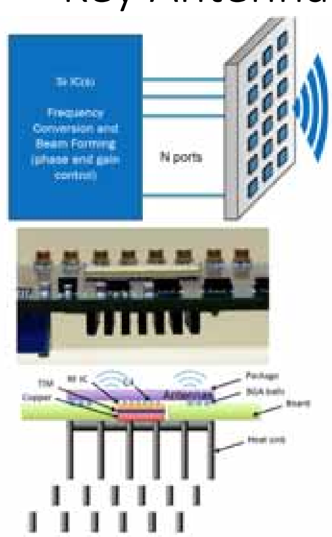
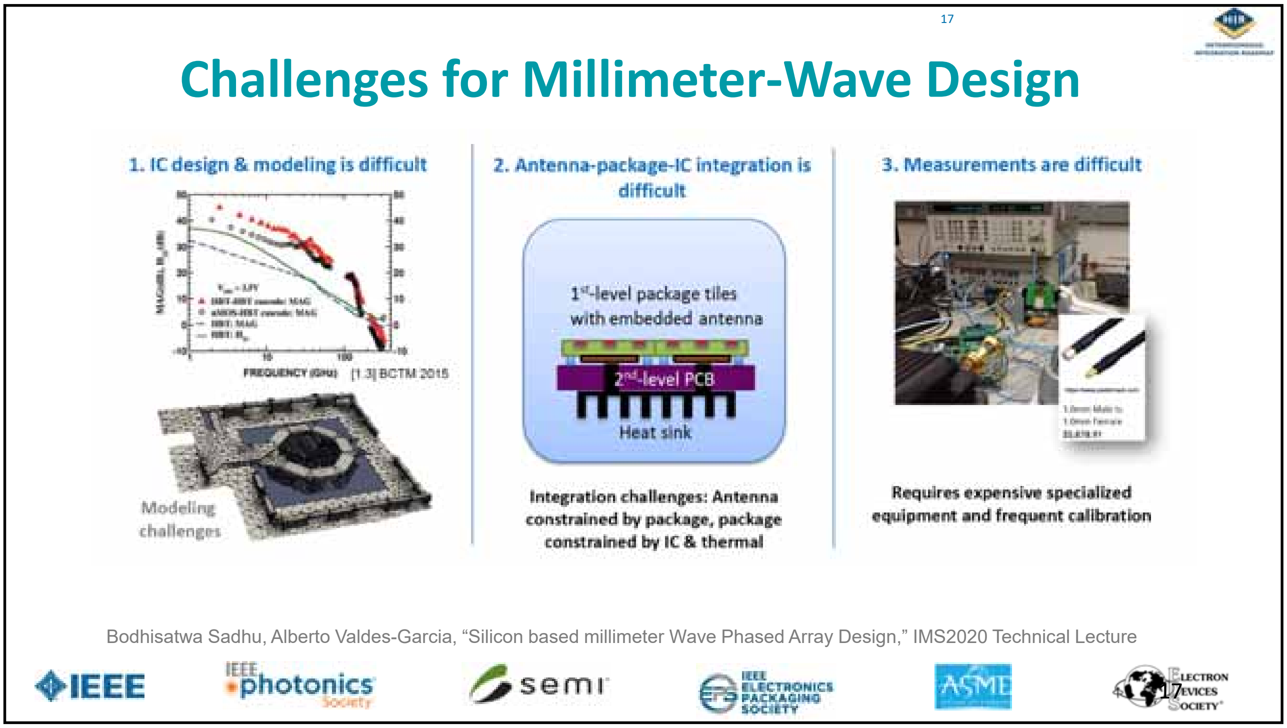


Electrical
- Impedance matching at each port
- Radiate EM energy efficiently
- Achieve low coupling between antenna elements
- Have equal signal delays between input ports and antenna feedlines
- Achieve near hemi-spherical radiation patterns, equal among radiation elements
- Feature sufficient layers for IC interconnects

Thermomechanical
- Provide mechanical support to the ICs
- Achieve low CTE mismatch with the ICs for mechanical stability over temperature
- Reliable mechanical connection to ICs and boards

