MATERIAL MEETS ENGINEERING
Westhafen Pier 1 in Frankfurt a. M., Germany

lyondellbasell
Advancing Possible

Design and Measurement of Covers for Automotive Radar Sensors (Radomes)

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(CEO)

Source:
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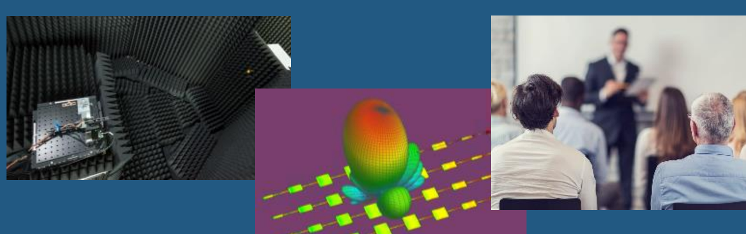
About perisens…

- ✓ Your reliable partner in automotive radar integration for more than 10 years!
- ✓ Located in Feldkirchen near Munich, Germany
- ✓ Founded as Spin-Off from the Technical University München (TUM) with ongoing cooperation

Services

- Technical Consulting / Studies
- RF Measurements & Simulations (up to 90GHz)
- Radar Signal Processing
- Development of RF Prototypes
- Radar Workshops
- Solutions in automotive Radar Sensors

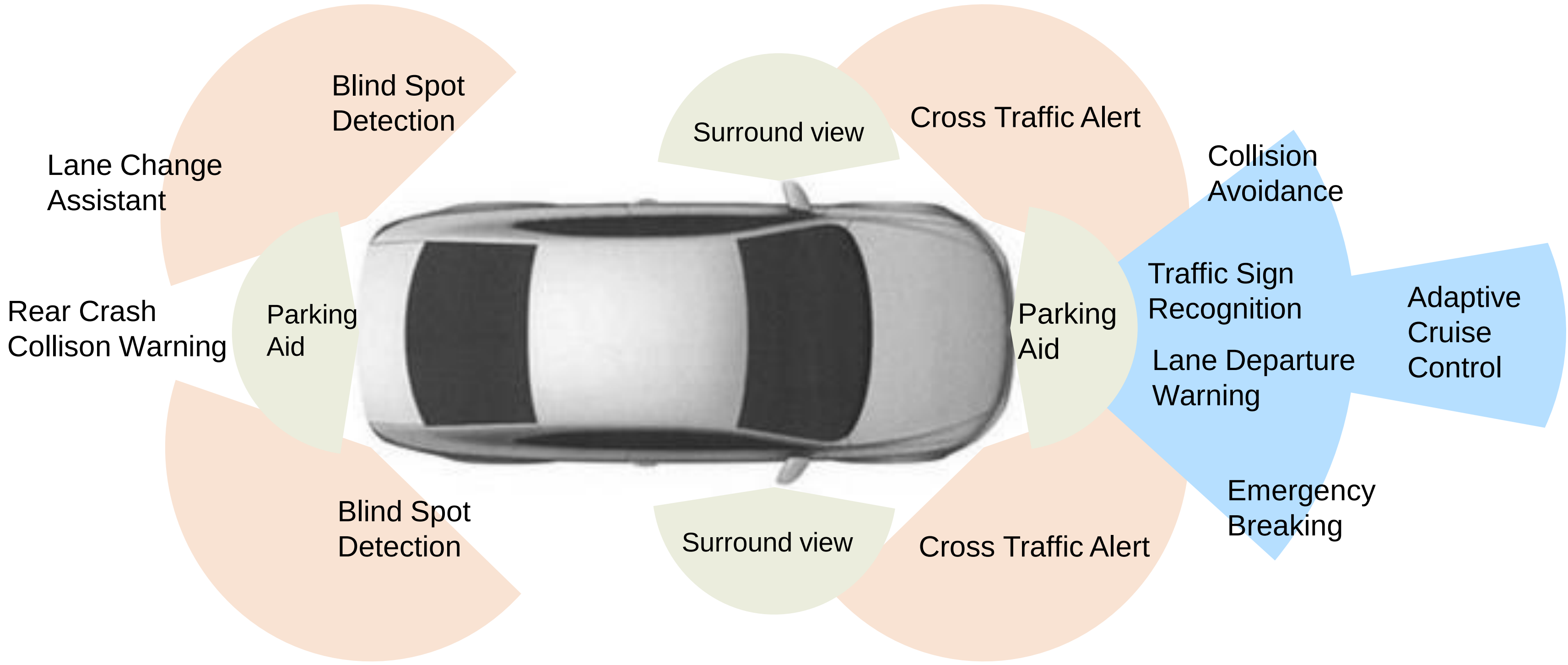


Products

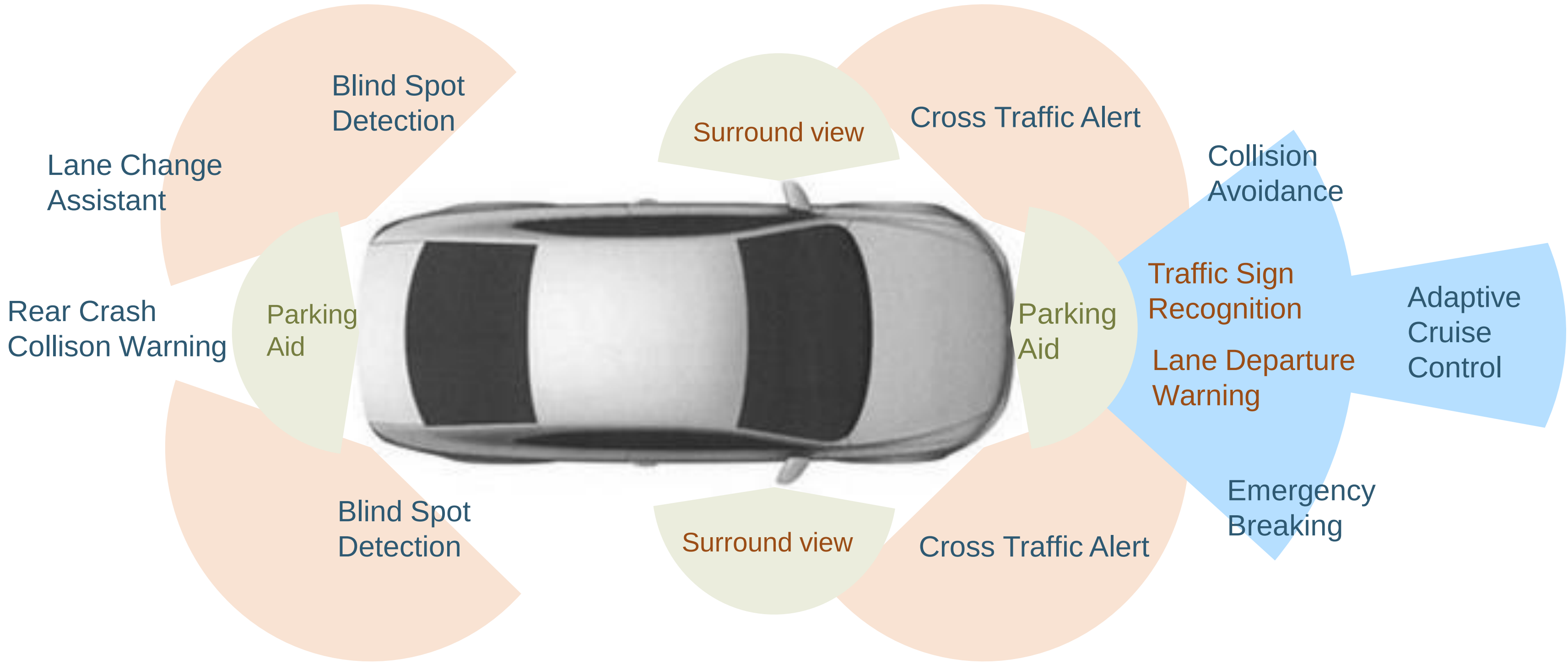
- In-House Development, Production and Sale of Radar Target Simulators (RTS) and Radome Measurement Systems (RMS)
- >50 Customer Installations Worldwide

MADE IN GERMANY

Today’s Advanced Driver-Assistance Systems (ADAS)



