Packaging and integration of antennas and chips at mm-Wave and beyond

CWTE RESEARCH RETREAT 2023, EINDHOVEN, NETHERLANDS, 25TH OCTOBER 2023

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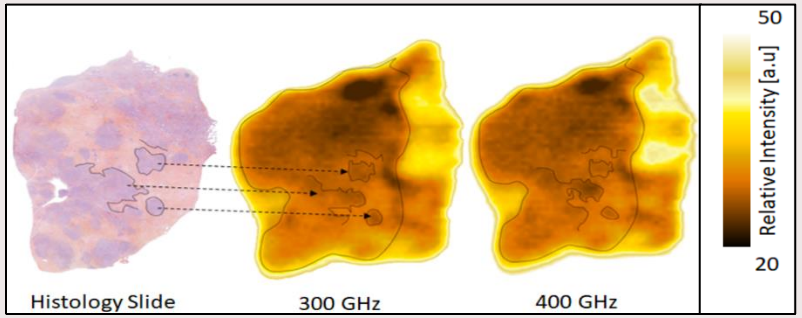

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Imaging

Communication

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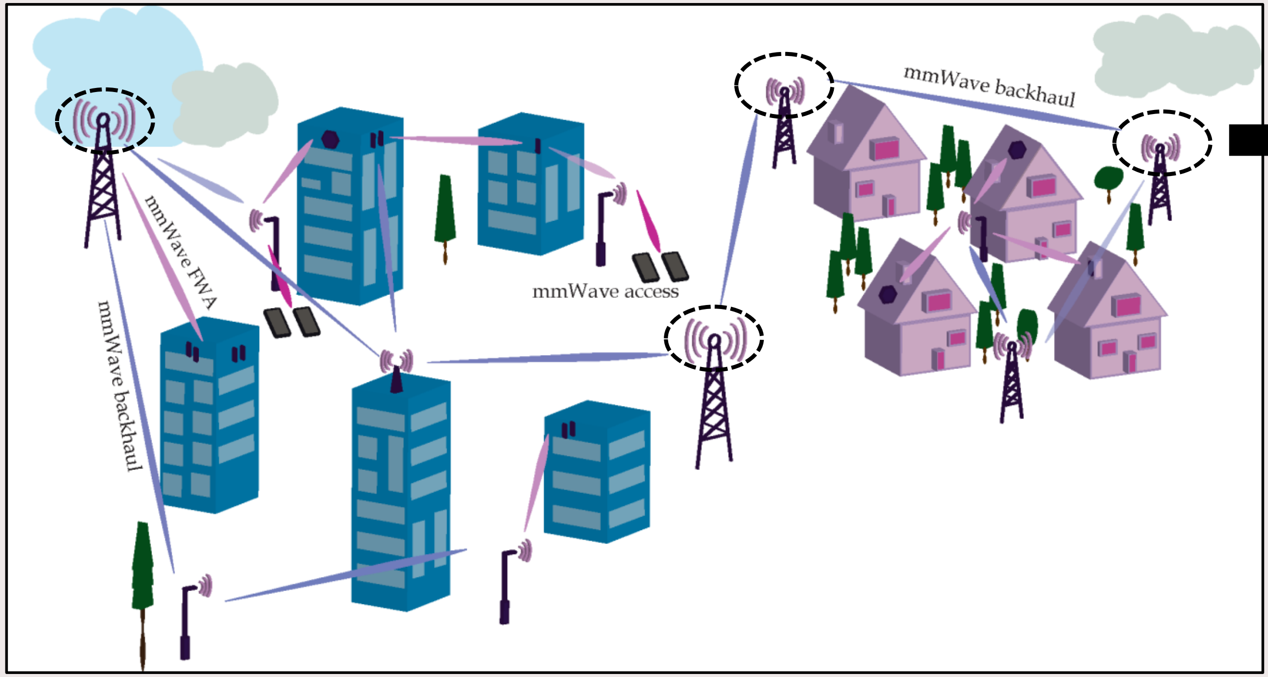
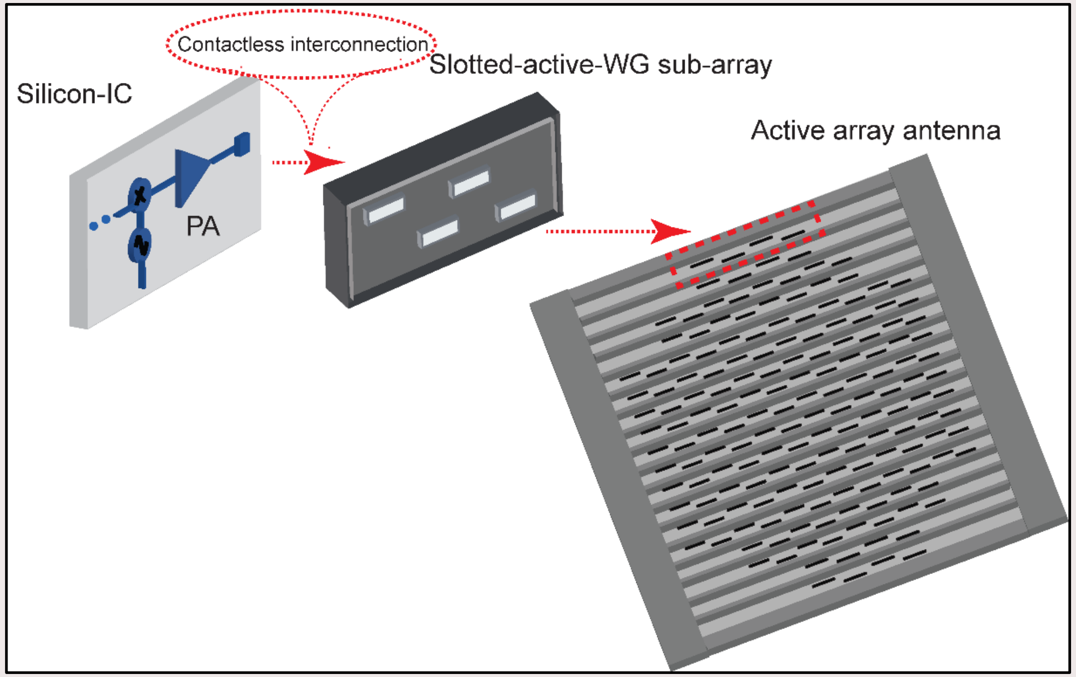
Introduction

