

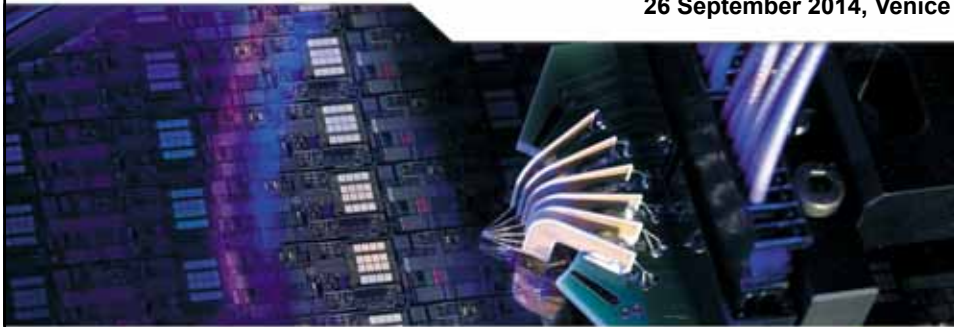


## Integrated Microwave Sensors

Andreas Stelzer

Johannes Kepler University Linz

THz-Workshop: Millimeter- and  
Sub-Millimeter-Wave circuit  
design and characterization  
26 September 2014, Venice



A European Project supported within the Seventh Framework Programme for Research and Technological Development



JOHANNES KEPLER  
UNIVERSITY LINZ | JKU

## Integrated Microwave Sensors in SiGe with Antenna in Package: From Concepts to Solutions

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## Motivation of Talk / Industrial Aspects



- Integrated radar sensors
  - Find sensor concepts suitable for integration
  - Digitally assisted RF
- Industrial microwave sensors
  - Applied for a specific measurement problem
  - High accuracy (whereby the targets are usually known)
  - Estimation problem instead of a detection problem
  - Short range, very high bandwidths required
  - Easy applicability, packaging, SMD soldering
  - Least „RF“ as possible to work with
  - Concentration on application-specific signal-processing

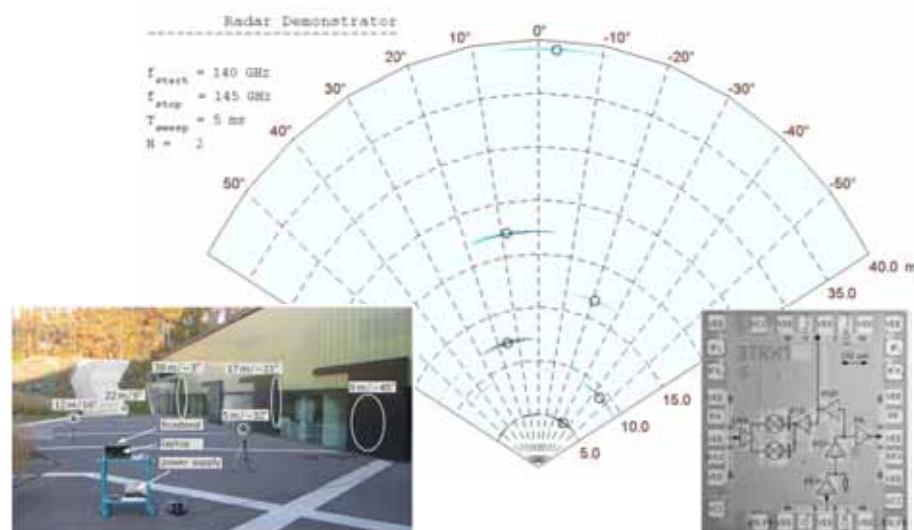
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## Example: 140 GHz DBF Radar (Range-Angle)



