Packaging Trends for Millimeter-Wave Radar and Communication Systems

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IPCEI
on Microelectronics

MIKON-2020

MRW 2020
Microwave and Radar Week

infineon

Agenda

Agenda

Global Trends

	Every year the world population increases by about 80 million people
	Demand for electricity is projected to rise by 50% until 2030
	Mobile life will be major driver of growth for the next decade

Rapid changes require innovative solutions

Trends in Communication and Radar Systems

- High-speed wireless communication
- **Frequency spectrum up to 100 GHz** (6 GHz, 28 GHz, 38 GHz, 60 GHz, 73 GHz, …)

- Internet connectivity for everyday items
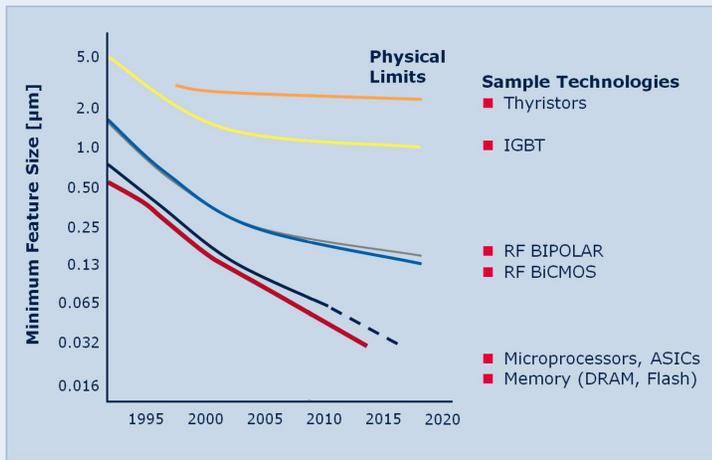- **High-speed wireless communication and environment sensing systems** (24 GHz, 61 GHz, 122 GHz, …)

- Making the car part of the internet
- High-speed wireline and wireless communication
- **Millimeter-wave radar for safety and sensing** (24 GHz, 77 GHz)

More Moore is Getting Out of Steam

Miniaturization
## More Moore reaches limits

By shrinking of ICs

- Better RF performance/higher speed
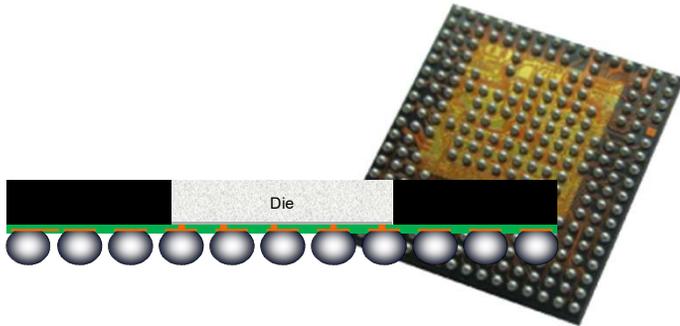- Lower energy consumption
- Smaller size
- Lower cost

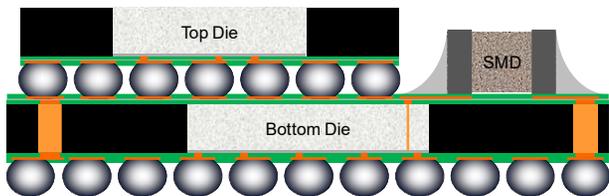## Functional diversification
More than Moore

- Trend toward functional diversification
- The assembly and packaging role is expanding to include system level integration functions
- System-in-Package (SiP) and heterogeneous integration
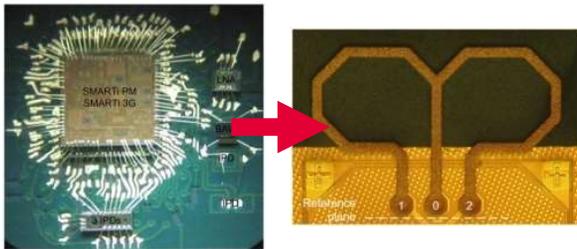

More Moore getting out of steam
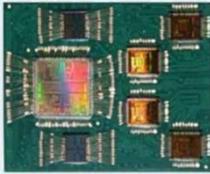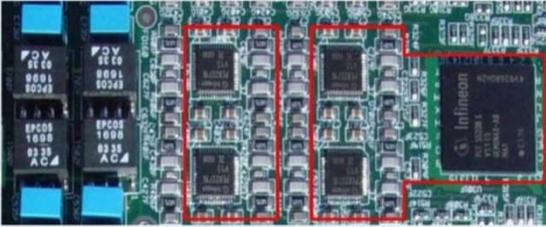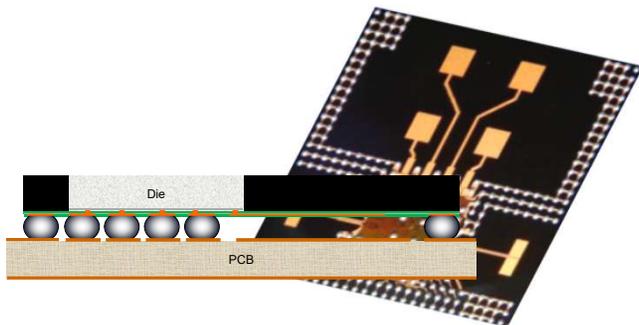
Developments for System-in-Package

- High I/O count
- Wafer level packaging (WLP)

- 3D integration
- Package-on-Package (TSV, TEV)

- Passive integration
- Coils, transformers, power dividers

- Antenna integration

Agenda

Challenges at Millimeter-Wave Frequencies

- Size of a package ~ λ
- Parasitic wave effects
  - □ Impedance mismatch and signal reflections
  - □ Crosstalk
  - □ EM radiation
- Increased impact of manufacturing tolerances
  - Large pitches
  - Coarse metal pattern resolution

| Frequency	λ ($\varepsilon_r = 3.0$)	λ/4 ($\varepsilon_r = 3.0$)
10 GHz	17.3 mm	4.3 mm
24 GHz	7.2 mm	1.8 mm
60 GHz	2.9 mm	0.72 mm
77 GHz	2.3 mm	0.56 mm
120 GHz	1.4 mm	0.36 mm

What is "high frequency"?

Wavelength ≈ geometrical dimension
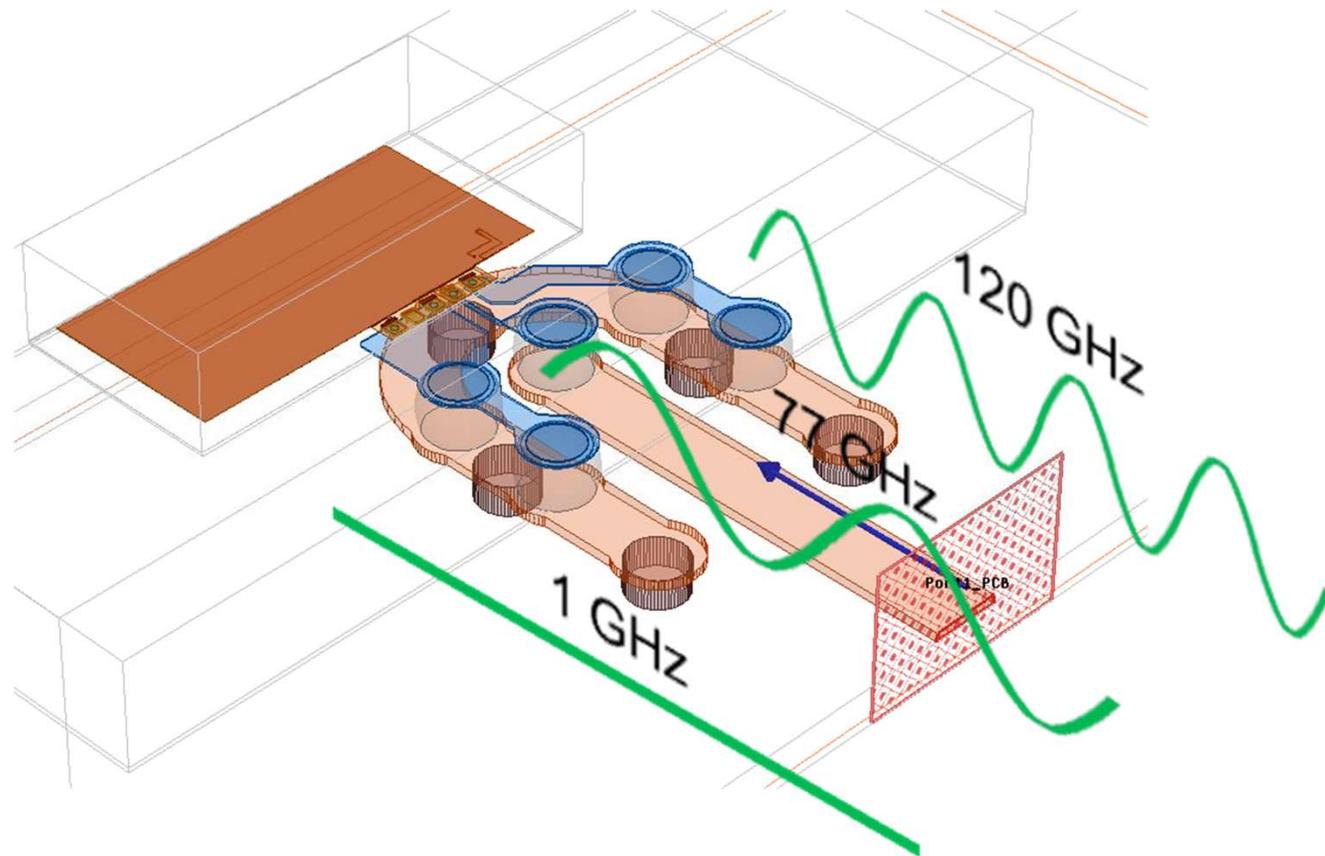
Chip-Package Interactions

- Strong chip-package EM interactions limit the use of standard modeling approaches based on the principle of partitioning and cascading