- A mm-Wave/THz integrated system: for instance, wireless backhaul links





Introduction

- A mm-Wave/THz integrated system: for instance, imaging/spectroscopy camera

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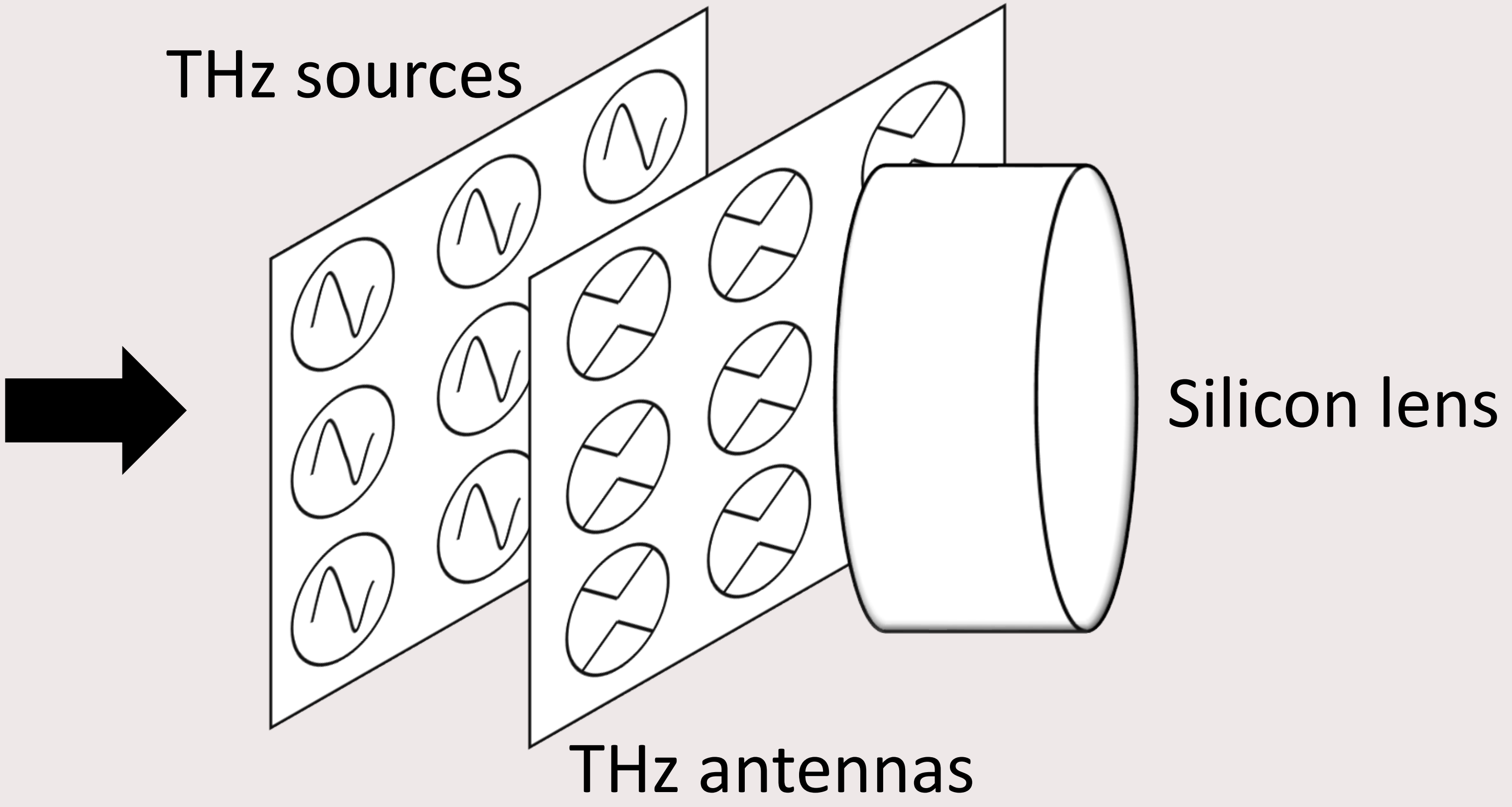

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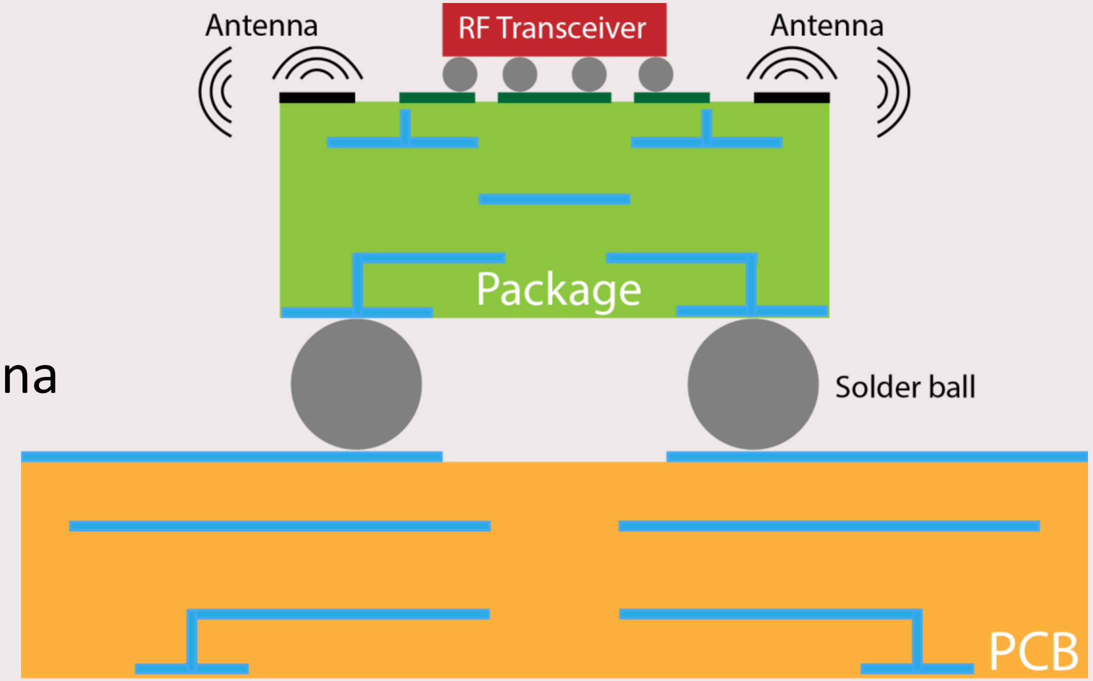
Packaging and integration methodologies trends

- Antenna-in-package (AiP)
  - Solution to implement antennas in a package that includes a RF transceiver chip
  - AiP can be further integrated with front-end, baseband, and power management modules
    → System-in-package (SiP)



- Advantages
  - Short interconnect between RF chip and antenna
  - Small form factor

Packaging and integration methodologies trends

- Antenna-in-package (AiP) design considerations
  - Antennas → popular types: patch, yagi-uda, and grid

