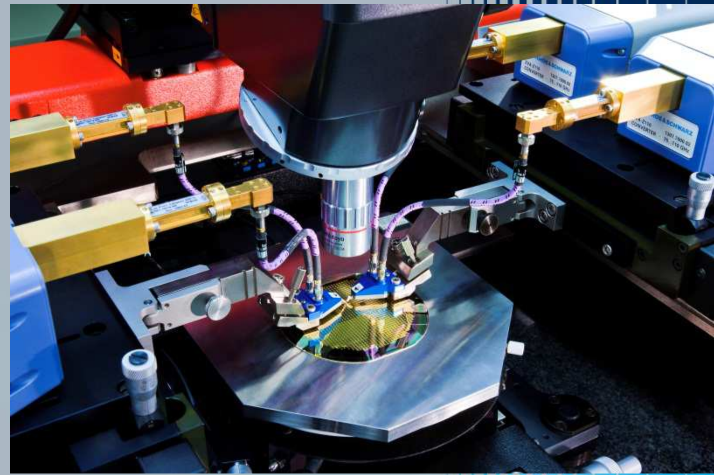
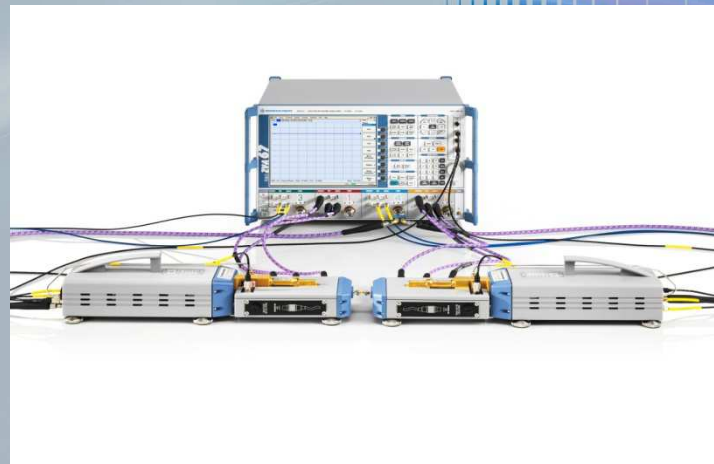
Amplifier Characterization in the millimeter wave range





Tera Hertz : New opportunities for industry
3-5 February 2015

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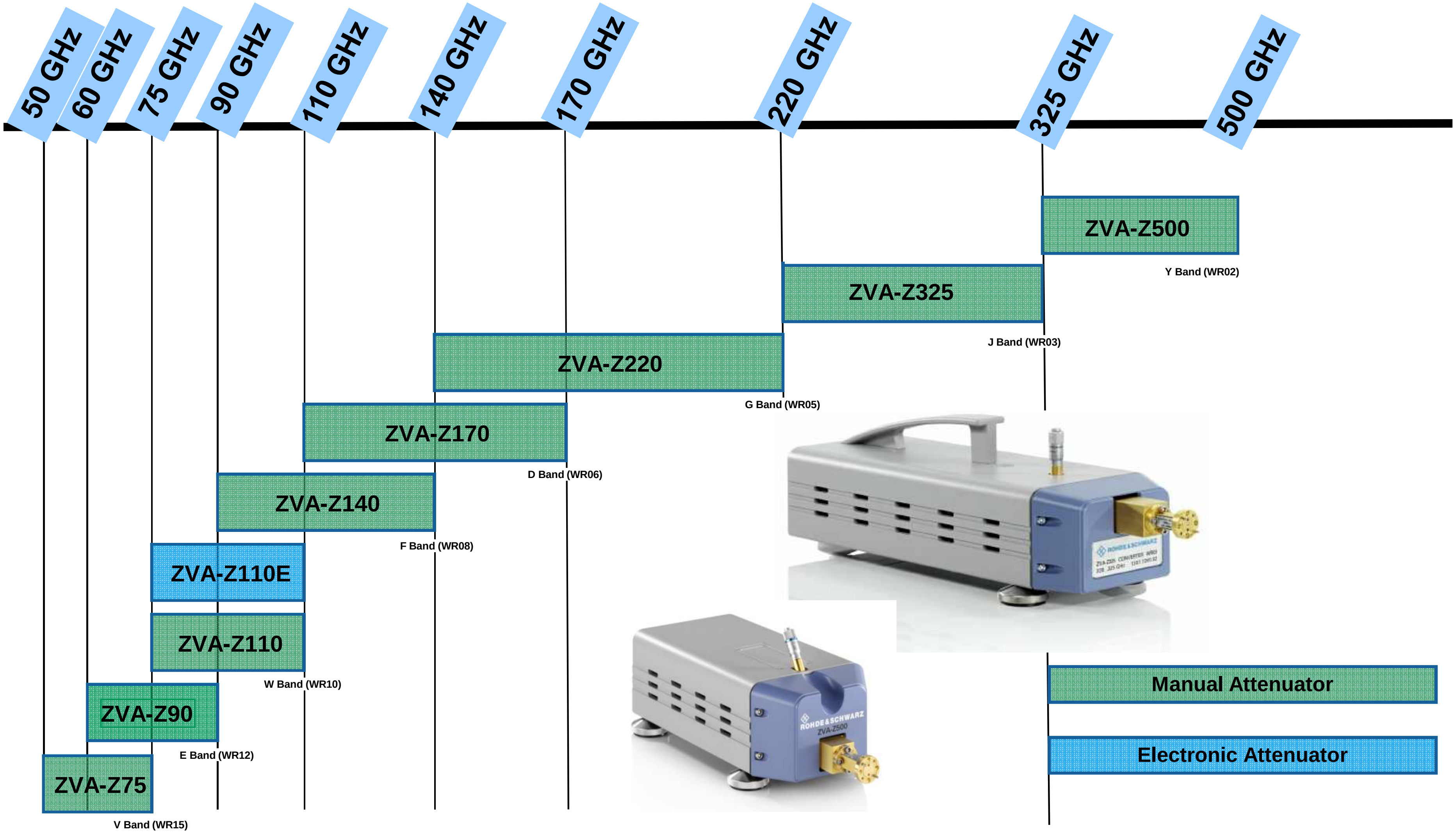
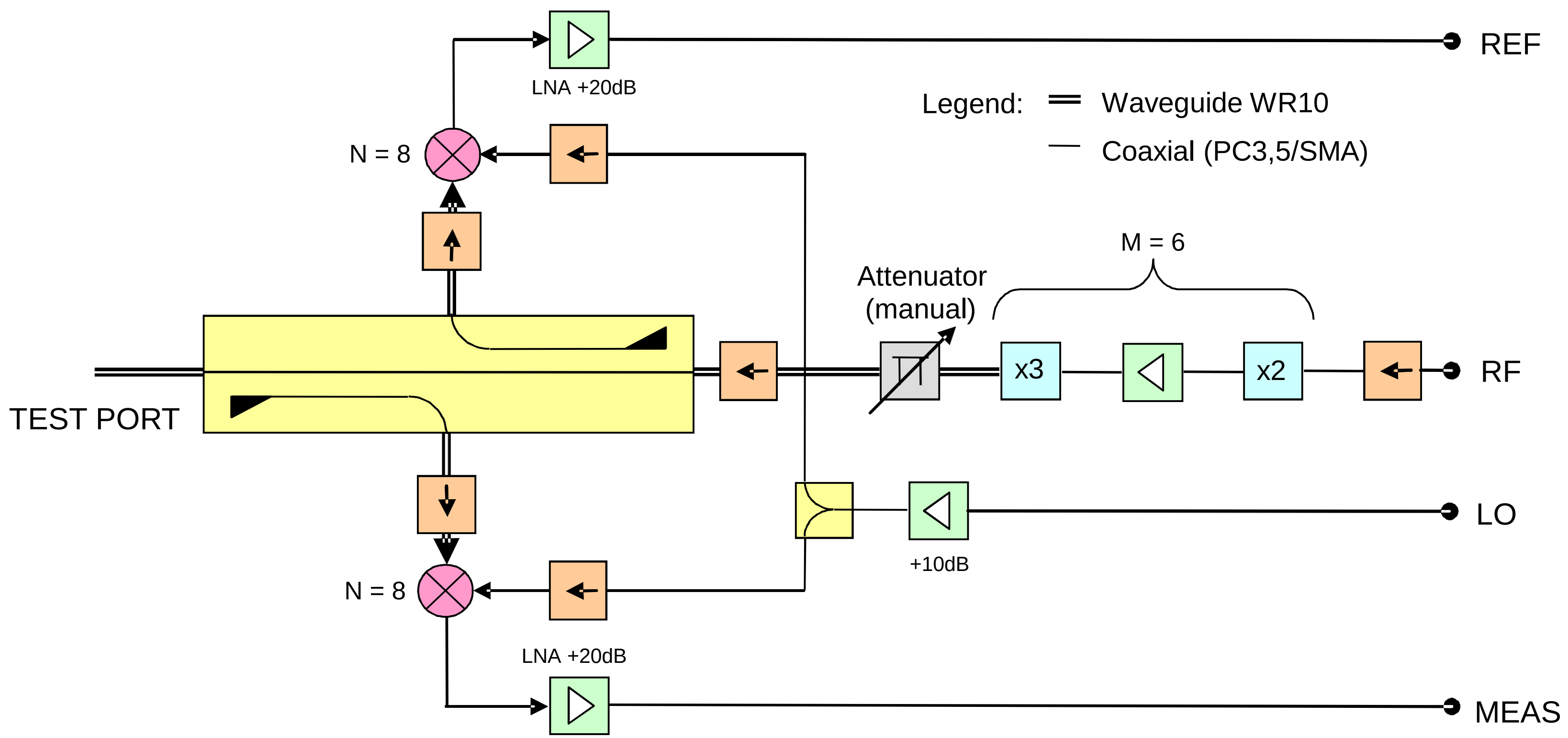
Millimeter Wave Converter Family



Converter block diagram (ZVA-Z110, WR10 band)