Circuit-based model   EM-based model

Impact of RDL-chip capacitance

Si chip

RDL

Port_1_PCB
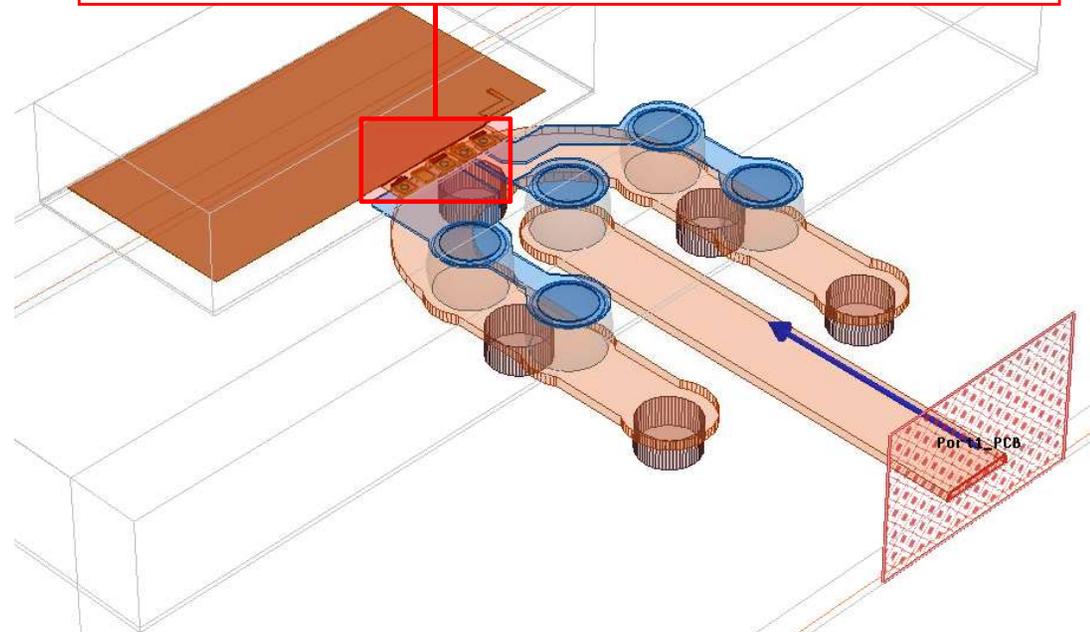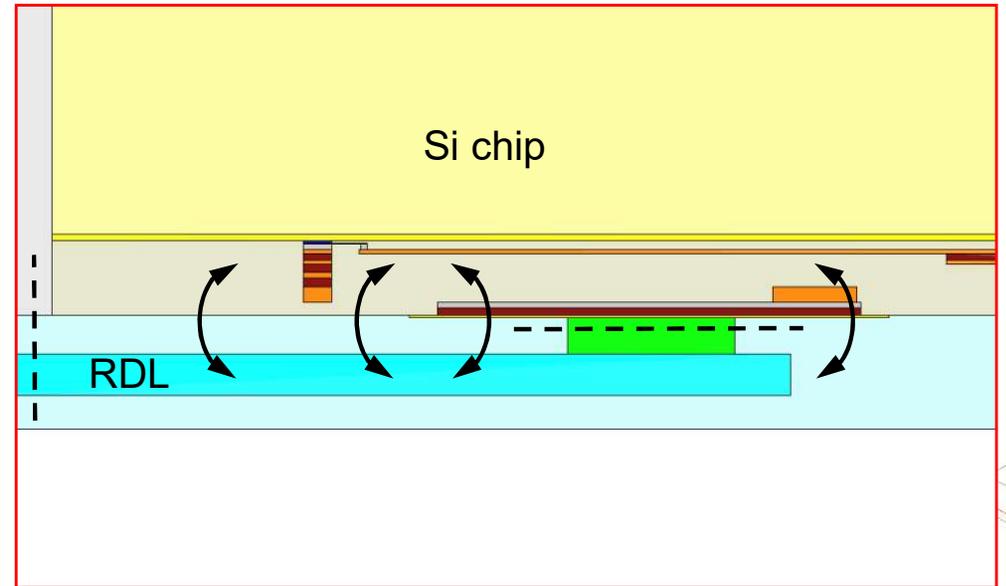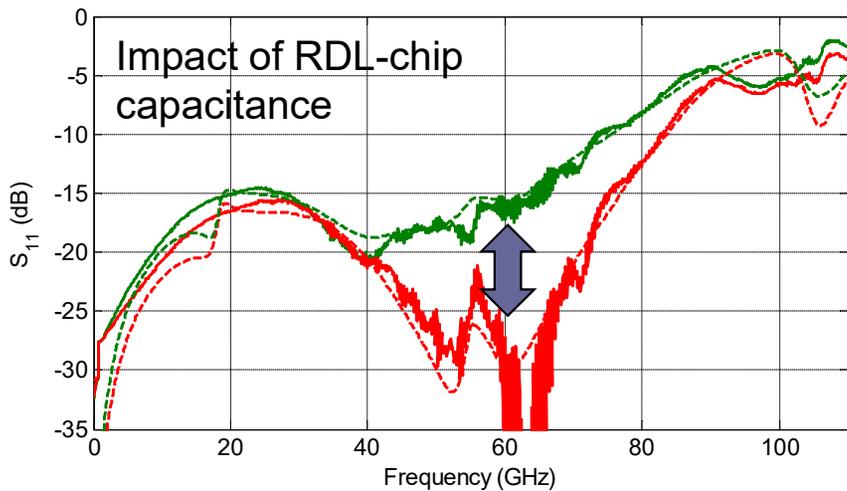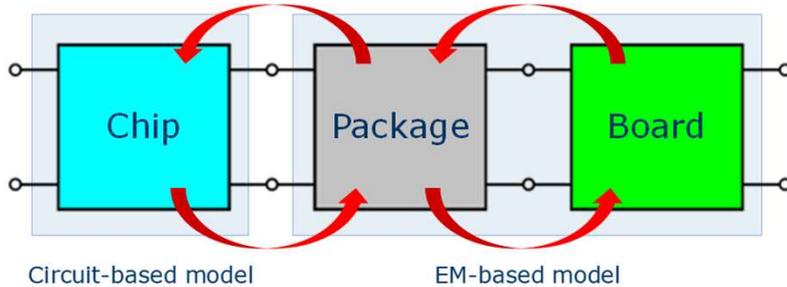
- New methodologies are needed for coherent chip-package-board co-design

Concurrent Editing

- Implementation of physical layout of both chip and package takes place in one design environment

- Successfully applied for development of Infineon mm-wave products
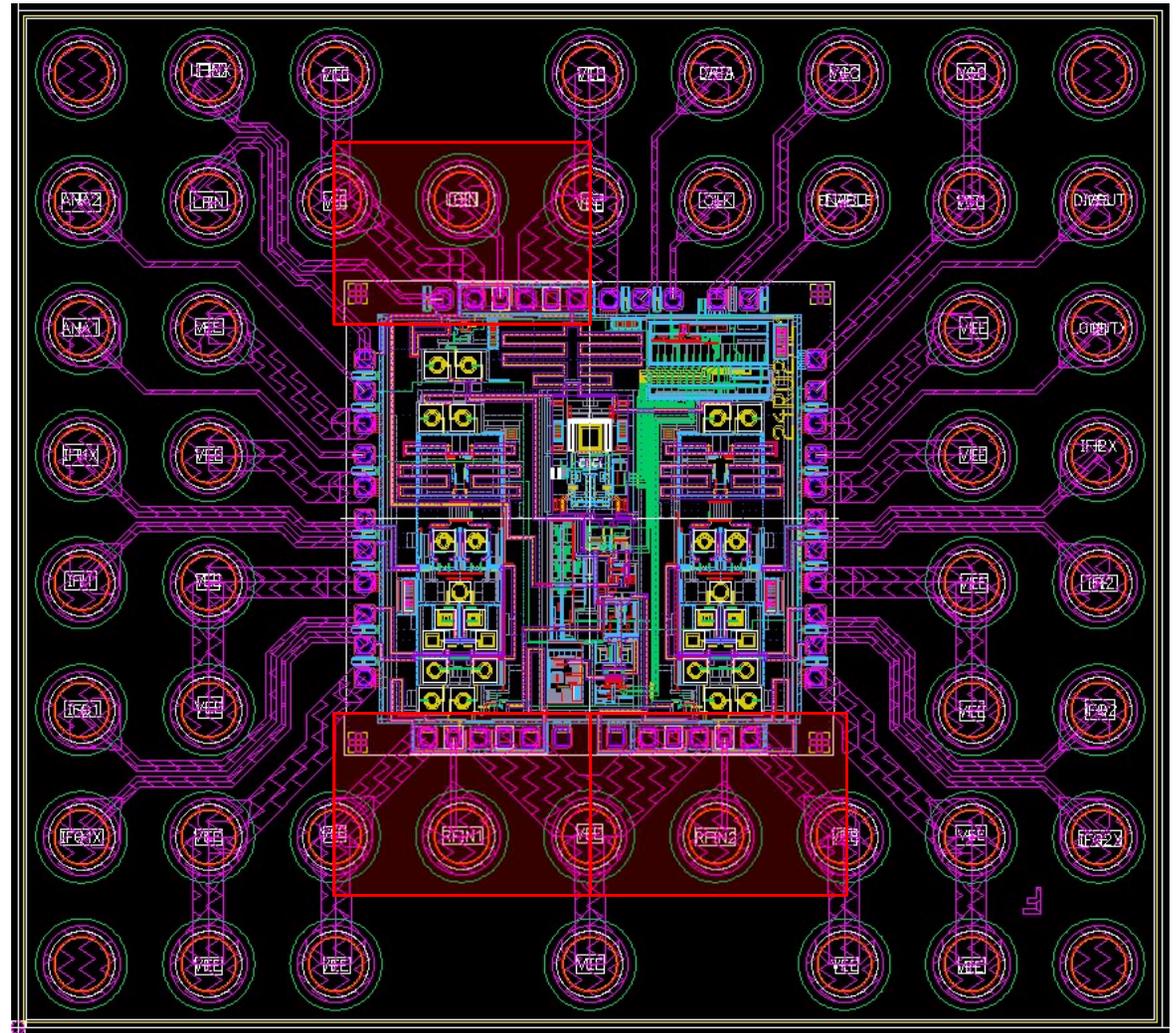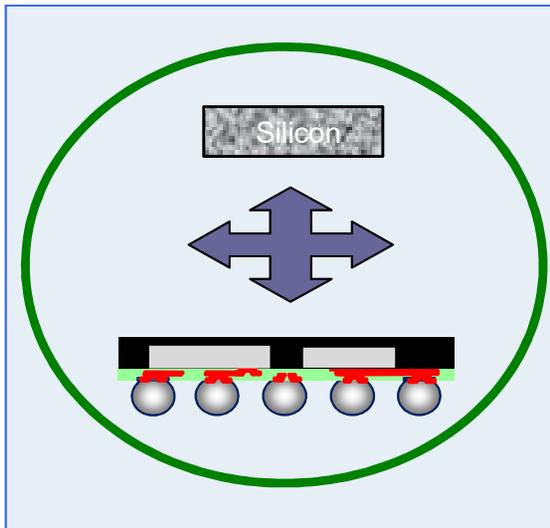
Agenda

Success Story of eWLB

2014
Waveguide integration
in eWLB

2015
3D eWLB using EZL
Novel concept for
vertical interconnection

2012
77 GHz SiGe TRX with
integrated antennas in eWLB
**ECTC 2012
Outstanding Paper Award**

2013
3D eWLB using TEV
Low-loss transitions and
high-Q inductors

2008
77 GHz SiGe mixer in eWLB

2011
6 GHz CMOS VCO with high-Q
fan-out inductors in eWLB

2006
Introduction of eWLB

2007
Low-loss transmission lines
and high-Q inductors in eWLB
**EPTC 2007
Outstanding Paper Award**

Embedded Wafer Level BGA (eWLB) Package

Fan-In area

Die

Die

Fan-Out area
(Mold compound)

Chip size
Package size
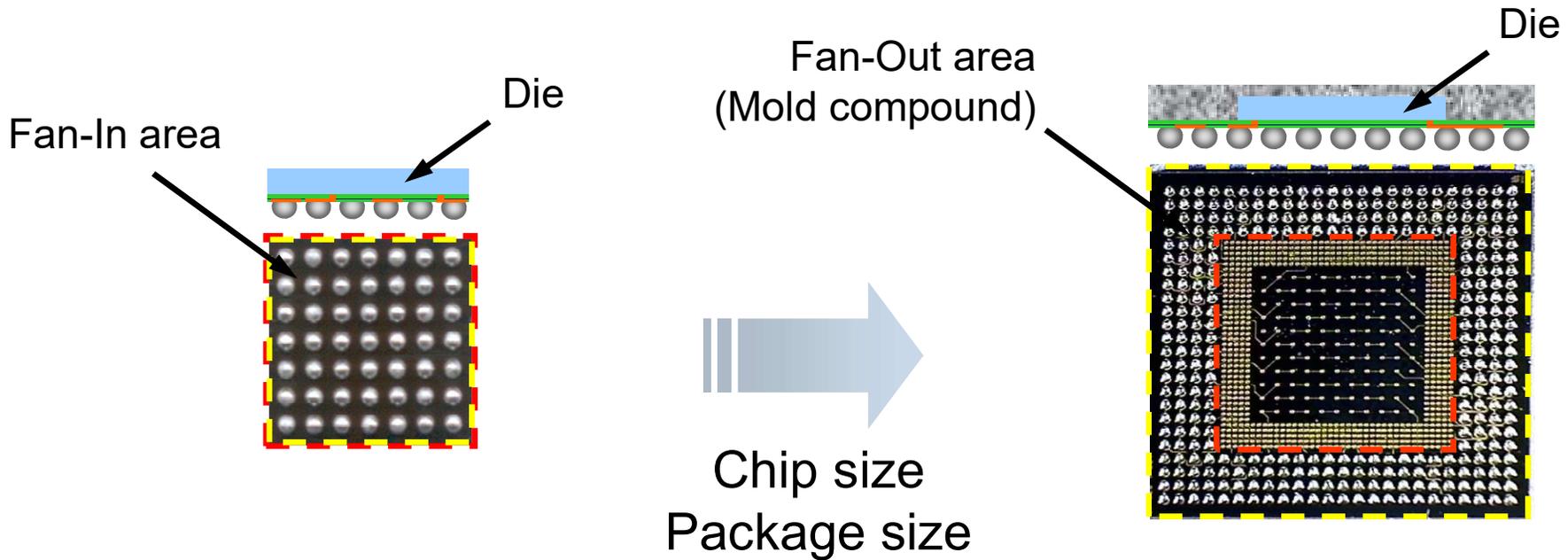
Classical WLB

- All interconnects must fit under the die area
- Number and pitch of interconnects must be adapted to the chip size