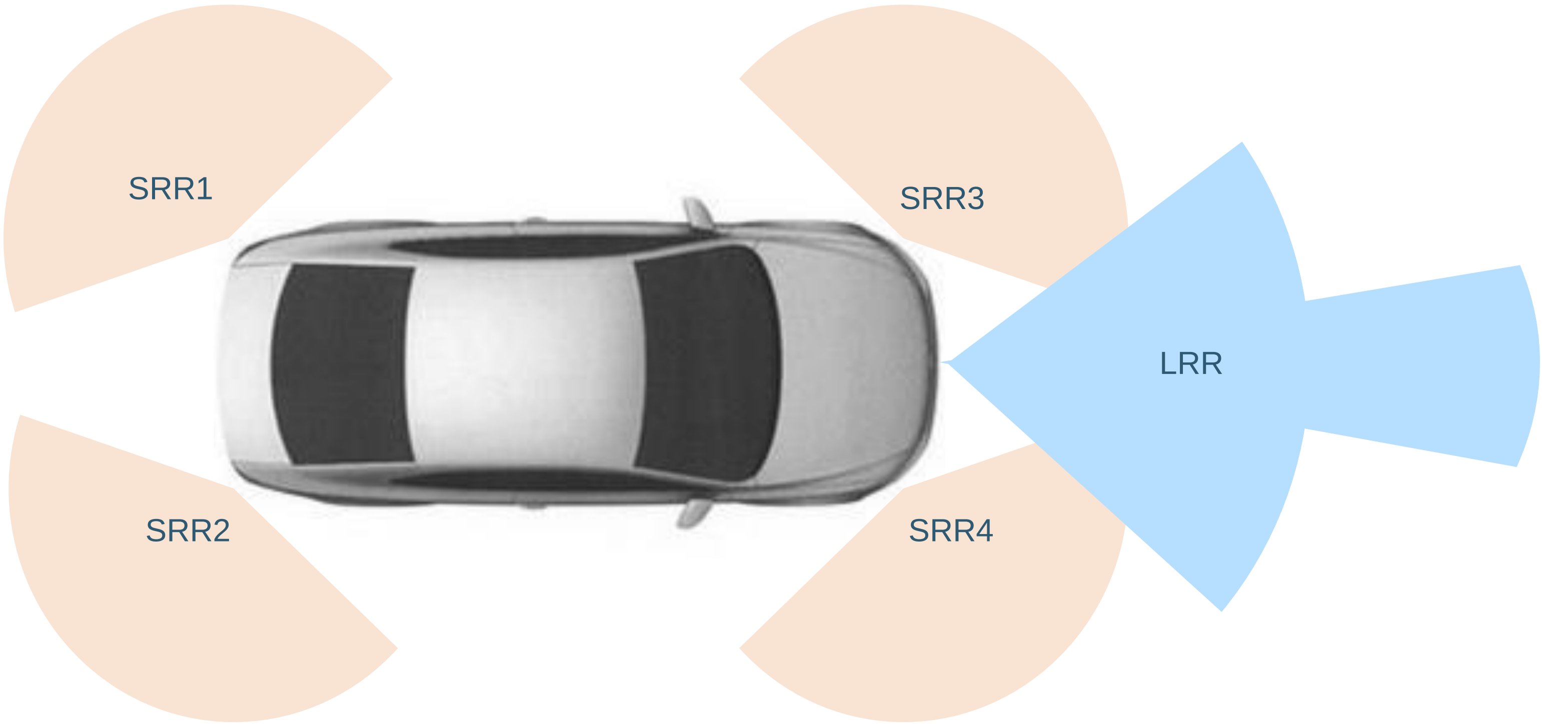
Today’s Advanced Driver-Assistance Systems (ADAS)



ADAS function (mostly) based on

- RADAR (LIDAR)
- Camera
- Ultra-Sonic

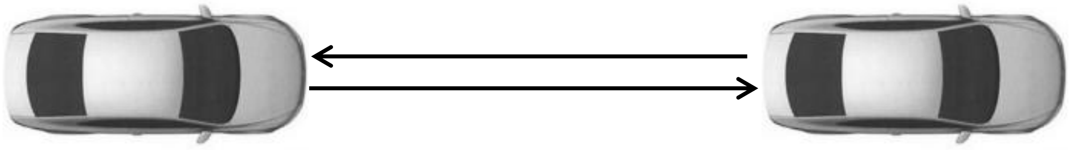
Today’s Radar Sensor Set



Different sensor depending on Field of View
- SRR (Short Range Radar) with distance up to 120m
- LRR (Long Range Radar) with distance up to 300m

RADAR (RAdio Detection And Ranging) Principle

- **Emission** of an electromagnetic (EM) wave at 77 GHz
- **Reflection** of EM wave at a target object
- **Reception** of reflected EM wave as „echo“ and measurement of object information
  - Distance
  - Angle/direction to target (horizontal and vertical)
  - Relative velocity
  - „Size“



Why using radar in the vehicle?

- Simultaneous measurement of
  - Target distance
  - Target angle
  - Relative velocity (Radar is the only sensor technology with direct velocity measurement)
- Low cost (below 30Euro/sensor)
- High availability in all weather situations
- Concealed integration possible - "without" design interference
- Usable in full speed range (0 to 200km/h)
- Multi-target situations (target separation!)

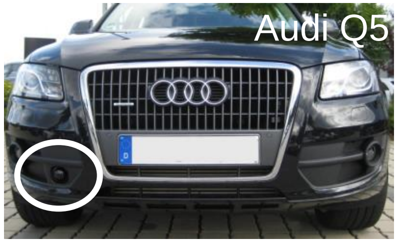



Integration of radar sensors in the vehicle

SRR (corner radar)	LRR (front radar)

- Behind bumper

- Open

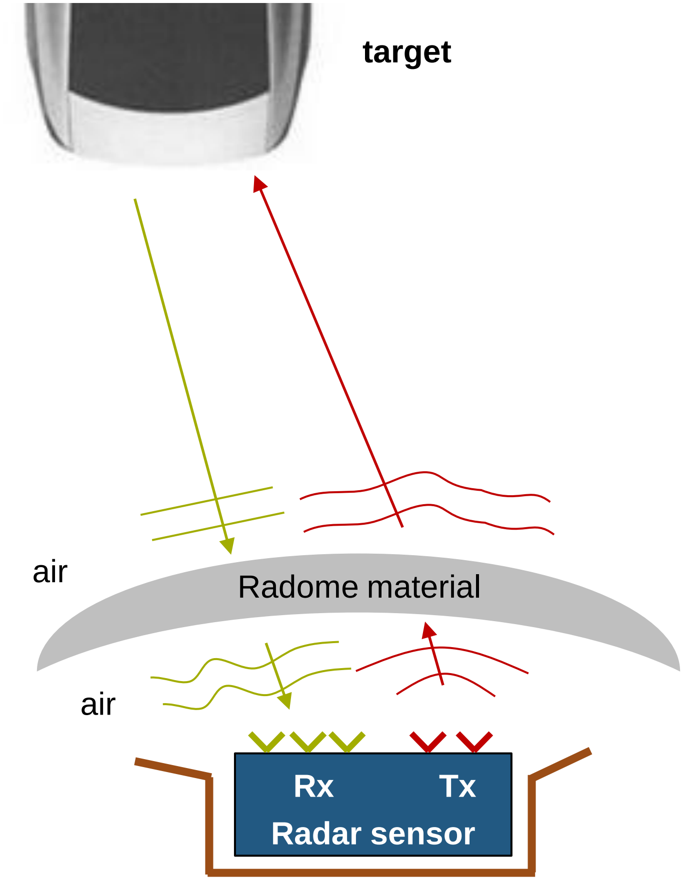


- Behind emblem

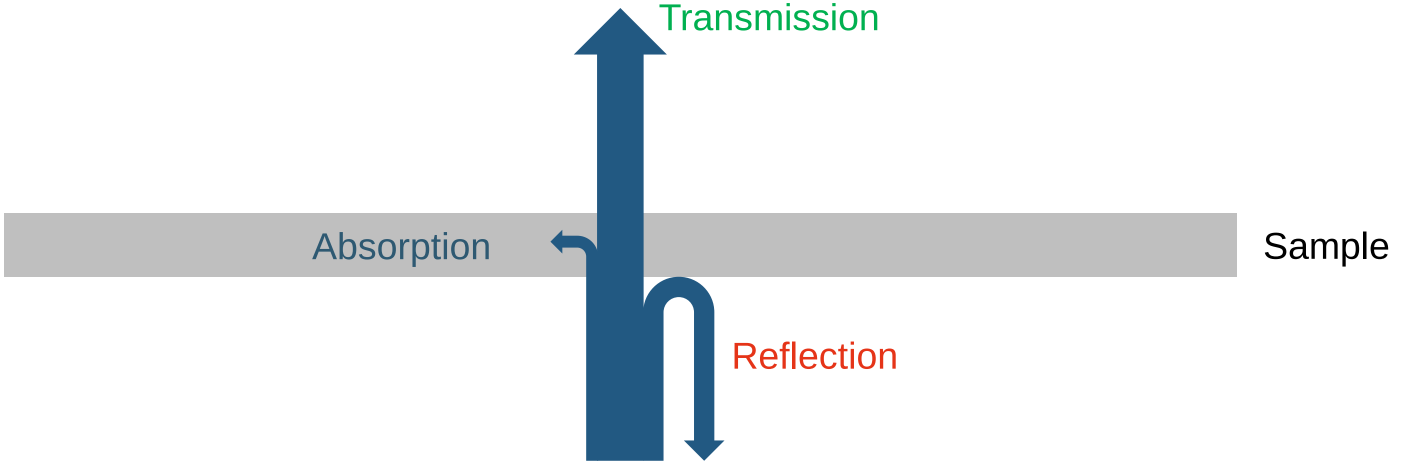
- Inside grill

Integration of Automotive Radar Sensors

- Effects from integration due to
  - material change from air
    to radome material and back to air
  - Geometry of radome
- Impact on the radar performance
  - Decrease of range
  - Errors in Angle Measurement
    (more critical for higher range!)