Antennas	Advantages	Limitations	Use-cases
Patch	Compact, light-weight, multi-band, polarization diversity, ESD	Narrow impedance bandwidth, low-power handling, warpage	Base station, mobile, Radar, AR/VR, imaging
Yagi-Uda	Compact, light-weight, wide impedance bandwidth, good front-to-back ratio	Non polarization diverse, low-power handling, PCB location sensitive	Mobile
Grid	Compact, light-weight, high-gain, wide impedance bandwidth, low cross polarization	Narrow gain bandwidth, low-power handling, Pattern squint	Radar

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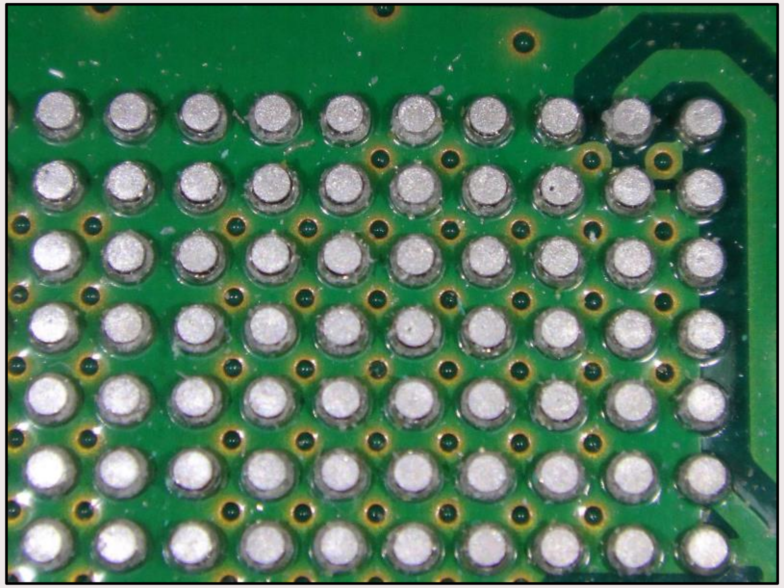
Packaging and integration methodologies trends

- Antenna-in-package (AiP) design considerations
  - Package → AiP acts as a package that connects to a PCB → ball-grid array (BGA) and quad flat no-lead (QFN) packages



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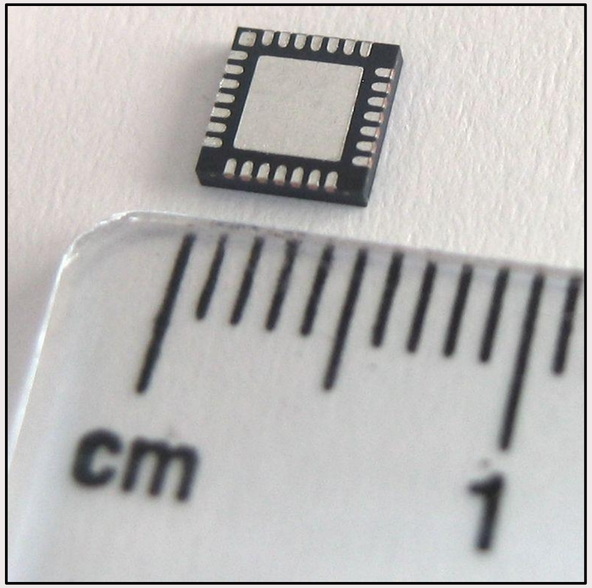
BGA



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QFN

Packaging and integration methodologies trends

- Antenna-in-package (AiP) design considerations
  - RF chip-Antenna interconnects → bond pads (GSG/GSGSG), traces (CPW/Microstrip), and vias
  - Bond pads implementation → wire-bonding or flip-chip
  - Antenna feed lines → multi-layer routing of transmission lines
  - Impact on performance → bond pad size, pitch, bump diameter, wire-bond length, etc.

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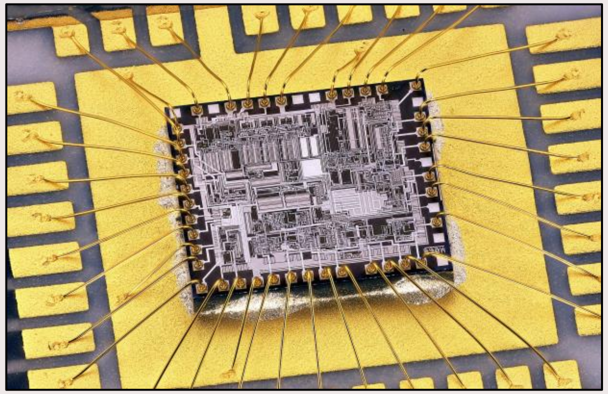
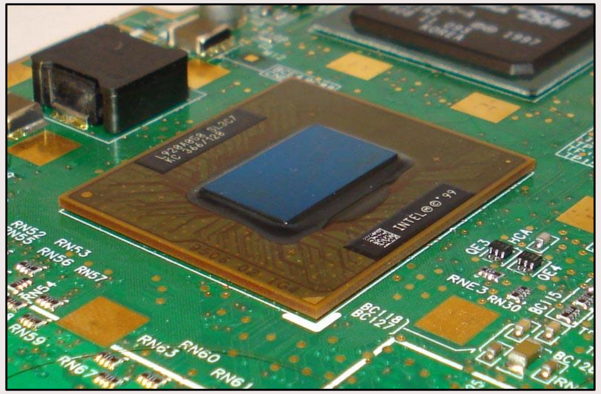