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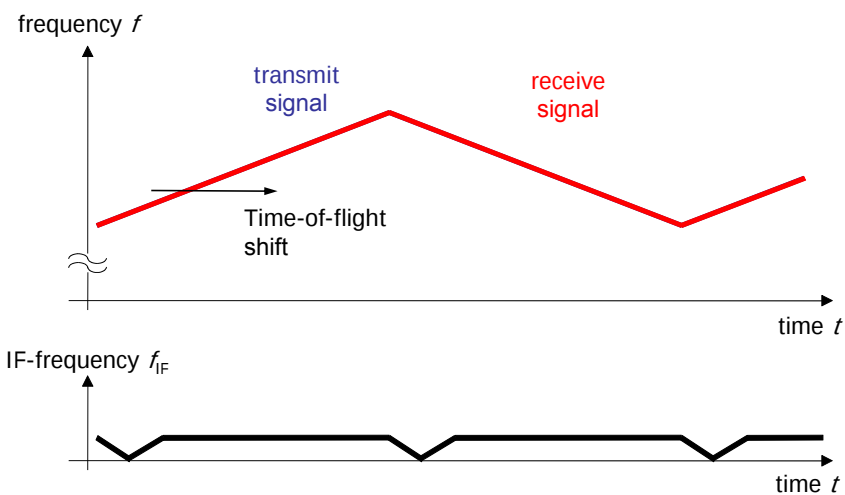


# Part I: Concept

- FDMA-MIMO,  $\Delta\Sigma$ -Mod.

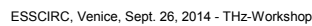


## FMCW Principle – Stationary Target



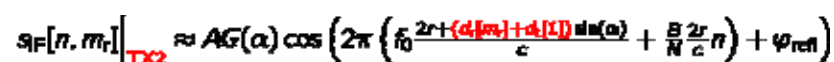


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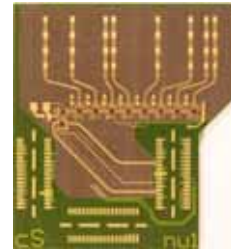
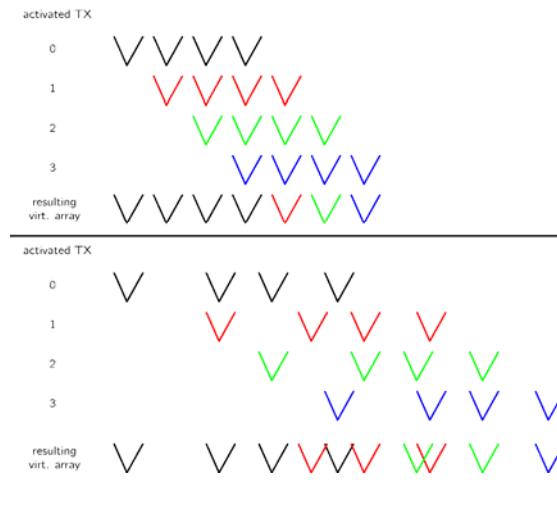


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## Uniform vs. Non-Uniform Arrays



R. Feger, C. Wagner, S. Schuster, S. Scheibhofer, H. Jäger, and A. Stelzer, "A 77-GHz FMCW MIMO Radar Based on a SiGe Single Chip Transceiver," *IEEE Trans. Microwave Theory Tech.*, IEEE-MTT, vol. 57, no. 5, May 2009, pp. 1020–1035.  
IEEE MICROWAVE PRIZE 2011

C. M. Schmid, R. Feger, C. Wagner, and A. Stelzer, "Design of a linear non-uniform antenna array for a 77-GHz MIMO FMCW radar," *IEEE International Microwave Workshop Series on Microwave Sensing, Local Positioning, and RFID*, (IMWS 2009-Croatia), Sept. 24–25, 2009, pp. 41–44.  
VDI PRIZE (diploma thesis) 2010

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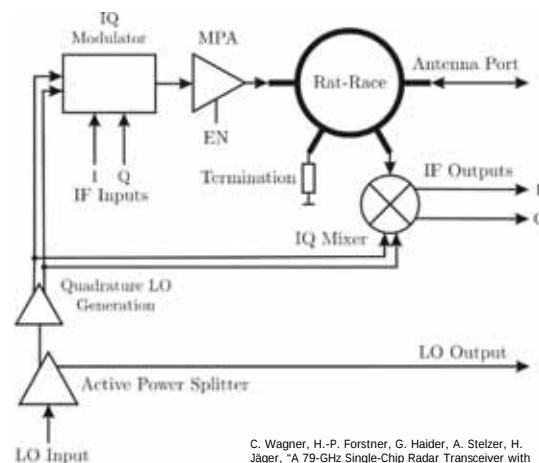
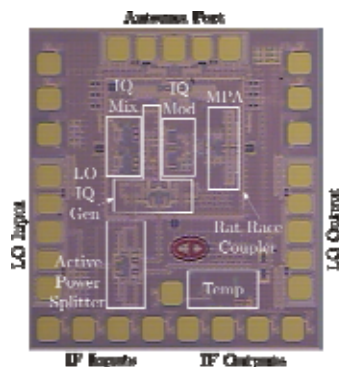
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## Multi-Mode – Radar Transceiver