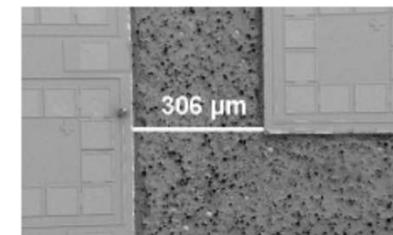## Embedded WLB

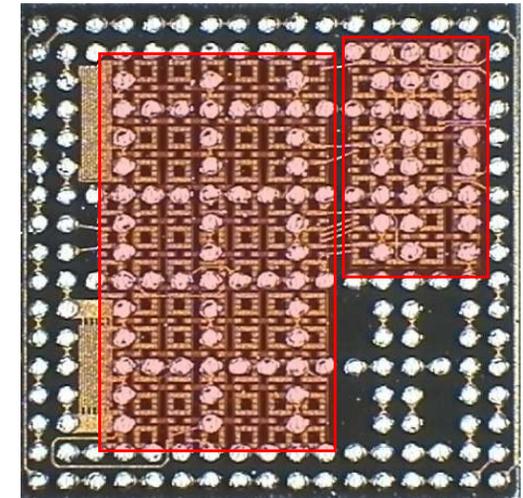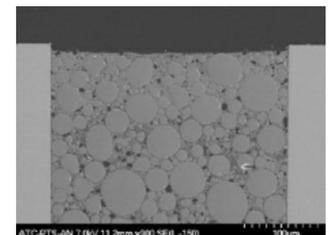- Fan-out area adaptable to needs
- No restrictions for ball pitch

Process Flow for eWLB Package

Side-by-Side Integration in eWLB

Fan-in area
Silicon chip

Fan-out area
Mold compound

Die 1   Die 2
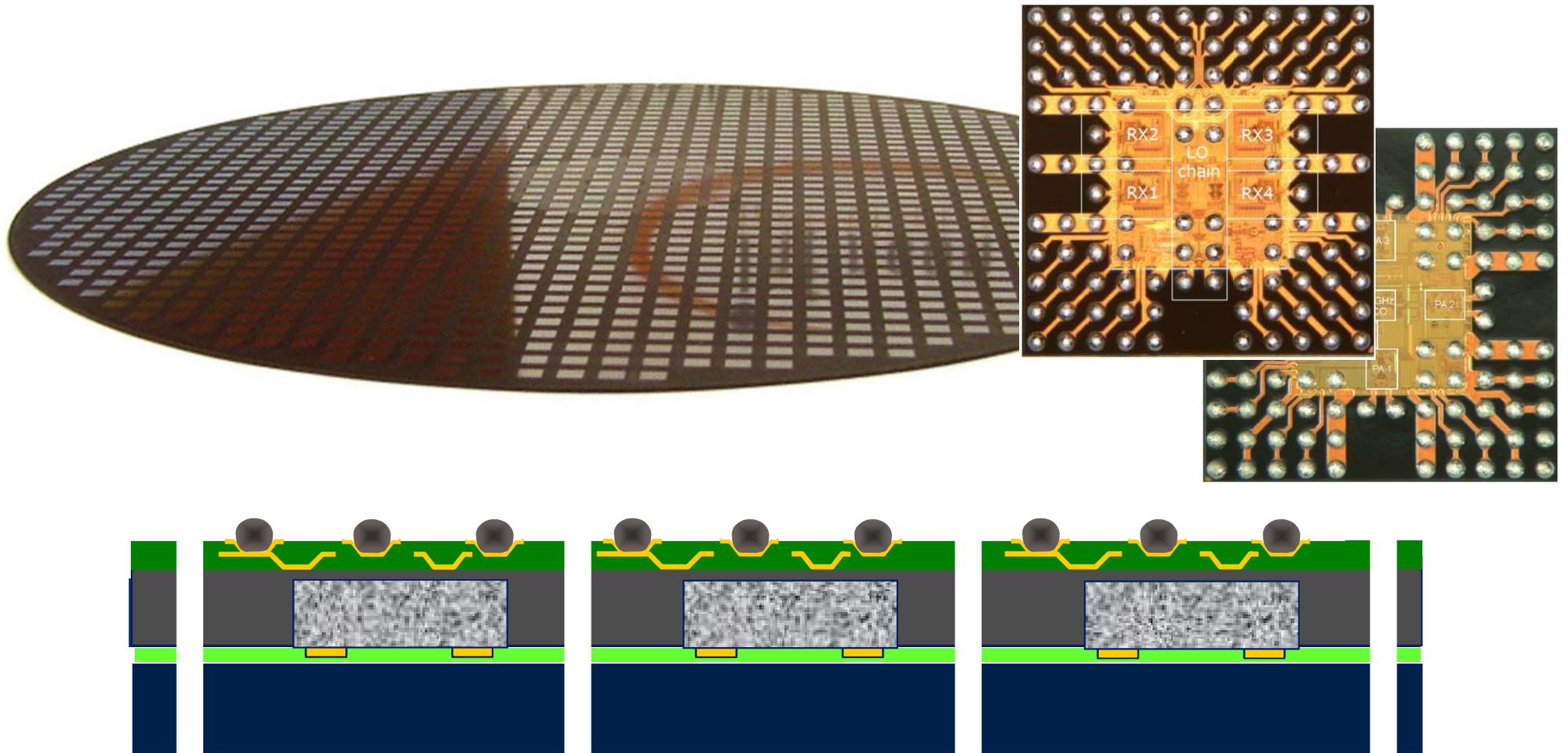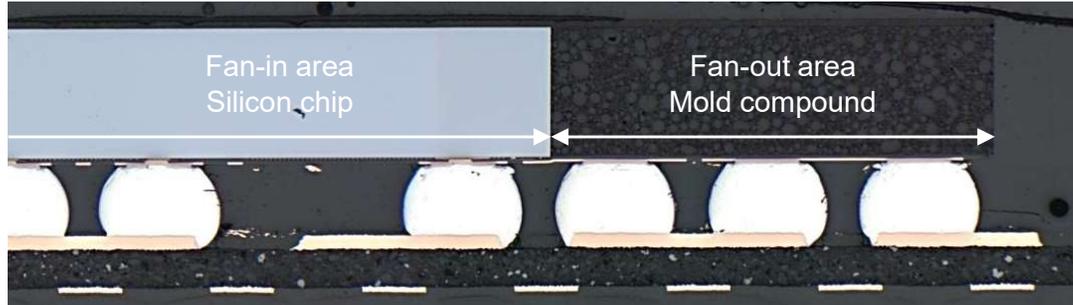
- Side-by-side integration for multichip modules and passives components e.g. SMD

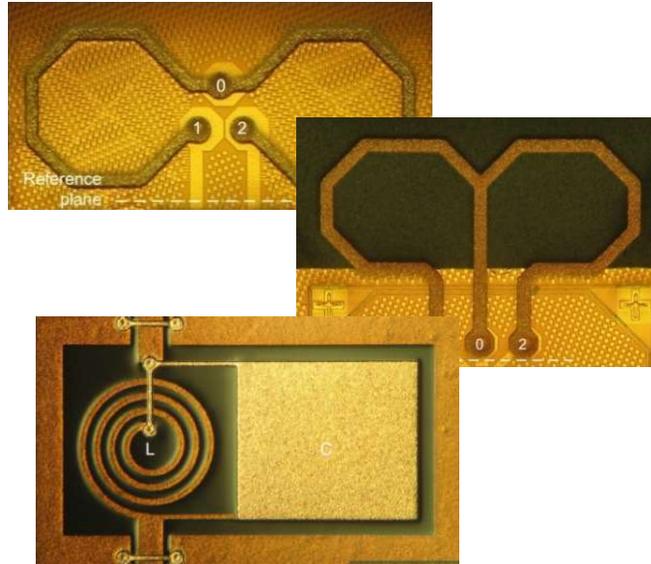- Measured loss tangent of mold compound = 0.004 @ 10 GHz and 0.005 @ 80 GHz

306 µm
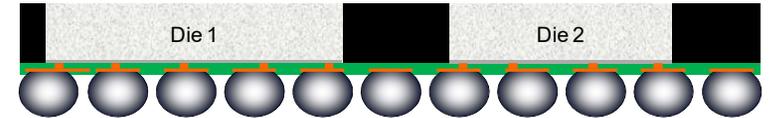
Top view   Cross section
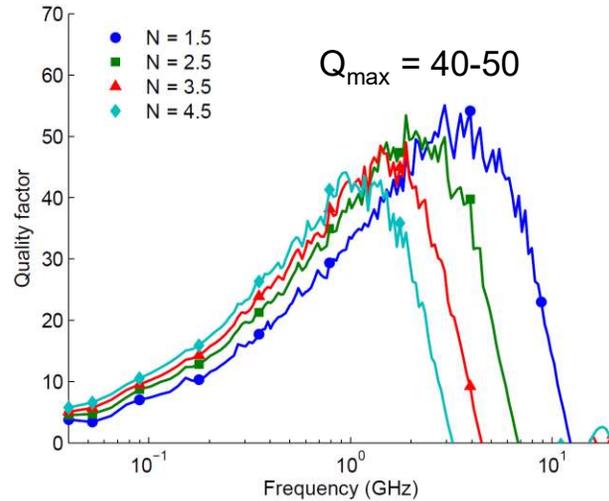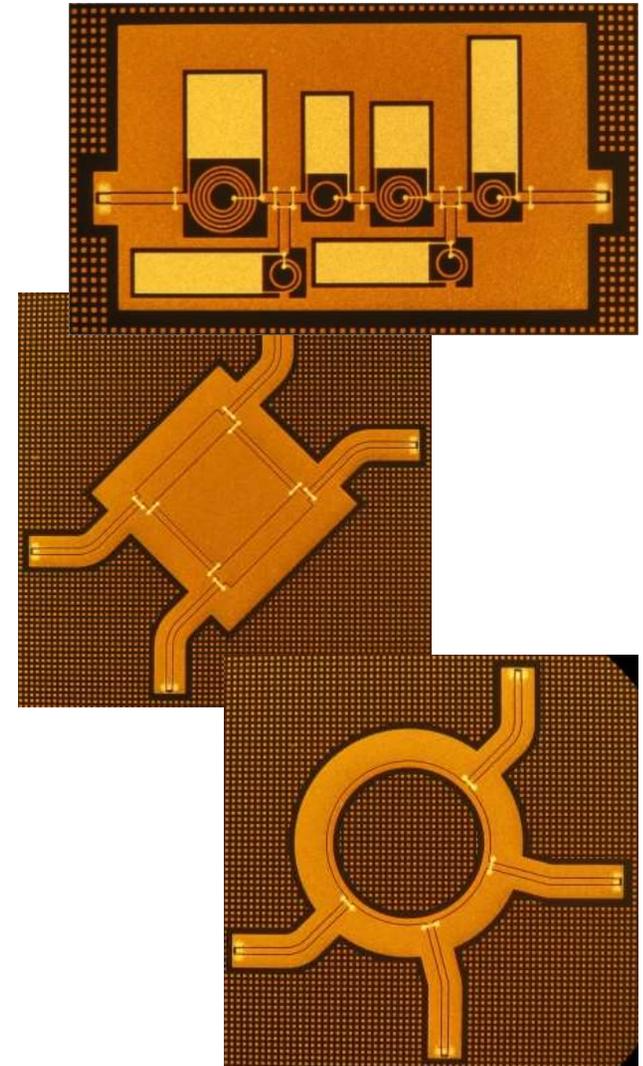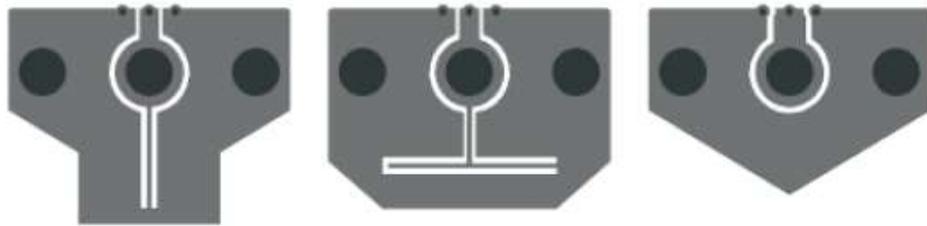
Passives Integration in eWLB
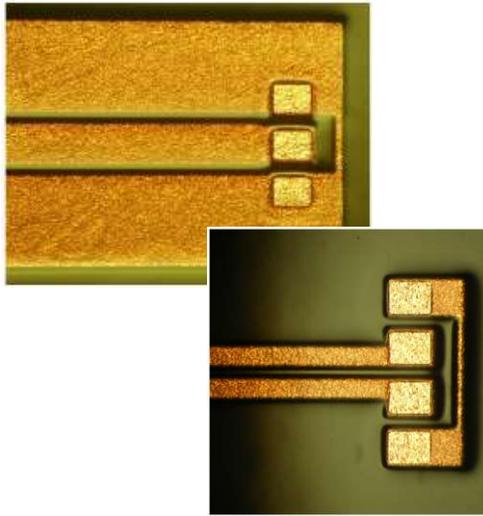
- **Transmission lines**
- **Inductors, Capacitors**
- **Filters**