Wire-bonding



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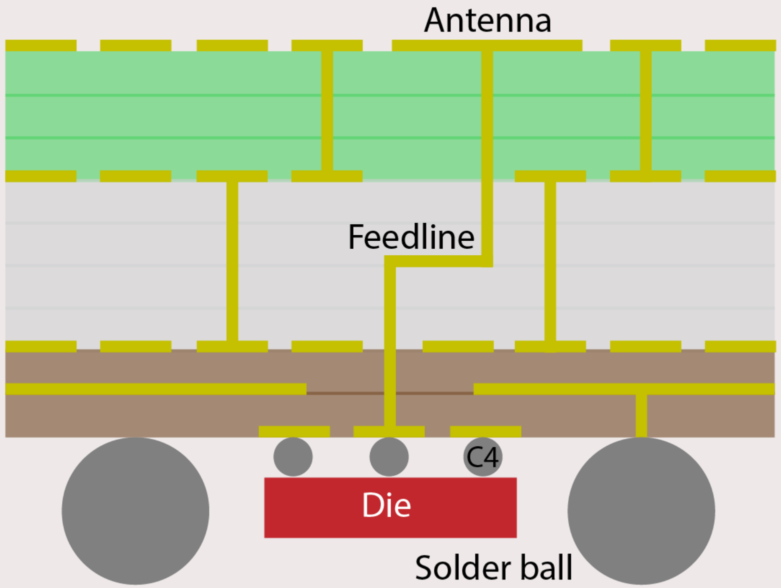
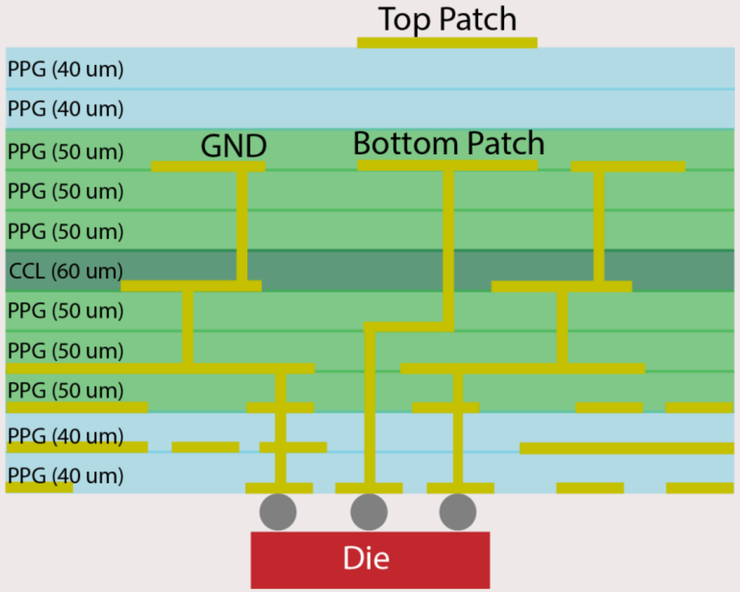
Flip-chip

Packaging and integration methodologies trends

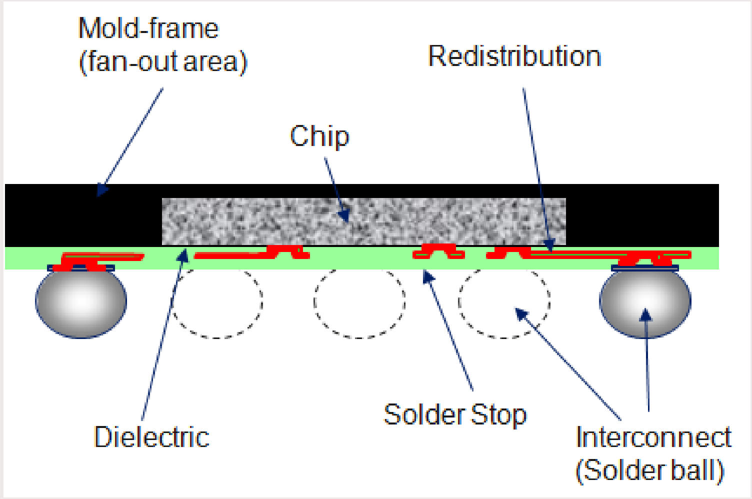
- Antenna-in-package (AiP) design considerations
  - AiP fabrication materials → LTCC, HDI (FR4, BT-resin, LCP), and eWLB



LTCC Stack



HDI (FR4) Stack



eWLB

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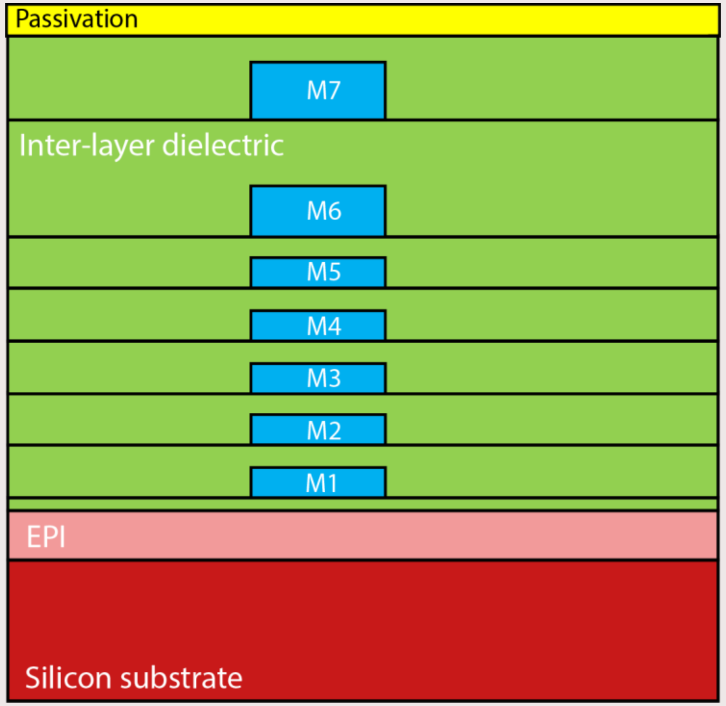
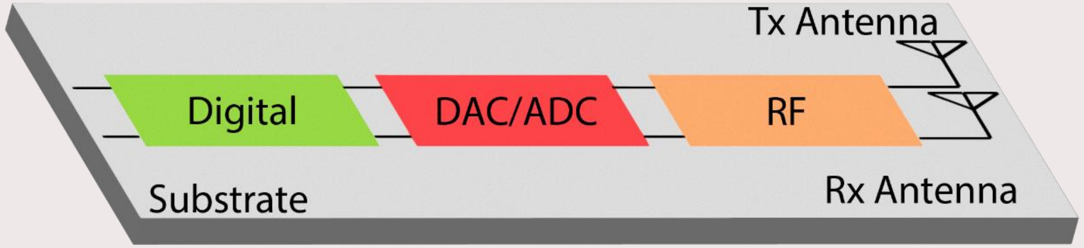
Packaging and integration methodologies trends

- On-chip antennas (AoC)
  - Solution to integrate wireless system modules on the same substrate (baseband to antennas)
  - Applications → wireless sensor systems, power generation and beam-steering, Radar sensors, imaging, IoT, etc.