- LO daisy-chaining
- IQ modulator in TX path
- IQ mixer in RX path
- On-chip quadrature LO signal generation



C. Wagner, H.-P. Forstner, G. Haider, A. Stelzer, H. Jäger, "A 79-GHz Single-Chip Radar Transceiver with Switchable TX and LO Feedthru in a Silicon-Germanium Technology", *Proc. IEEE Bipolar / BICMOS Circuits and Technology Meeting* (BCTM2008), Oct. 13–16, 2008, Monterey, CA, USA.

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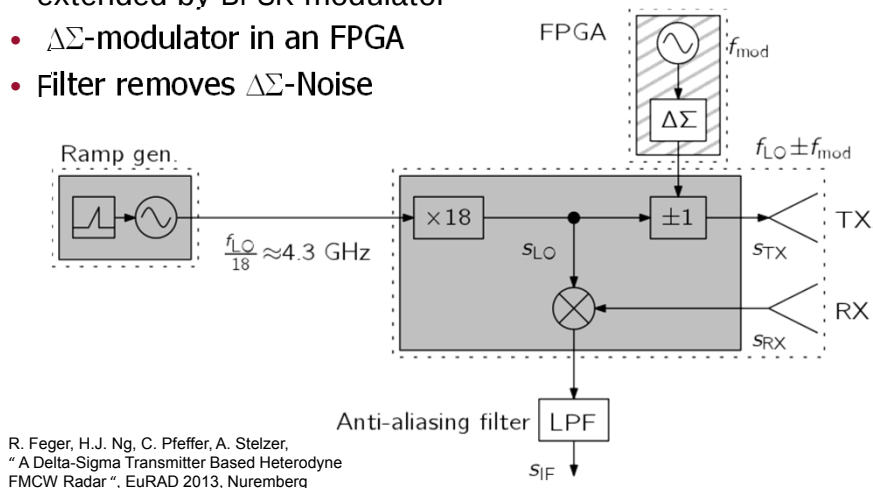
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## Heterodyne Radar with BPSK and $\Delta\Sigma$ -Mod.



- Conventional FMCW architecture extended by BPSK modulator
- $\Delta\Sigma$ -modulator in an FPGA
- Filter removes  $\Delta\Sigma$ -Noise



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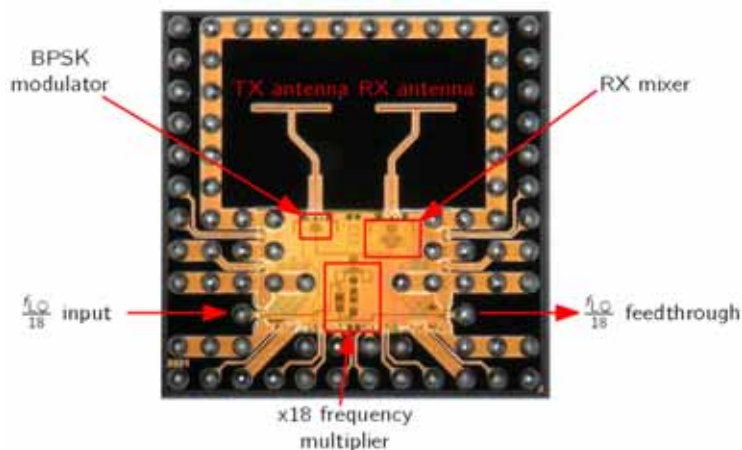
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## Heterodyne Radar with BPSK and $\Delta\Sigma$ -Mod.



- All required RF components inside a single package
  - Additional space required for BPSK modulator is very small