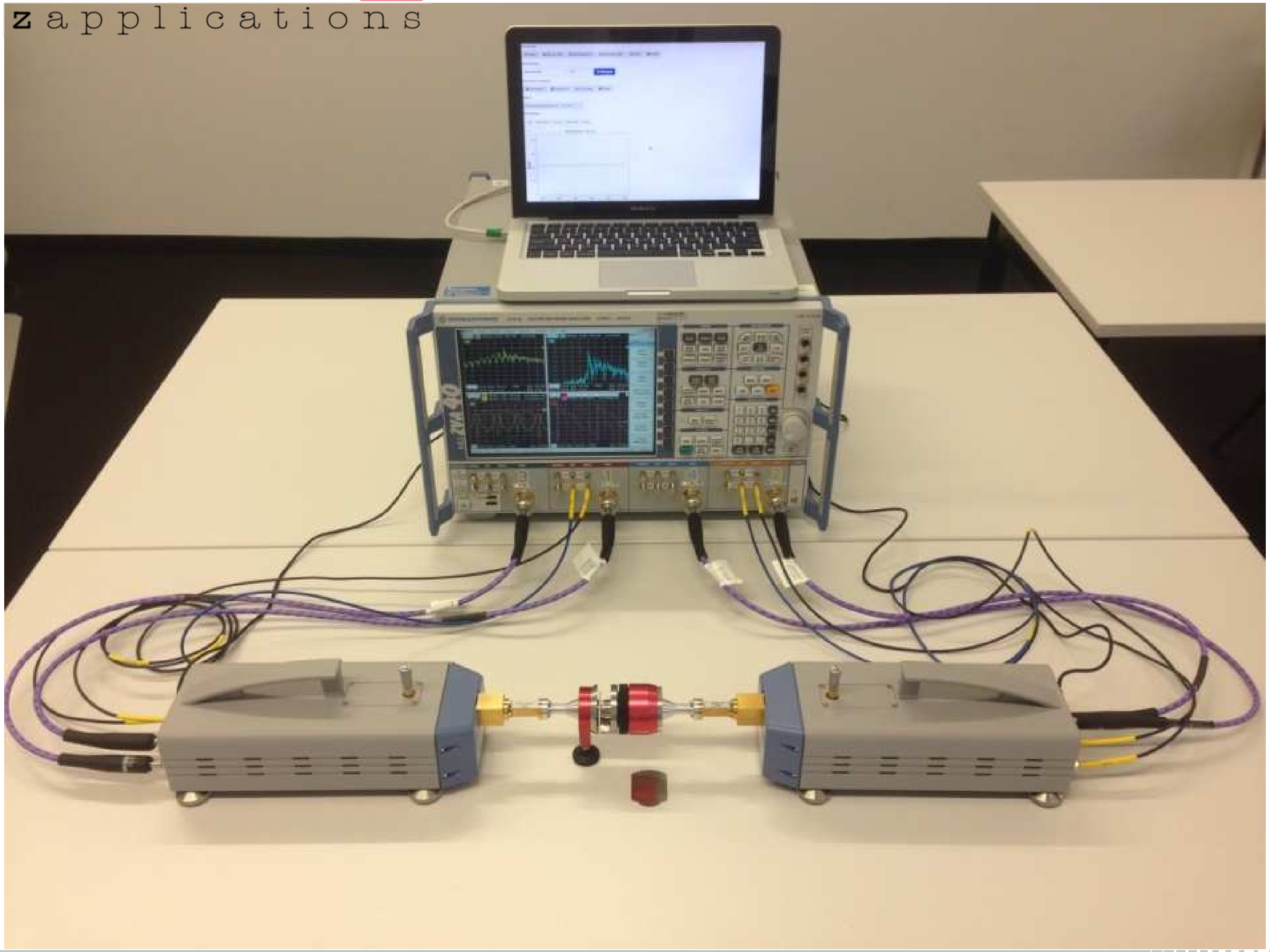
Rohde & Schwarz ZVA-Z110

RF, LO, IF parameters

- Source Input (from VNA):
  - Frequency Range: 12.5 GHz to 18.333334 GHz (x6)
  - Input power range: +4 dBm to +10 dBm
- Local Oscillator Input (from VNA/ext source)
  - Frequency Range: 9.3375 GHz to 13.74875 GHz (x8)
  - Input power Range: +5 dBm to +10dBm
- Measurement/Reference Output (to VNA)
  - Frequency Range: 10 MHz to 300 MHz

Material measurements in the millimeter wave range

Swissto12®
terahertz applications



Amplifier Characterization

Compression point measurement , e.g. 1dB CP

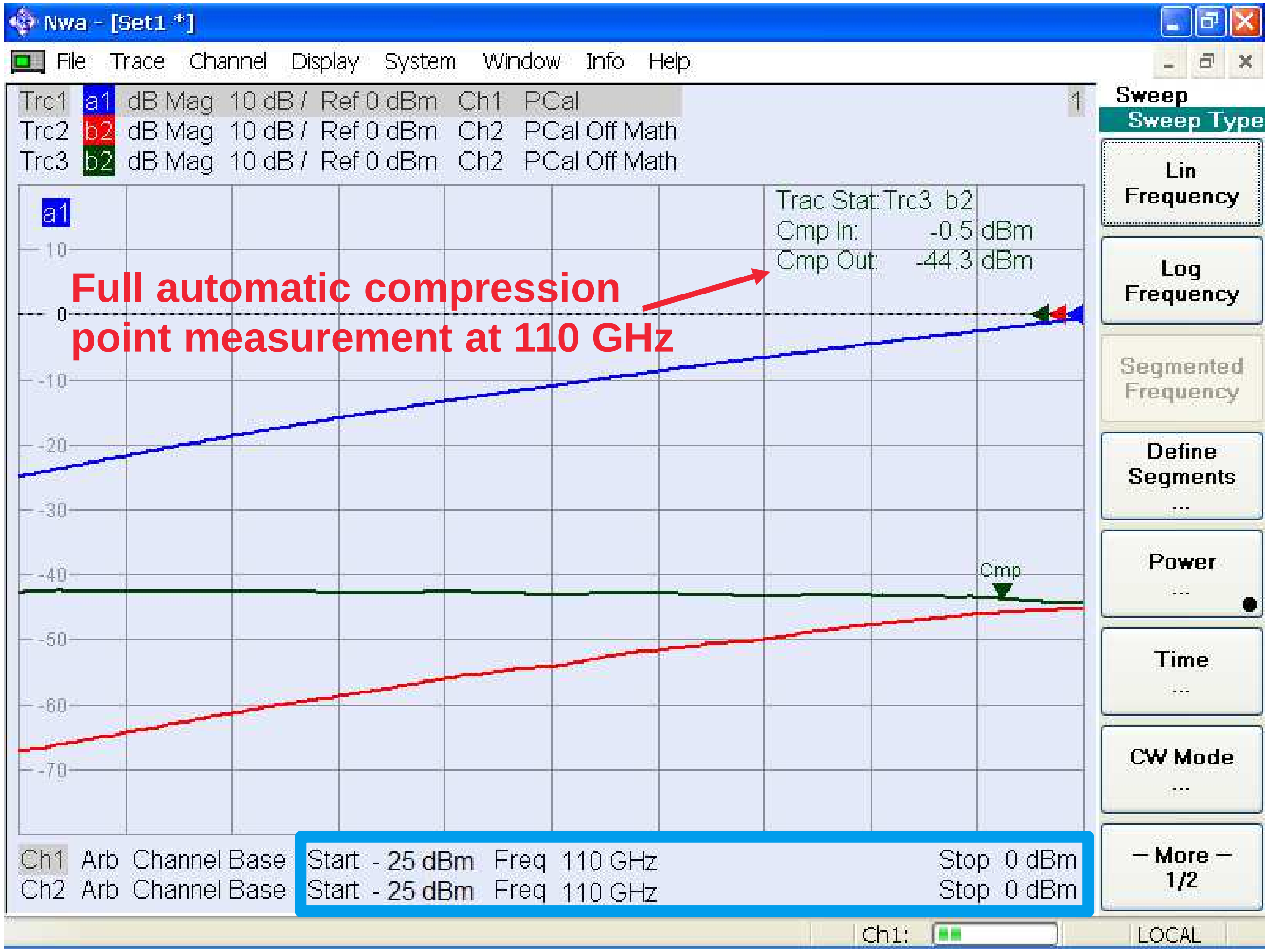
- Requires power sweep capability
- For accurate compression measurements we need
  - A flat input power @ DUT input
  - A defined (calibrated) power level @ DUT input

- Consequence : Power calibration is a must

ZVA-Z110E with electronic power control

- 75 to 110GHz with electronic power control
- 0 to 25 dB attenuation
- Allows power sweep and compression point measurement on amplifiers

