Karlsruhe Institute of Technology

Multiple Antenna Optimization for VHF Receive

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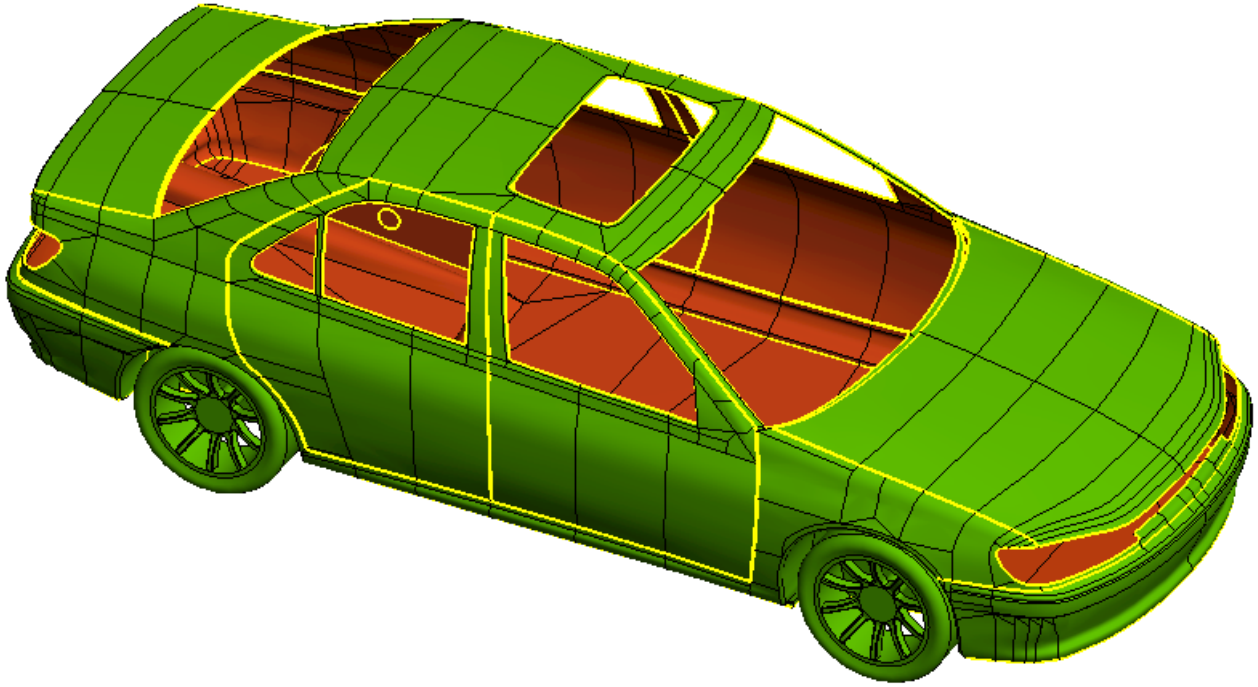
INSTITUT FÜR HOCHFREQUENZTECHNIK UND ELEKTRONIK