Bodhisatwa Sadhu, Alberto Valdes-Garcia, "Silicon based millimeter Wave Phased Array Design," IMS2020 Technical Lecture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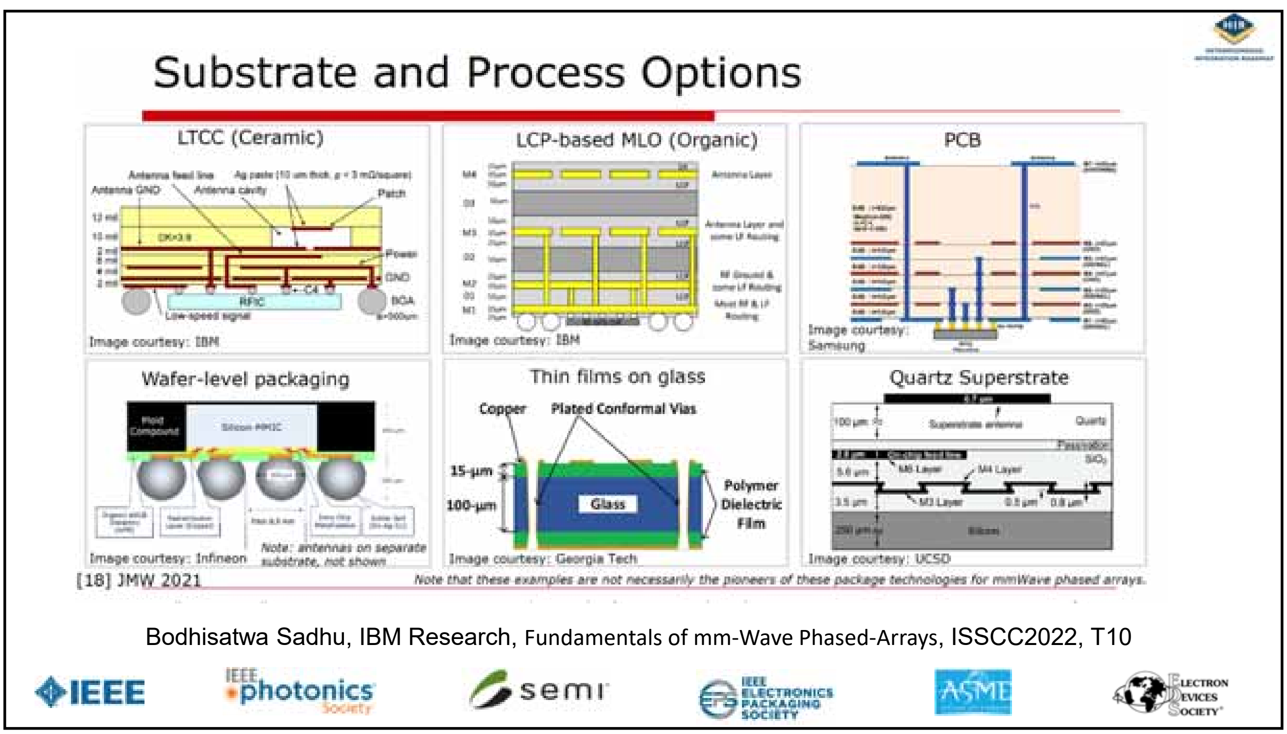
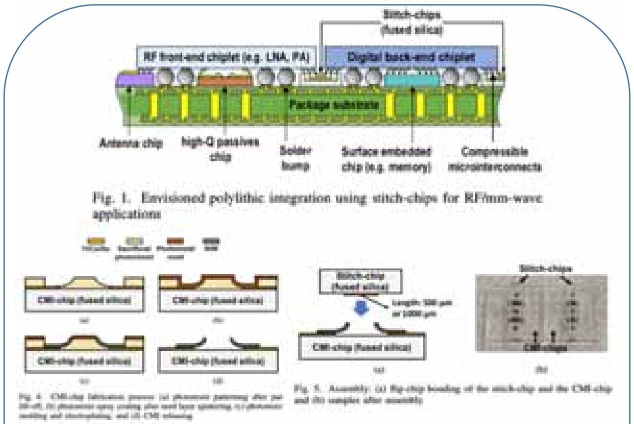
Challenges for Millimeter-Wave Design
1. IC design & modeling is difficult
FREQUENCY (GHz)
[1.3] BCTM 2015
Modeling challenges
2. Antenna-package-IC integration is difficult
1st-level package tiles with embedded antenna
2nd-level PCB
Heat sink
Integration challenges: Antenna constrained by package, package constrained by IC & thermal
3. Measurements are difficult
Requires expensive specialized equipment and frequent calibration
Bodhisatwa Sadhu, Alberto Valdes-Garcia, "Silicon based millimeter Wave Phased Array Design," IMS2020 Technical Lecture