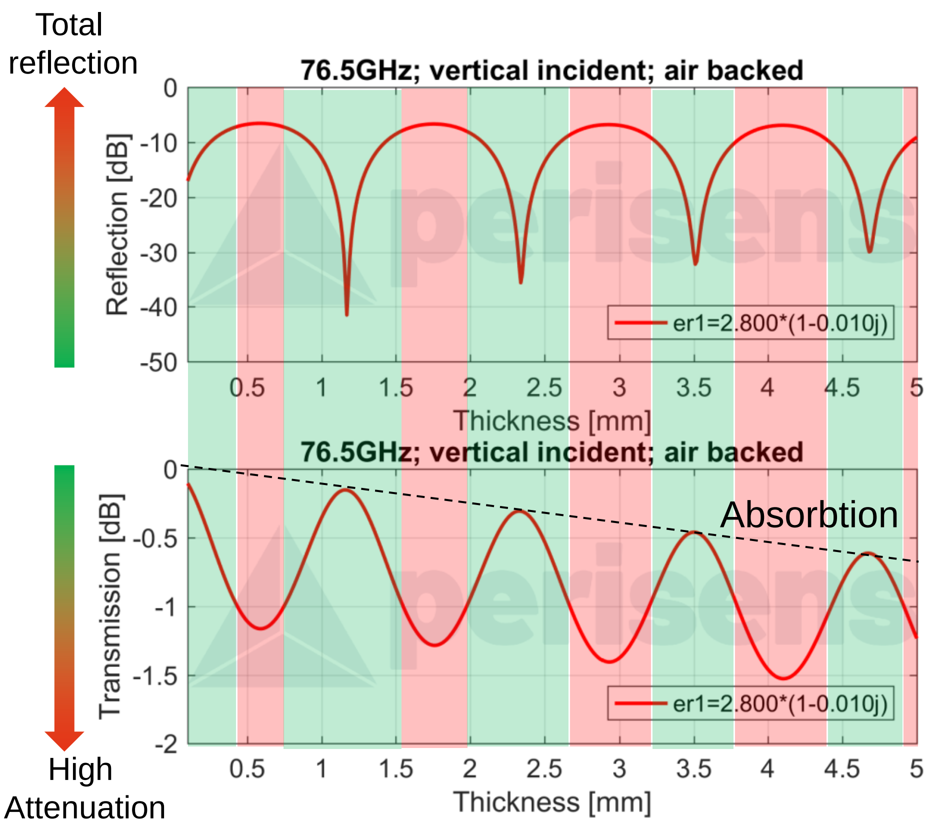


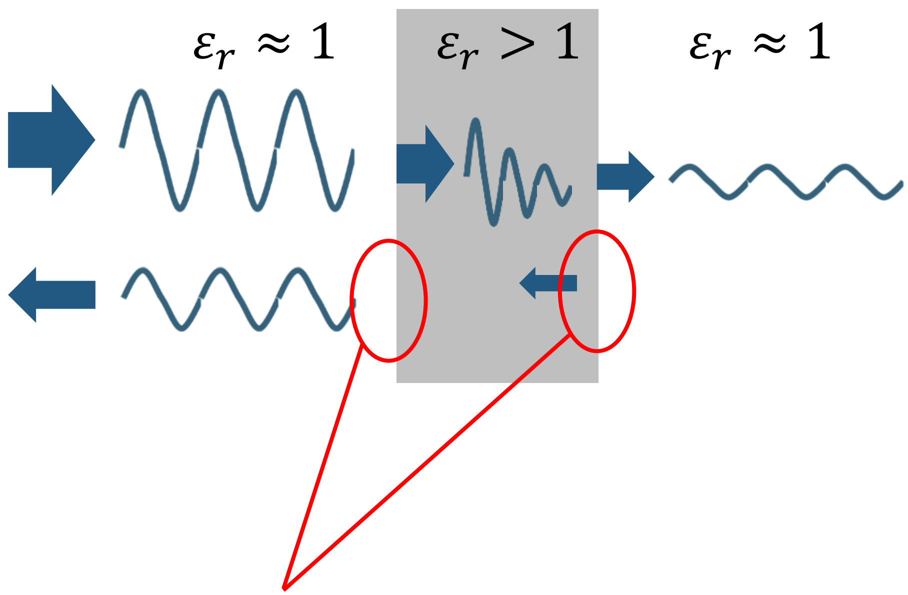
Wave Propagation through Single Dielectric Layers



Transmission [%] + Reflection [%] + Absorption [%] = 100%
(energy conservation)

Wave Propagation through Single Dielectric Layers

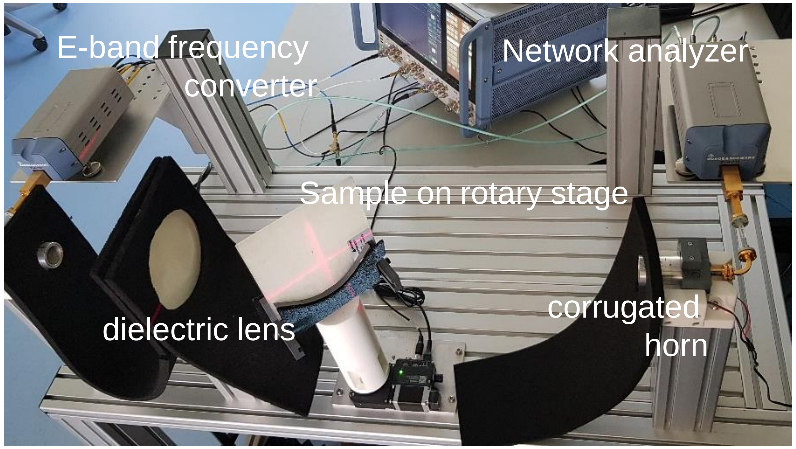




Reflection at both material transitions leads to interference depending on thickness of layer!

Material Characterization at Millimeter Wave

Traditional Way



Focus Beam Measurement System, perisens (60 to 90GHz)

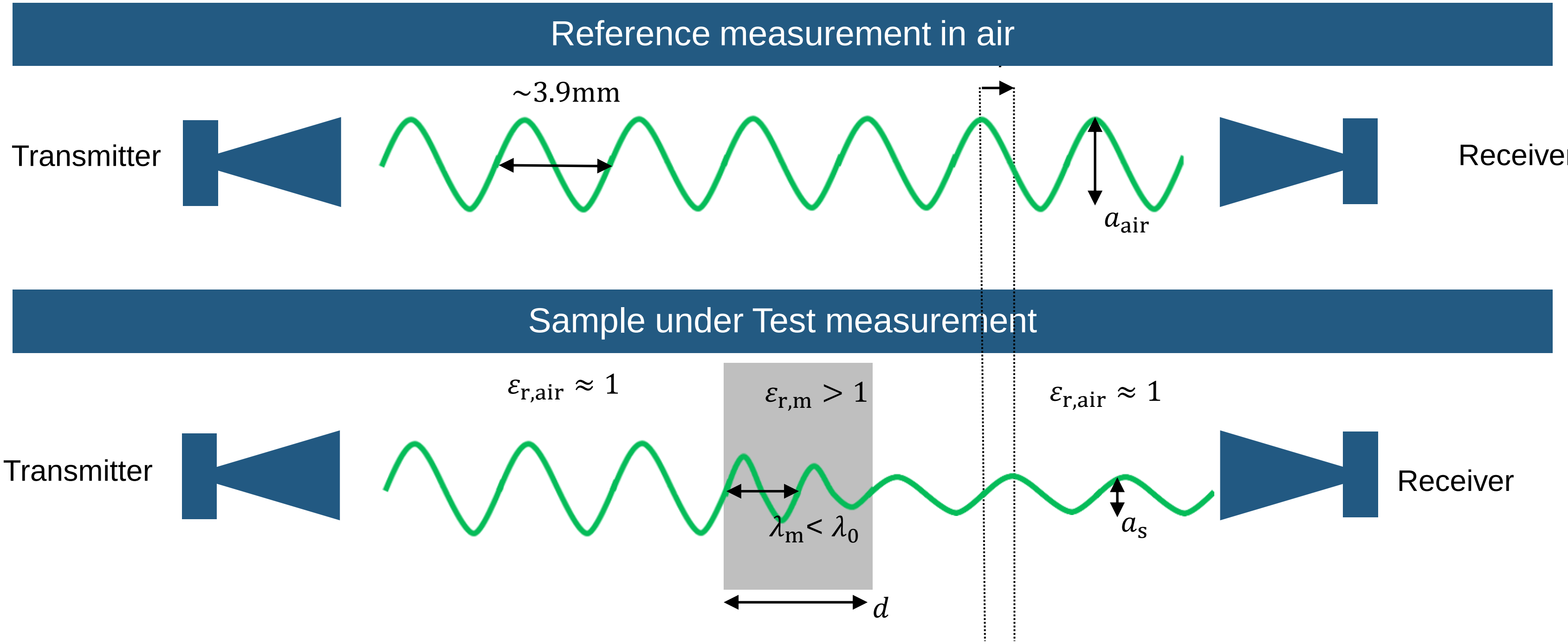
- Complex radio frequency (RF) equipment
- Complex measurement procedure
- Requires RF engineer