CPW on mold (eWLB)
CPW on Si 1–100 Ωcm
TFMSL on BCB
MSL on RO3003 laminate

0.25 dB/mm @ 60 GHz
0.30 dB/mm @ 80 GHz

Q_{max} = 40-50

N = 1.5
N = 2.5
N = 3.5
N = 4.5
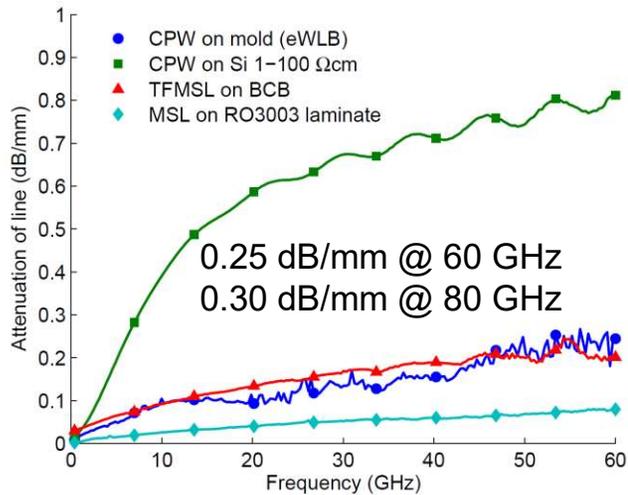
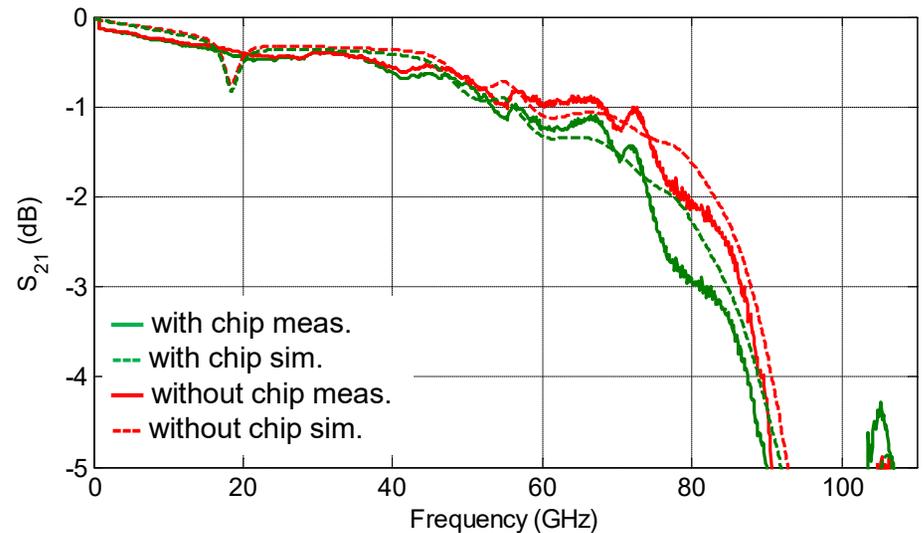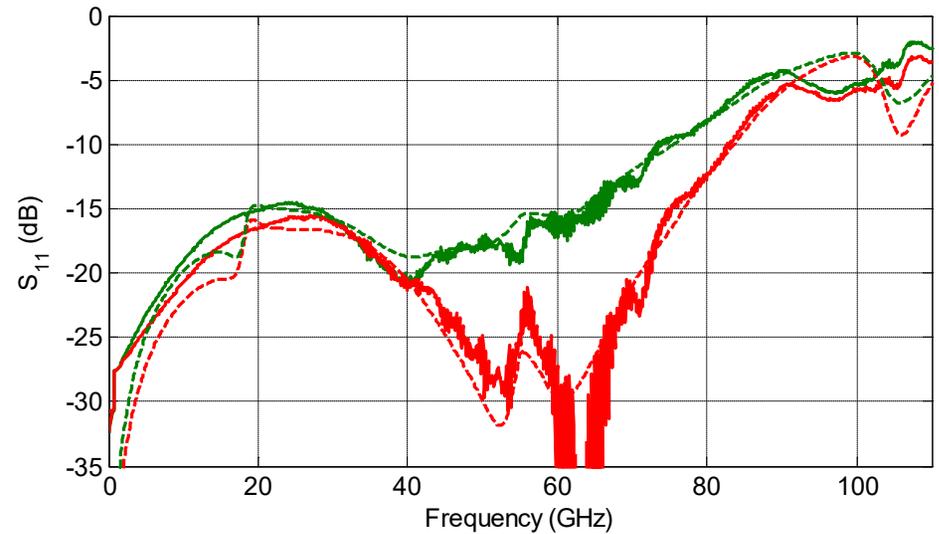# RF Transitions in eWLB
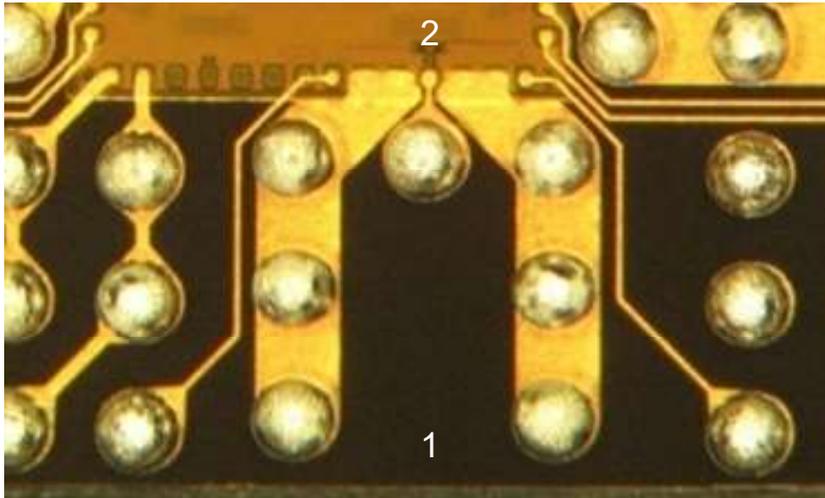
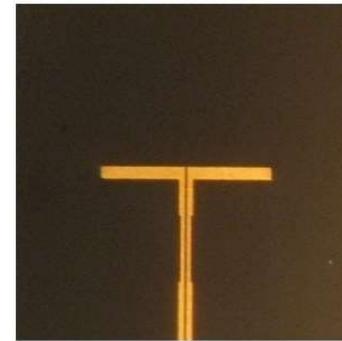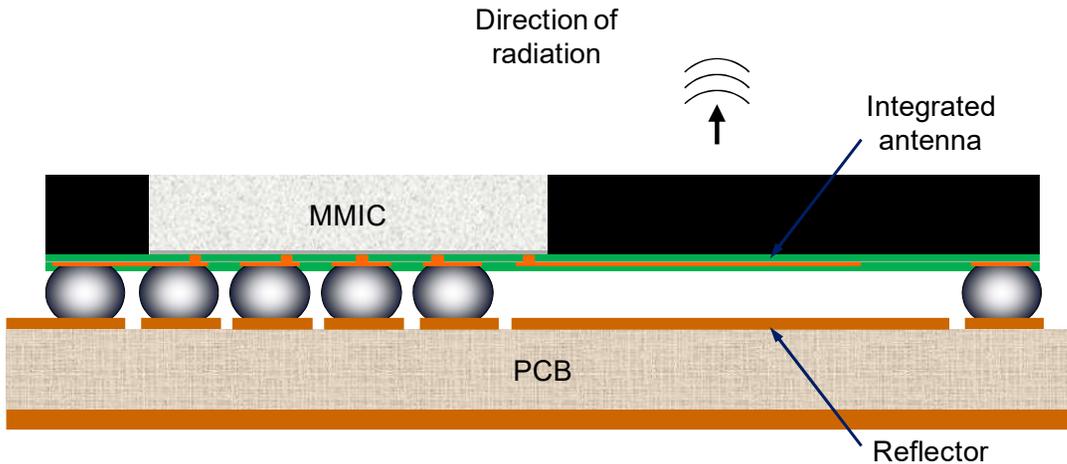- ■ **Performance without external matching at 60 GHz**

  S_{21} = -1.0 dB, S_{11} = -15 dB

- ■ **Broadband and bandpass RF transitions possible using RDL**

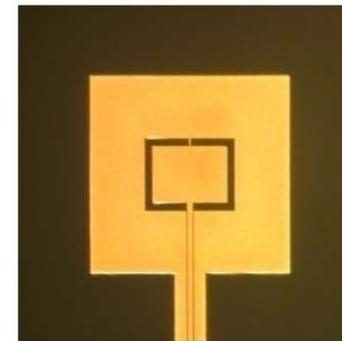# Antenna Integration in eWLB

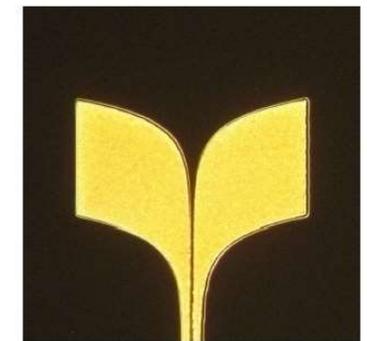Direction of radiation

Integrated antenna

MMIC

PCB
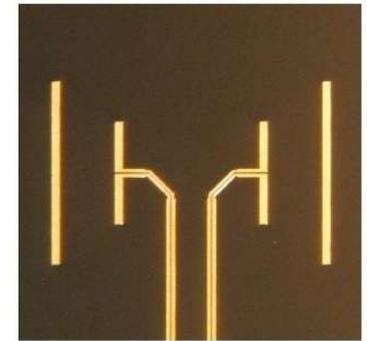
Reflector

(a) Dipole

(b) Array of two dipoles

(c) CPW patch

(d) Vivaldi

- **Antenna realized using RDL in the fan-out area of eWLB**

- **Plain ground underneath the antenna used as a reflector makes the antenna unconstrained by the actual PCB material**

| Frequency	λ	Max. antennas	Directivity Nx1	Directivity NxN
40 GHz	7.50 mm	3x3	11.3 dBi	14.6 dBi
60 GHz	5.00 mm	4x4	13.0 dBi	18.1 dBi
80 GHz	3.75 mm	5x5	14.3 dBi	20.6 dBi
100 GHz	3.00 mm	6x6	15.3 dBi	22.5 dBi
120 GHz	2.50 mm	7x7	16.0 dBi	24.1 dBi

