mm-Wave System-On-Chip & System-in-Package Design for 122 GHz Radar Sensors

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Content

- **122 GHz ISM band and applications**
- **mm-Wave SoC & mm-Wave Built-In-Self-Test**
- **Low-cost mm-Wave SiP with integrated antennas**

122.5 GHz ISM Band

- **Industrial, Scientific, Medical Bands**
  Weakly regulated, unlicensed bands
  Ideal for consumer applications (wireless communications, distance sensors etc.)

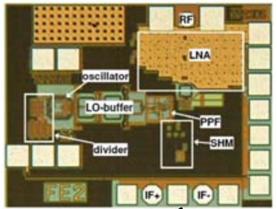
Frequency band	Bandwidth	Transmit power	λ in air
2.4 GHz	80 MHz	100 mW (20 dBm) EIRP	12.5 cm
5.2 GHz	100 MHz	200 mW (23 dBm) EIRP	5.8 cm
60 GHz	ca. 5 GHz	10 W (40 dBm) EIRP	5 mm
122.5 GHz	**1 GHz**	**100 mW (20 dBm) EIRP**	**2.5 mm**
245 GHz	2 GHz	100 mW (20 dBm) EIRP	1.25 mm

- **Advantages of 122.5 GHz band**
  High bandwidth (1 GHz)
  Small wavelength -> dipole antenna w. <1.25 mm diameter (ε_r > 1)
  Sufficient power for short-range applications

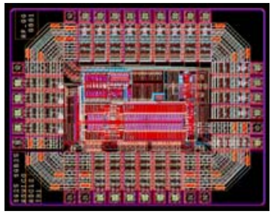
- **Applications: distance, speed, angle of incidence measurement**
  Industrial, consumer, building infrastructure, automotive, security systems

Vision of a mm-wave System-On-Chip

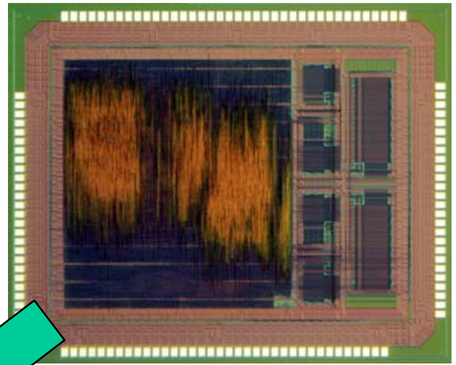
122 GHz Radio[1]

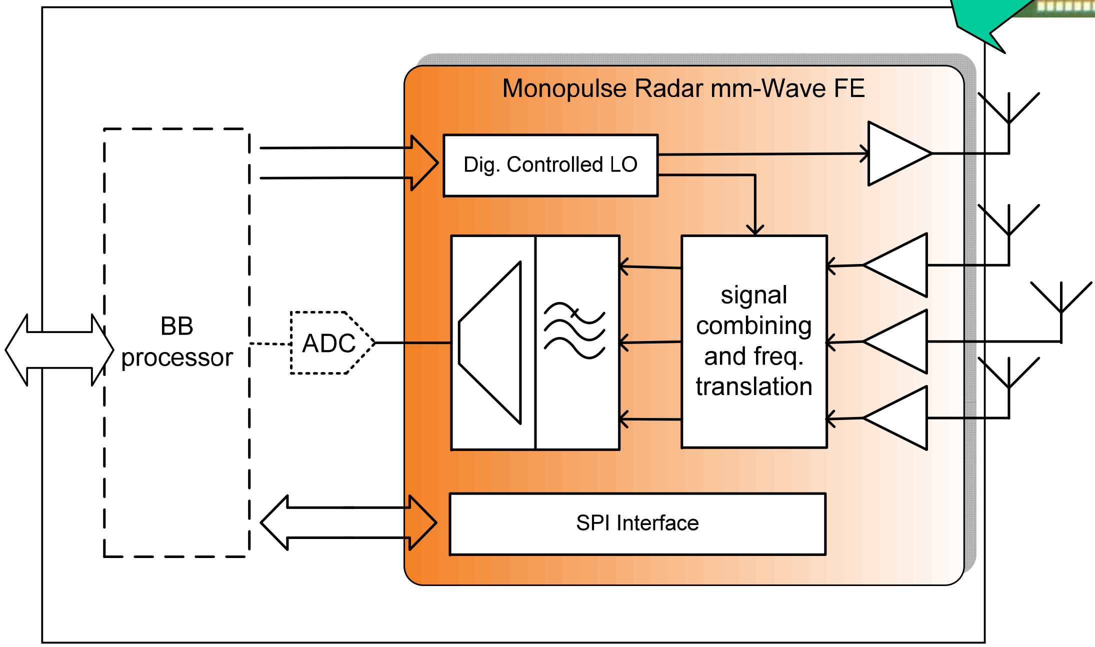


ADC



Processor





- „Bits in, mm-Wave out“
- Radio ~ 1 mm^2 chip area
- Complete mm-wave SoC area dominated by digital content ~ 4 to 10 mm^2
- Complete electronics ~ 1 to 2 USD

[1]“122 GHz Receiver in SiGe Technology”, K.Schmalz et al., IEEE BCTM 2009

mm-Wave BIST

- **Mm-wave IC production test is hardly feasible**
  - Measurement equipment not available
  - On-wafer test (fragile probes, reliability of results)
  - To be operated by technicians not scientists
  - Packaged test ?
  - Cost !!