Electronic power control



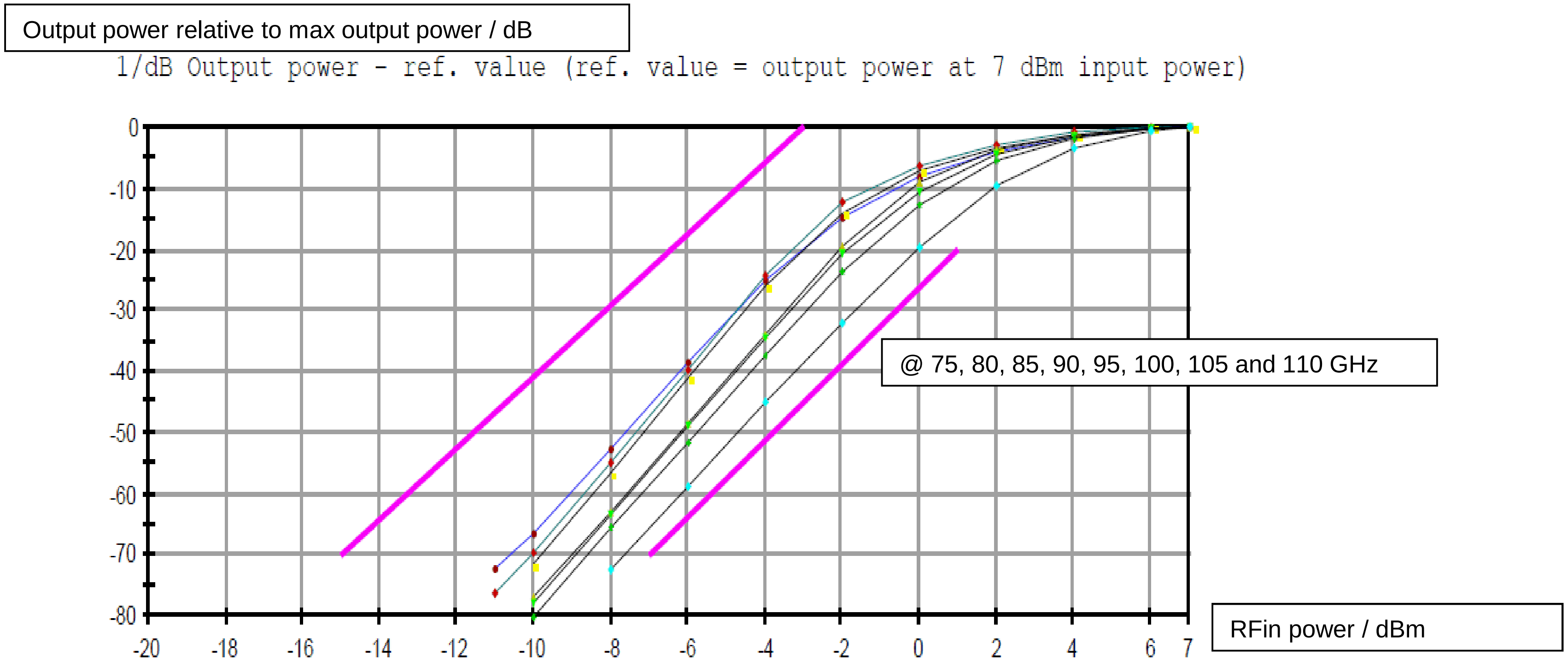
25dB Electronic Power Sweep Range

To R&S® ZVA-Z110E

Option R&S®ZVA-B8

Power Sweep by RF input variation
Example WR10 band

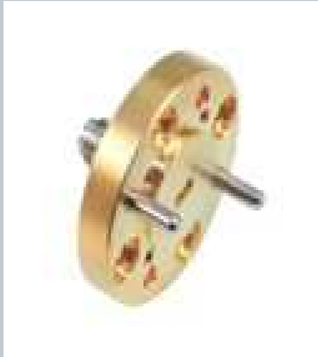
- Power sweep range of 70dB by RF input power variation
- Frequency dependency can be calibrated out by software tool



Power Calibration
in the millimeter wave range

Precise power calibration up to 110GHz

- Unique power measurements from DC up to 110GHz with 1.0mm connector
- First millimeter power sensor that is traceable to a national metrology institute
- S-Parameters of waveguide transition can be loaded directly into sensor for accurate power measurements
- USB interface means the power sensor can be used directly with the ZVA or PC running the free NRP analysis software.
- Lowest uncertainty 0.040 to 0.318dB
  Highest Linearity 0.010dB @110GHz
  30% faster than competition



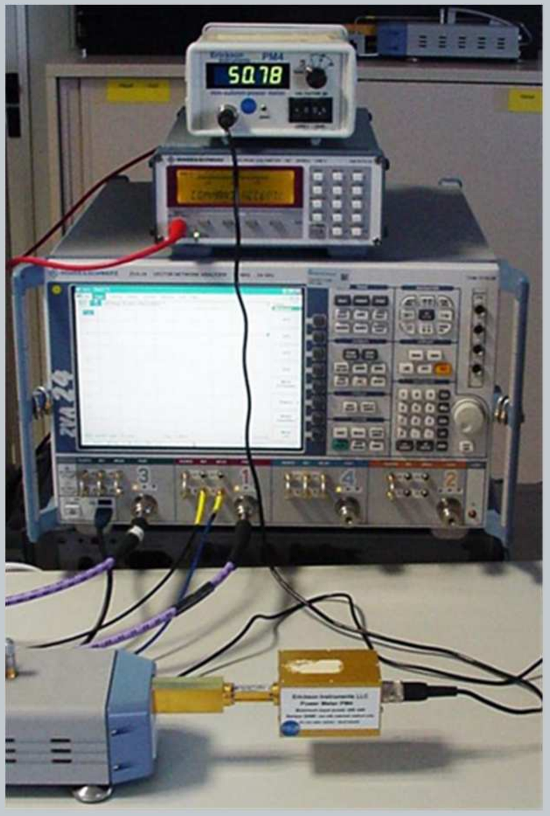
Power calibration above 110GHz

Compatibility for power measurements up to 220GHz with the ELVA DPM power meter.

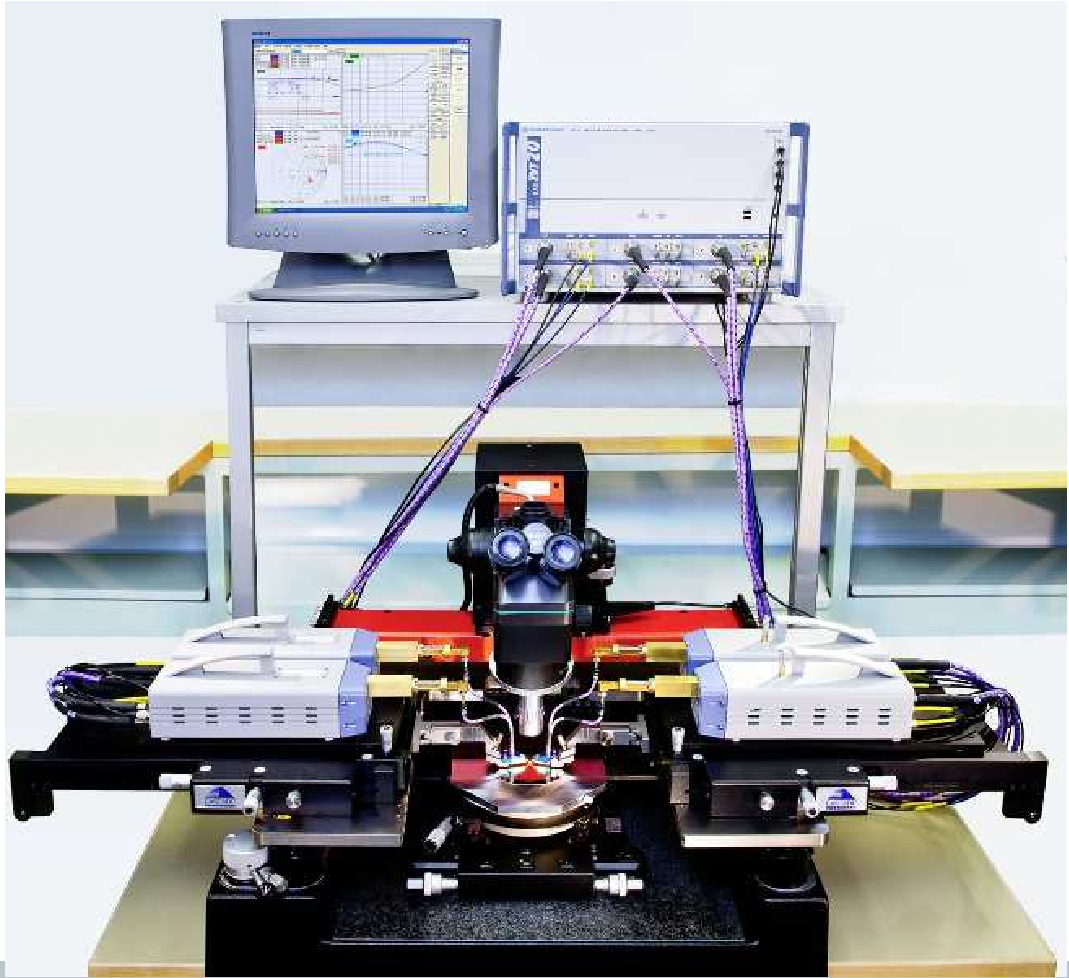
Compatibility with VDI (Erickson) PM4/5 Calorimeter power meter for use from 75GHz to 2 THz.

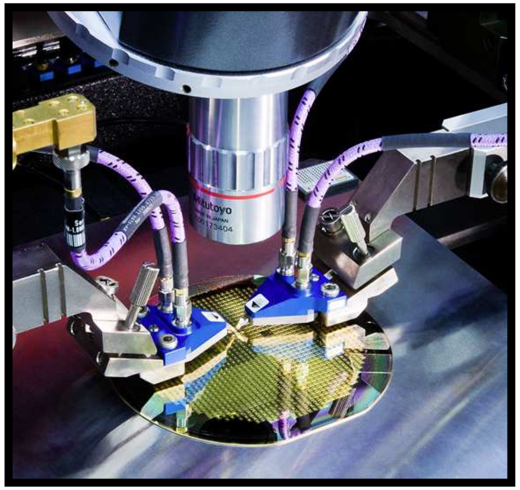
Flexible ZVA external device implementation allows customer developed drivers