60 GHz 6-Channel Transceiver Module in eWLB
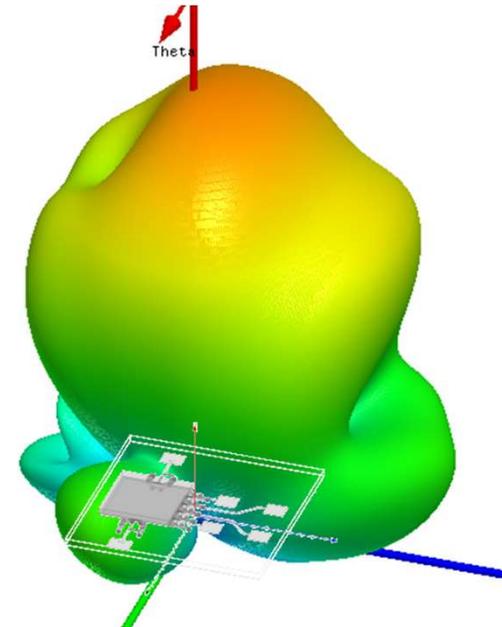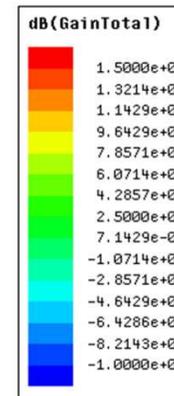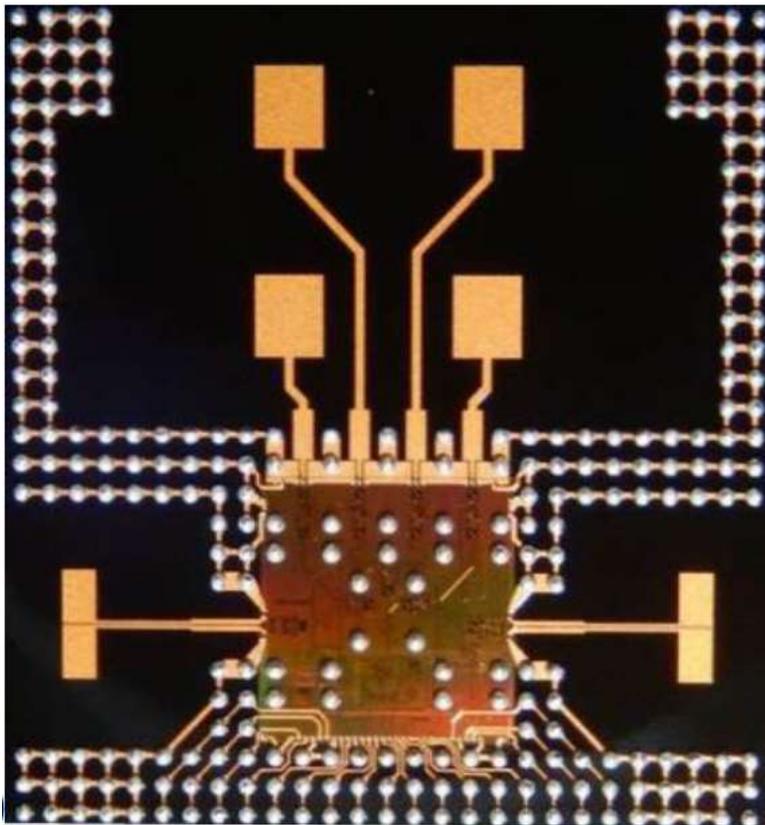
- 14 mm x 14 mm eWLB package
- 4xRX patch antennas and 2xTX dipole antennas
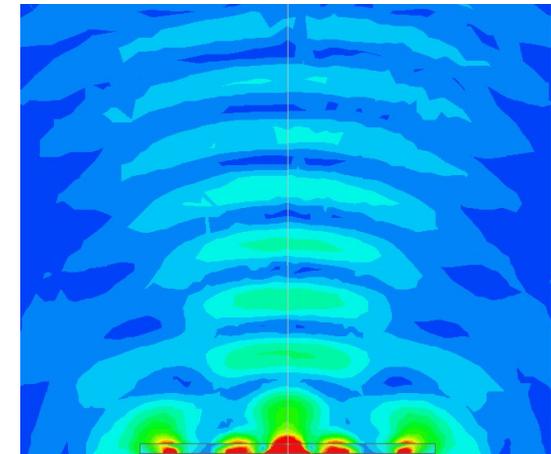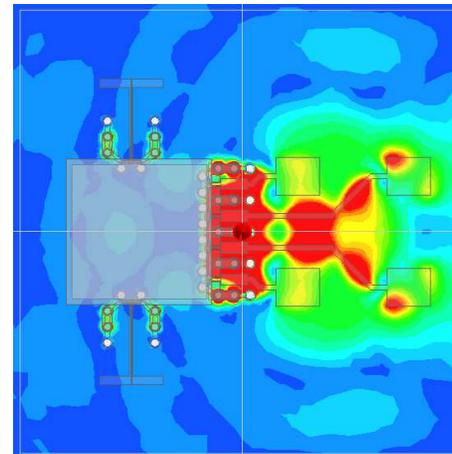
Google's Pixel 4
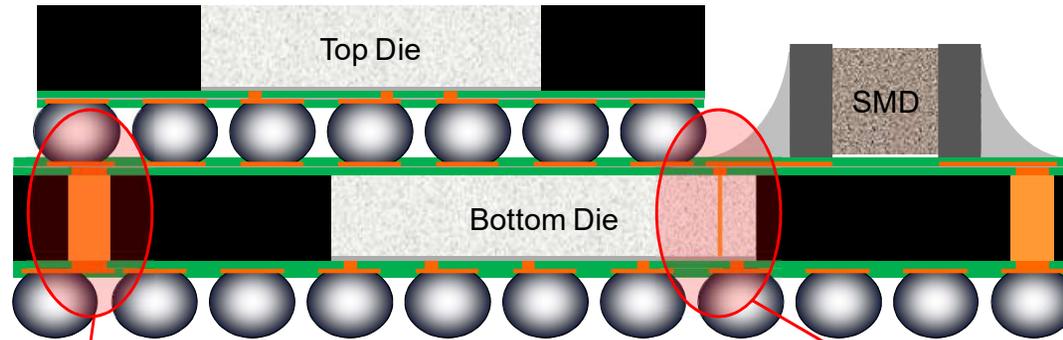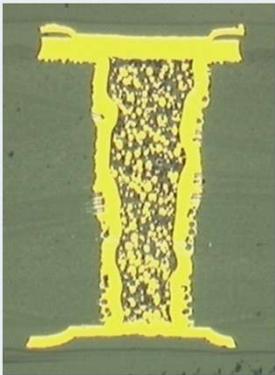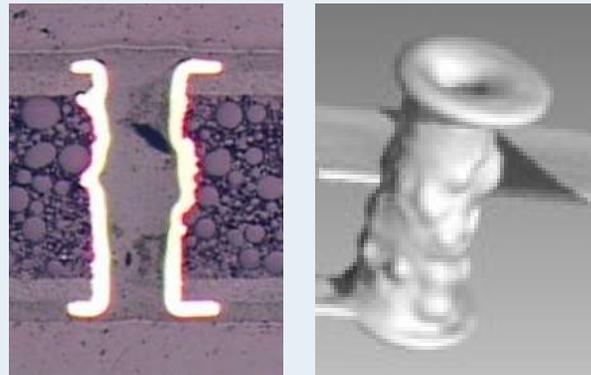# Worldwide First Radar Sensor in a Smartphone
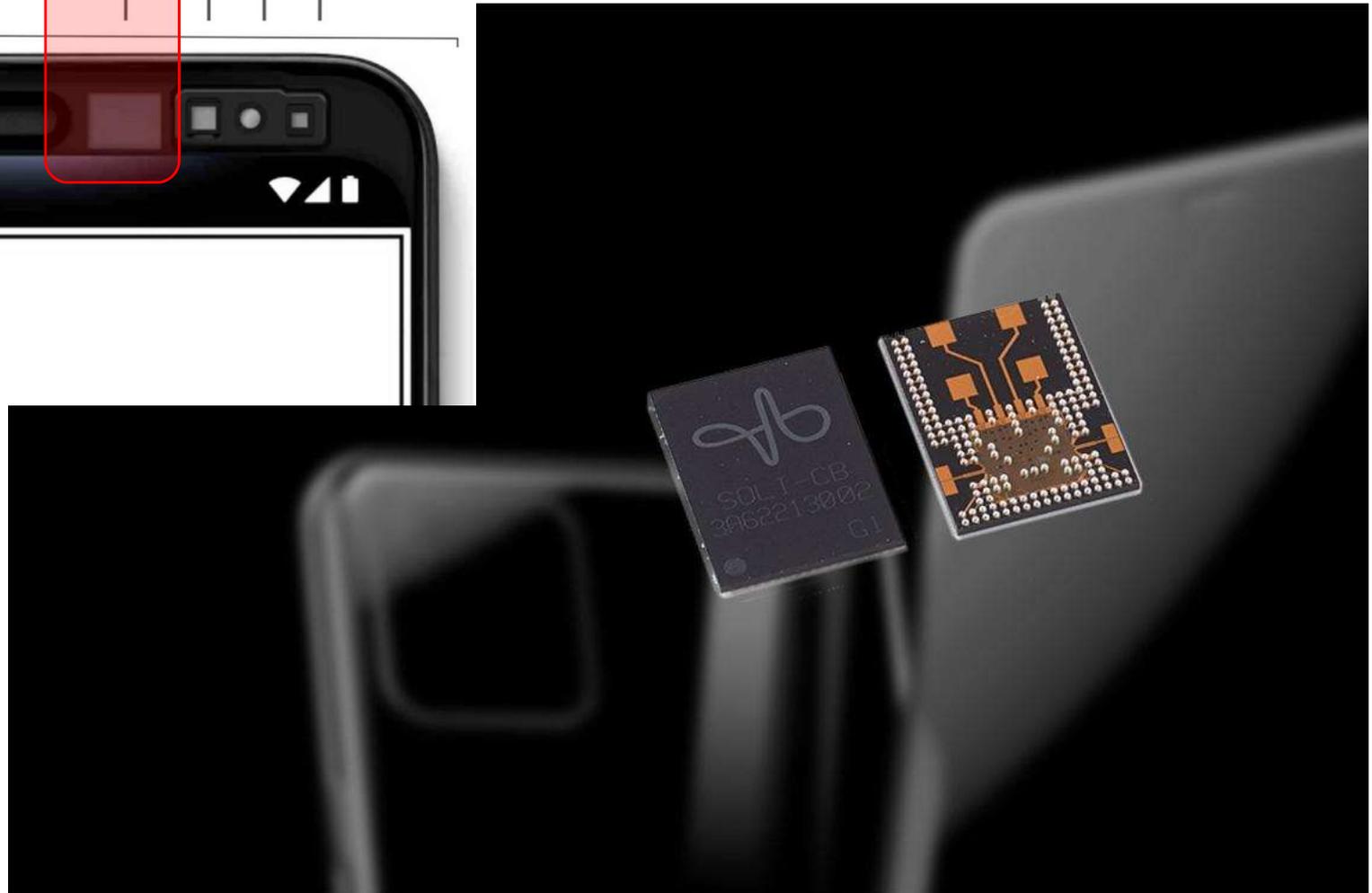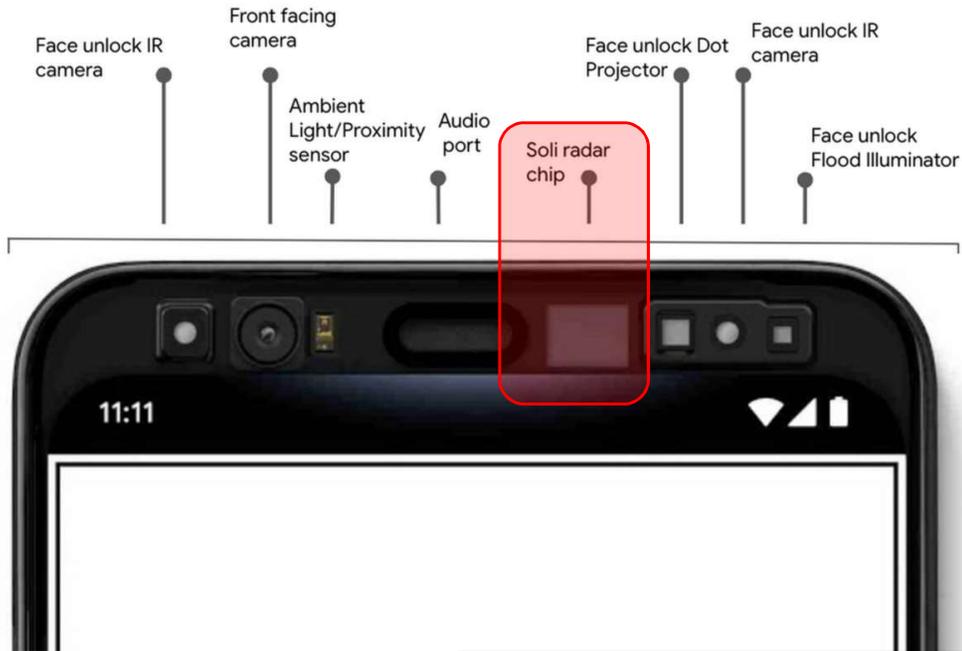
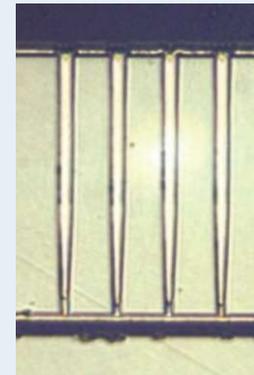# Agenda

Vertical Interconnections in 3D eWLB

3D eWLB

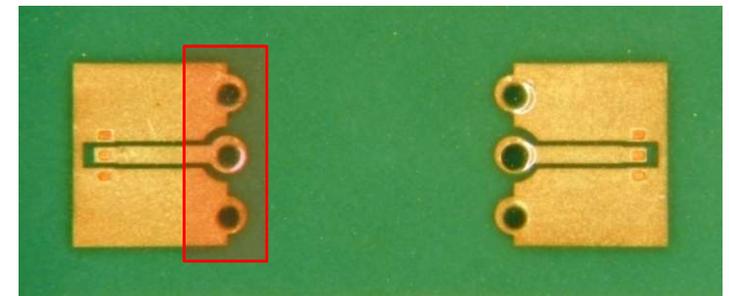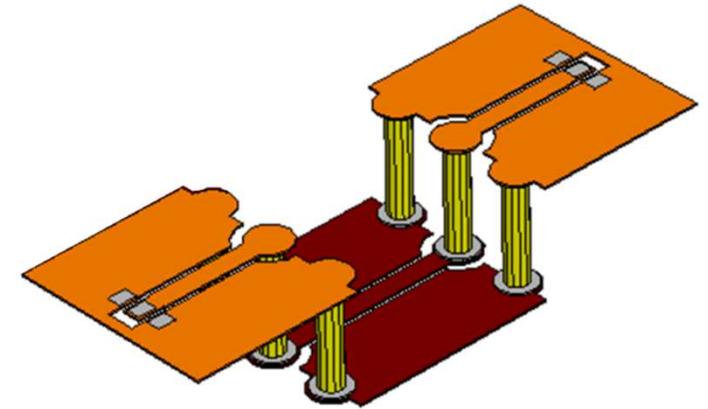**Embedded via bar**