- **Built-In-Self-Test (BIST) can solve this problem**
  - Transceiver loop-back test, on-chip S-parameters etc.
  - Digital read-out of results
  - → Full mm-Wave test with ***standard digital test equipment*** possible

→ mm-Wave BIST enables volume testing of mm-wave ICs at the cost of digital testing

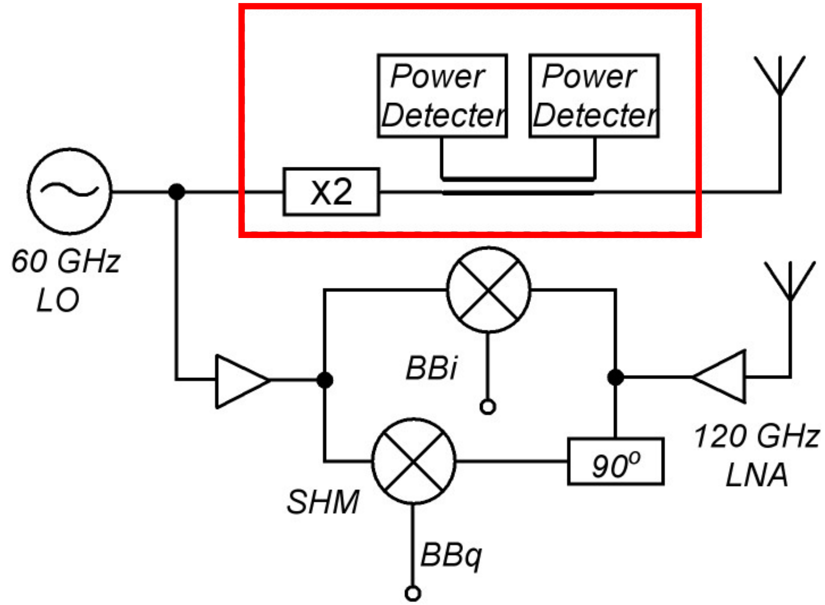
mm-Wave BIST Example

- **Measurement of transmitted and reflected power at 122 GHz**
  → P_{out}
  → S11

Allows detection/measurement of

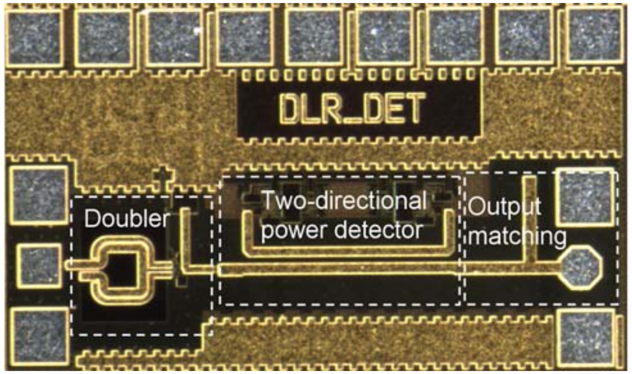
- **Electronic defects,**
- **IC parameter tolerances**
- **Antenna impedance**
- **Missing bond wire or bump**

122 GHz Transceiver, simplified block diagram



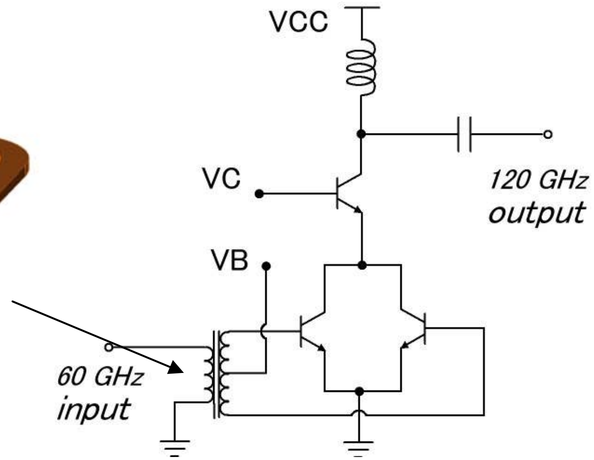
mm-Wave BIST Example

122 GHz Transmitter Test Chip[1]



- **Transmitter test chip featuring**
  - 60 GHz input transformer (Balun)
  - Active frequency doubler
  - Bi-directional coupler with weak coupling (-20 dB)
  - 2 power detectors