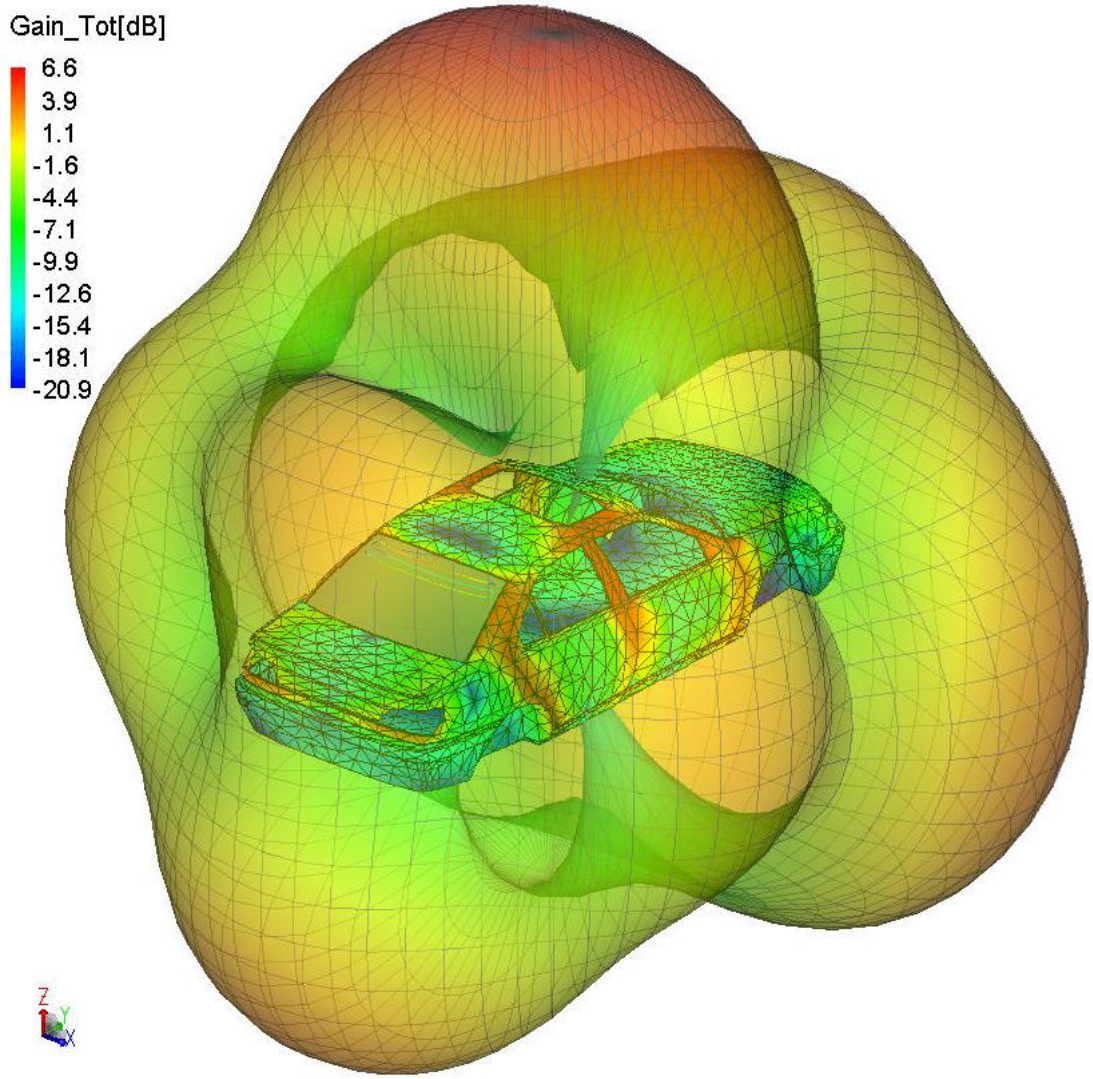
EM Modeling Check



Test of modeled areas for material and connections f.e. by FEKO

Courtesy EMSS

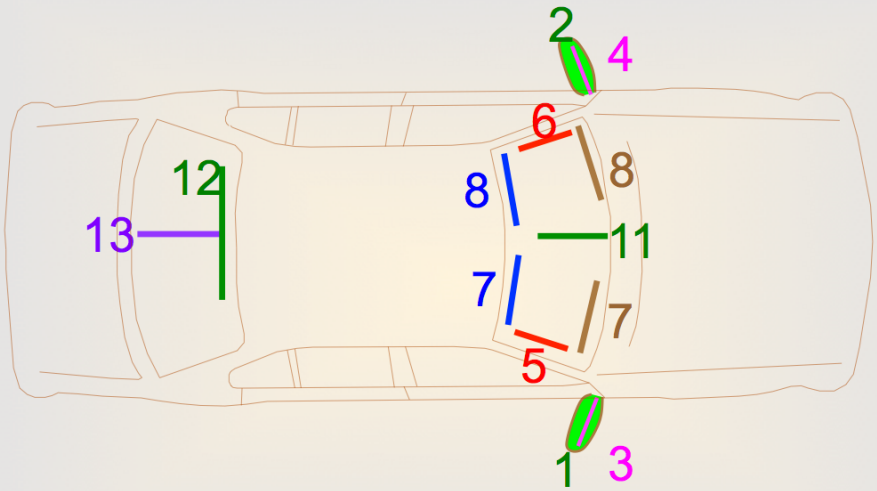
Windscreen Antenna Radiation Pattern