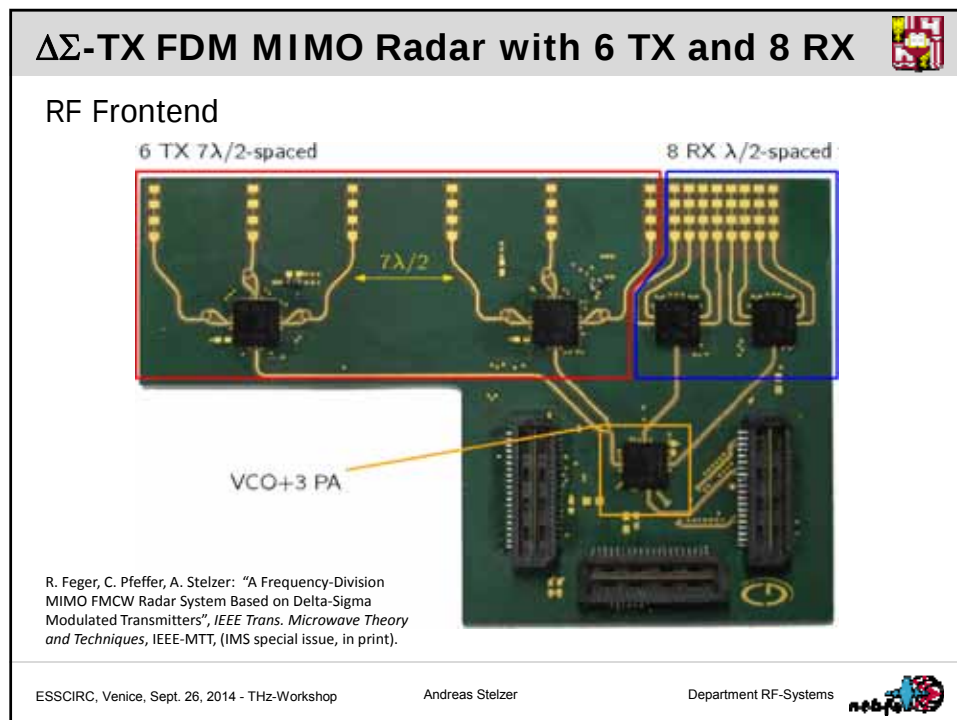
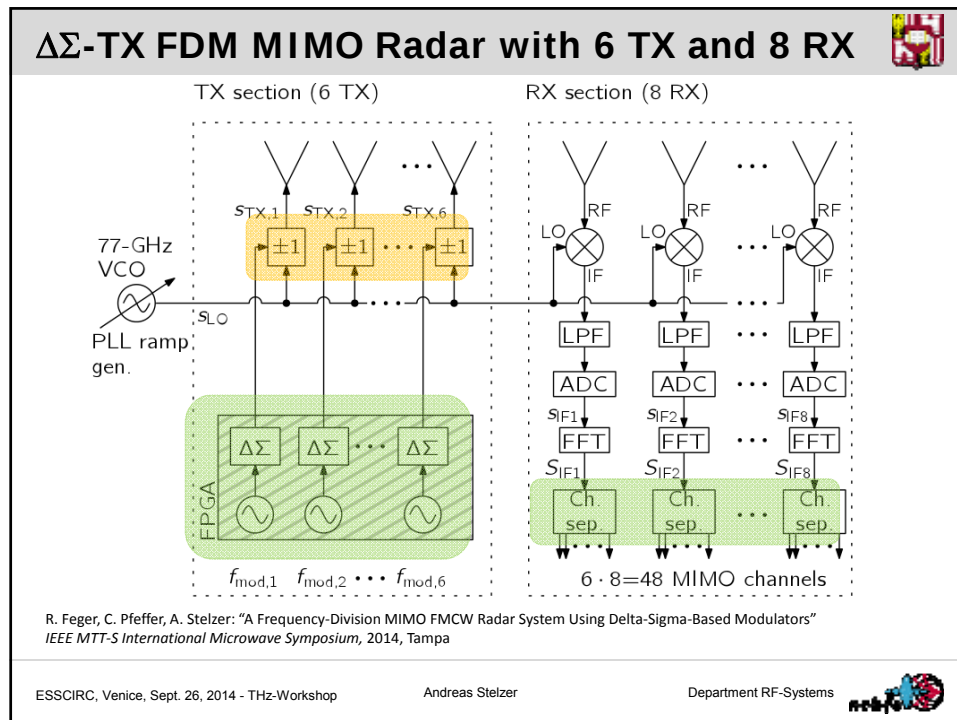


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## Part II:

### • Antenna in Package

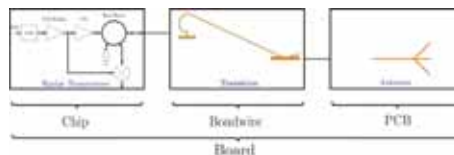


## Antenna on Board – on Chip – in a Package



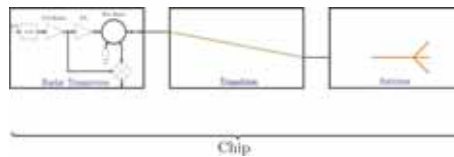
- Antenna on Board (AoB)