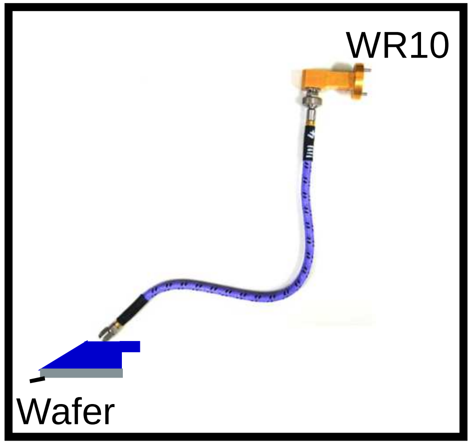
Readout and Sensor



Power Calibration on the Wafer







Challenges for accurate Power Levels On-Wafer

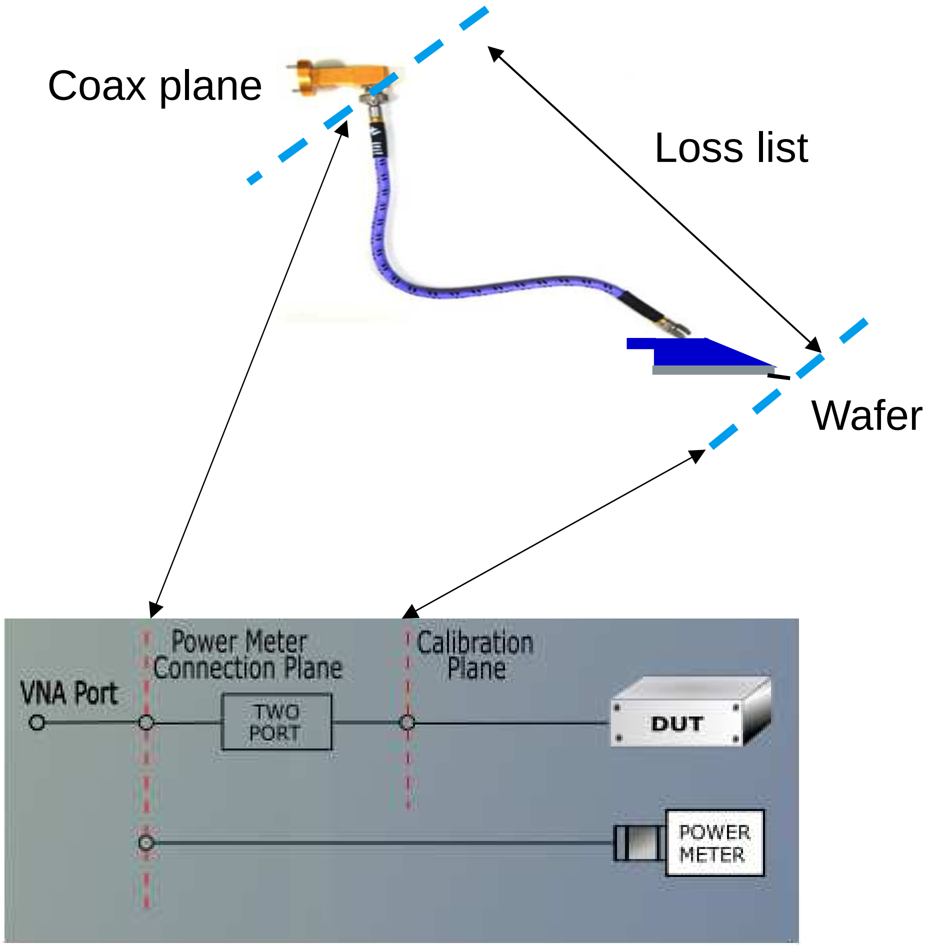
Goal : Power calibration in the reference plane of the DUT (amplifier)

Problem : No access with coaxial power meter possible

Solution:

- Characterization of the S-parameter between coaxial interface and the wafer prober tip
- Correction of the coaxial power calibration with this loss list

Power Correction with Loss List



Power Calibration in Reference Plane on the Wafer

<u>1st Step:</u>

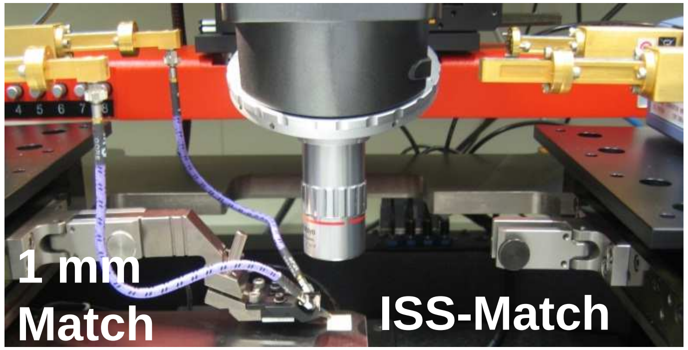
UOSM calibration to characterize the connection between coaxial interface and on-wafer reference plane

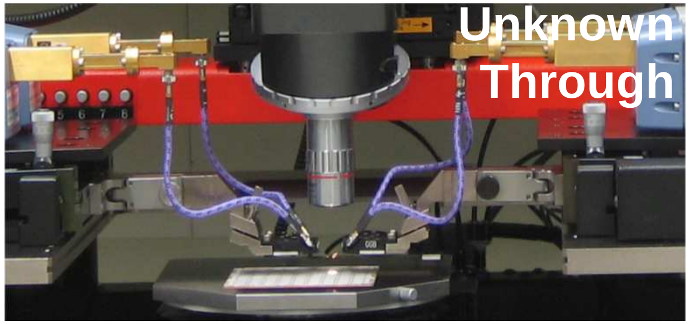
⇒ Power loss list for each port

Alternatively ´Delta´ Calibration between coaxial plane and On-Wafer plane

<u>2nd Step:</u>

Power calibration at the coaxial interfaces using the power loss list from the 1st step.





Millimeter Wave Imaging Systems
Phase Error Sensitivity

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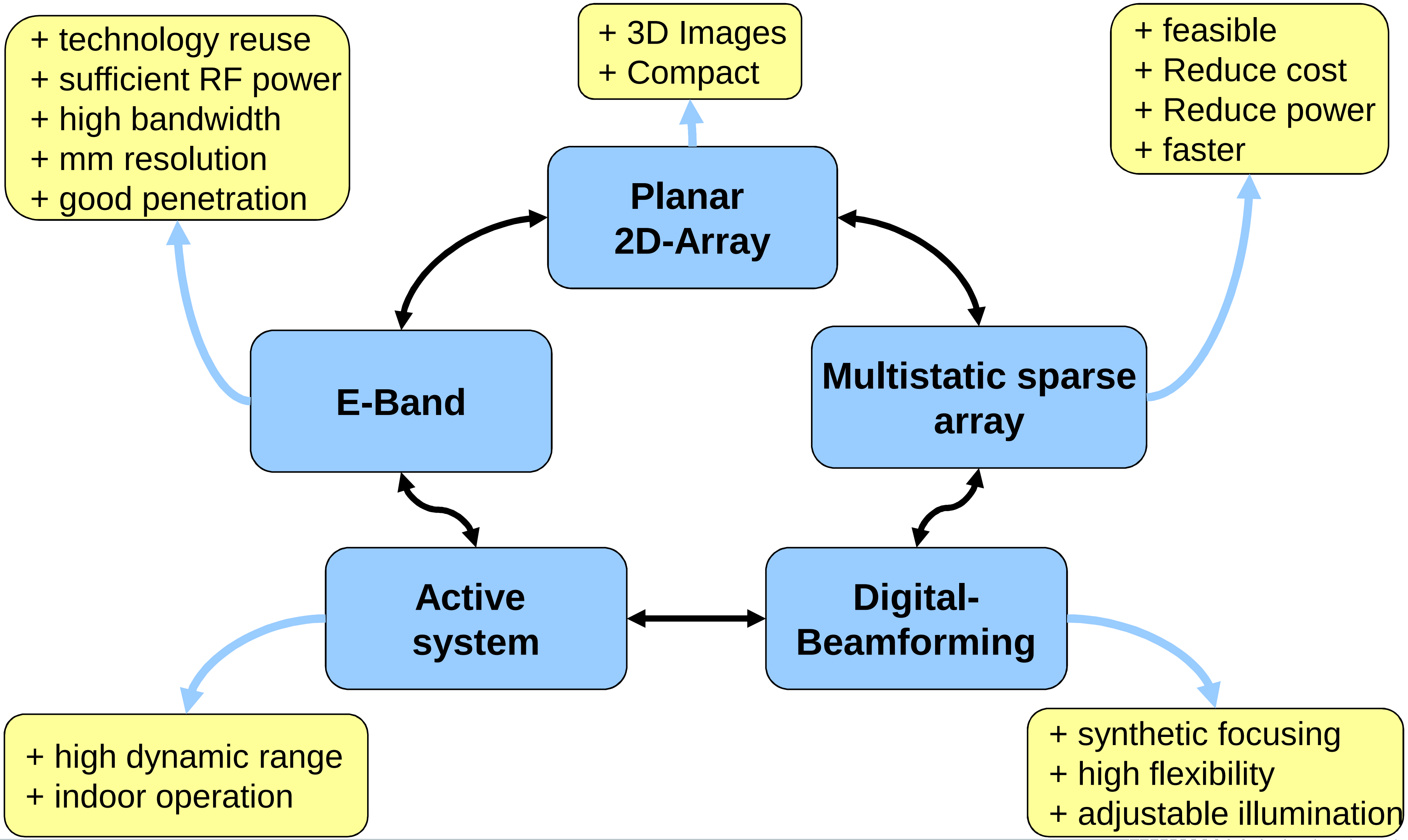
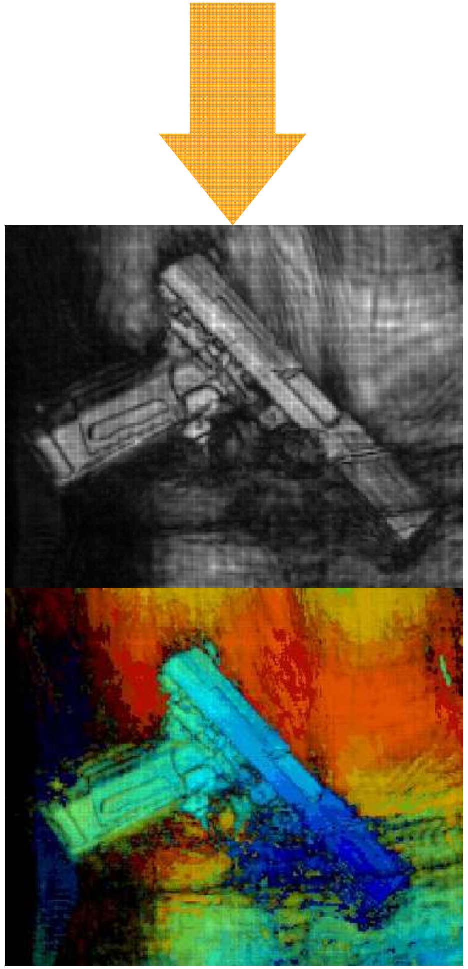
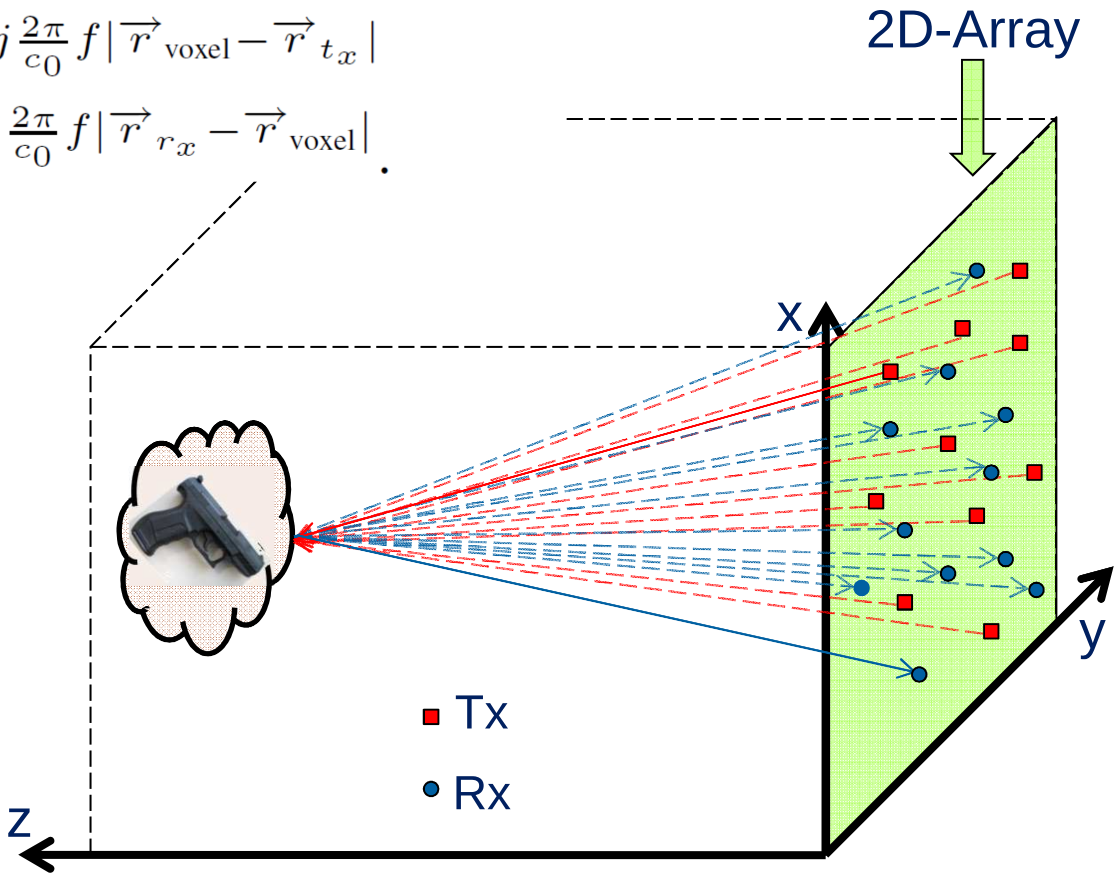
Technology choices