Frequency Doubler Core

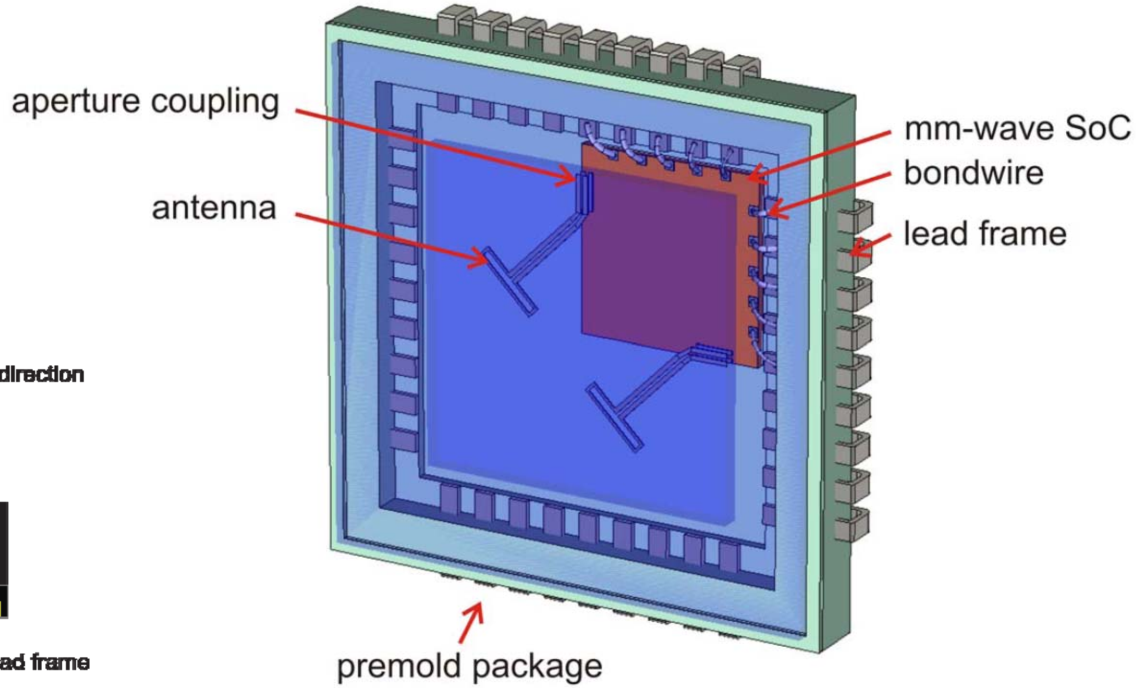


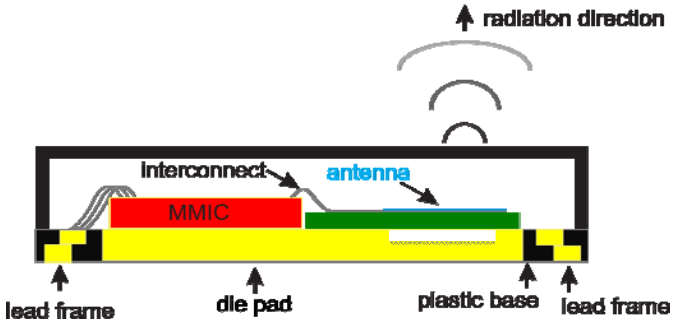
Parameter	**Measured Results**
Output Power	**5 dBm**
VCC	**2.5 V**
ICC	**17 mA**
Conversion Gain	**2.5 dB**
Technology	**IHP SG13S (0.13 µm SiGe BiCMOS)**

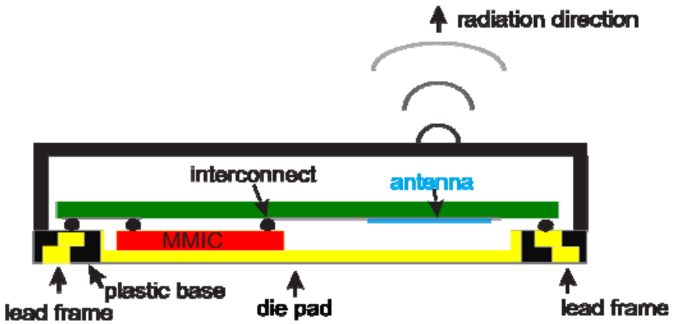
[1]**Y. Sun, C. Scheytt „An Integrated Harmonic Transmitter Front-End for 122 GHz FMCW/CW Radar Sensor“, European Microwave Week 2011, Manchester, UK**

Vision of a mm-Wave SiP

- **System-In-Package**
- **Integration of antennas**
- **SMD-type plastic package**
- **Precision RF substrate**
- **Allows for low cost package and easy assembly**