- + large aperture
- + low-cost material
- bond-wire transition
- loss on PCB



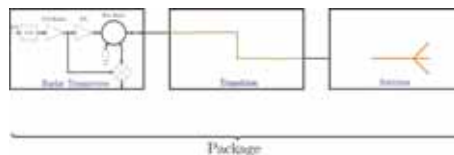
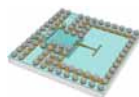
- Antenna on Chip (AoC)

- + short interconnects
- + no bond-wires
- low efficiency
- chip area expensive

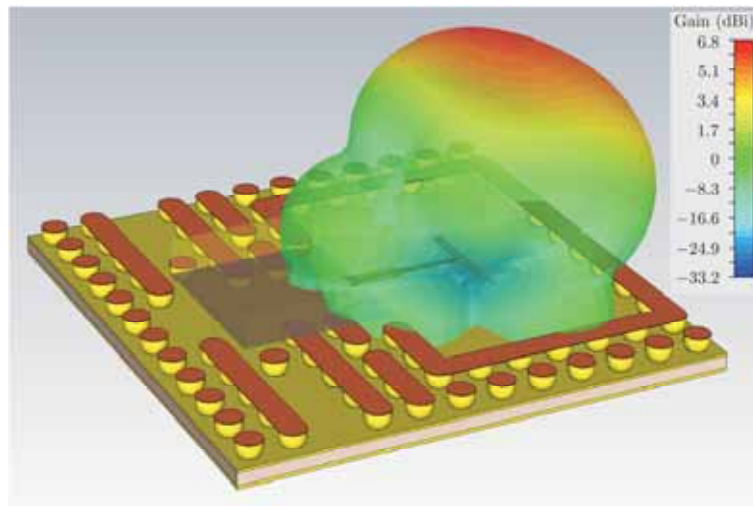


- Antenna in Package (AiP)

- + low cost
- + high efficiency
- + no bond-wires
- medium size



## eWLB-Technology: EM-Simulation (CST)



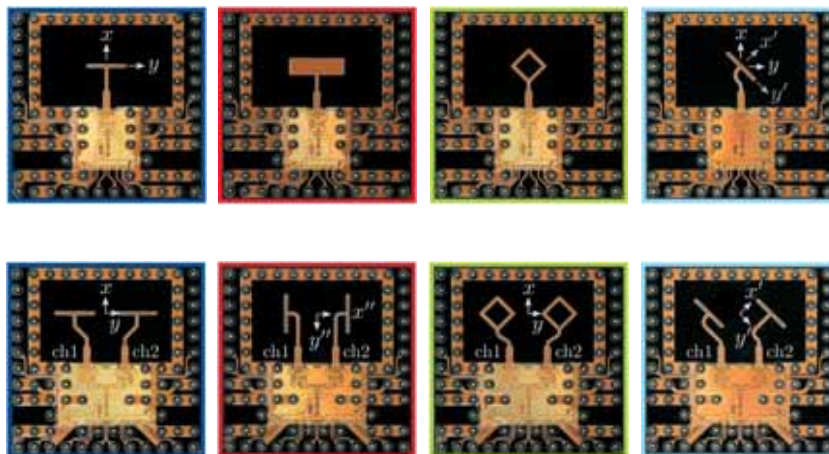
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## eWLB-AiP: 1 and 2-Channel Radar Sensors



A. Fischer, Z. Tong, A. Hamidipour, L. Maurer, A. Stelzer: "77-GHz Multi-Channel Radar Transceiver with Antenna in Package"  
*IEEE Transactions on Antennas and Propagation*, IEEE-AP, vol. 63, no. 3, March 2014, pp. 1386–1394, ISSN 0018-926X.