Multistatic imaging - Focusing

$$R(x,y,z) = \sum_{f=1}^{n_F} \sum_{t_x=1}^{n_T} \sum_{r_x=1}^{n_R} M(f,t_x,r_x) \cdot e^{+j\frac{2\pi}{c_0} f |\vec{r}_{\text{voxel}} - \vec{r}_{t_x}|} \cdot e^{+j\frac{2\pi}{c_0} f |\vec{r}_{r_x} - \vec{r}_{\text{voxel}}|}.$$



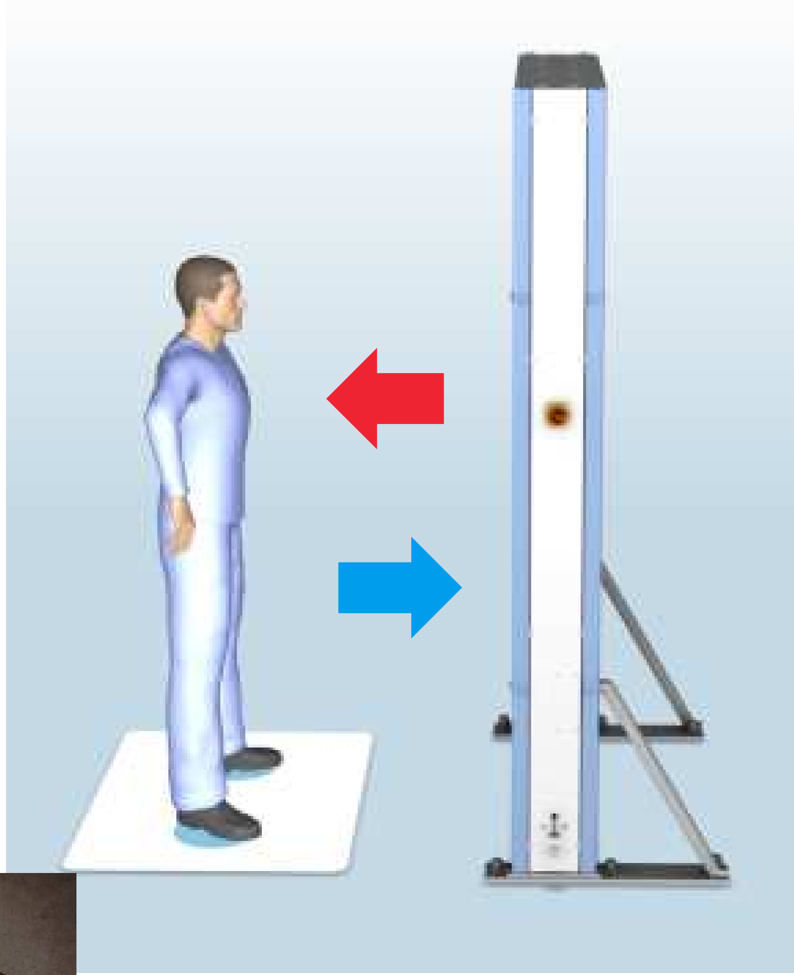


Reconstruction in space domain

Principle of Operation

- Person is illuminated by microwaves with very low intensity
  (No X-rays → non ionizing radiation)
- Waves penetrate the clothing
  (but <u>not</u> the skin)
- Scanner detects the reflected (backscattered) signal from the skin or concealed objects
- Unique technique analysing reflections from floor mirror
- Automatic evaluation and analysis of image data by an automatic detection software (algorithm)

  metallic and non-metallic
  plastics
  ceramics
  explosives
  liquids and gels
  powder