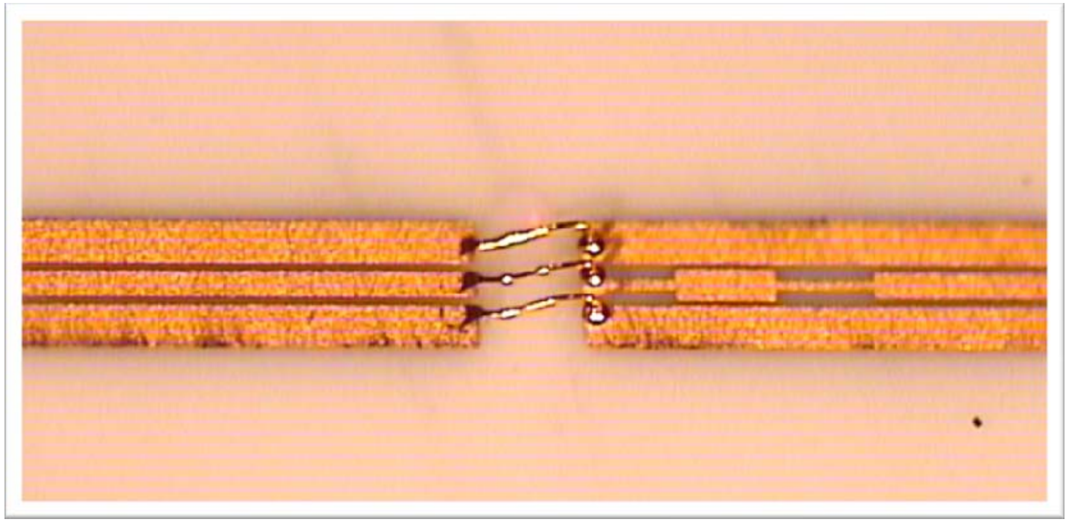






400 µm Wire-Bond with compensation

2



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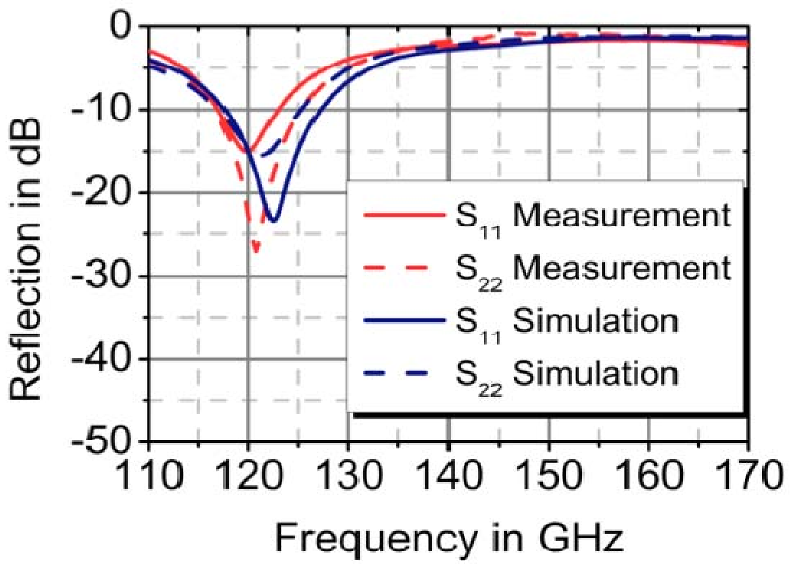
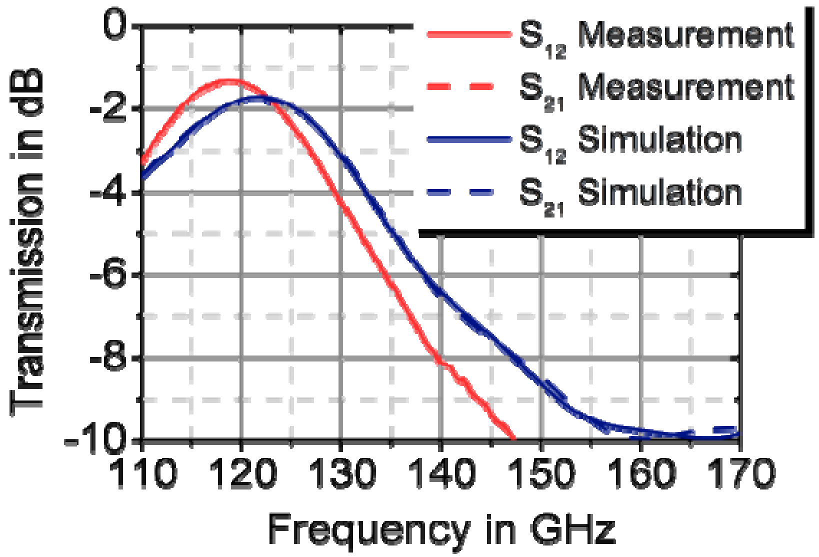




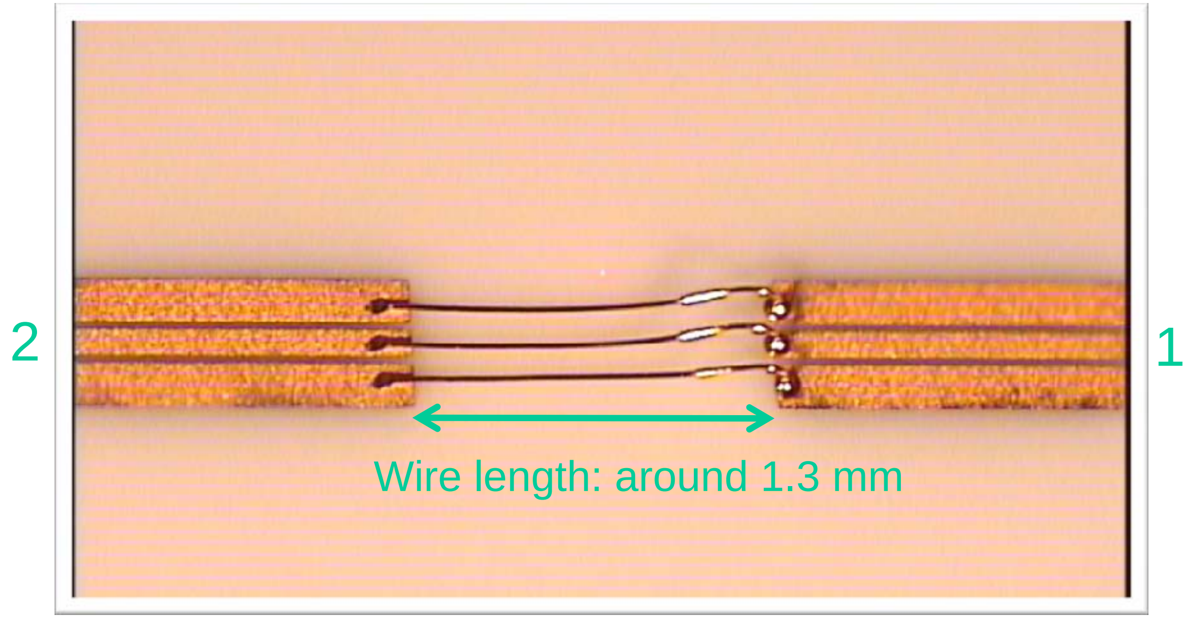
Simulation:

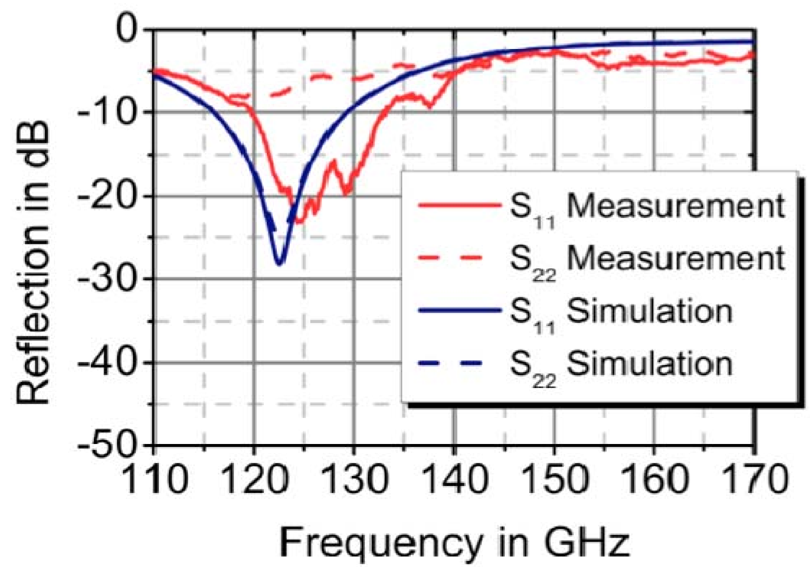
- 122.5 GHz: -1.49 dB
- 0.95 dB loss by the transition and compensation