New Way

RMS-D 77/79G, perisens (76 to 81GHz)

- Single device – ready to use
- Measurement at a push of button
- Requires any instructed person

RMS Measurement Principle



- **Phase difference to air**: $\Delta\varphi \approx 360° \cdot \frac{d}{\lambda_0} \cdot \left(\sqrt{\varepsilon_r} - 1\right)$
- **Amplitude difference to air (attenuation)**: $\Delta A = \mathrm{dB}\left({}^{a_s}/_{a_{air}}\right)$

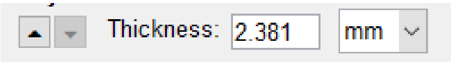
Procedure of Single Layered Material Characterization

(1) Thickness measurement

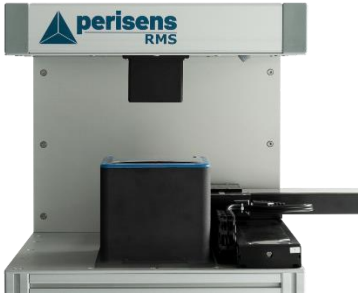
- Micrometer screw for total thickness

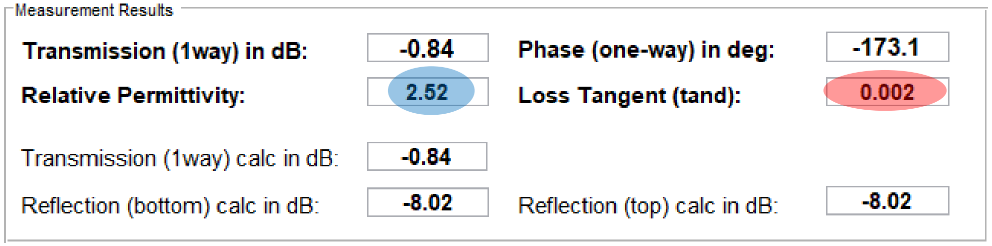
(2) RMS measurement

- Thickness is entered in layer stack tool



- Reference measurement is performed without sample
- Sample is placed on RMS measurement table
- Complex Permittivity of coating is measured with a push of button





Material Properties of Plastic

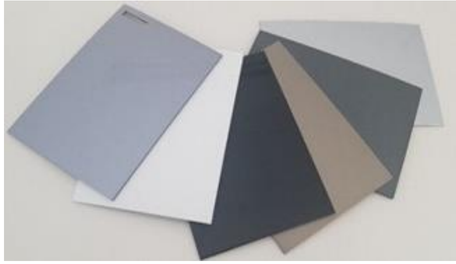
Real part of relative permittivity is between **2.2 and 3.2**
(**Conducting pigments** and **glass fiber/talcum** increase the value)

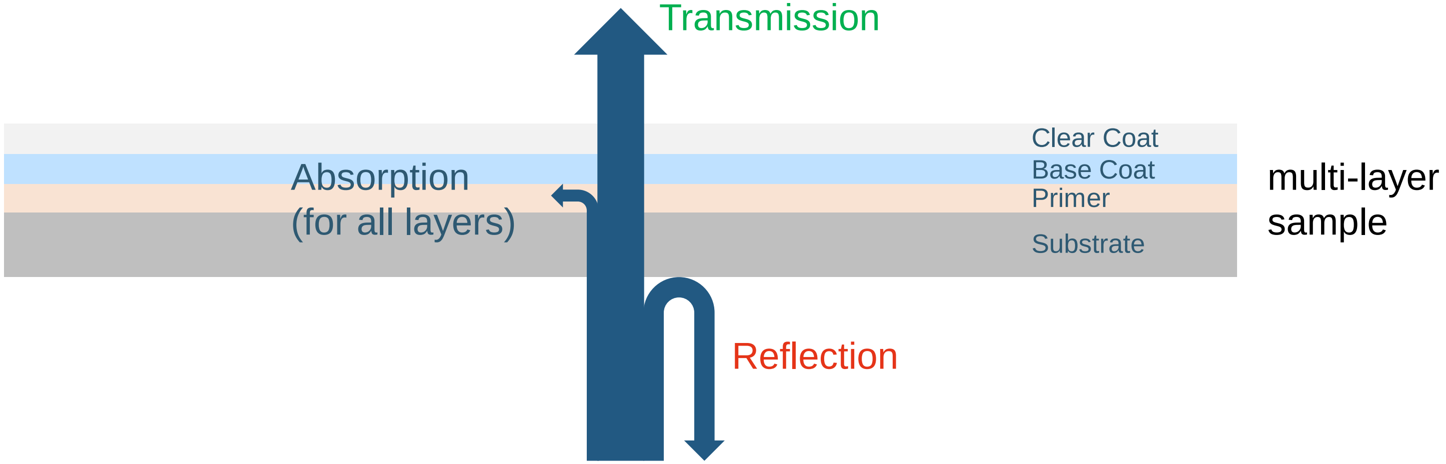
Material	Relative Permittivity	Loss factor (tanD)	Optimum thickness (*) [mm]	2-way Absorption [dB]
PP	2.3	0.003	2.61	0
PC	2.77	0.006	2.35	0.3
PC/PET	2.8	<0.01	2.34	1.1
ASA	2.9	0.014	2.30	1.5
PP/EPDM	2.24	~0	2.62	0
PP/EPDM TD30	2.68	~0	2.39	0

Measured with RMS-D, perisens at 76.5GHz (*) 2nd transmission maxima

Note:
The thickness of the cover must be matched to the material (and wavelength and tilt angle)!

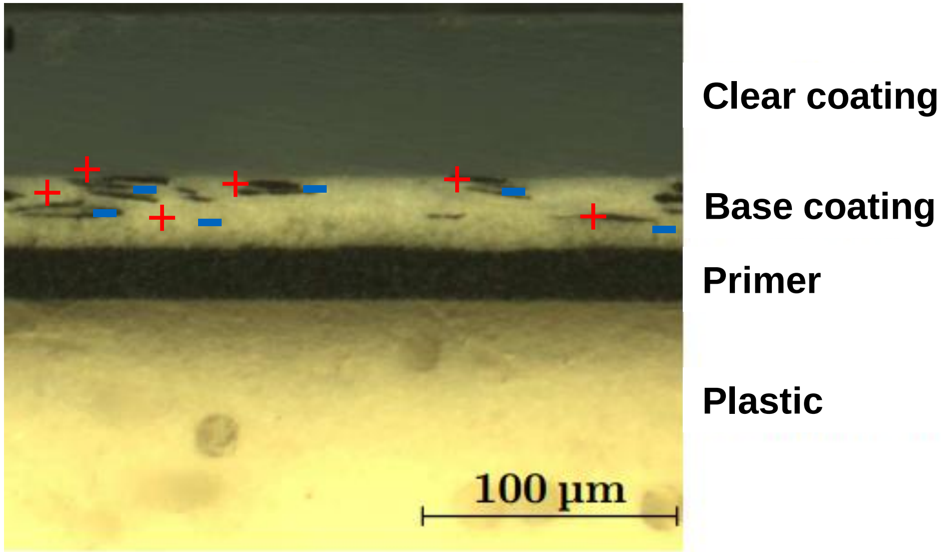
Material Characterization (multi-layer sample)



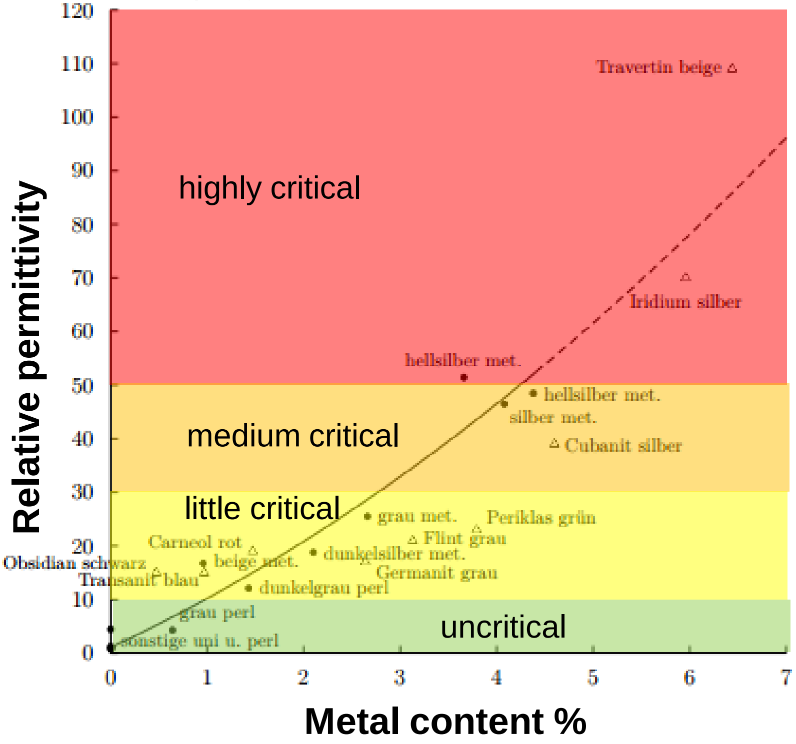


Effect of Metallic Paint

- Metal pigments (= good conductor with free electrons) are separated by isolator in metallic paint
- In present of an electro-magnetic wave the electrons are oscillating inside the metal (surface polarization) which strongly increases the electric density (permittivity)