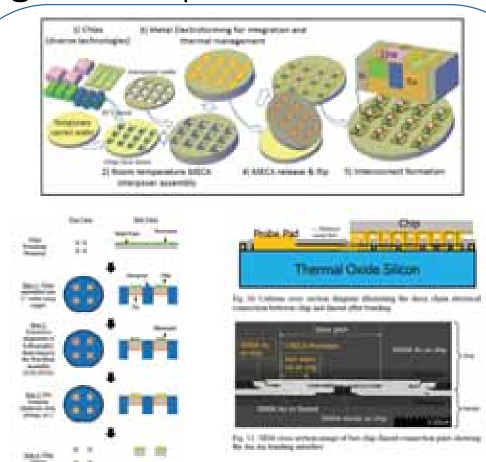

Substrate and Process Options
LTCC (Ceramic)
Image courtesy: IBM
LCP-based MLO (Organic)
Image courtesy: IBM
PCB
Image courtesy: Samsung
Wafer-level packaging
Image courtesy: Infineon
Note: antennas on separate substrate, not shown
Thin films on glass
Copper
Plated Conformal Vias
15-μm
100-μm
Glass
Polymer Dielectric Film
Image courtesy: Georgia Tech
Quartz Superstrate
Image courtesy: UCSD
[18] JMW 2021
Note that these examples are not necessarily the pioneers of these package technologies for mmWave phased arrays.
Bodhisatwa Sadhu, IBM Research, Fundamentals of mm-Wave Phased-Arrays, ISSCC2022, T10

Examples of Advanced Packaging Techniques for 5G



GaTech: 0.2dB Insertion Loss @ 28 GHz!

T. Zheng, "Polylithic Integration for RF/MM-Wave Chiplets using Stitch-Chips: Modeling, Fabrication, and Characterization," IMS2020, https://ieeexplore.ieee.org/document/9223887



HRL: Wafer-Level integration for III-V

S. Nadre, "10um Pitch Bumping of Singulated Die Using a Temporary Metal Embedded Chip Assembly Process," 2022 ECTC

IEEE photonics Society semi IEEE ELECTRONICS PACKAGING SOCIETY 19 ASME ELECTRON DEVICES SOCIETY

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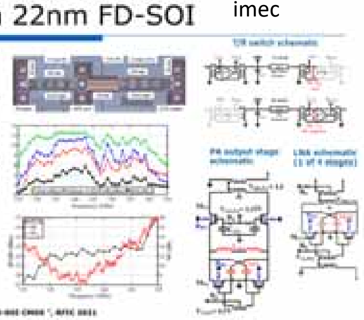
Highly Integrated D-Band Phased-Arrays for 6G wireless Communications

A 140 GHz FEM in 22nm FD-SOI imec

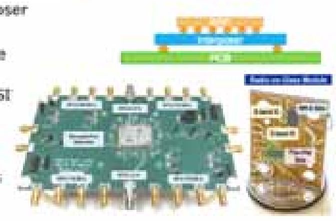
- Design
  - 4-stage PA, LNA
  - Asymmetric T/R Switch with T/L
  - ESD robustness
  - Stacked-FET PA
  - Gain boosting technique
  - Backgate terminated with 15KW R to enhance linearity and PAE
- Results (including switch loss)
  - Tx: 33.6 dB Gain, 12.5 dBm Psat, 10.8% PAE max
  - Rx: 20 dB Gain, 9.2 dB NF, 20mW



X. Tang, "A 140 GHz T/R Front-End Module in 22 nm FD-SOI CMOS, RFIC 2021,RFIC2021

Radio-On-Glass Technology Nokia

- Glass is used as an interposer
- Carrier DC, digital and RF
- integrated SIW waveguide
  - Low loss (0.04 dB/mm)
  - Conversion from GSG to SI
  - SIW to WR-6 conversion
- PCB carries baseband interface
- LO interface for both chips



Mohamed Elkhouly, Shahriar Shahramian, Nokia: ISSCC 2022, 6G Forum

What is the breakpoint for AiP versus AoC? And for 2.5D versus 3D?

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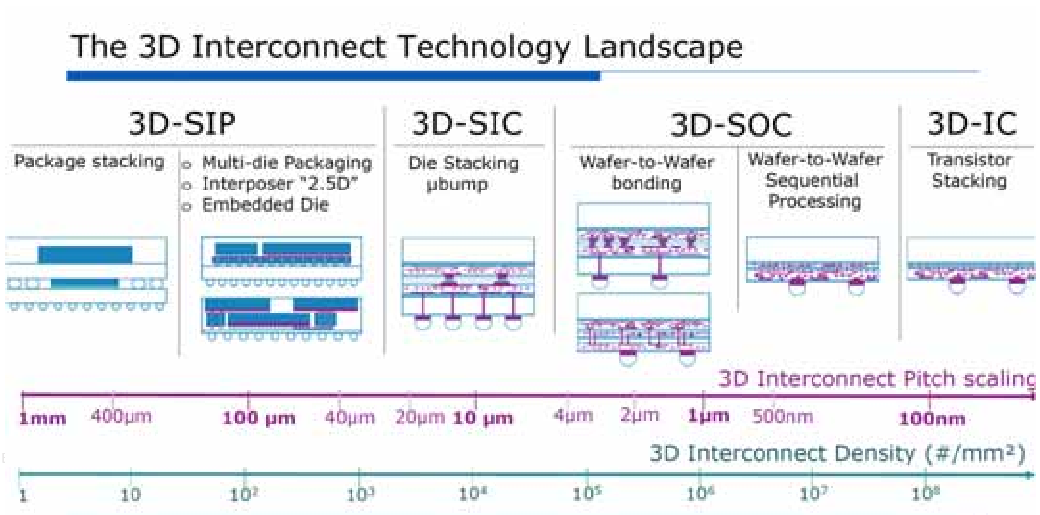