- Advantages
  - Miniaturization
  - Cost-effective
  - High-level of integration



Packaging and integration methodologies trends

- On-chip antennas (AoC) applications

Applications	Advantages	Limitations
5G/6G Transceivers	Compact, low-cost, Massive MIMO, easy integration	Mutual coupling, multi-band operation, RF-EM interference
IoT	Low power, low cost, compact, IoT @ mm-Wave	Antenna size @ low frequency operation
Wireless sensor networks	Ultra-low power implementation, compact, low cost, low profile	Antenna size @ low frequency operation, efficient energy transfer, sensor range
Biomedical/Medical	Ultra-low power implementation, cost-effective, optimized EM energy harvesting	Miniaturization, robustness, performance degradation, multi-band, EMI
Wireless interconnects	Mitigate issues with wired interconnects; delay, loss, bandwidth, data rate	Mutual coupling, Antenna size @ low frequency operation
Automotive	Compact integration of multiple antennas within vehicles	Multi-band operation, mutual coupling, antenna size @ low frequency operation

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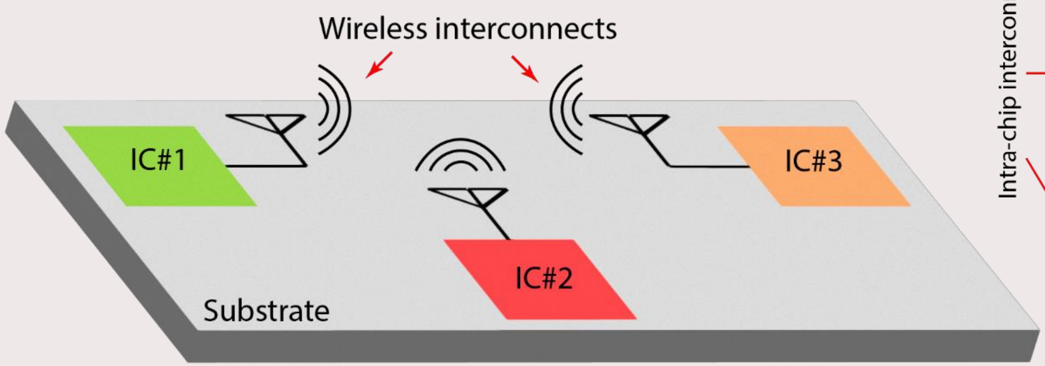
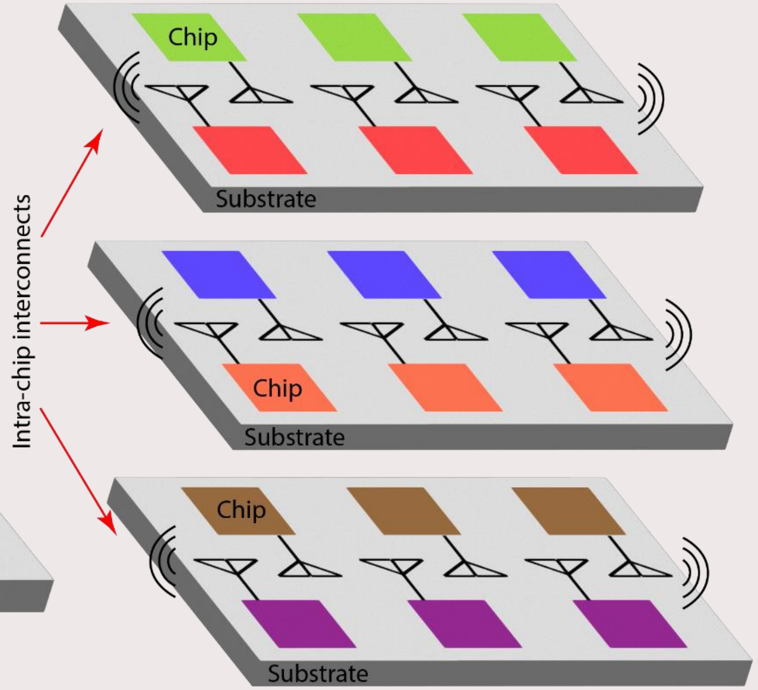
Packaging and integration methodologies trends

- On-chip antennas (AoC) design considerations
  - Antennas → popular types: dipole, bow-tie, slot, loop, monopole, patch, tuning fork, etc.
  - Antenna type considerations:
    - Gain
    - Bandwidth
    - Array implementation
    - Mutual coupling

Packaging and integration methodologies trends

- ❑ On-chip antennas (AoC) design considerations
  - ❑ Module to antenna interconnects → galvanic and non-galvanic
  - ❑ Interconnect considerations
    - ❑ Loss
    - ❑ Delay
    - ❑ Signal bandwidth
    - ❑ RF-EM isolation
    - ❑ Data-rate (chip-to-chip communication)

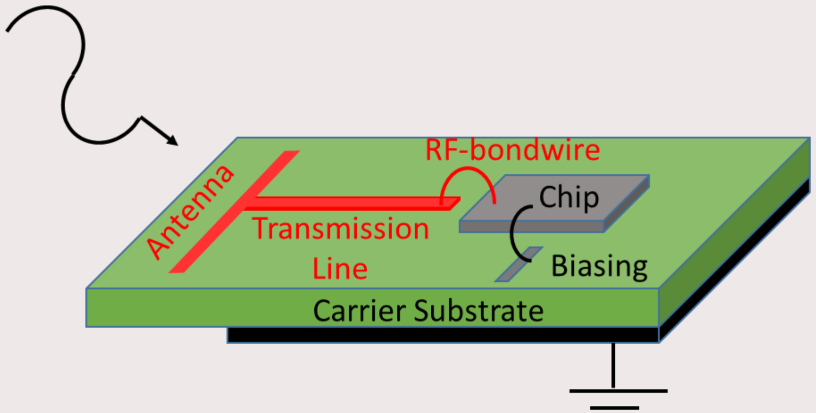




Packaging and integration methodologies trends

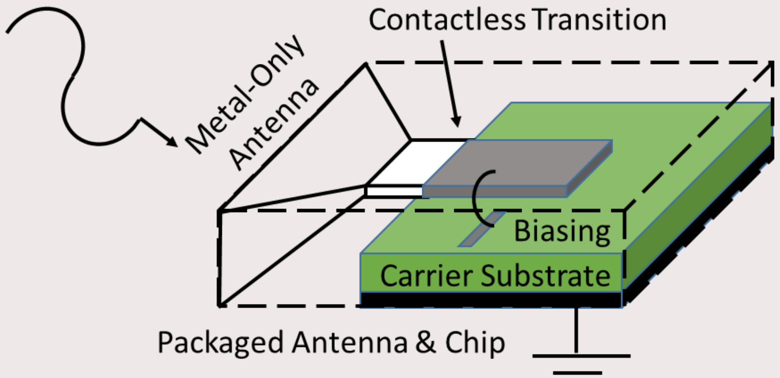
- Towards waveguide integration → mitigate limitations of substrate antennas

Currently examined integration concepts



- 🙁 Lossy antenna and transmission line
- 🙁 Performance degrading RF-bondwire
- 🙁 Packaging problems (resonances)
- 🙂 Small antenna size (substrate)