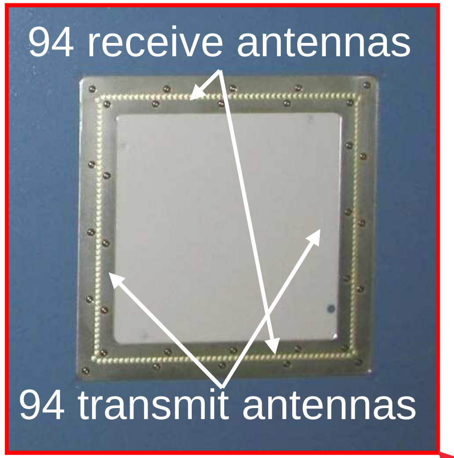


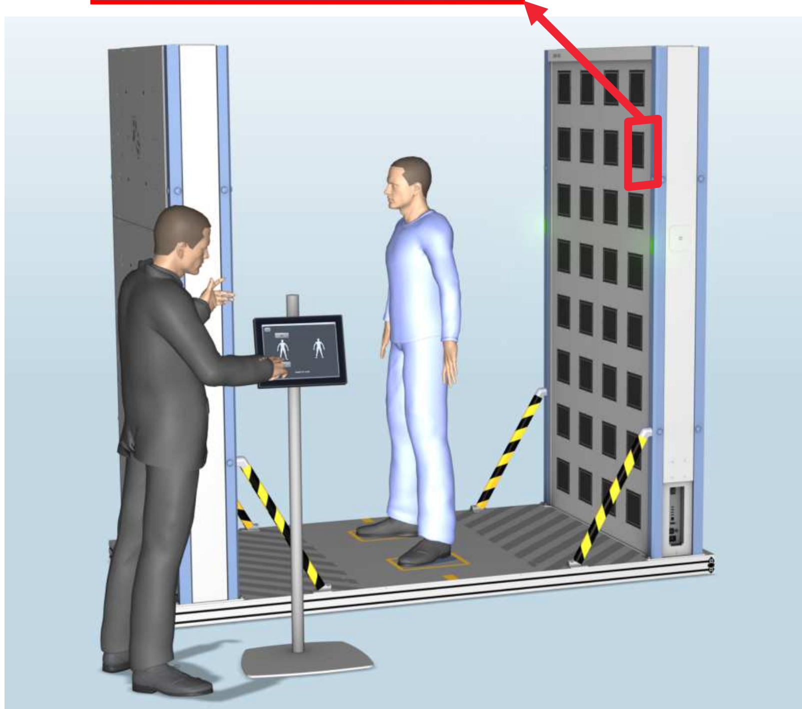
Incident wave
Reflected wave

Technical Overview Panel

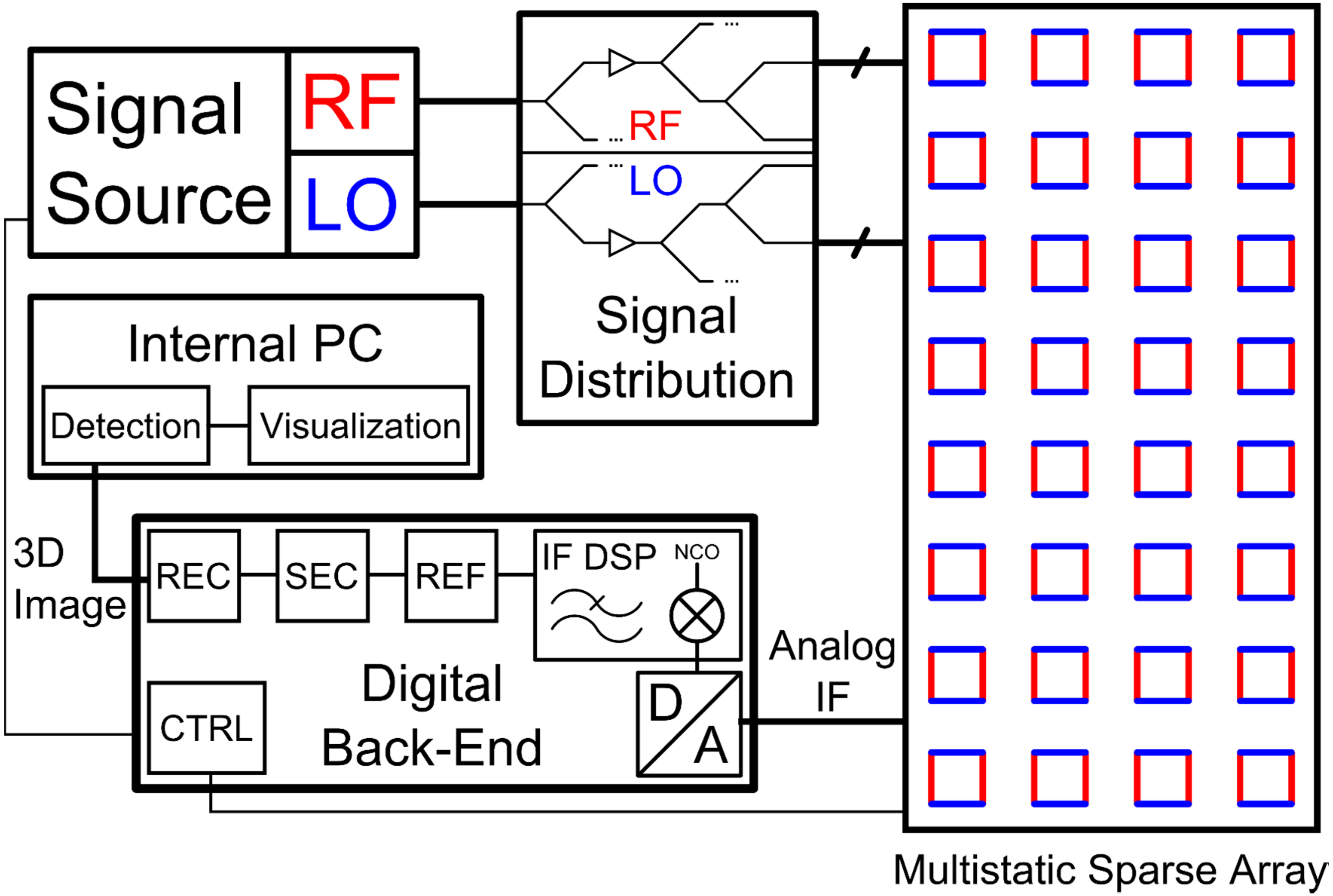
- Aperture 2 m x 1 m
- 3008 Tx & 3008 Rx elements in 32 Clusters
- Data acquisition time
  ≈ 16 ms for QPS100 (per scan)
  ≈ 64 ms for QPS200 (single)
- Frequency 70 to 80 GHz (λ ≈ 4 mm)
- High resolution < 2 mm
- Image dynamic range > 30 dB
- Processing time
  ≈ 7 sec (QPS100, result of front scan)
  ≈ 10 sec (QPS100, complete result)
  ≈ 7 sec (QPS200, complete result)

Cluster



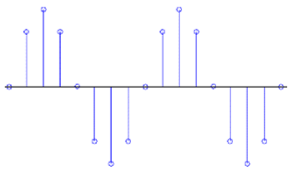


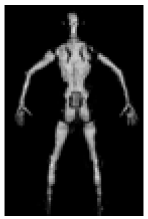
System Block Diagram

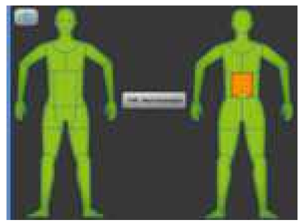


Digital Signal Processing Chain

1. digitized IF signals
2. DDC, low-pass filter
3. correct for system drift
4. system error correction
5. image reconstruction
6. automatic detection algorithm
7. detection result