Nadine Collaert, imec, Emerging device and heterogenous integration technologies for sub-THz Applications, ISSCC 2022, 6G Forum.

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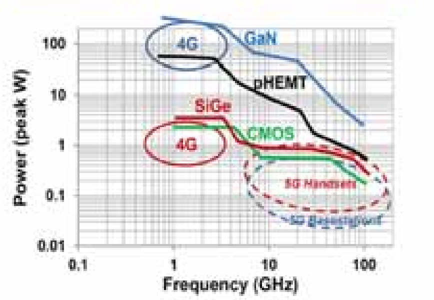
Technology/Capability Gaps and Showstoppers

Challenge 2: Selection of Semiconductor Technology Based on Output Level

5G Application Scenarios & Requirements 2018 (estimated)

	Handset	Access point	Base station	Backhaul	Last mile
EIRP (ave)	30 dBm	43dBm	60dBm	60dBm	75 dBm
Number antennas	4-6	32	256	256	256
Pave / PA	14dBm	11dBm	10dBm	10dBm	25dBm
Pmax/PA	23dBm	20dBm	19dBm	19dBm	33dBm
Efficiency (ave)	20%	20%	20%	20%	20%
DC power	0.6W	2W	12W	12W	390W

Estimated Power Ranges for 5G TX ICs & *Estimated* Max Power of Different Technologies



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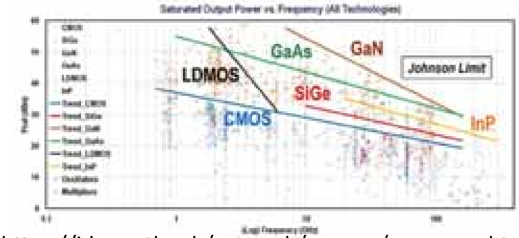
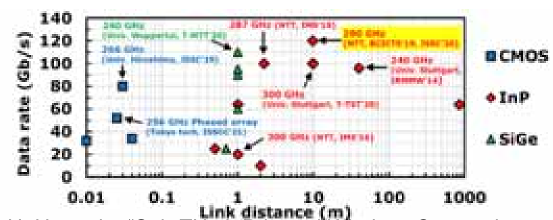
Necessary Semiconductor Technologies for 6G

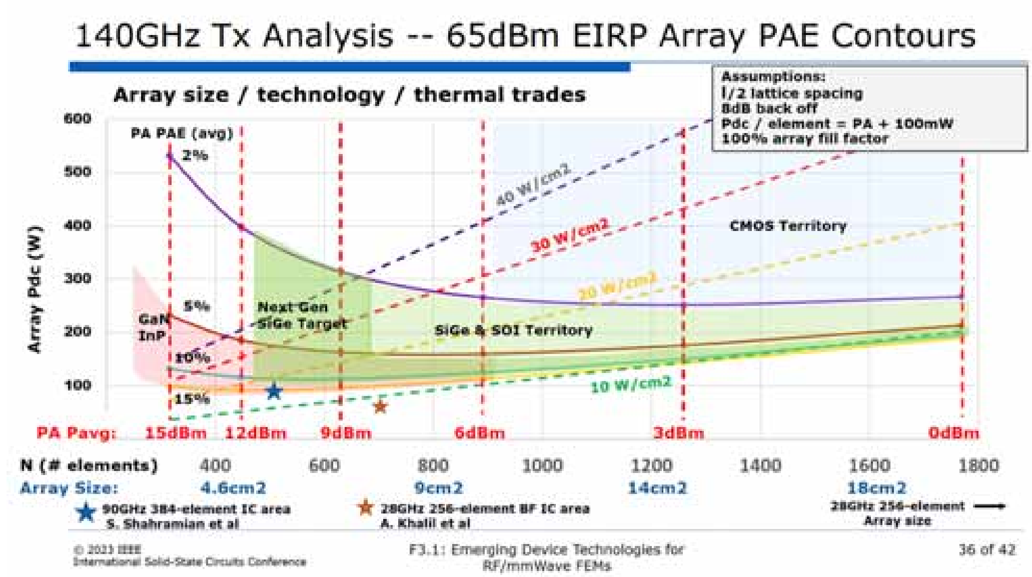
- Objective
  - Support high data rate Communications
  - Spatial multiplexing for high capacity
- Benefits (140 – 1000 GHz)
  - Large available spectrum
  - Shorter wavelength – more channels for same sized array
- Challenge
  - Atmospheric attenuation
  - PAA element spacing - –λ/2 @ 150 GHz is 1 mm
  - Challenging packaging technologies
- Technologies
  - III-V: **InP HBT**, InP HEMT, GaN HEMT, SiGe
  - Heterogeneous Integration
  - Small Form Factor
  - Antenna On Chip