Measurement:

- 119.8 GHz: -1.53 dB
- 0.78 dB loss by the transition and compensation
- -1 dB-Bandwidth: around 3 GHz

Half-Wave Wire Bond Interconnection



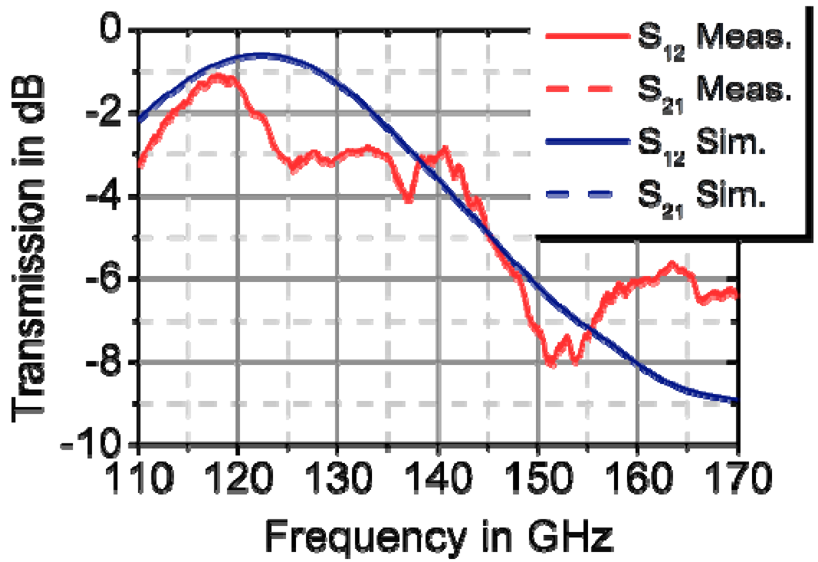


Simulation:

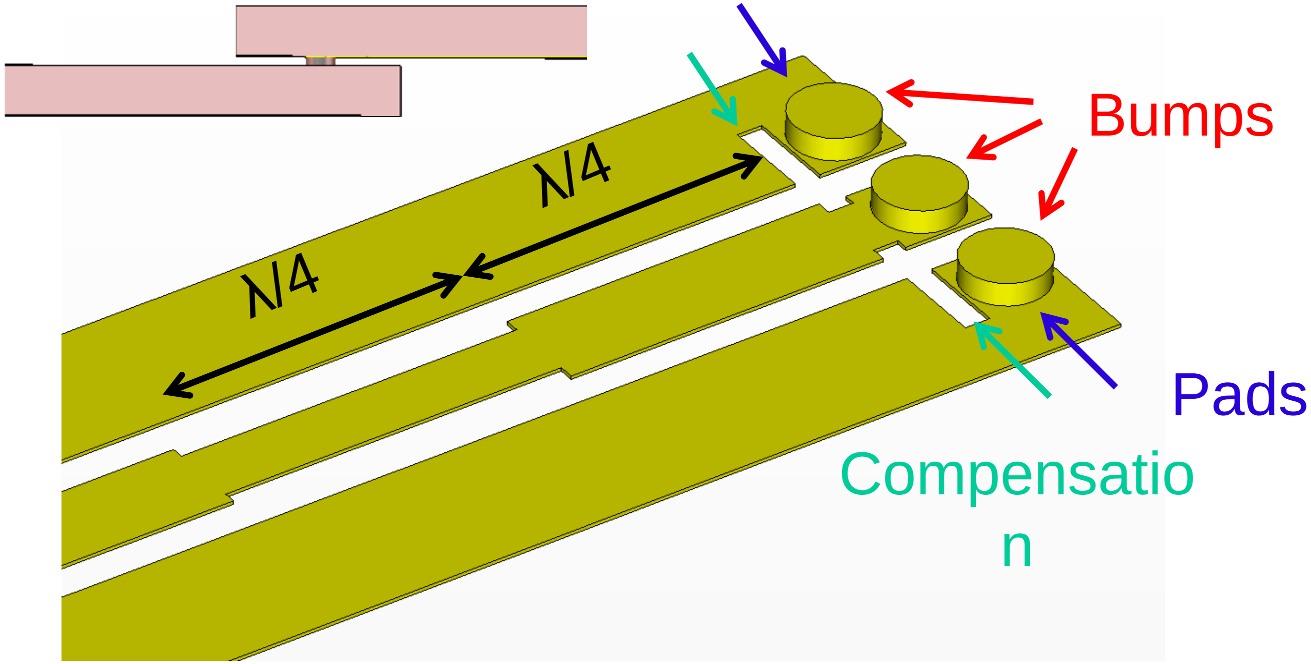
- 122.5 GHz: -0.63 dB
- 0.22 dB loss at interconnect