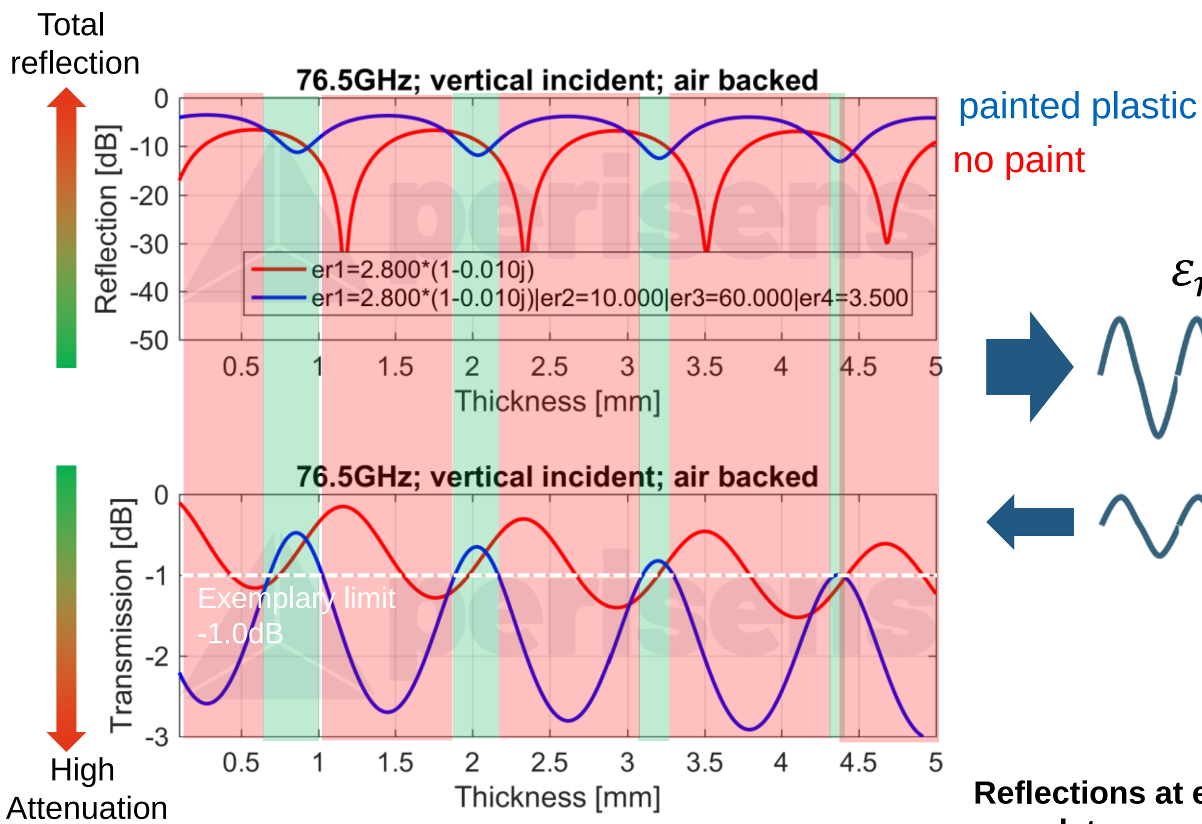


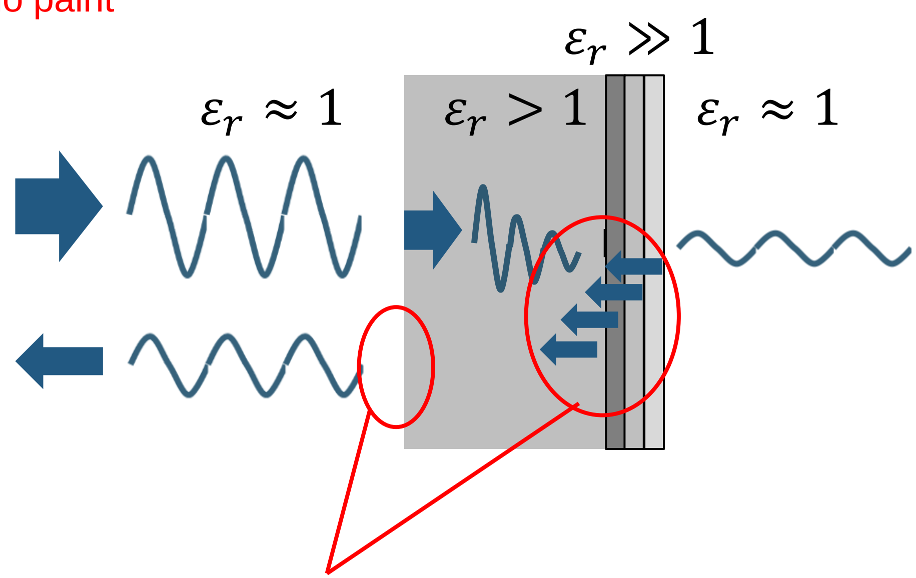
exemplary classification



Source: PhD thesis Florian Pfeiffer, Analyse und Optimierung von Radomen für automobile Radarsensoren, 2010:

Wave Propagation through Multiple Dielectric Layers

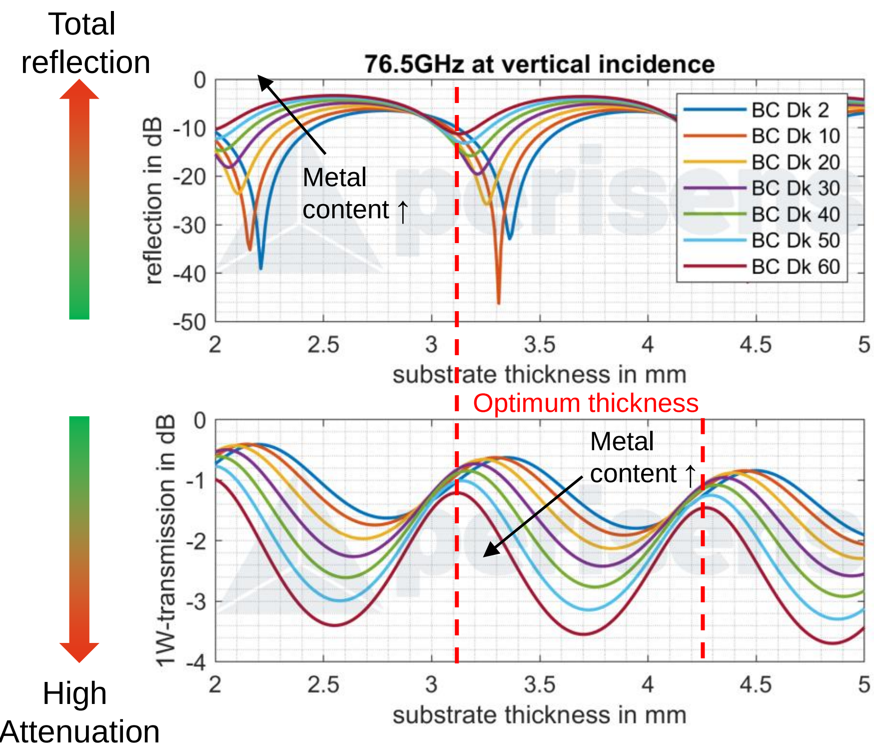


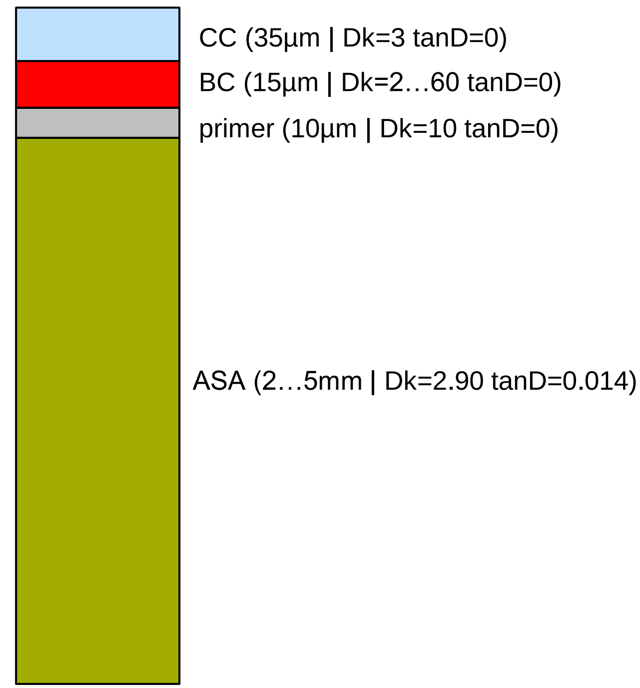


Reflections at every material transitions does not allow complete compensation of reflections!