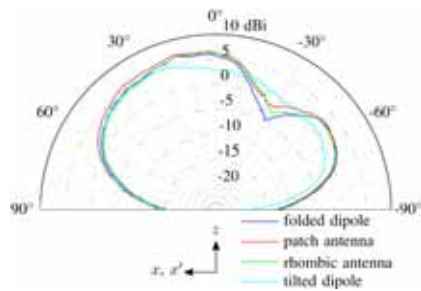
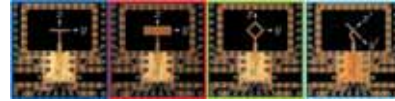
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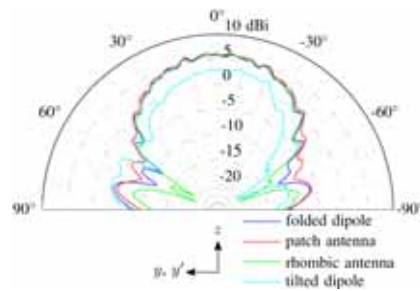
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## Measurements: 1-Channel Sensors



- ▶ H-plane
- ▶  $f_{\text{OUT}} = 76.5 \text{ GHz}$



- ▶ E-plane
- ▶  $f_{\text{OUT}} = 76.5 \text{ GHz}$

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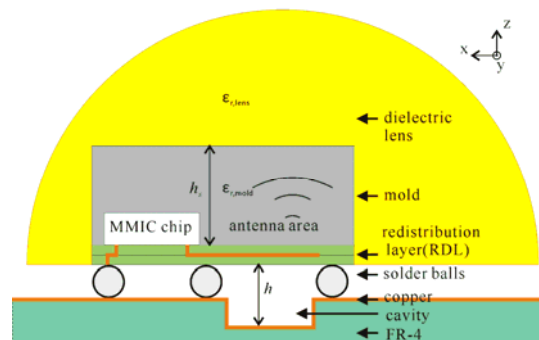
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## eWLB-AiP: Dielectric lens



- Structure of hemisphere lens
  - Material: PEEK (dielectric constant 3.2)



Cross section of hemisphere lens with AiP on PCB

\*not to scale

Z. Tong, A. Fischer, A. Stelzer, and L. Maurer: "Bandwidth and Gain Enhancement of Antenna in Package", 21<sup>st</sup> Conference on Electrical Performance of Electronic Packaging and Systems (EPEPS 2012), Oct. 21–24, 2012, Tempe, USA, pp. 149–152, ISBN 978-1-4673-2539-4

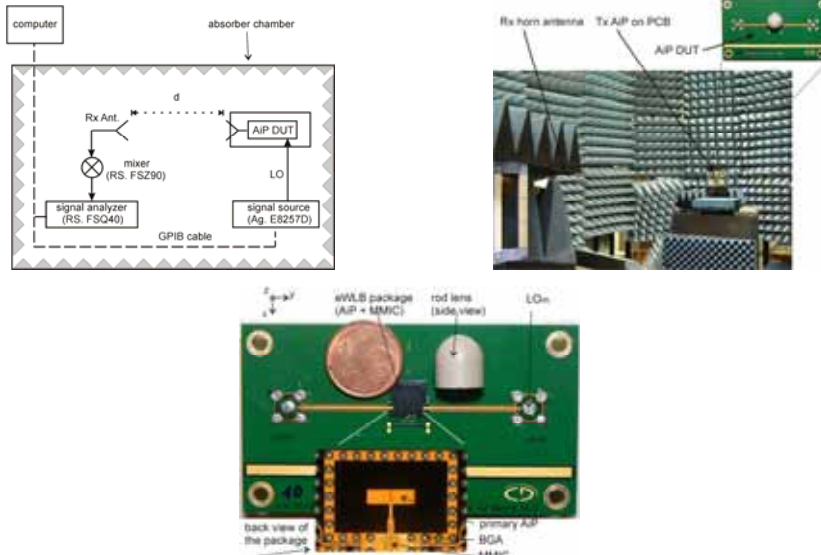
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## eWLB-AiP: Test Setup



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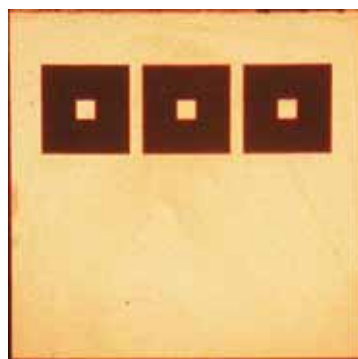


## eWLB-AiP with Backside Metallization

- AiPs with stacked metallization



Front-side



Back-side

A. Hamidipour, A. Fischer, L. Maurer, W. Hartner, and A. Stelzer: "Antennas in Package With Stacked Metallization", 43<sup>rd</sup> European Microwave Conference 2013 (EuMC), Oct. 6–10, 2013, Nuremberg, Germany, pp. 56–59.