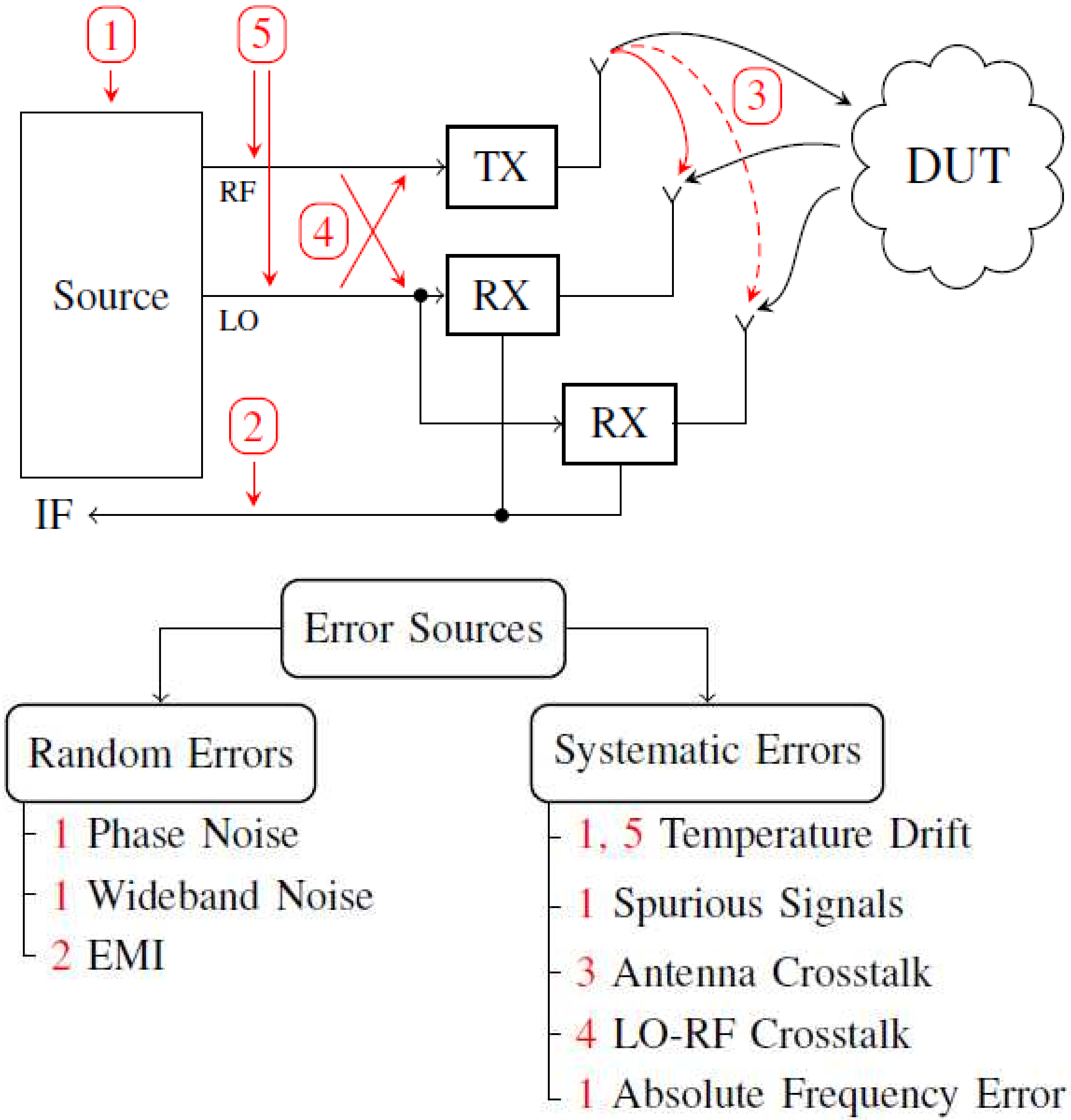






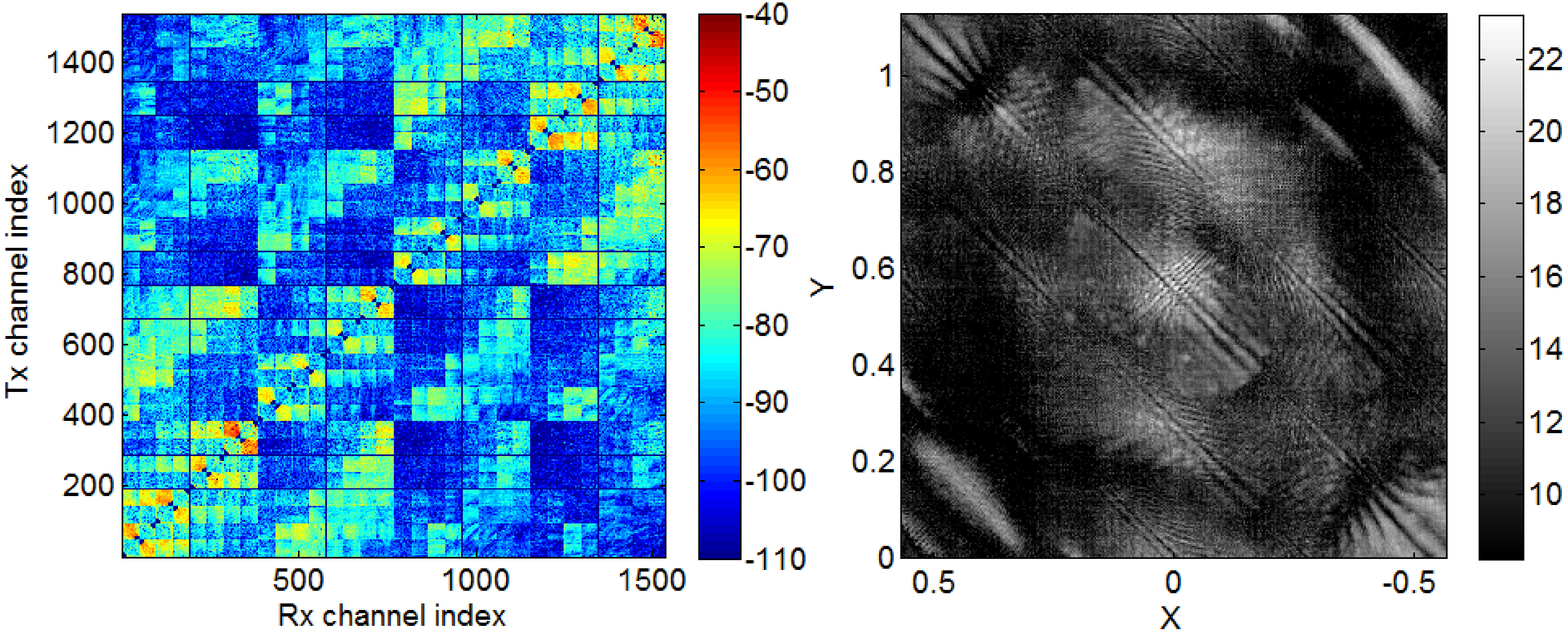
Sources of Noise

- Various sources of errors within the system
- Dominant errors:
  - Thermal noise of receiver
  - Phase noise of signal source
  - Temperature drift (phase drift of received signal), compensated by referencing
  - Antenna crosstalk, compensated by system error correction
- Noise affects performance of compensation



Cross-coupling

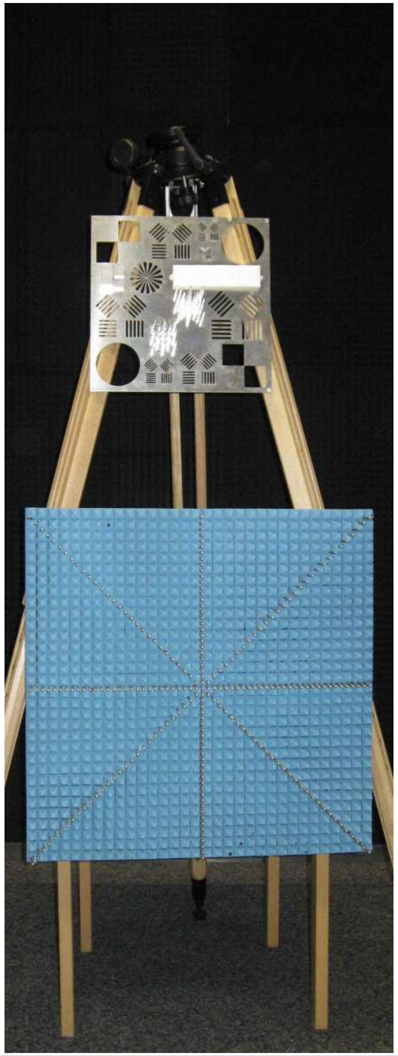
- As a systematic signal, residual cross-coupling shows up as artifact within the microwave image

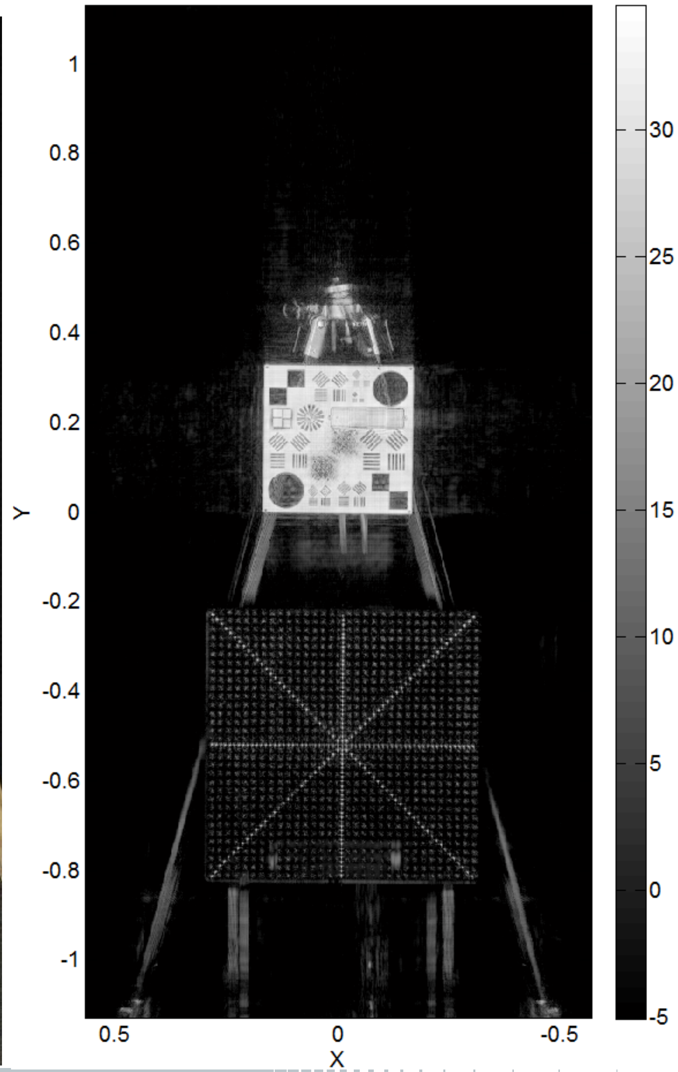


Test scenario – ideal image

- Resolution test chart
- Dynamic range test („bed of nails“)
- Heavy averaging used for best available data quality
  → more than 40 dB noise and artifact free image dynamic range

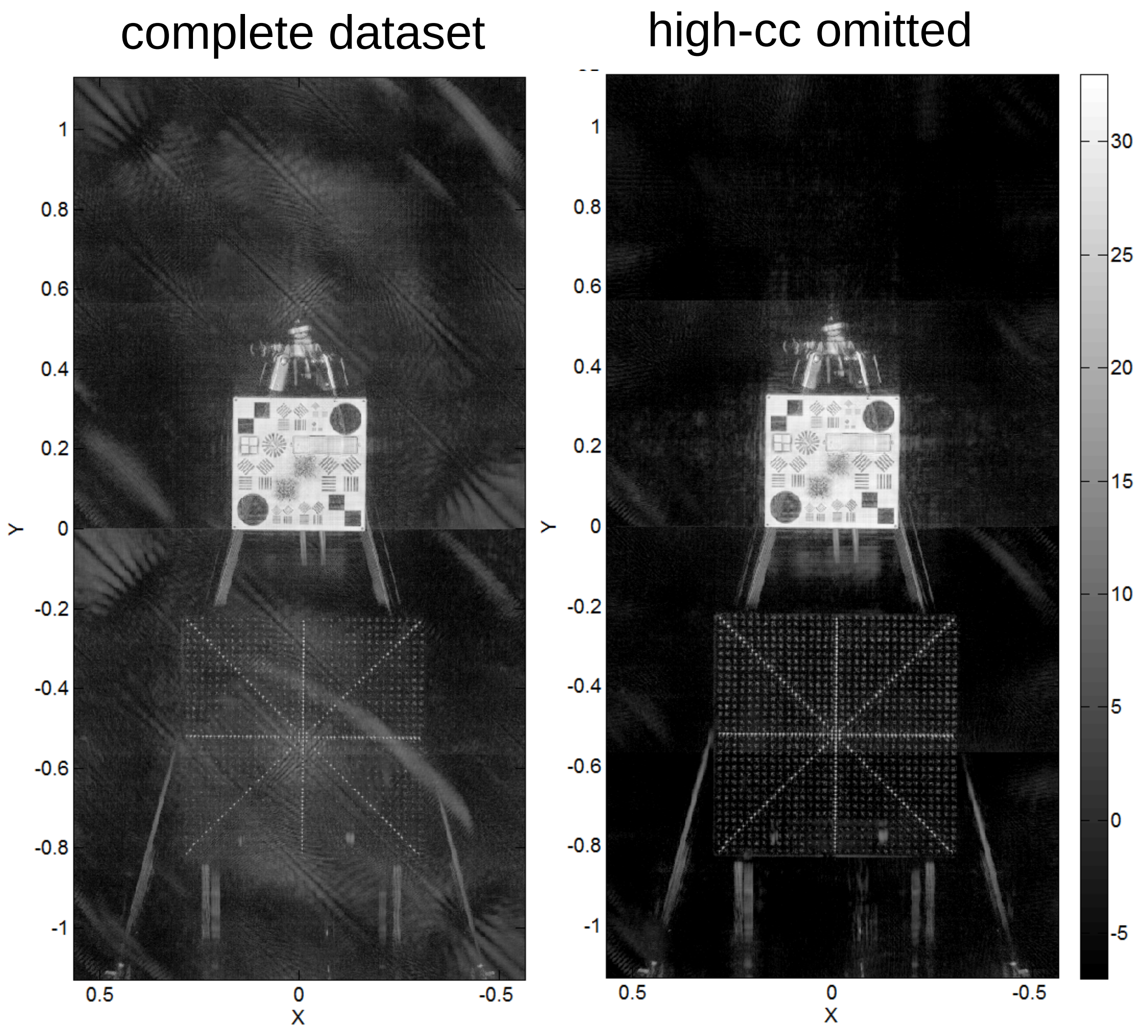
- This data is used as reference data set and modified by adding systematic and random phase errors
- The modified data are reconstructed and effects of phase errors on image quality are examined





Test scenario – systematic phase drift added (e.g. temperature drift)

- Systematic phase drift of 20 degree added to raw data
- Cross-coupling is not compensated completely
  → shows up as artifact
- Dynamic range is decreased to 27 dB
- When omitting channels with high cross-coupling from adjacent transmitters, dynamic range is 33 dB