Simulation of Reflection/Transmission vs Substrate Thickness

76.5GHz at vertical incidence



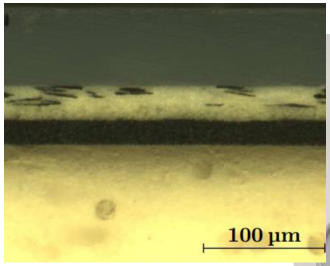


Rule of thumb:
Substrate thickness has to be matched to paint with highest permittivity!

Procedure of Coating Characterization

(1) Thickness measurement of each individual layer

- Micrometer screw for total thickness
- Microscopic analysis or co-painting of metal plates and inductive measurement for coatings

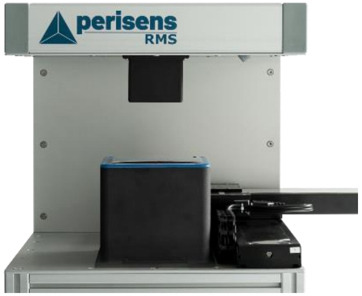


(2) RMS Measurement

- Thickness and complex permittivity of all layers except of unknown coating is entered in layer stack tool

Layer	Thickness	Unit	εr	tan(δ)	Select as Unknown	
Layer 1	36	µm	3.50	0.000	☐	Choose Material
Layer 2	13	µm			☑	Choose Material
Layer 3	2.381	mm	2.844	0.008	☐	Choose Material

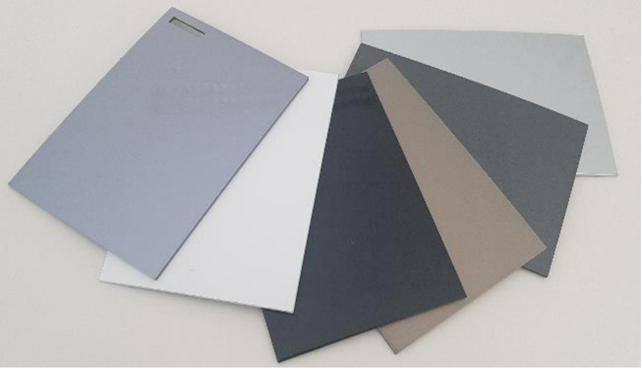
- Reference measurement is performed without sample
- Sample is placed on RMS measurement table
- Complex Permittivity of coating is measured with a push of button



Measurement Results

Transmission (1way) in dB:	-1.16	**Phase (one-way) in deg:**	-171.2
Relative Permittivity:	31.64	**Loss Tangent (tand):**	0.031
Transmission (1way) calc in dB:	-1.16		
Reflection (bottom) calc in dB:	-7.82	Reflection (top) calc in dB:	-7.66

Material Characterization
Multi Layer Samples (coatings)



Paint	RMS Relative Permittivity	1W Transmission [dB]	Layer Thickness [µm]
Brilliant black (uni)	3.05	-0.37	12.5
Ibis white (uni)	5.62	-0.69	43.5
Deep green (pearl)	2.76	-0.36	17.0
Daytona gray (metallic)	13.70	-0.69	16.0
Akoya silver (metallic)	20.80	-0.93	14.5
Ice silver (metallic)	53.87	-2.96	18.5

Measured with RMS-D, perisens at 76.5GHz

Angle Error Estimation from Transmission Phase

- Automotive radar sensors **use phase information** to derive **angle of arrival** (AoA)

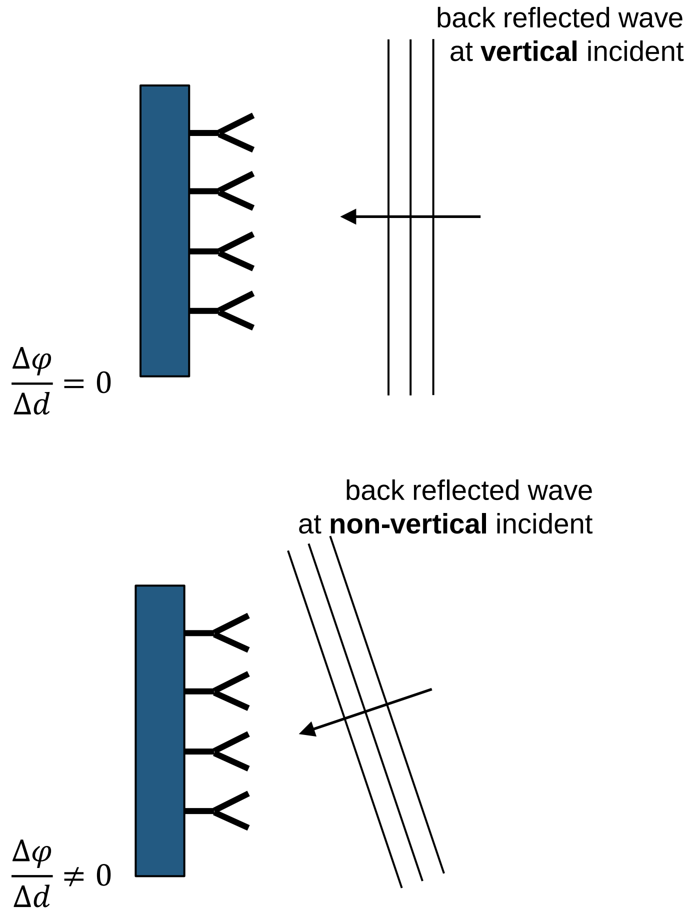
- The phase difference $\Delta\varphi$ between several antennas is measured and used to calculate the angle α of the wave reflected from the target

$$\alpha = asind\left(\frac{\Delta\varphi}{\Delta d}\frac{\lambda_0}{2\pi}\right)$$

$\Delta\varphi$…phase difference

d…distance between antennas

λ_0 ...wavelength (e.g. 3.9mm @76.5GHz)



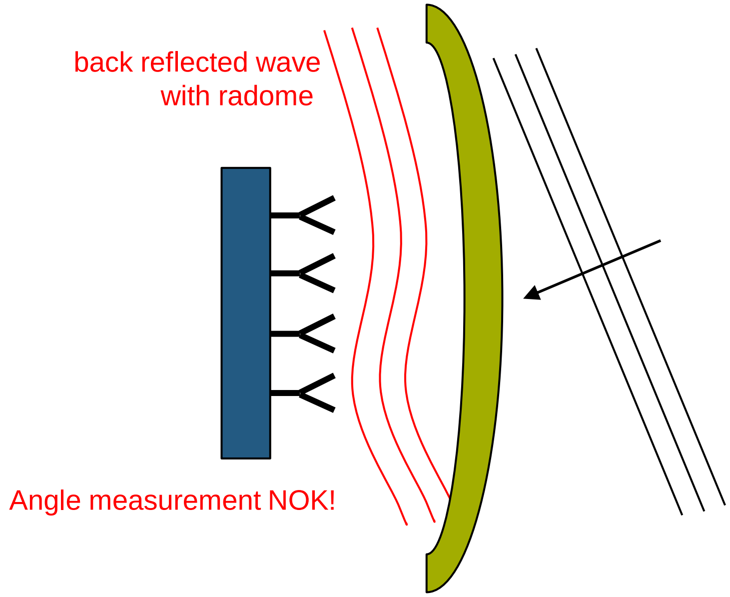
Angle Error Estimation from Transmission Phase

For small incident angles α (<30°) in °

$$\alpha \approx \frac{\Delta\varphi}{\Delta d}\frac{\lambda_0}{2\pi}$$

At 76.5GHz the angle error can be approximated by

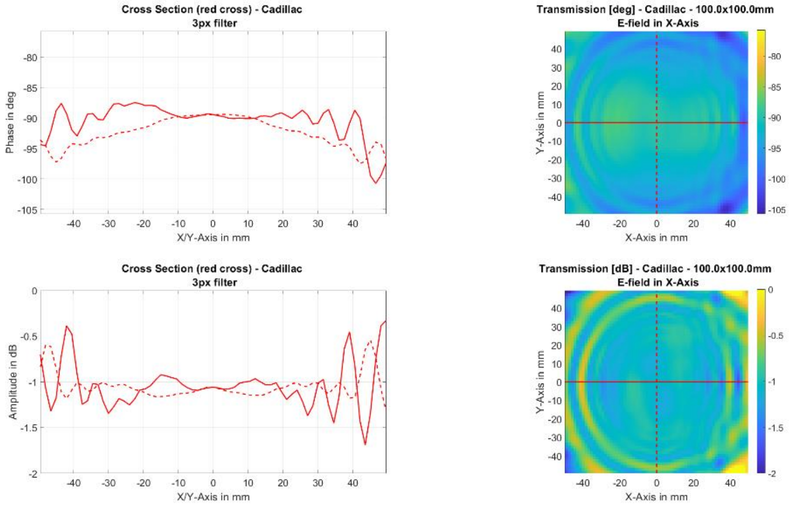
$$\alpha \approx \Delta\varphi\left[{}^{\circ}/_{\mathrm{mm}}\right] \cdot 0.62\mathrm{mm}$$