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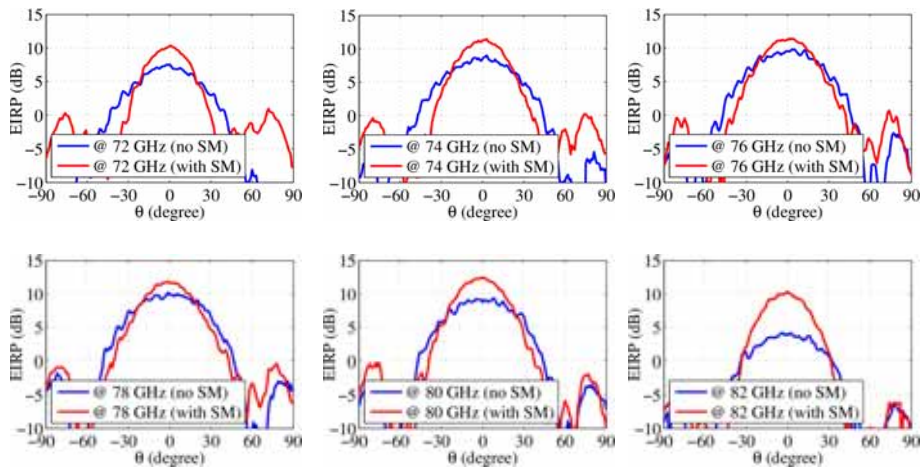
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## eWLB-AiP with Backside Metallization



- Beam pattern in E-plane from 72 to 82 GHz



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## Part III:

- Applications

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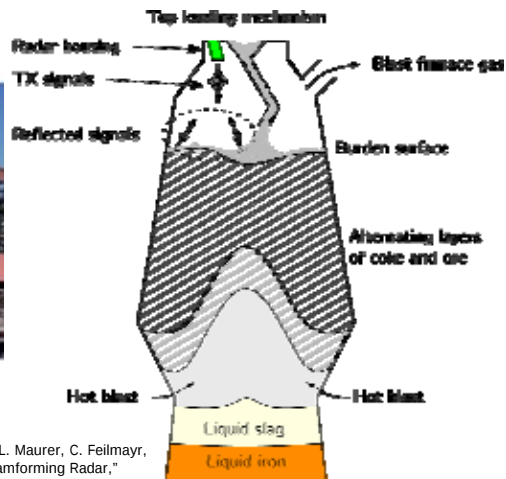
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## 3D-Blast Furnace Radar



- Continuous monitoring of the blast furnace burden surface



R. Feger, S. Schuster, D. Zankl, R-W. Jungmaier, A. Stelzer, L. Maurer, C. Feilmayr,  
 "Blast Furnace Burden Surface Monitoring Using a Digital Beamforming Radar,"  
 13th Mechatronics Forum International Conference, Linz, Austria, 2012

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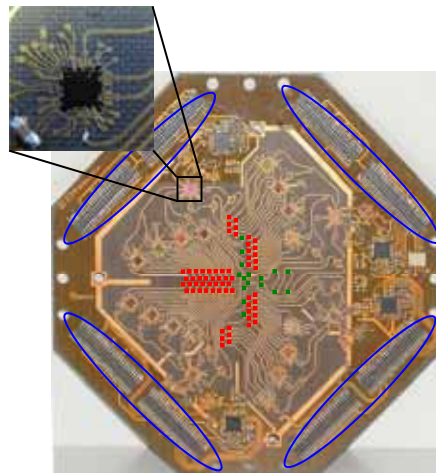


## 3D-Blast Furnace Radar



RF frontend ( $16 \times 16 \text{ cm}^2$ ):

- 64 RX antennas ■
- 16 TX antennas ■
- 256 virtual antennas
- Virt. aperture of  $50 \times 50 \text{ mm}^2$
- Bandwidth = 2 GHz
- Conventional patch antennas
- Microstrip technology
- 2 layers for routing + Ground
- Interfaces for programming, power supply



R. Feger, S. Schuster, D. Zankl, R-W. Jungmaier, A. Stelzer, L. Maurer, C. Feilmayr,  
 "Blast Furnace Burden Surface Monitoring Using a Digital Beamforming Radar,"  
 13th Mechatronics Forum International Conference, Linz, Austria, 2012