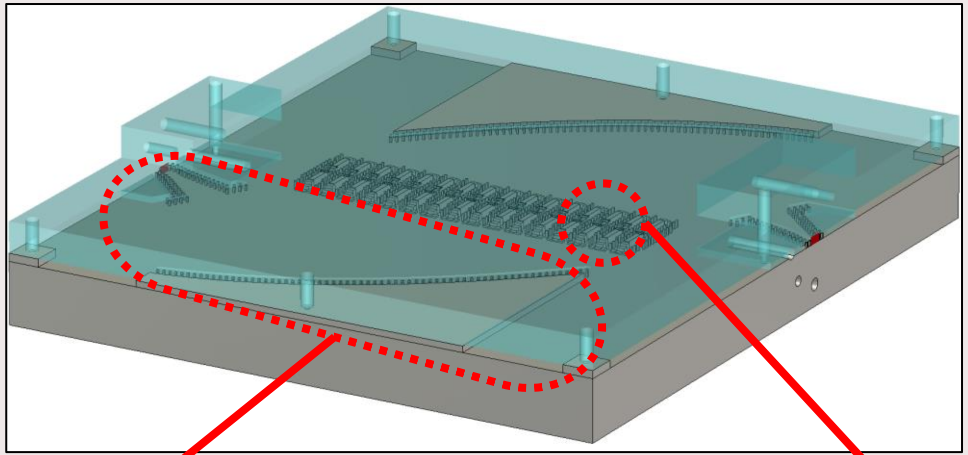
Proposed **ultra low-loss** packaging & integration concept



- 🙂 Low loss antenna and waveguide
- 🙂 Low loss **contactless** waveguide to waveguide-on-chip transition
- 🙂 Resonance-free antenna-chip packaging
- 🙁 Larger antenna size (no substrate)

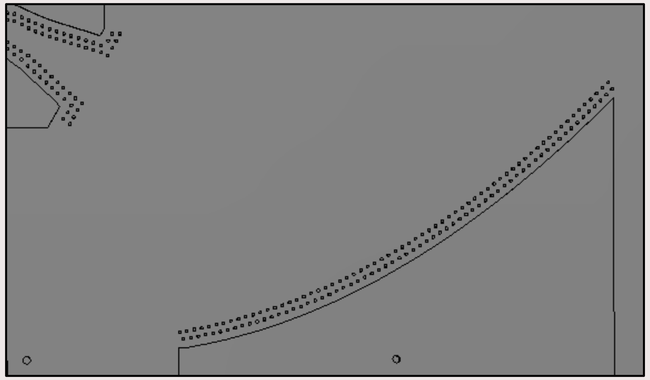
Packaging and integration methodologies trends

- Towards waveguide integration → contactless IC-WG integration; grid amplification

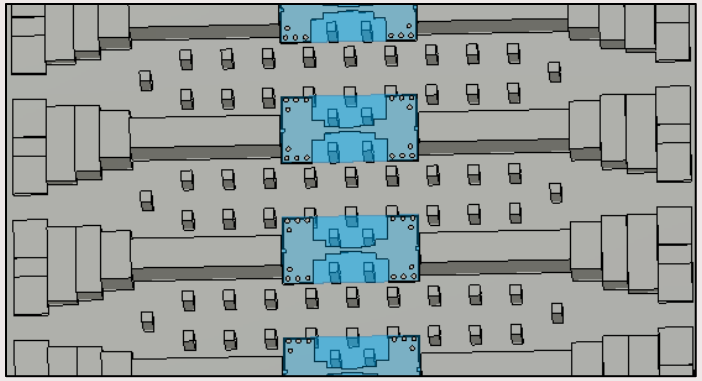


B2B single unit structure

Horn-Reflector transition



Chip-Waveguide transition



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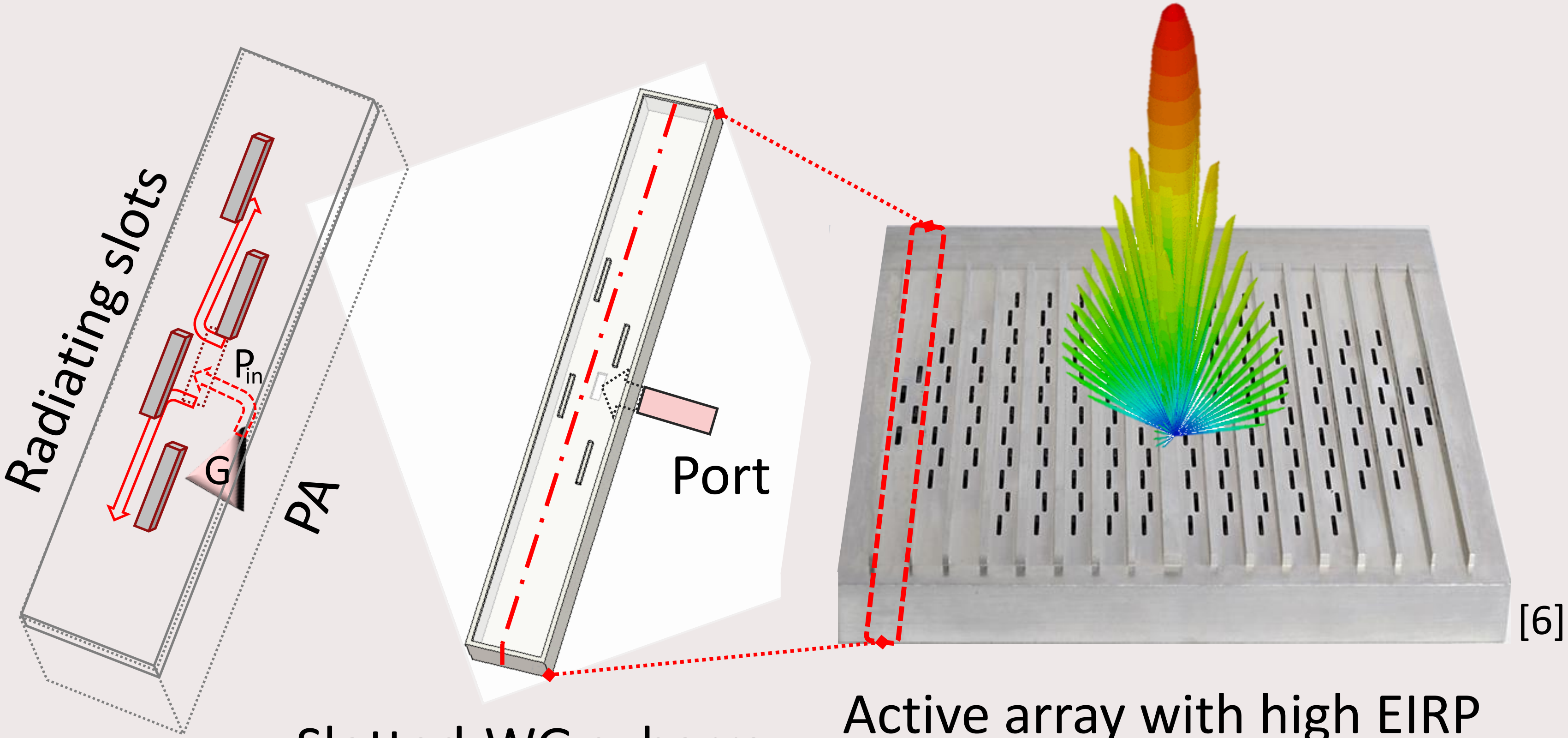
Packaging and integration methodologies trends