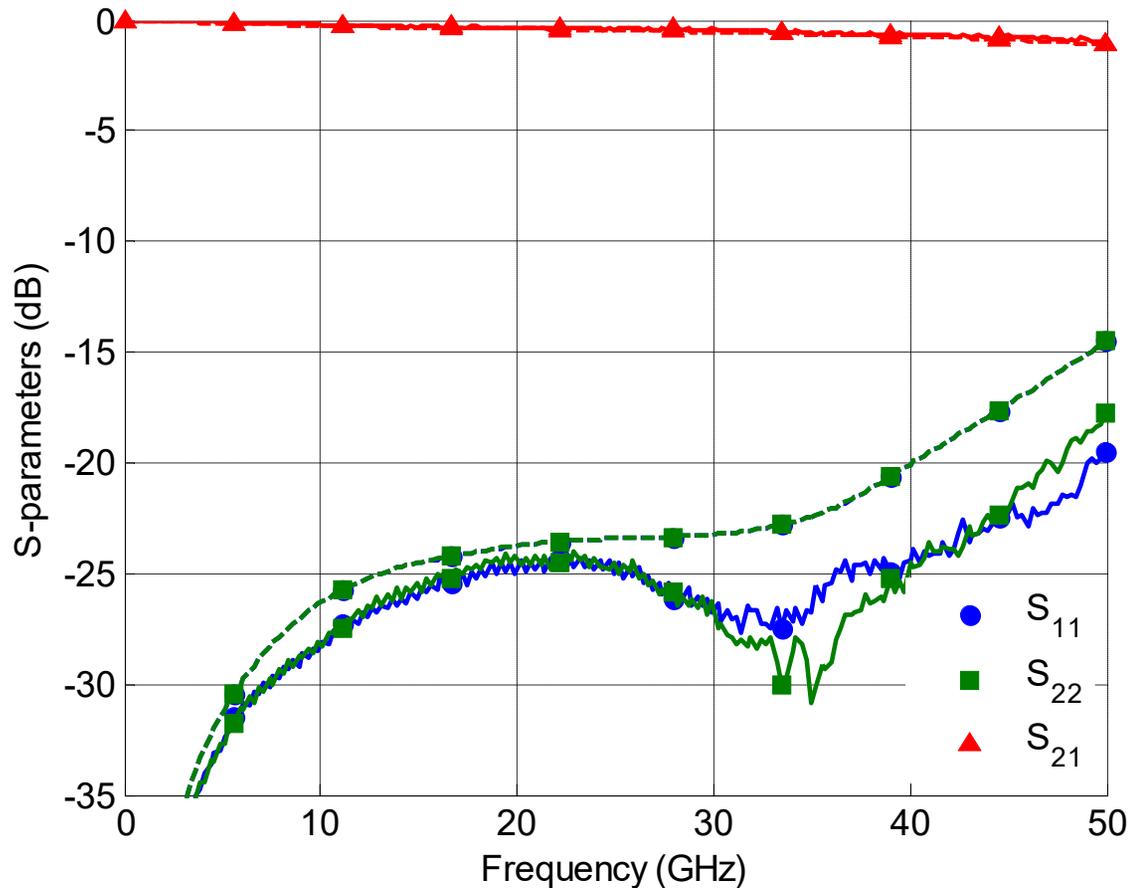**Thru encapsulant via (TEV)**

- Diameter = 200 µm
- Depth = 300 µm
- Pitch = 300 µm

Thru silicon via (TSV)

- Diameter = 10 µm
- Depth = 75 µm
- Pitch = 50 µm
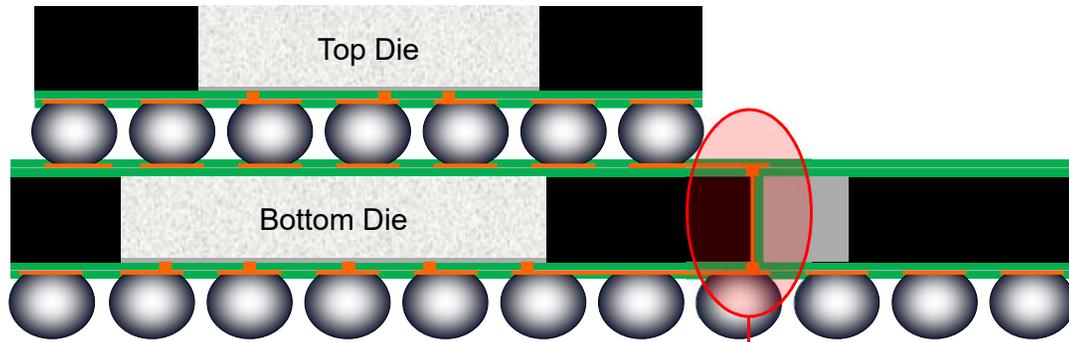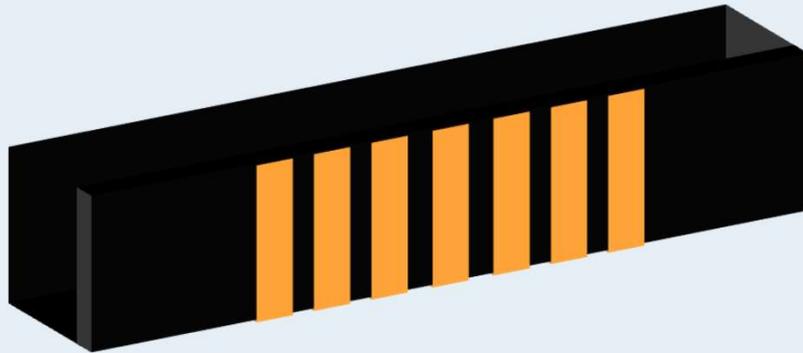
Vertical RF Transitions Using TEV

- Measured back-to-back connection of two GSG vertical transition realized using TEV in eWLB

- RF performance up to 50 GHz S_{21} < 1 dB, S_{11}, S_{22} < -15 dB

Embedded Z Line (EZL) Concept

3D eWLB

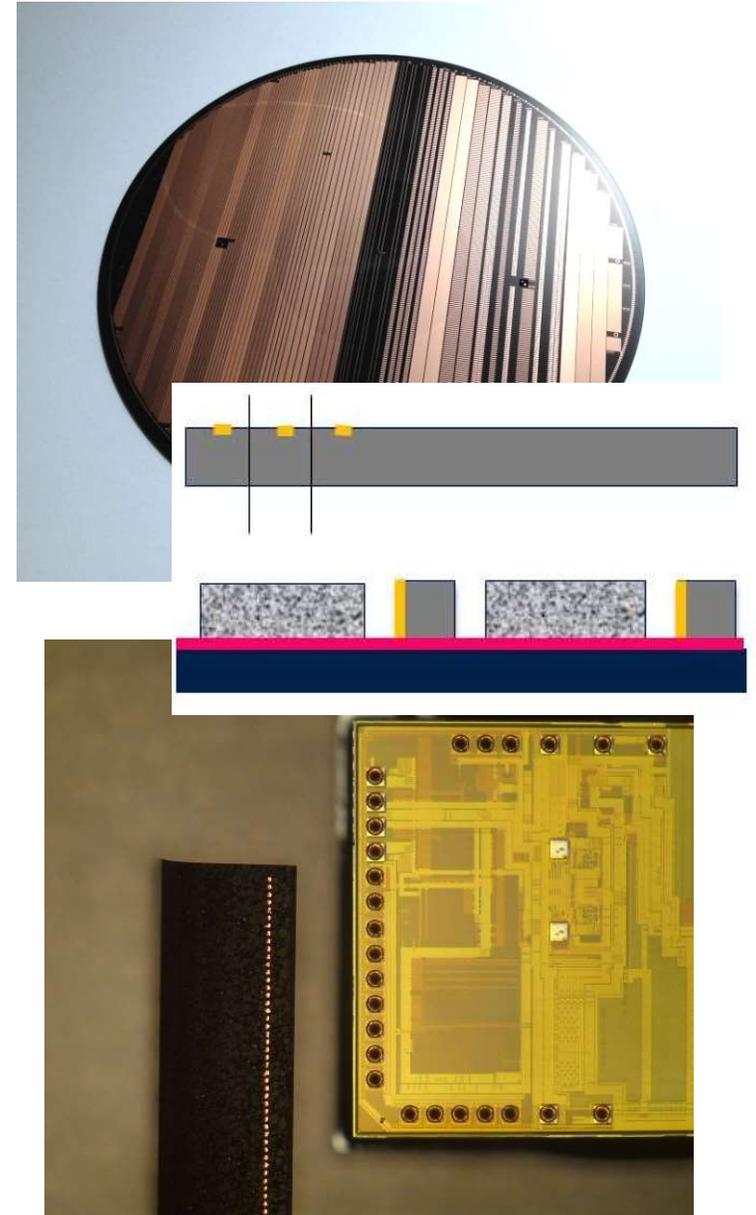### Embedded Z Line (EZL)

- EZLs are pre-fabricated bricks of mold compound turned by 90° with interconnections realized using RDL

Embedded Z Line (EZL) Concept

Advantages of horizontal RDL

- **High metal-pattern resolution**

- **Wide range of widths and pitches from few up to hundreds of μm**

- **Non-uniform cross section**
  - ☐ Skewed, stepwise interconnections
  - ☐ Complex signal/power distribution networks
  - ☐ Transmission lines and matching networks

Top Die

Bottom Die
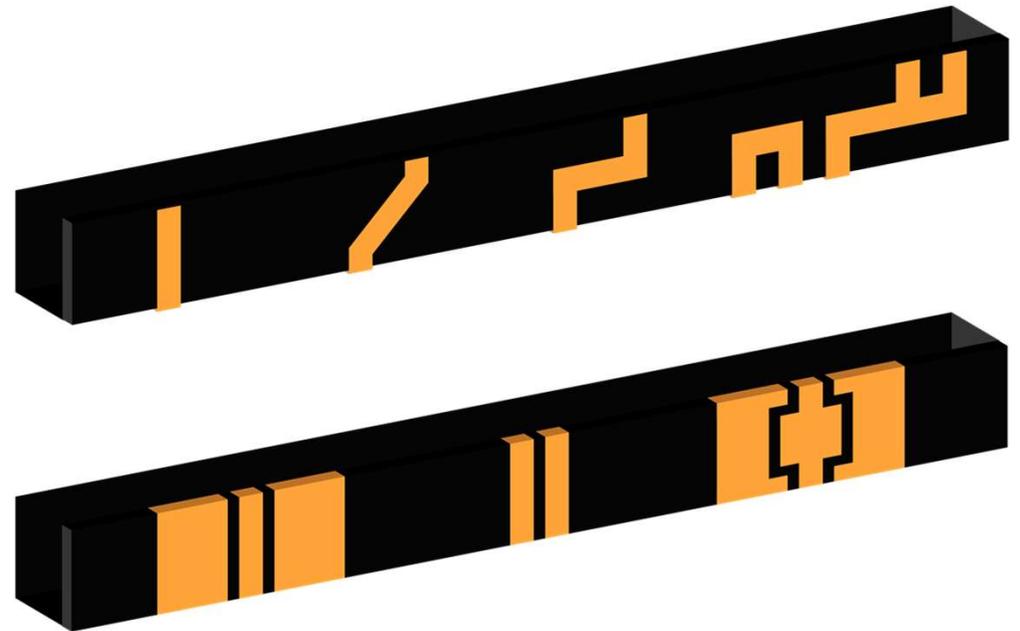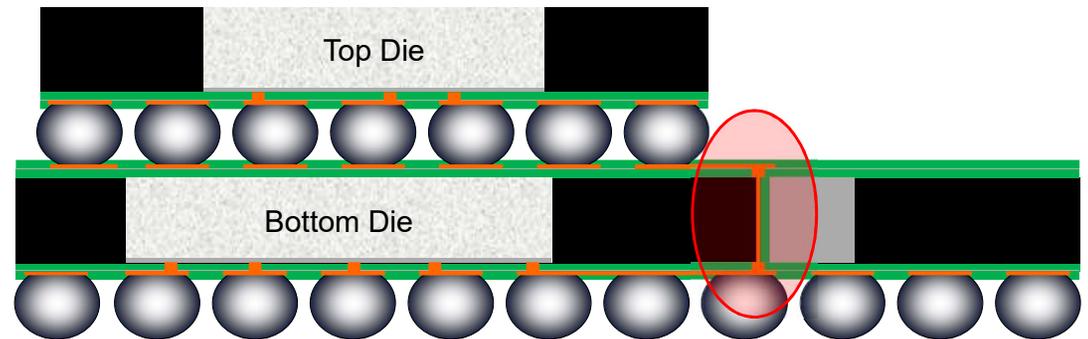
Vertical Dipole Antenna using EZL