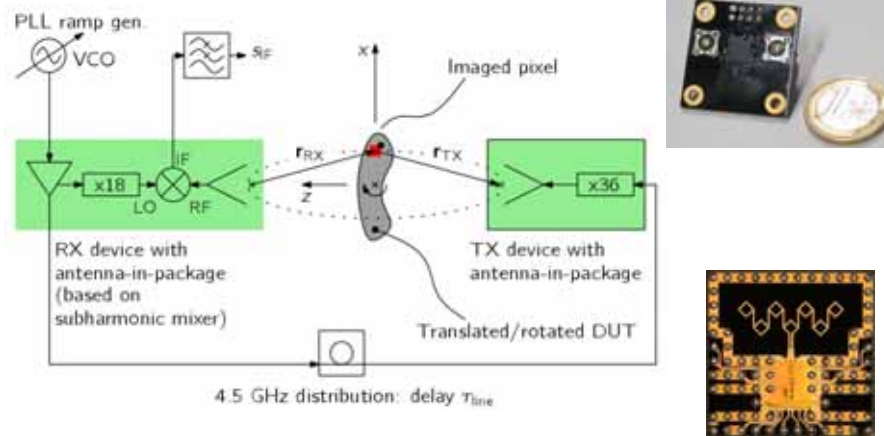
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## Block Diagram of Imaging @160 GHz



R. Feger, A. Hamidipour, A. Stelzer: "Integrated mm-Wave Sensors in a Package"  
Asia Pacific Microwave Conference 2013 (APMC), Seoul, Korea, Nov. 5–8, 2013

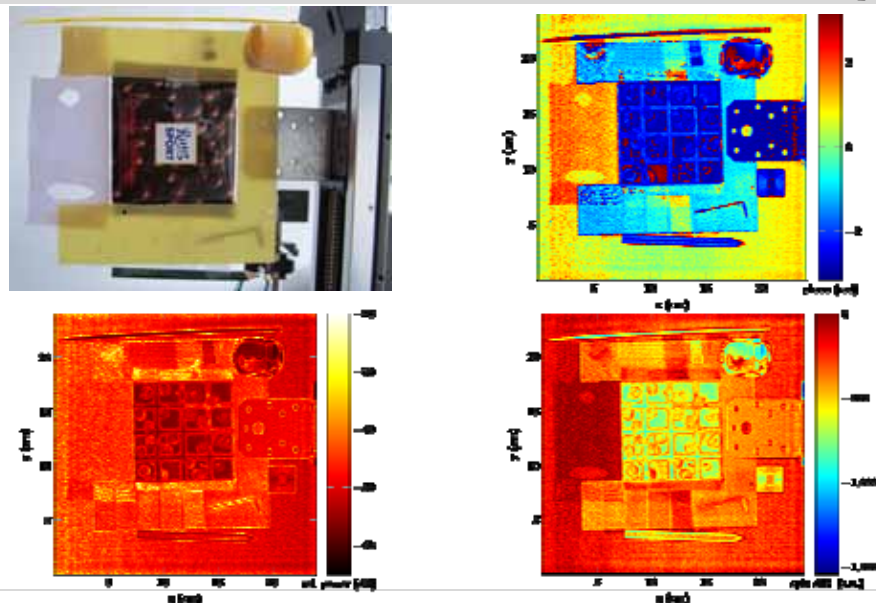
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## Transmission Imaging @160 GHz: Results



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## Summary / Conclusion



- Research Lab for Integrated Radar Sensors @ JKU
  - we work on concepts, circuits and systems for microwave sensing applications, ready for integration
- Introduced a digitally assisted heterodyne FMCW FDMA MIMO with high angular resolution and simultaneous transmission on each transmitter
- Integration of complete sensors in eWLB technology
- SiGe frontends with AiP are ready for applications
- The transition to more flexible radars require more powerful baseband circuitry
- Current research towards *Software Defined Radar* (cp. radio)
  - difficult due to (extremely) high bandwidth
  - required in some way to apply algorithmic progress (STAP)

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## Acknowledgment for Funding and Support



- European Union's 7th Programme for research, technological development and demonstration under grant agreement No 316755
- Christian Doppler Research Association
- Infineon and DICE
- Austrian Center of Comp. in Mechatronics
- Johannes Kepler University  
Institute for Communications Engineering and RF-Systems



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