- waveguide integration → contactless IC-WG integration; slotted-waveguide antennas



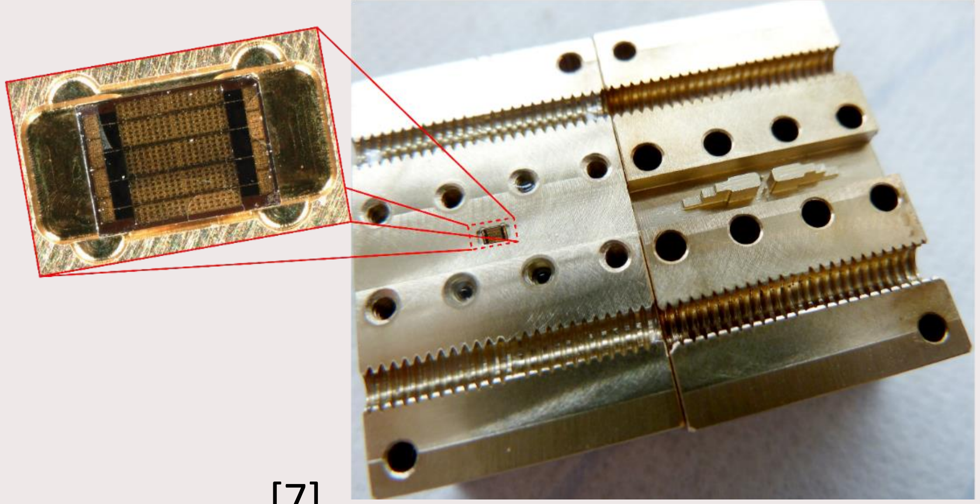
One column description

Slotted-WG subarray

Active array with high EIRP

Packaging and integration methodologies trends

- waveguide integration → contactless IC-WG integration; active waveguide unit



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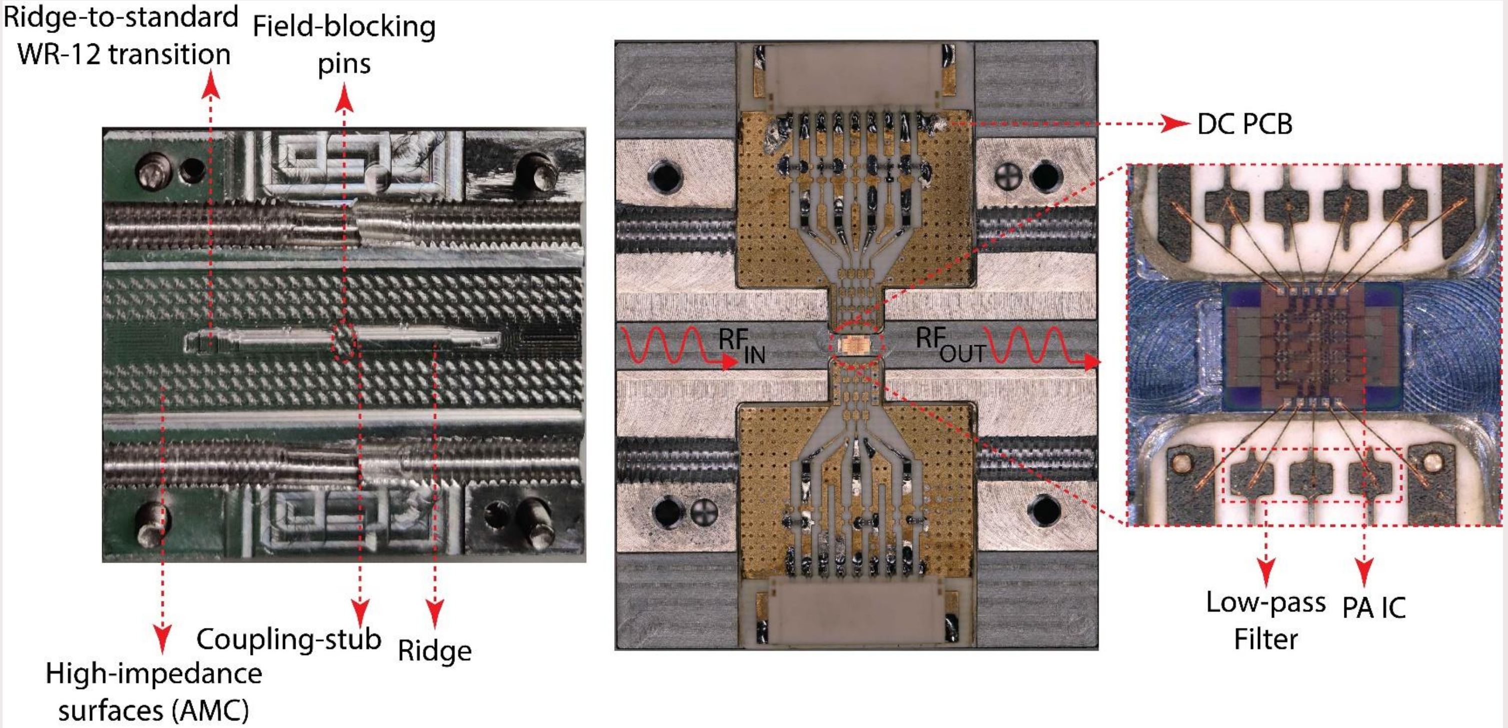