EZL antenna

- Reflector realized using the horizontal RDL
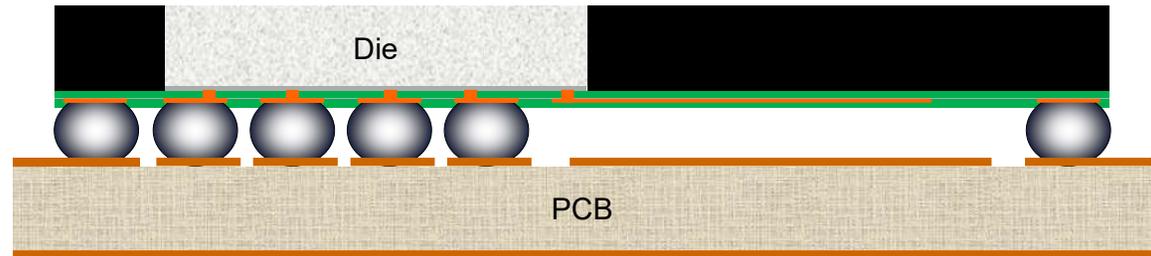
- More compact and less sensitive to assembly tolerances

Horizontal RDL   Vertical EZL
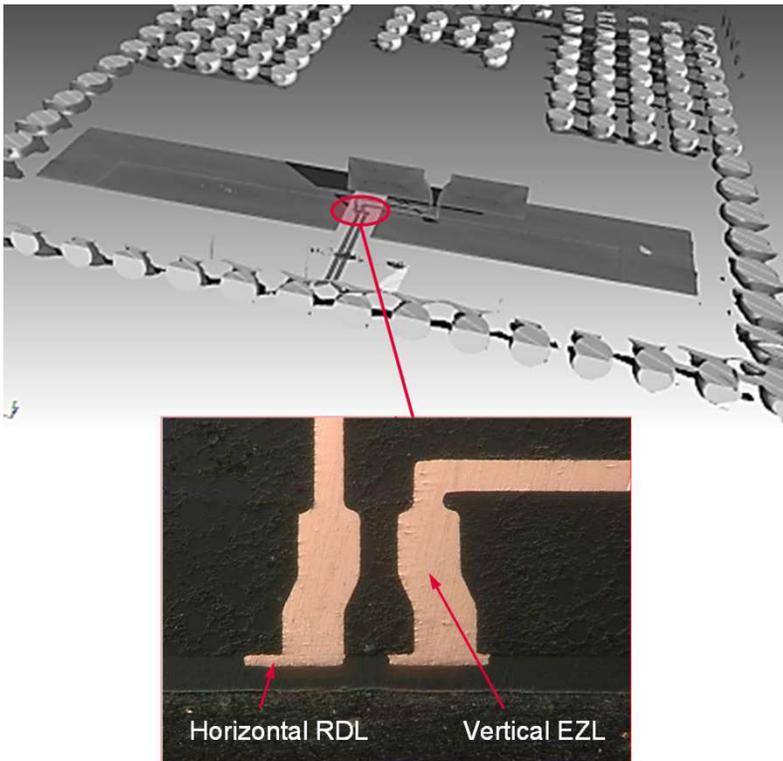
Traditional antenna integration using RDL

New antenna integration using EZL

Substrate Integrated Waveguide (SIW) in eWLB
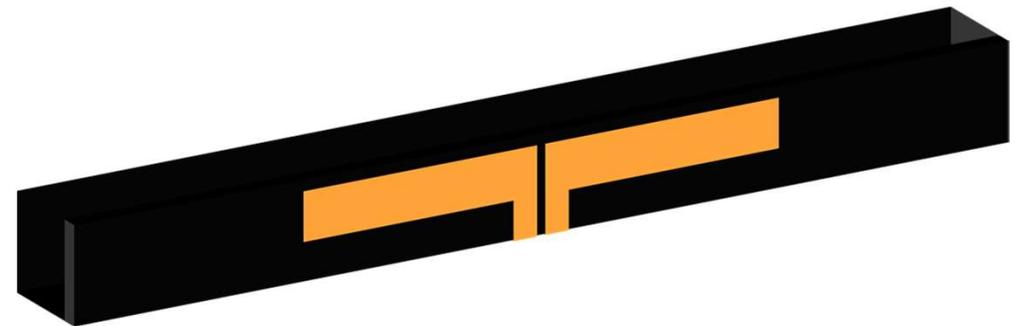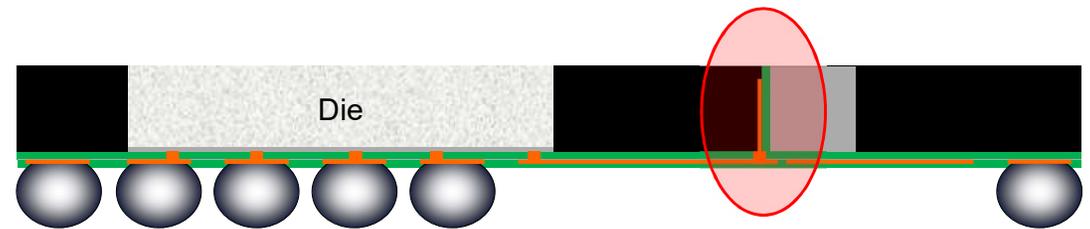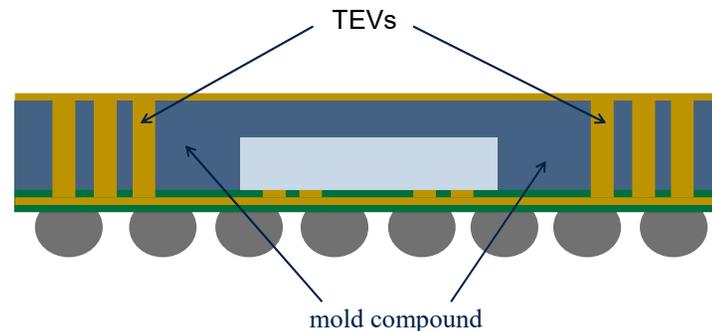
- **Rectangular waveguides offer the lowest transmission losses**
- **Substrate integrated waveguide (SIW) in eWLB**
  - Propagation characteristics of travelling waves similar to those of rectangular waveguides
  - Sidewalls created with vias
  - Propagation mode TE_{10}
  - Radiation and leakage can be neglected

TEVs

mold compound
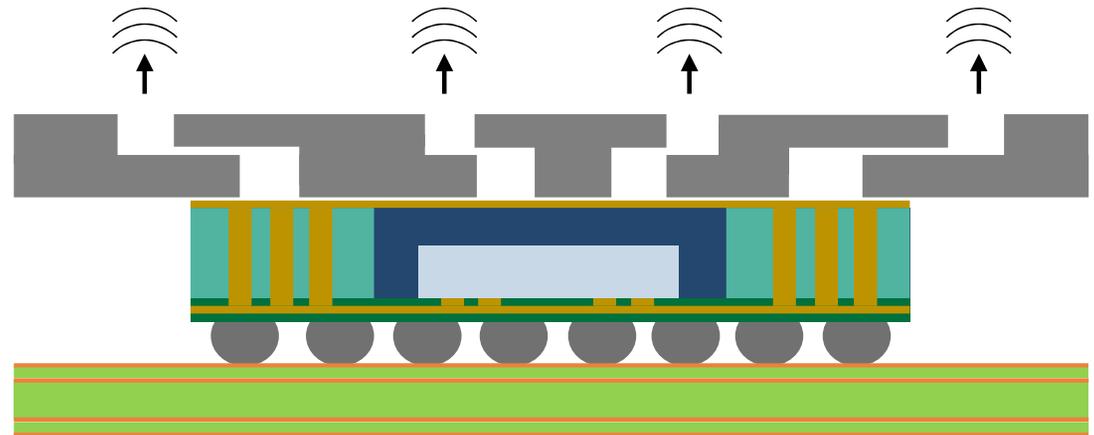
Sidewalls realized using TEVs

via bars

RF laminate
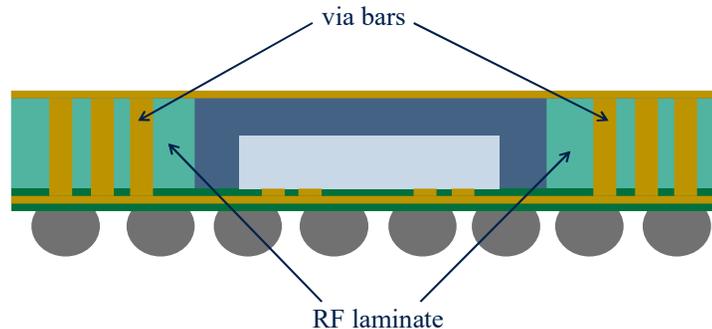
Sidewalls realized using via bars

Chip-SIW Transition in eWLB

- **Transition needs to realize mode conversion from CPW to TE_{10} mode**
- **Novel fully planar transition using taper**
  - ☐ Broadband matching by shaping the taper
  - ☐ More degrees of freedom for layout and optimization
  - ☐ Reduced impact of tolerances