https://ideas.ethz.ch/research/surveys/pa-survey.html



H. Hamada, "Sub-THz InP-based Wireless Connection Techniques toward 6G, " ISSCC 2022, 6G Forum



Nicholas Comfoltey, "Emerging Device Technologies for RF/mmWave FEMs," ISSCC2023 Forum

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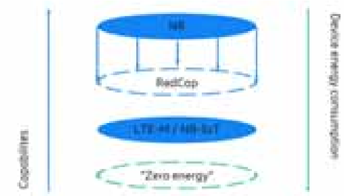
Technology/Capability Gaps and Showstoppers

Challenge 3: Lower Energy Consumption

Breaking the Energy Curve

Rollout Green 5G

6G: Zero-Energy Devices



- **Ericsson and MIT collaborating on the design of SOTA hardware that could power future 5G / 6G networks**
- **Neuromorphic computing, promising exponentially more energy efficient AI-algorithms**
- **"zero-energy" devices able to harvest energy directly from the received radio signal and use it to connect to the mobile network**

https://www.ericsson.com/495d5c/assets/local/about-ericsson/sustainability-and-corporate-responsibility/documents/2020/breaking-the-energy-curve-report.pdf

https://www.ericsson.com/en/blog/2021/9/zero-energy-devices-opportunity-6g

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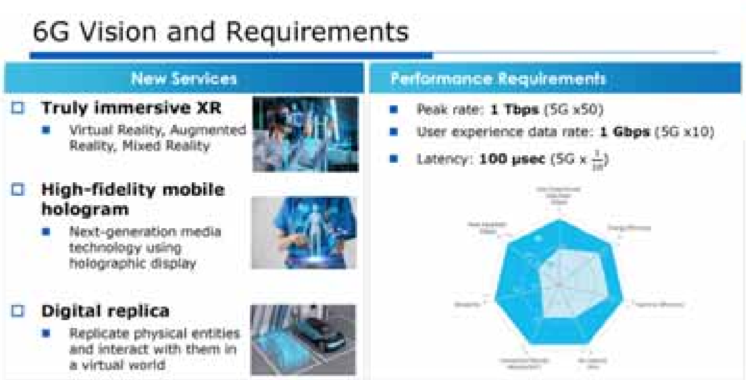
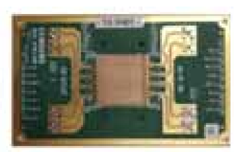
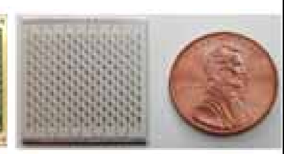
Next Stop For R&D: 6G



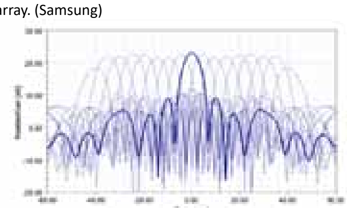
Gary Xu: THz for 6G Communications: Vision and Challenges, ISSCC2022 6G Forum



144 GHz TX beamformer module with eight dual-channel 45nm RFICs wire bounded to the antenna array. (Samsung)



Antenna array with 16 RF channels at 144 GHz carrier frequency.



Antenna pattern shows 21 dB of realized gain and +/-40 degree steerability.