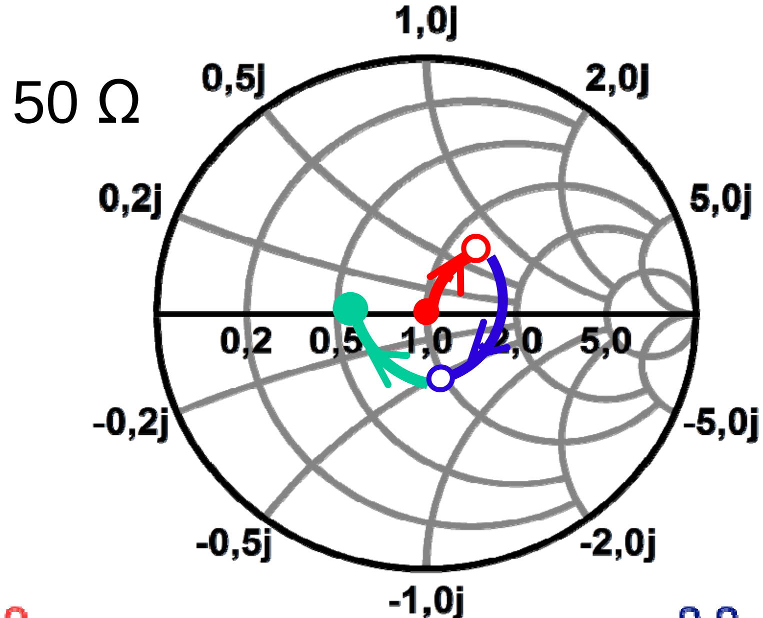
Measurement:

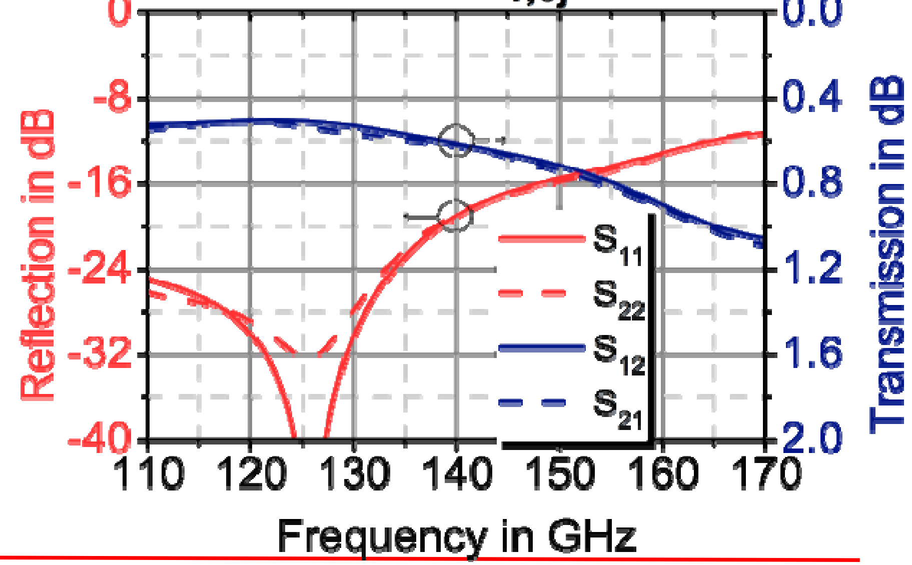
- 118.2 GHz : -1.1 dB
- 0.44 dB loss at interconnect
- -1 dB-bandwidth: around 6 GHz