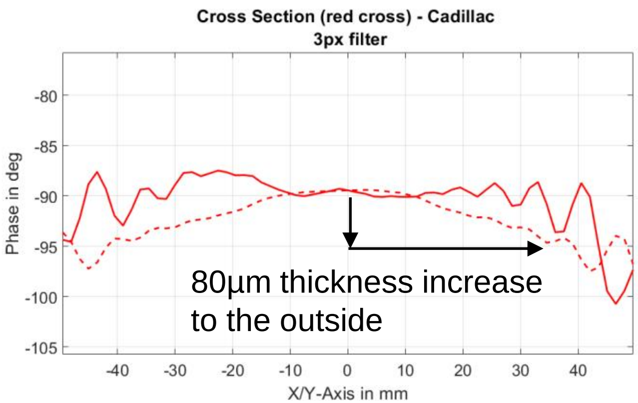
Rule of thumb:
A phase error of 10° per 10mm results in an angular error of 0.62°

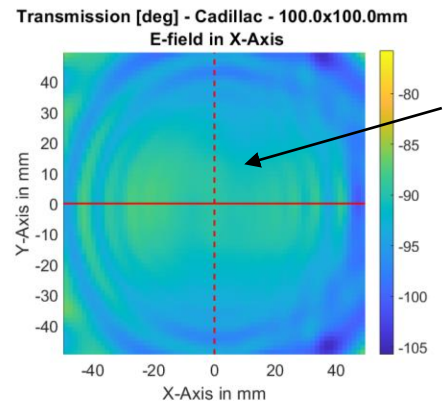
RMS Scanning Measurement

- ✓ xy positioning system for grid measurements allows homogeneity measurements
  as option available

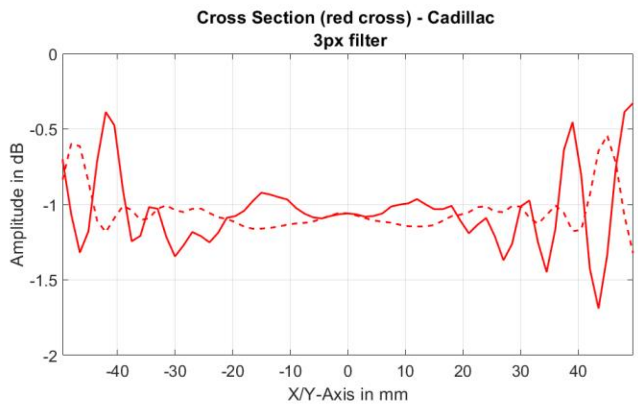


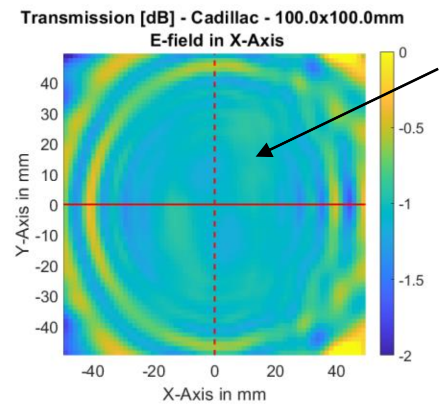
RMS Scanning Measurement





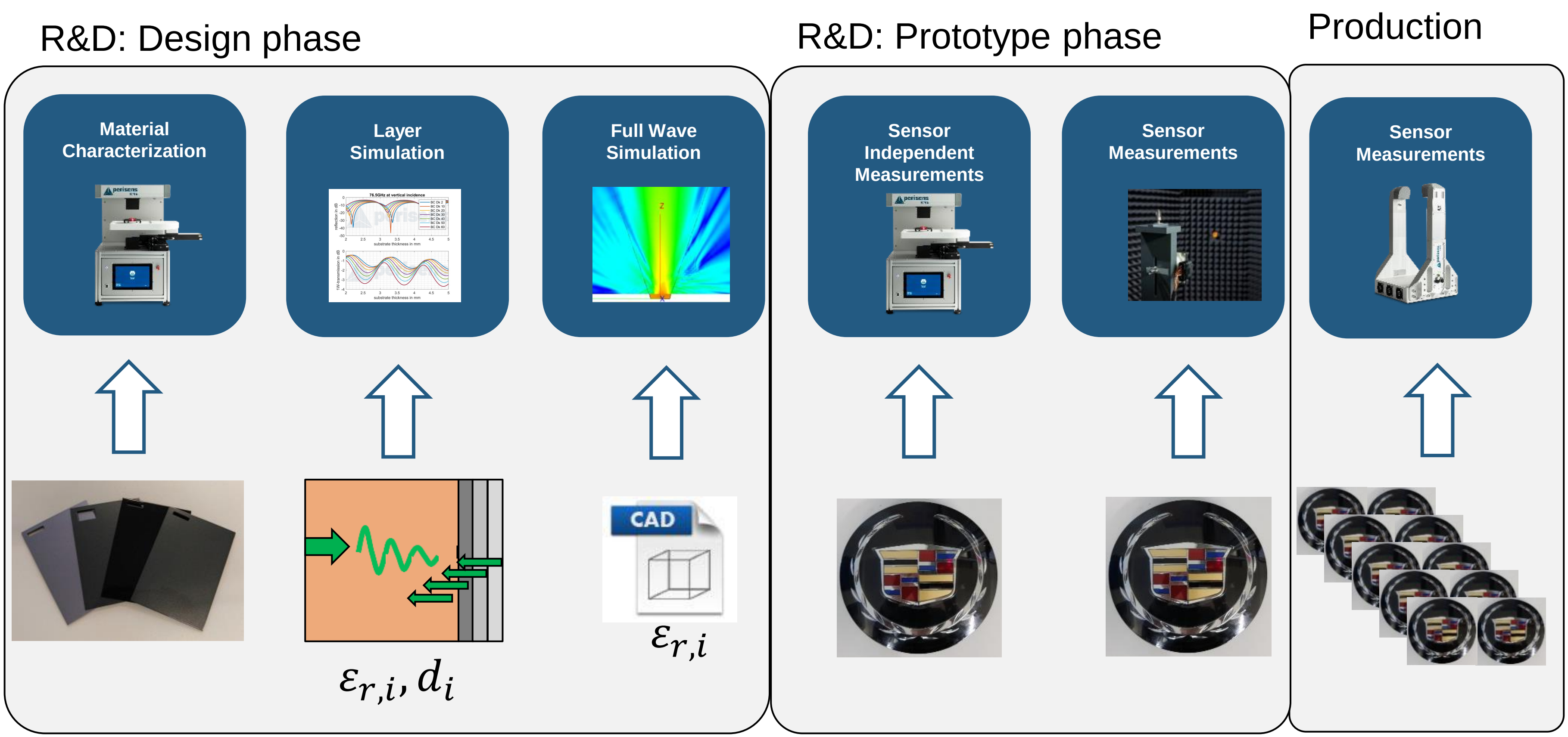
thickness change





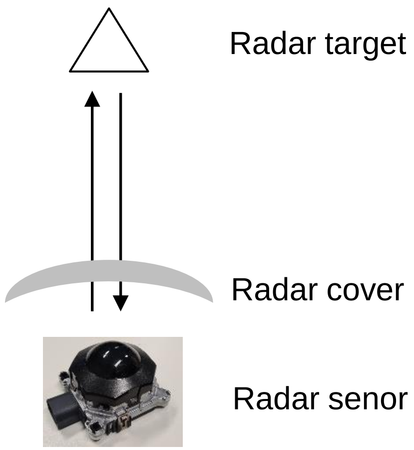
Paint influence

Radome: From Development to Production



End-of-Line Measurement of Radar Sensors

Traditional Way



Radar sensor based Installation (77GHz)