Shadi Abu-Surra et al, "End-to-end 140 GHz Wireless Link Demonstration with Fully-Digital Beamformed System, " 2021 IEEE ICC Workshop" Samsung . UCSB

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Promise of 5G

https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/Qualcomm-Whitepaper-Vision-market-drivers-and-research-directions-on-the-path-to-6G.pdf

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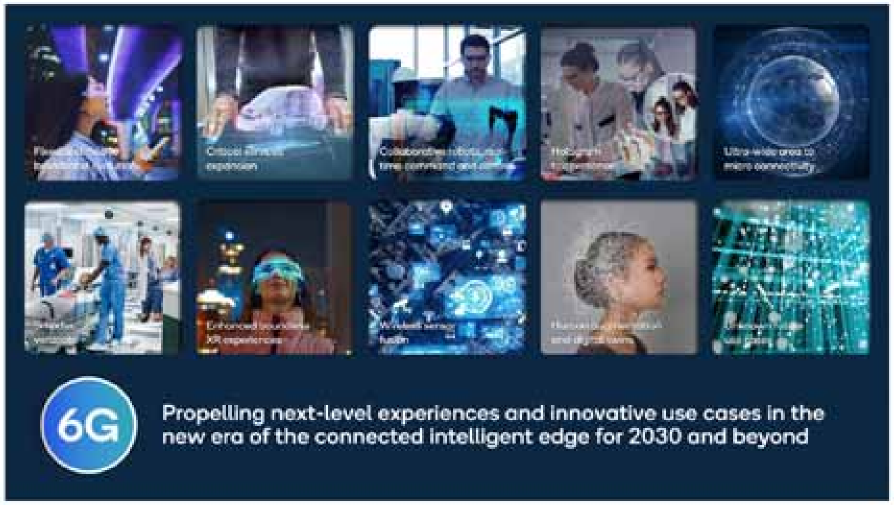
6G will bring new and enhanced user experiences across the connected intelligent edge



https://www.qualcomm.com/content/dam/qcomm-martech/dm-assets/documents/Qualcomm-Whitepaper-Vision-market-drivers-and-research-directions-on-the-path-to-6G.pdf

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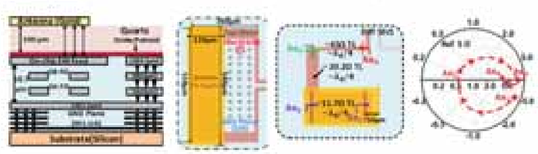
6G 140-GHz Phased Array

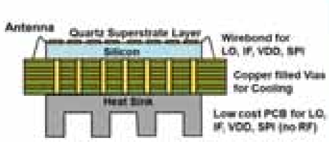
IMS Antenna on Quartz Superstrate



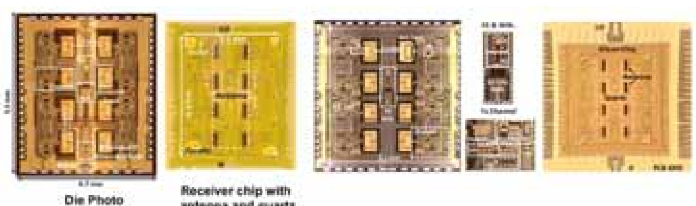
- Patch antenna arrays fabricated on the quartz superstrate
- EM wave coupled between the on-chip feed and the antenna
- Antenna feed matching network based on microstrip TL

IMS Build Phased-Array Systems at 140 GHz

Method : Wafer-Scale with Quartz Superstrate (Used above 60GHz)

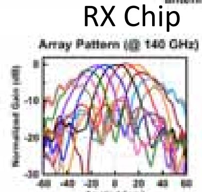


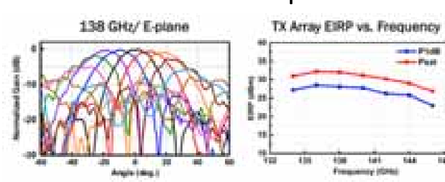
Pros	Cons
Low-cost carrier PCB	More chip-level design effort
Only IF and LO distribution, SPI, VDD on PCB	Antennas may not be wideband
Can be used at high frequency	Possible air gap between Quartz and silicon



RX Chip

TX Chip





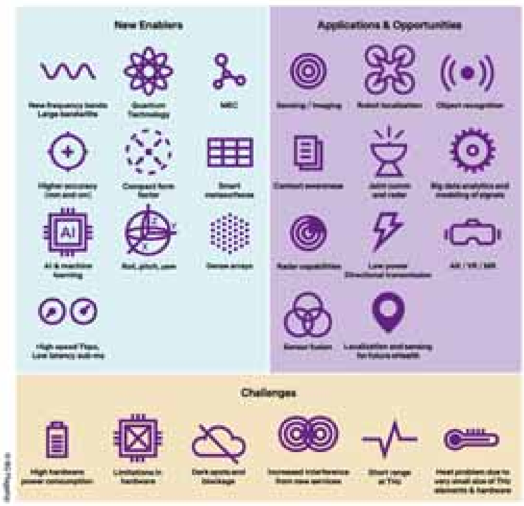
RX Meas

TX Meas

Li & Rebiez, "A 140GHz CMOS RFSOI Transmit-Receive Phased-Array Wireless Link with 11–12Gbps and 16 and 64-QAM Operation," IMS2022