Single Flip Chip Interconnect

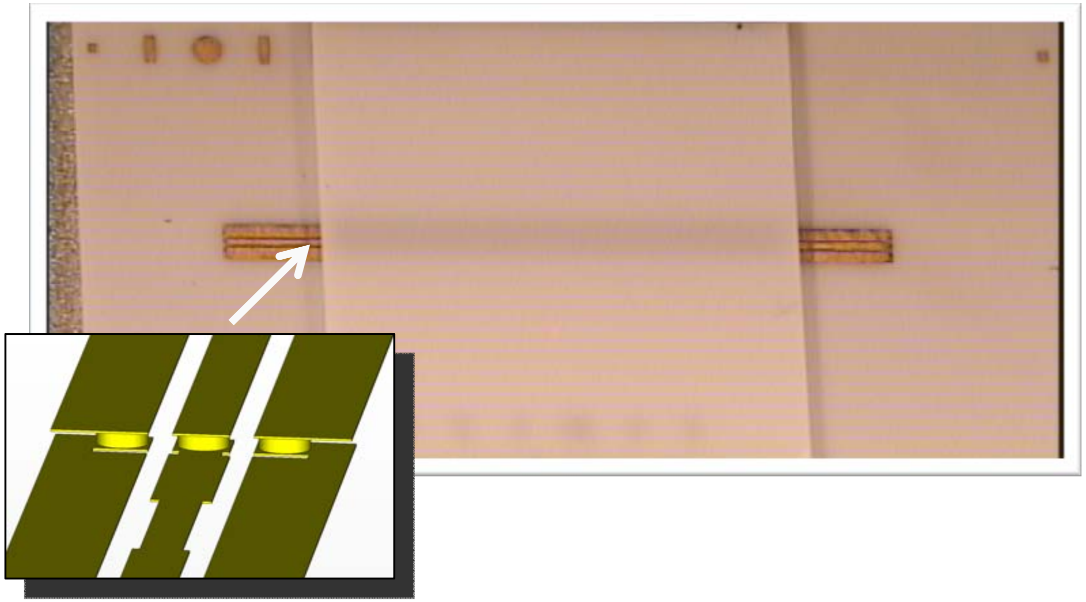


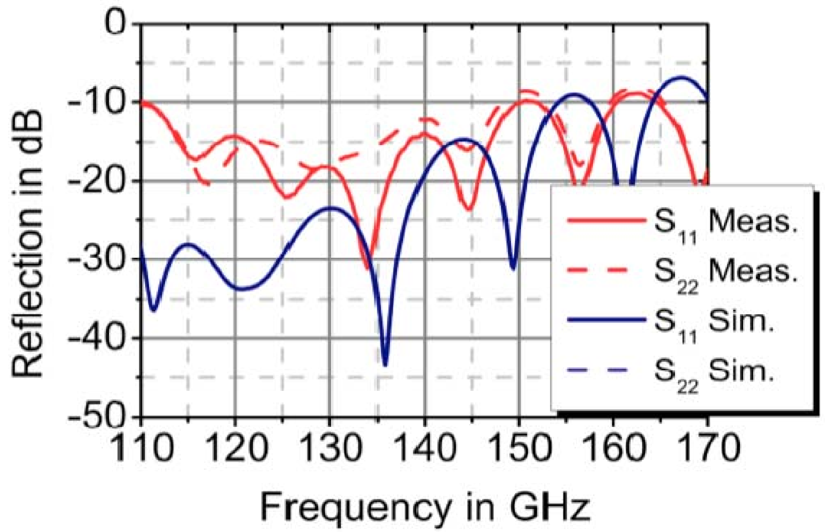




- **-20 dB Bandwidth: 14 GHz**
- **No loss at bumps**

122 GHz Flip Chip Interconnect



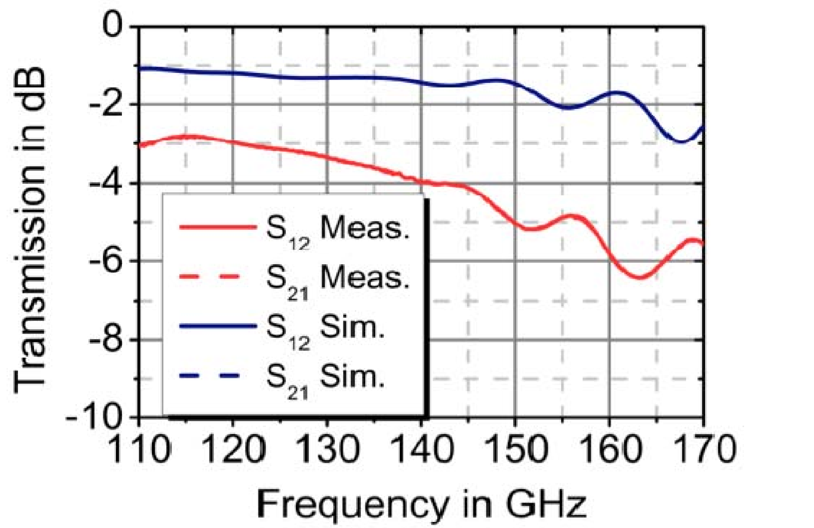


Simulation:

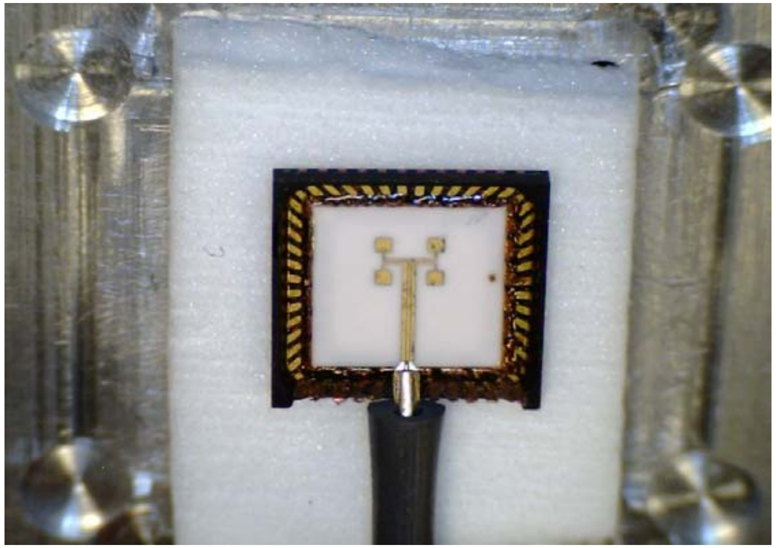
- 122.5 GHz: -1.38 dB
- No losses at bumps

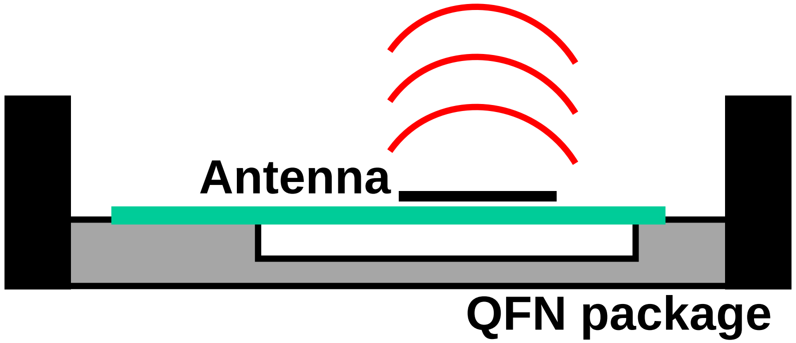
Measurement:

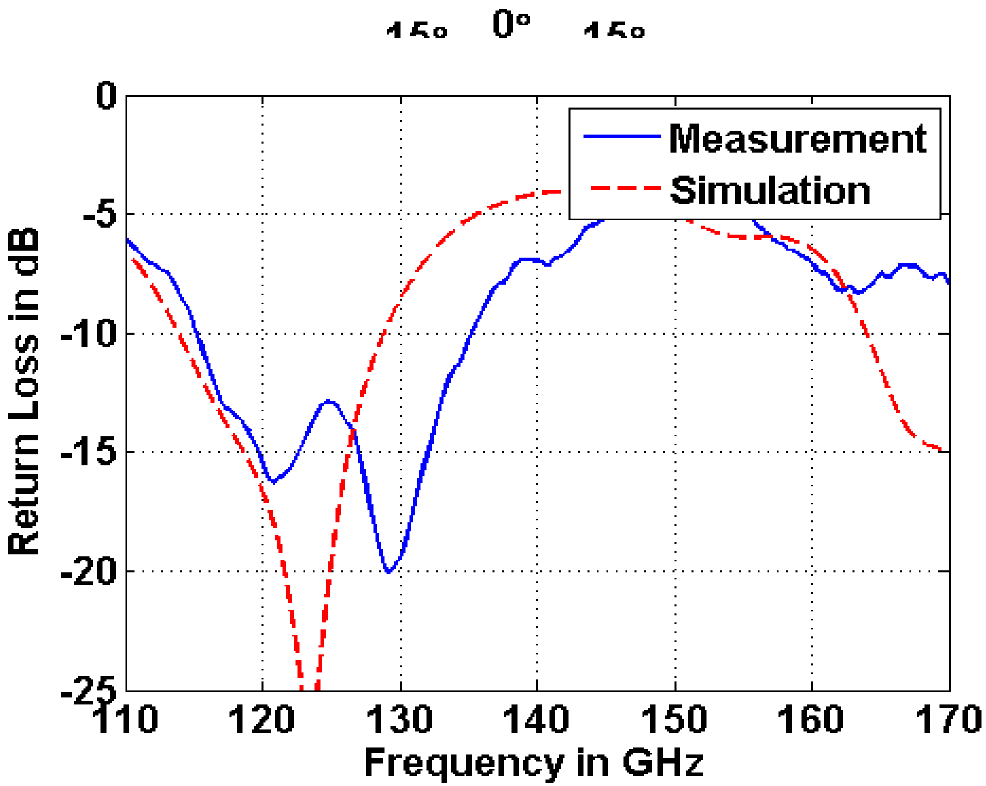
- 122.5 GHz: -2,91 dB
- 0.63 dB losses at bumps and compensation networks
- -1 dB-Bandwidth: > 13.8 GHz



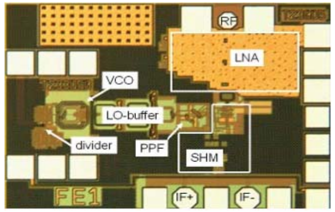
Antenna in QFN package







Future Work on mm-Wave SiP



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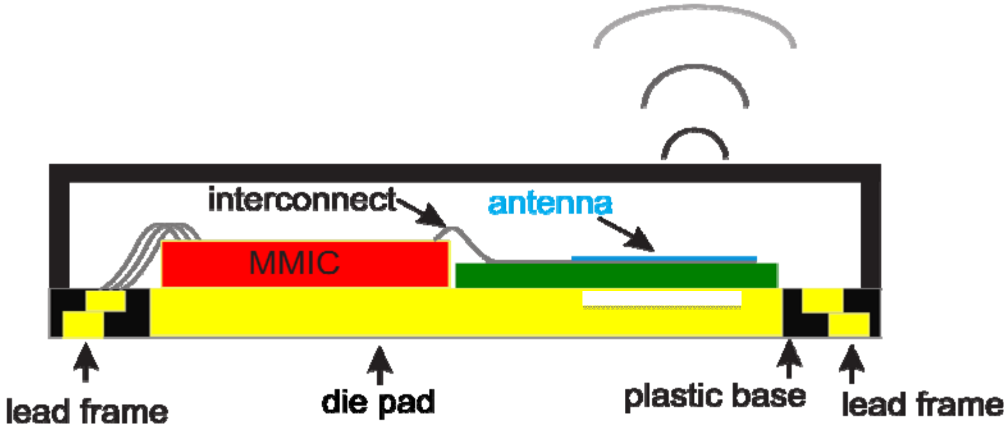

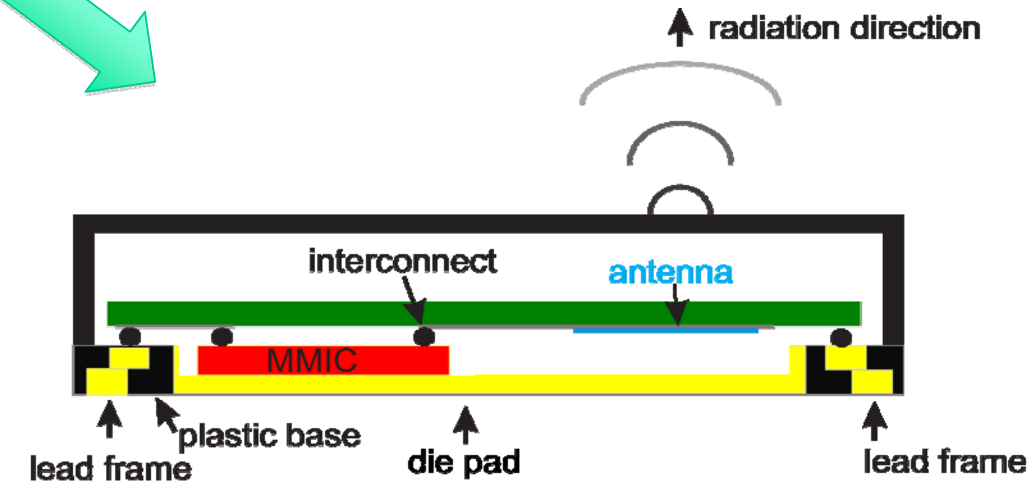

Summary

- **SUCCESS project addresses mm-wave SoC design, mm-wave BIST, and mm-wave SiP to enable high-volume, low-cost, mm-wave applications in silicon technology**
- **Demonstrator: 122 GHz radar system for low-cost applications**
- **mm-wave BIST example:**
  on-chip measurement of P_{out} and S_{11} at 122 GHz
- **Mm-wave SiP concepts with integrated antennas**
- **Investigations of different chip-to-package interconnects**
- **Antenna integration**

Acknowledgements

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Thank you to the audience!