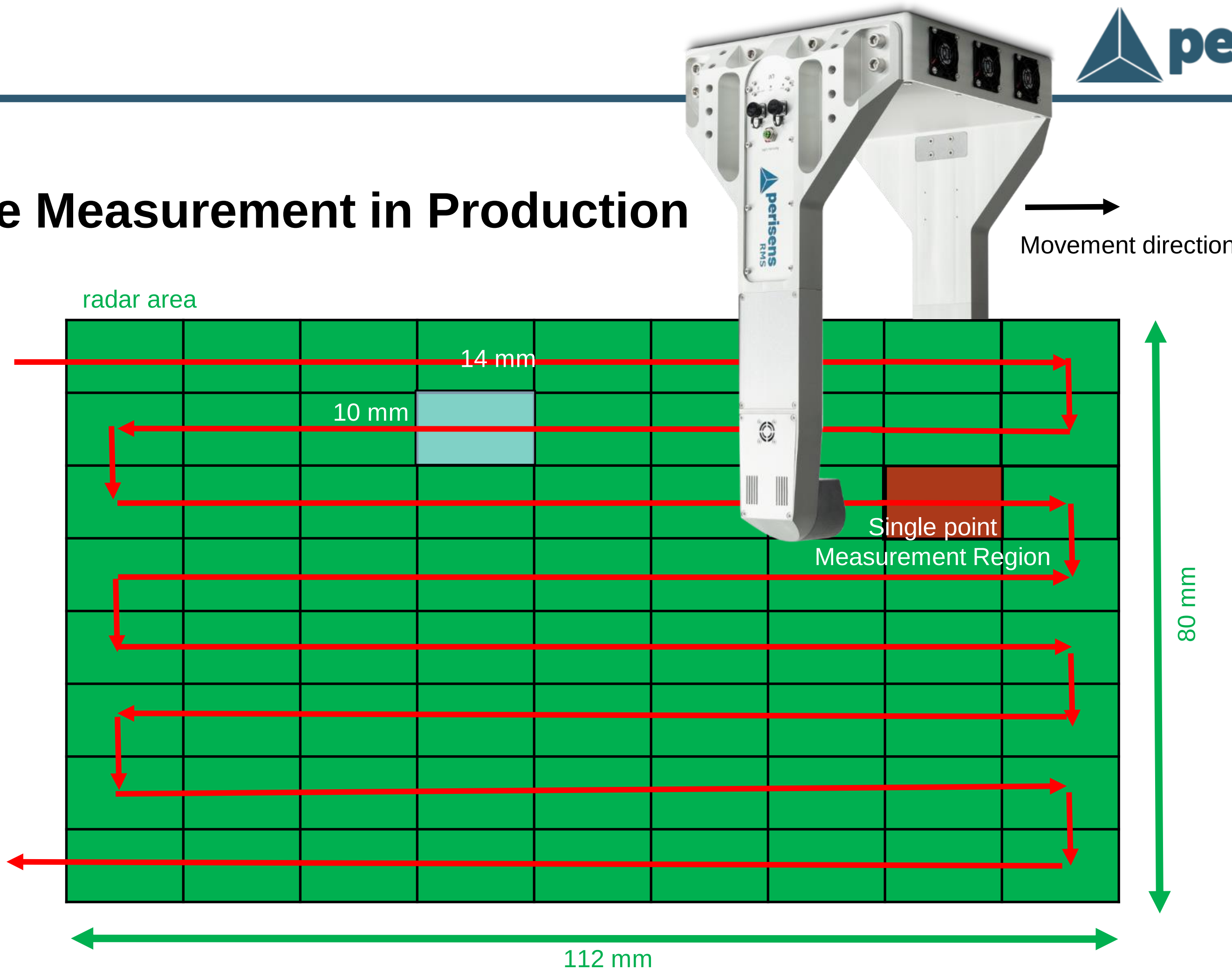
- Sensor based measurement

New Way

RMS-D 77/79G, perisens (76 to 81GHz)

- Radar independent Measurement

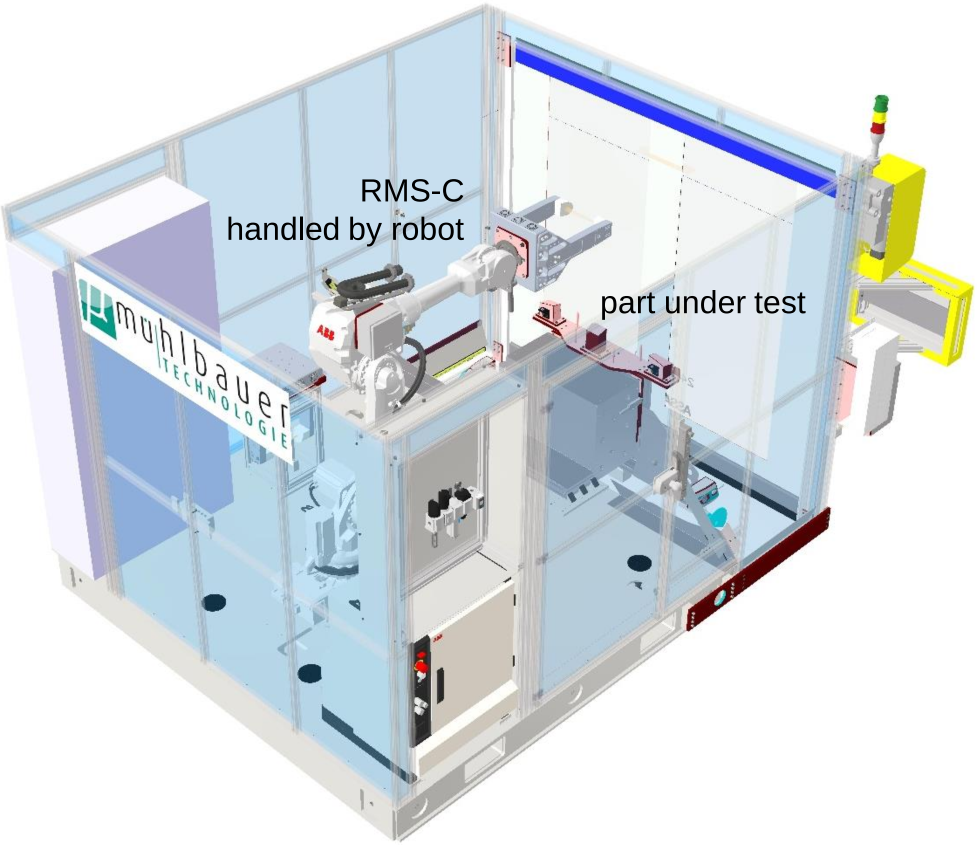
Radome Measurement in Production



Red line shows movement trajectory (measurement during movement)
e.g. a region of 80x112mm² with 72 points (=8x9)
→ **cycle time ~5s (= 60ms x 72pts | requires movement of 200mm/s)**

Example Setup 1:
RMS-C Handled by Robot with Fixed Part

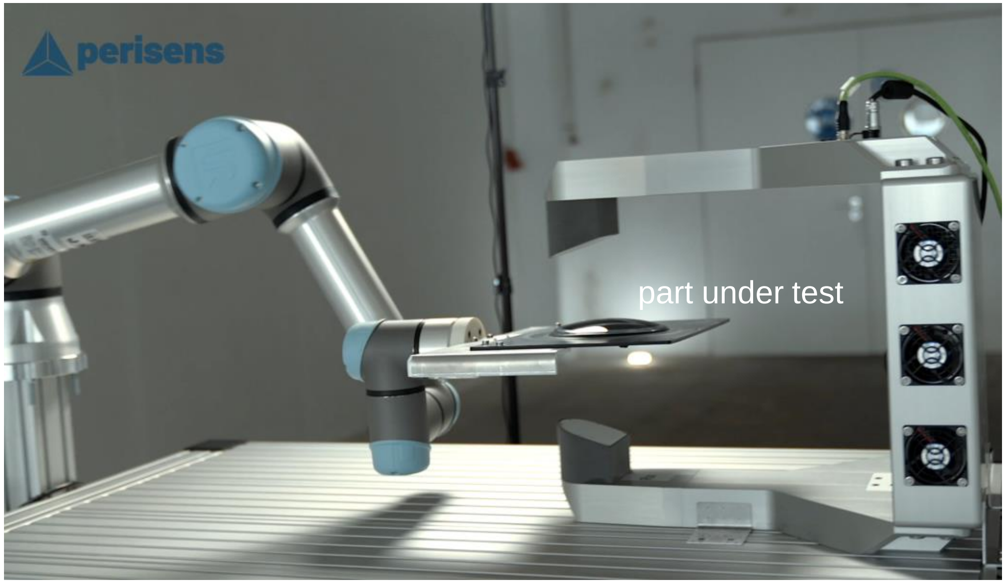
- Full measurement flexibility with 3D movement of RMS
- Allows scanning of curved parts
- Integration into the production process using standard robots in fully or partly automated solutions
- Especially suitable for **large parts** (e.g. bumper, black panel)



Exemplary production cell (manually loaded)
by mühlbauer TECHNOLOGIE GmbH

Example Setup 2:
RMS-C Fixed with Part Handled

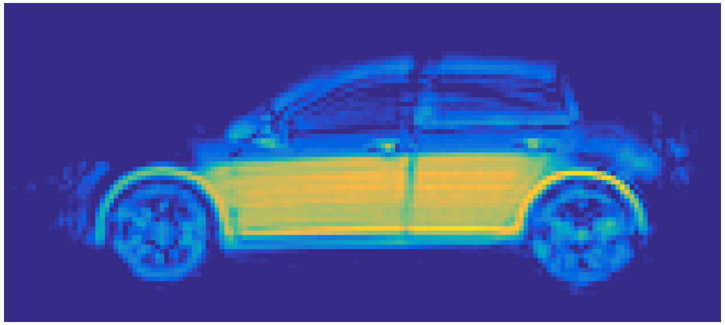
- Integration example with 3D handling of the part using a robot and fixed RMS-C
- Compact unit with a small footprint
- Integration into the production process in fully or partly automated solutions
- Especially suitable for **small parts** (e.g. emblems, radar covers)



Exemplary setup
by perisens GmbH

photography, Nikon
380 – 780nm wavelength

imaging radar, perisens
3.9 – 4.0mm wavelength



1:18 model

We are looking forward to a good cooperation on the same wavelength!

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