Enabling technologies, 6G new application opportunities and technological challenges

- RF spectrum for future localization and sensing systems
  - Leap in available bandwidths and carrier frequencies
- The transition to THz frequencies has several important benefits.
  - Signals at these frequencies are unable to penetrate objects, leading to a more direct relation between the propagation paths and the propagation environment.
  - At higher frequencies, larger absolute bandwidths are available, leading to more resolvable multi-path in the delay domain with more specular components.
  - Shorter wavelengths imply smaller antennas, so that small devices can be packed with tens or hundreds of antennas, which will be beneficial for angle estimation.
  - The high-rate communication links offered by 6G will be able to be leveraged to quickly and reliably share map and location information between different sensing devices.
- **6G is not not just new frequency bands – it will be AI-enabled for sensing, communications and imaging**



http://jultika.oulu.fi/files/isbn9789526226743.pdf

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Summary

- **We are at a unique point in time when there is a global recognition on the critical roles of semiconductor and microelectronics as foundational pillars to nations economies.**
- **There is immense need for a Heterogeneous Integration technology roadmap addressing future vision, difficult challenges, and potential solutions to pave the way for Microelectronics Resurgence**
- **Our Greatest Challenge are ourselves : will we take full advantage of unique opportunities today collaboratively advancing the the science & technology for the benefit of humankind.**
- **Heterogeneous integration (e.g SiP & Chiplets & more) is a broad & deep base for Science & Technology Renaissance & Microelectronics Resurgence**

Thank You!

https://eps.ieee.org/technology/heterogeneous-integration-roadmap.html

Backups

Decadal Plan for Semiconductors

- The Challenge: Innovation in semiconductor technology is needed to advance information and communication technologies (ICT) critical to our economic growth and national security
- The Decadal Plan provides an overview of the global drivers and constraints for the future ICT industry, focusing on creative solutions and measured impact. The Decadal Plan has three key objectives:
  - Identify significant trends, applications, and challenges in semiconductors that are driving ICT.
  - Quantitatively assess the potential impact of the five seismic shifts on ICT.
  - Identify fundamental goals to alter the current trajectory of semiconductor technology to better address coming challenges

https://www.src.org/about/decadal-plan/

Five Seismic Shifts That Will Define The Future of Semiconductors and ICT

1. Fundamental breakthroughs in analog hardware are required to generate smarter world-machine interfaces that can sense, perceive, and reason. Annual investment need: $600M throughout this decade to pursue analog-to-information compression/reduction with a practical compression/reduction ratio of 10[illegible]:1 for practical use of information more analogous to the human brain.

2. The growth of memory demands will outstrip global silicon supply, presenting opportunities for radically new memory and storage solutions. Annual investment need: $750M throughout this decade to develop emerging memories/memory fabrics with >10-100X density and energy efficiency improvement for each level of the memory hierarchy. Discover new storage systems and storage technologies with >100x storage density capability.

3. Always-available communication requires new research directions that address the imbalance of communication capacity vs. data-generation rates. Annual investment need: $700M throughout this decade for communication enabling data movement of 100-1000 zettabyte/year at the peak rate of 1Tbps@ <0.1nJ/bit. Develop intelligent and agile networks that effectively utilize bandwidth to maximize network capacity.

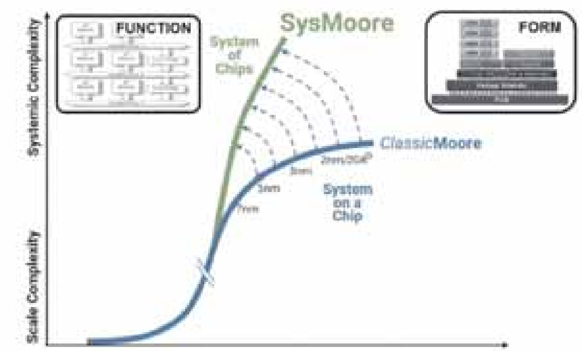
4. Breakthroughs in hardware research are needed to address emerging security challenges in highly interconnected systems and AI. Annual investment need: $600M throughout this decade for privacy and security hardware advances that keep pace with new technology threats and use cases (e.g., trustworthy AI systems, secure hardware platforms, and emerging postquantum and distributed cryptographic algorithms).