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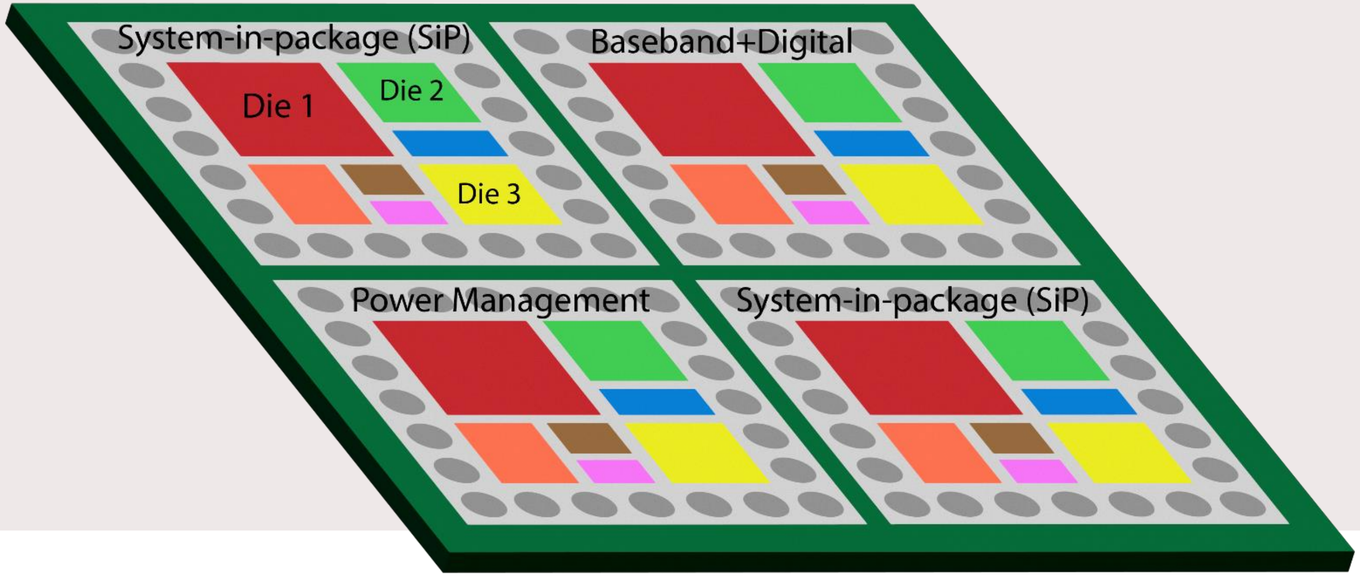
Packaging and integration methodologies trends

- Heterogeneous integration
  - Solution to package modules implemented in different technologies with separate functionalities
  - Costly technology downscaling → packaging is being recognized as a driver in performance growth
  - Products are being designed to break a larger design into smaller “chiplets”
  - Applications; electronics-photonics integration for communication, sensor systems, healthcare, etc.



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Conclusions

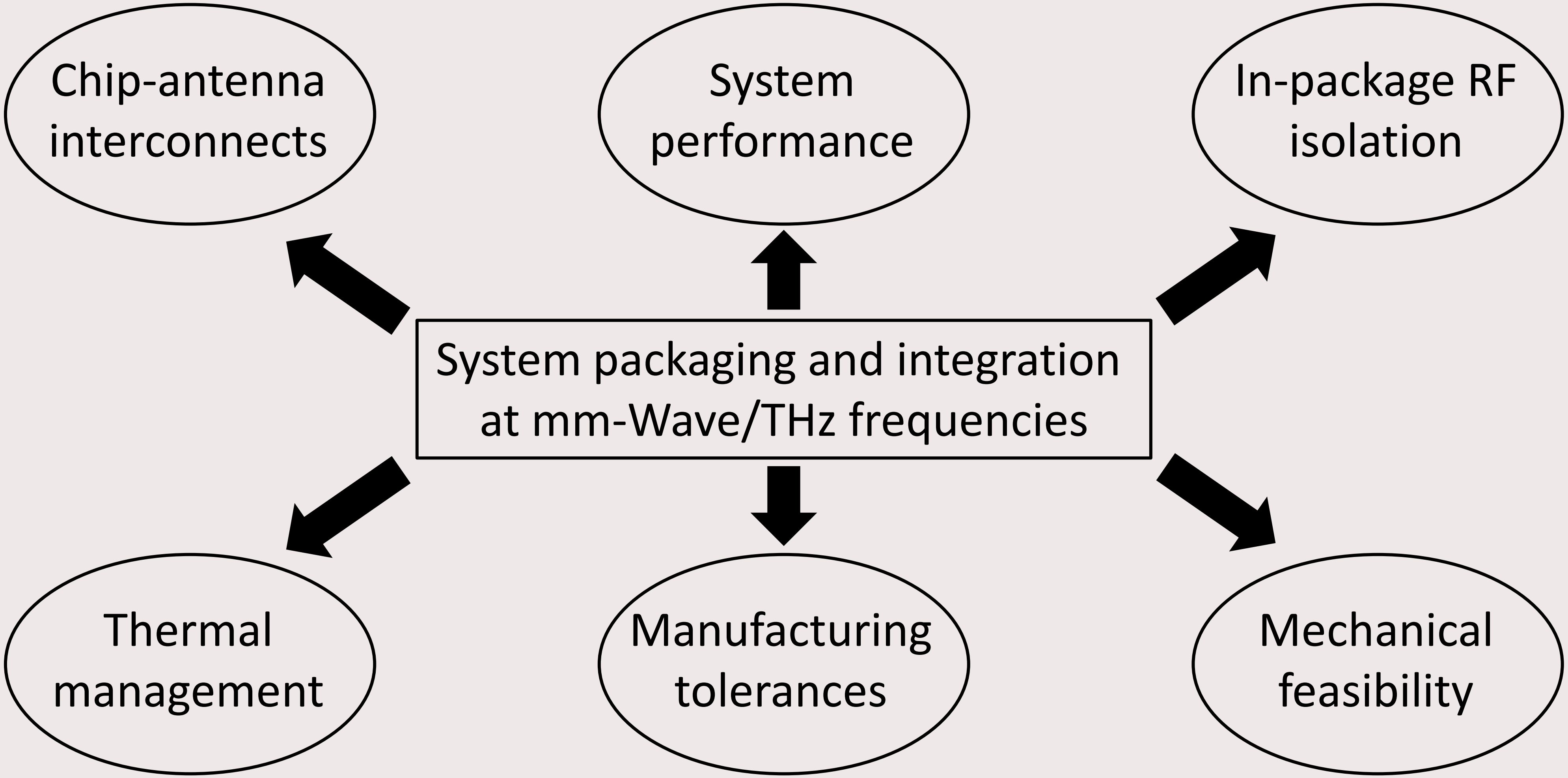
- Research and development @ mm-Wave/THz frequencies → packaging and integration is a driver for performance growth

- Type of packaging and integration methodology depends,
  - Application domain (communication, imaging, etc.)
  - Number of antennas (single, multiple, array, etc.)
  - Substrate (AiP or AoC) or metal-only antennas (waveguide integration)

- As mm-Wave/THz frequencies gain popularity → imperative that packaging and integration is considered during the design procedure

Conclusions

System packaging and integration considerations



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Thank you for your attention!

- Questions?