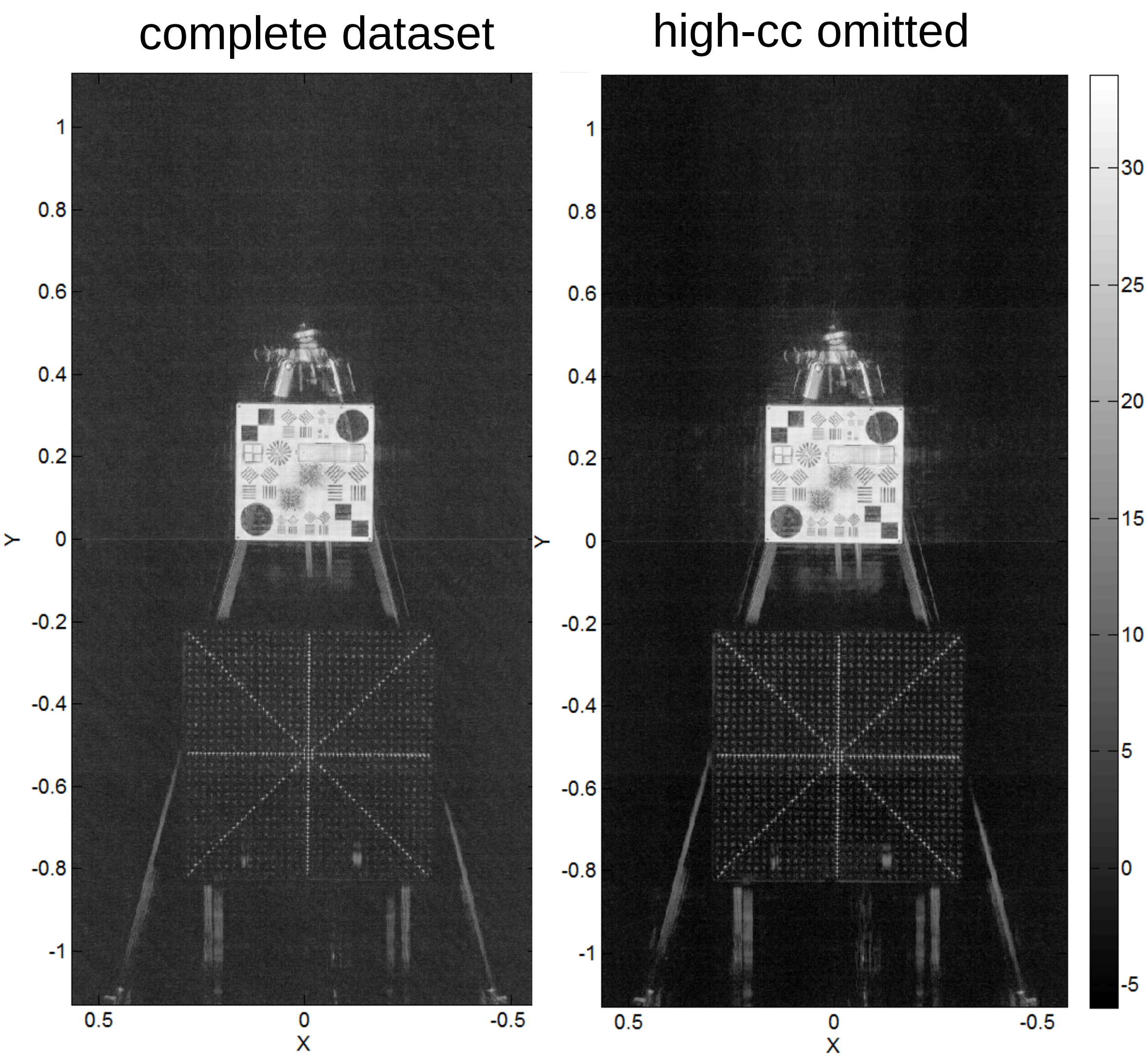


Systematic Phase Errors - Summary

- Normally the cross coupling between the antennas is calibrated out (Match calibration)
- But if temperature drift (= phase error, phase drift) happens the cross coupling can not be fully eliminated
- Consequence : Artifacts come up in the picture
- Measures :
  - Omitting channels with high cross coupling

Test scenario – random phase added (e.g. source phase noise)

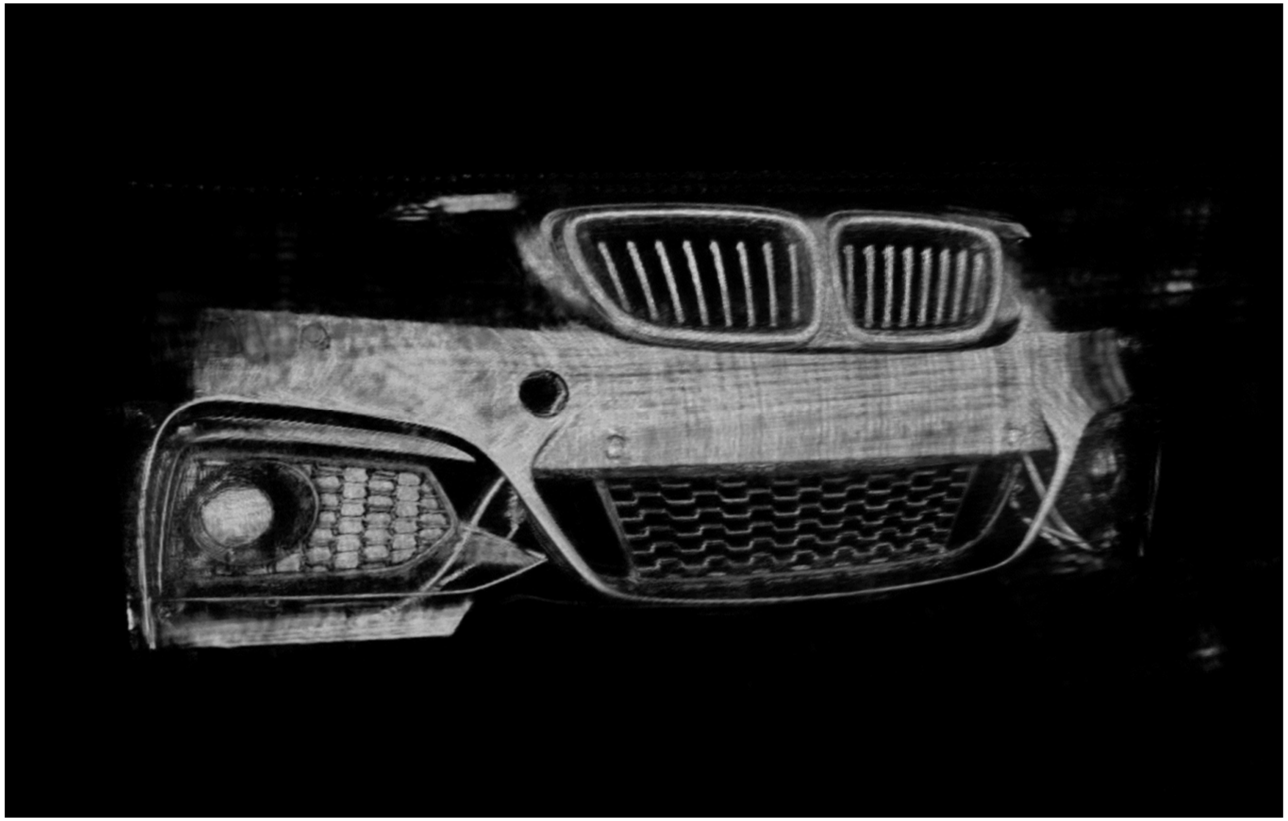
- Random phase drift, standard deviation 20 degree added to raw data
- Random error → no systematic artifacts, but significant increase in noise level
- Dynamic range is decreased to 33 dB
- When omitting channels with high cross-coupling from adjacent transmitters, dynamic range is 36 dB

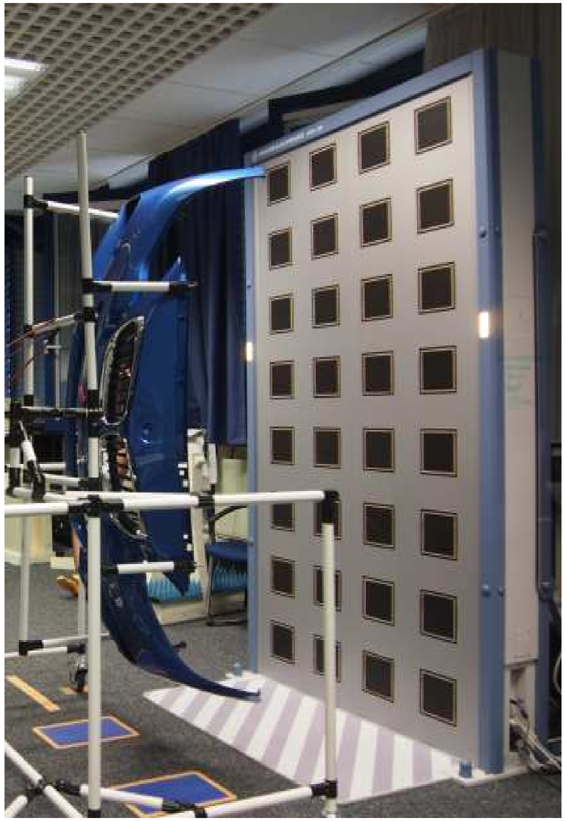


Random Phase Errors - Summary

- Noise level increases
- No artifacts
- Consequences :
  - Decrease in dynamic range
  - Unclear picture
- Measures :
  - Reference channels near Tx/Rx antennas
  - Omitting channels with high cross coupling

Other application areas for microwave imaging





Non-Destructive Test with 3D-Pictures (QPS100)

Thank you for your attention

1950 : World´s first Vector Network Analyzer
- made by R&S

Direct display of S-Parameters in a complex plane

> 50 years of experience in network analysis