5. Ever-rising energy demand for computing vs. global energy production is creating new risk, and new computing paradigms offer opportunities to dramatically improve energy efficiency. Annual investment need: $750M throughout this decade to discover computing paradigms/architectures with a radically new computing trajectory demonstrating >1,000,000x improvement in energy efficiency.

https://www.src.org/about/decadal-plan/

Paradigm Shift: SysMoore Era
System on Chip -> System of Chiplets

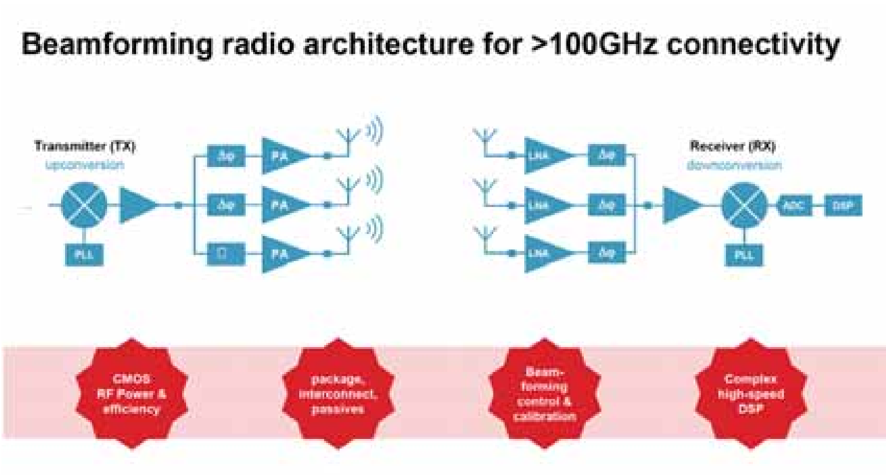
- SysMoore Era – the confluence of Moore's Law ambitions in transistor design and now packaging coupled to systemic complexity that together will bring about a 1,000X increase in compute across devices and systems of all kinds and lead to a "smart everything" world. (Aart de Geus, CEO of Synopsys)
- The complexity that comprises a modern chip complex, full of chiplets and packaging, is mind-numbing and the pressure to create the most efficient implementation, across its many possible variations, is what is driving the next level of AI-assisted automation.
- The synthesis of logic and the placing and routing of that logic and its memories and interconnects, is done by tools such as those supplied by Synopsys, to what we would call **AIDA**, short for Artificial Intelligence Design Automation,



https://www.synopsys.com/glossary/what-is-sysmoore.html

https://www.nextplatform.com/2022/02/25/sysmoore-the-next-10-years-the-next-1000x-in-performance/

EU: Data and telecom in the beyond-5G era



Jo De Boeck, imec, KU Leuven, "EU Chips Act drives pan-European full-stack innovation partnerships," ISSCC 2023 Plenary

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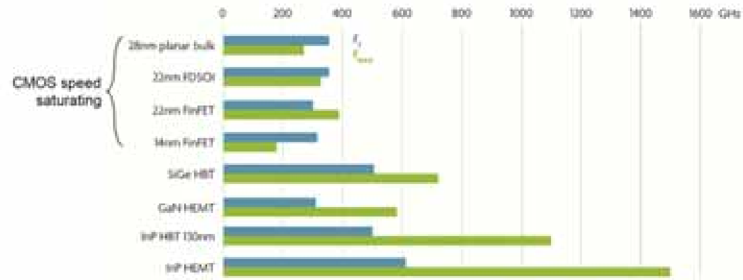
EU: Data and telecom in the beyond-5G era

More transmit power at mm-Wave: SiGe and III-V

1. Power: GaN is the champion below 100 GHz, above 100 GHz InP is superior
2. Speed: CMOS saturating, growth still possible with InP, GaN and SiGe



Jo De Boeck, imec, KU Leuven, “EU Chips Act drives pan-European full-stack innovation partnerships,” ISSCC 2023 Plenary

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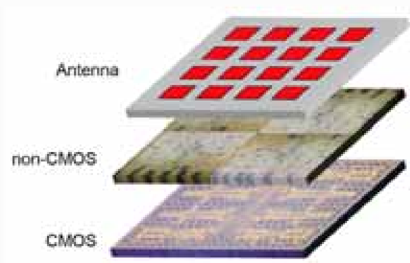
EU: Data and telecom in the beyond-5G era

Entire communication transceiver: complex blend of materials
Heterogeneous integration is key

System-Technology Co-Optimization will drive technology/material choices

- Architecture partitioning
- Challenge for EDA tools: electrical, electromagnetic, thermal and mechanical simulations needed



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