Transition using via

Novel planar transition

via bars

RF laminate

Chip-Package-WR10 Waveguide Transition in eWLB

waveguide
launcher
chip
eWLB package

opening in back-side
metallization

mode
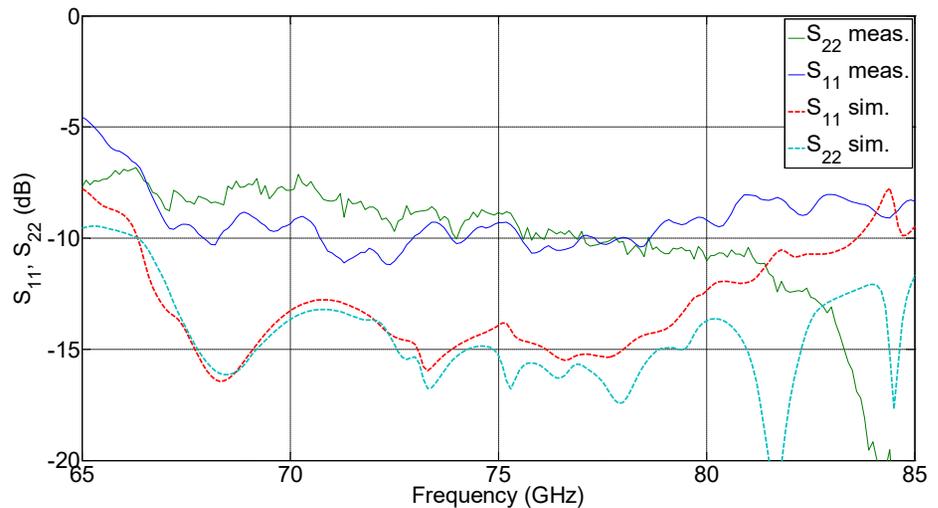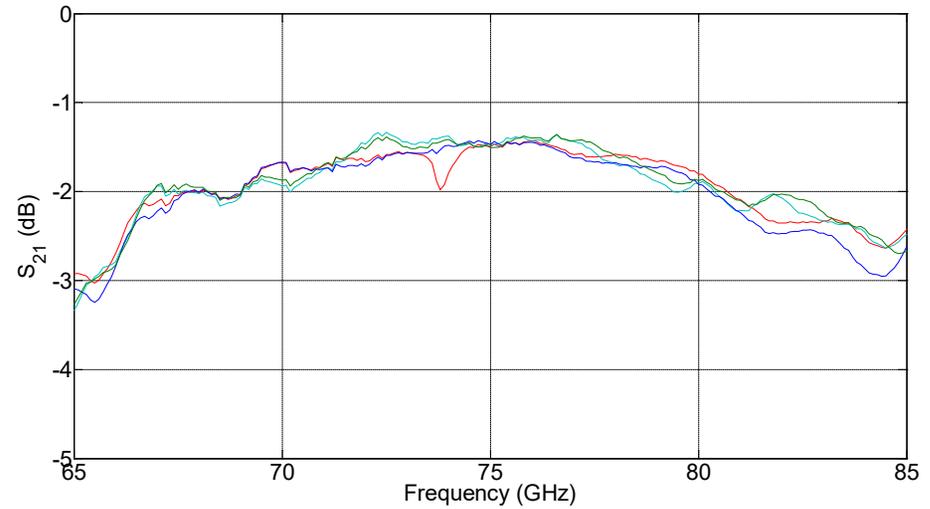transformation
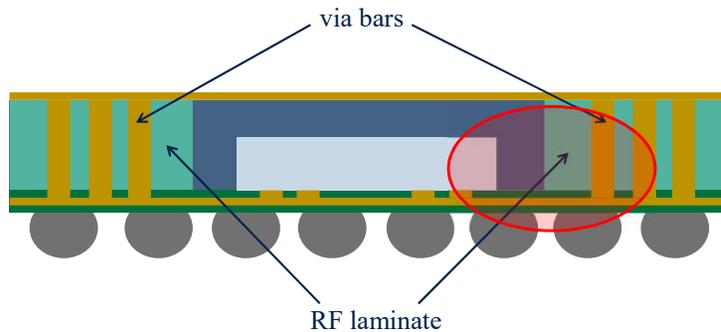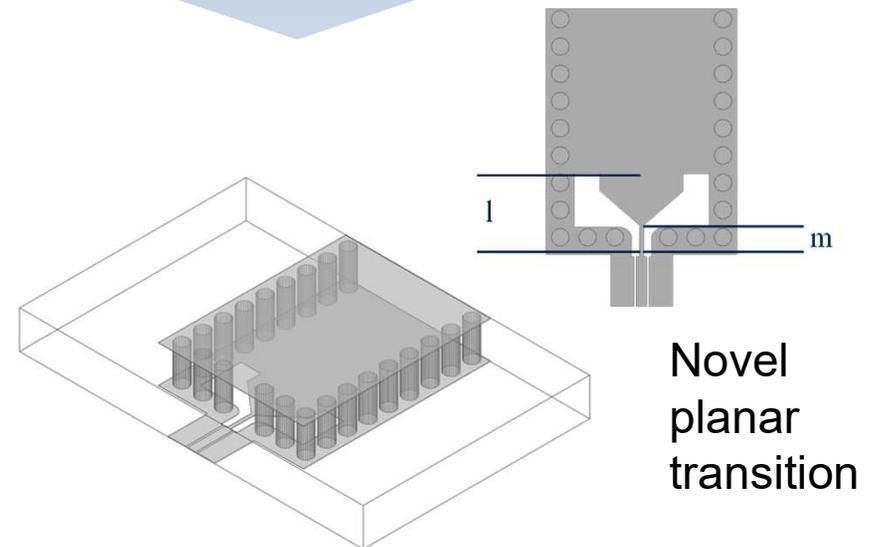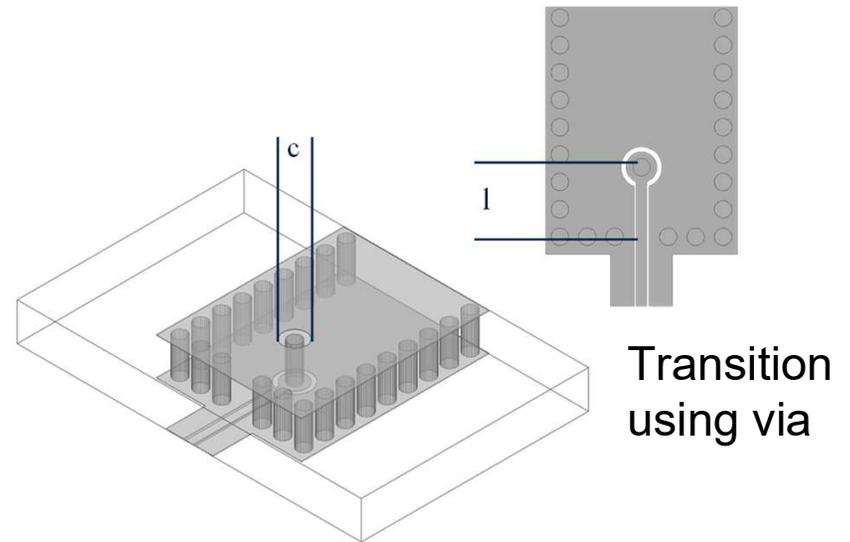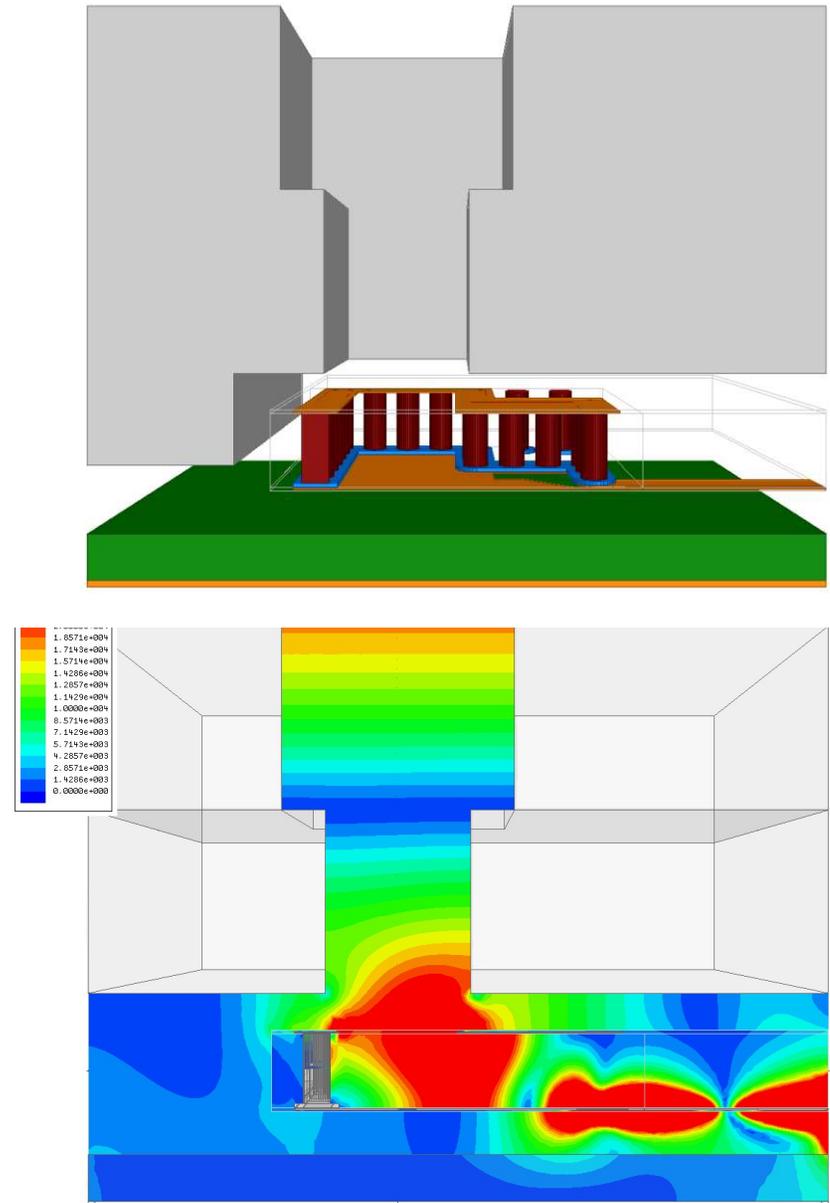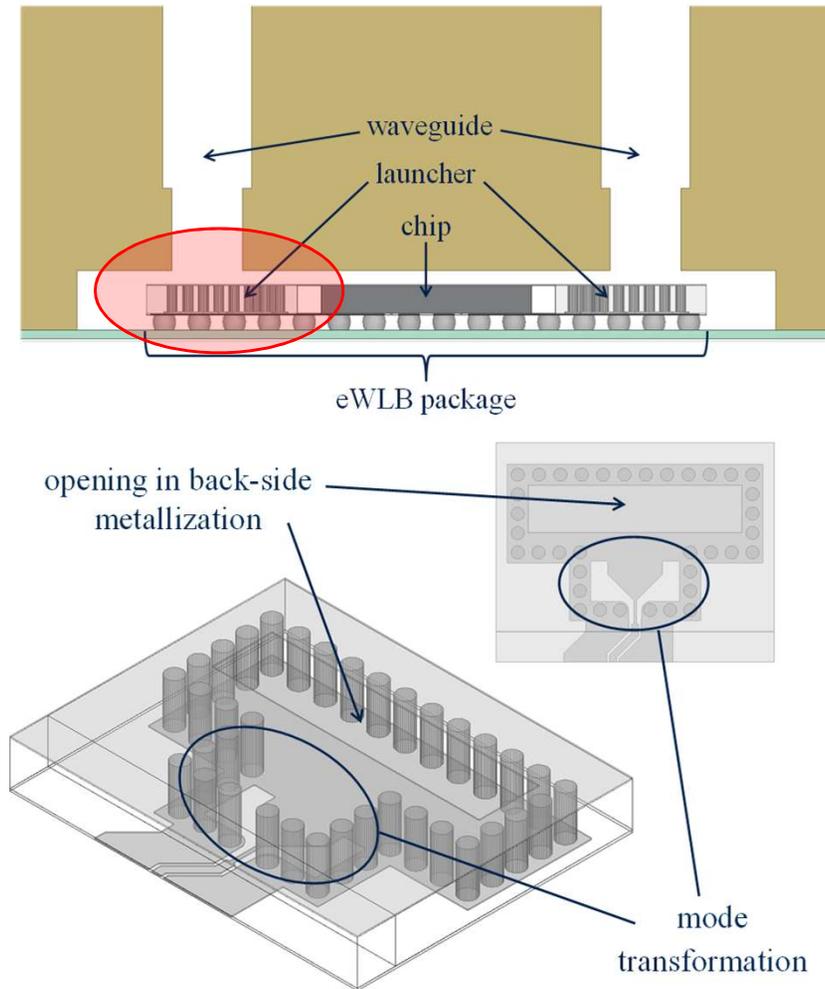
■ Compact low-loss chip-package-WR-10 waveguide RF transition in eWLB realized using taper

Chip-Package-WR10 Waveguide Transition in eWLB
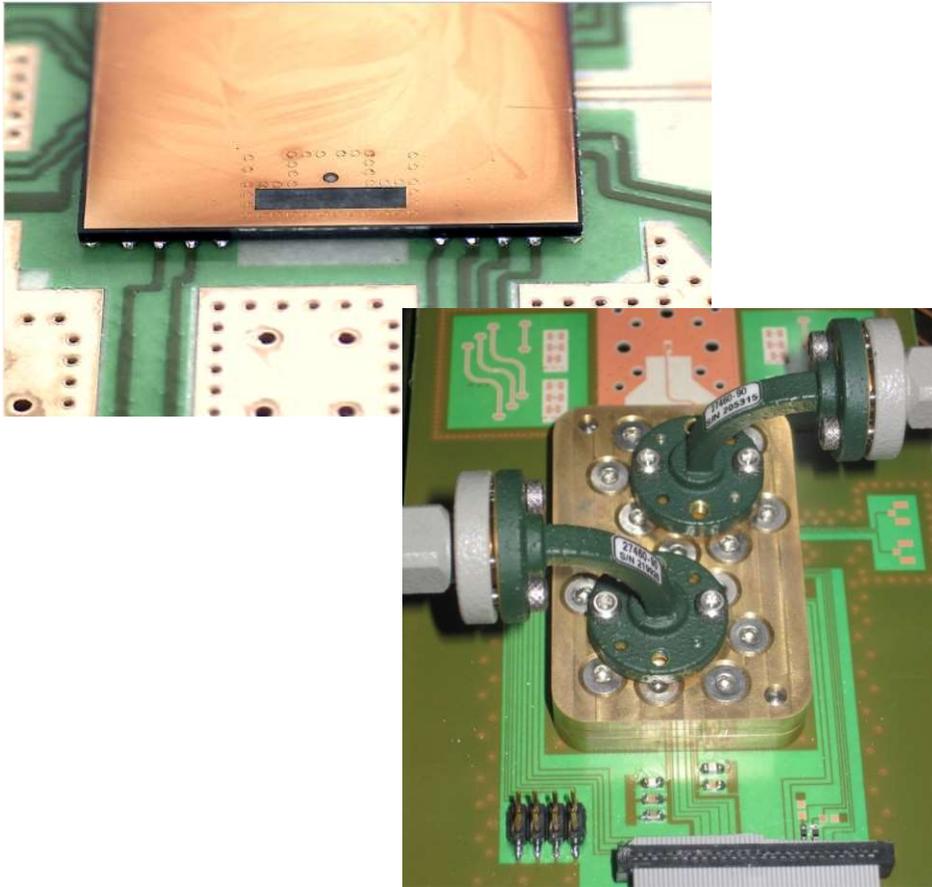
Transition using taper

- Measured and simulated chip-WR10 transition using taper
- Performance at 77 GHz

$S_{21} = -1.5$ dB, S_{11}, $S_{22} < -10$ dB

Agenda

Summary

- **More than Moore trend pushes packaging development toward system-in-package**

- **System design at mm-waves requires new methodologies for coherent chip-package-board co-design**

- **Embedded wafer level BGA (eWLB) is a universal SiP integration platform for RF/mm-wave applications**

  - ☐ High I/O and interconnect density

  - ☐ Outstanding RF/mm-wave performance

  - ☐ Outstanding flexibility for 2D/3D system integration: multichip, embedded passives, antenna and waveguide

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