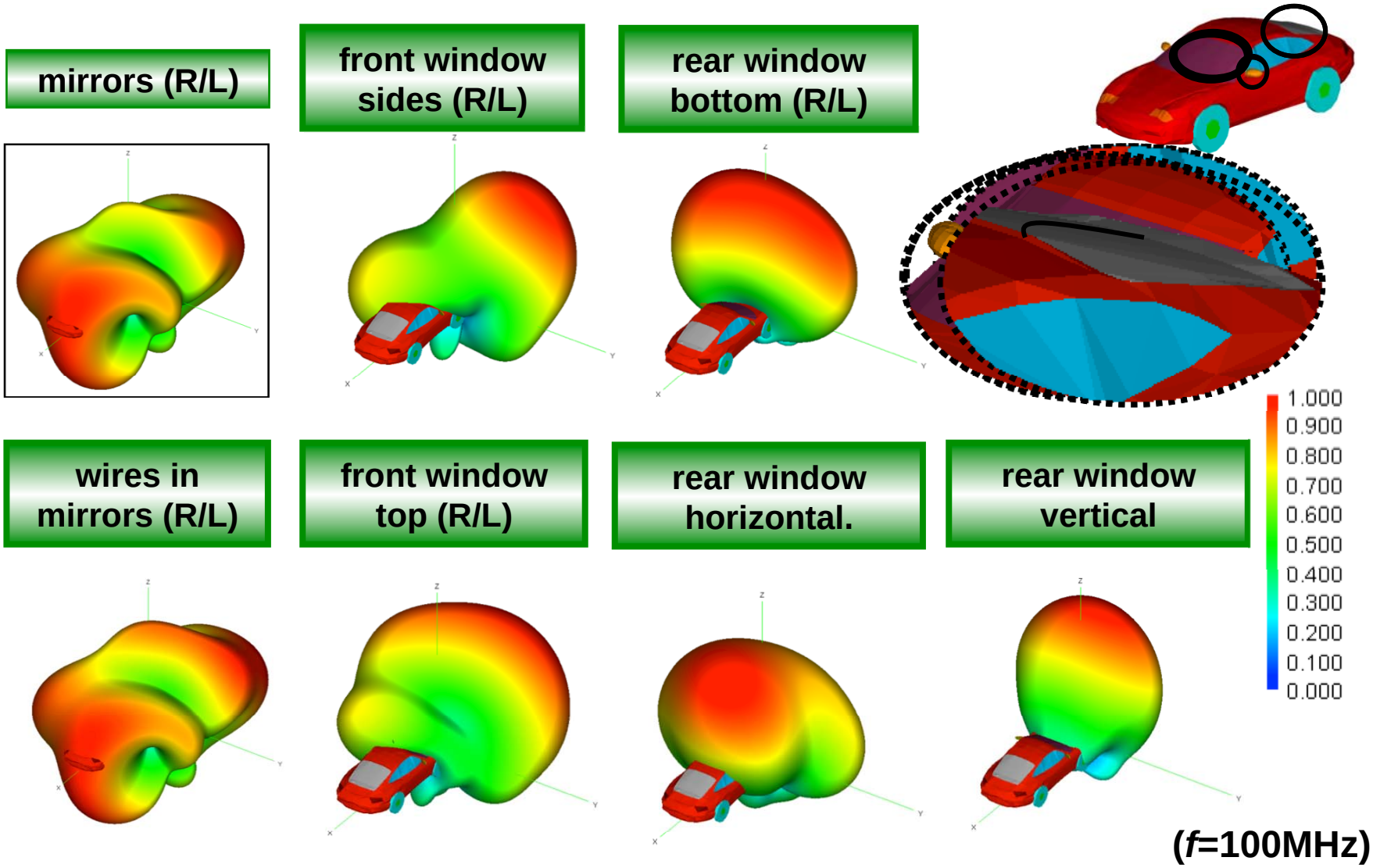
Critical:
- material
- slots
- ground

Courtesy EMSS

Example for Car Integrated Antennas



Characteristics of Car Integrated Antennas



(*f*=100MHz)

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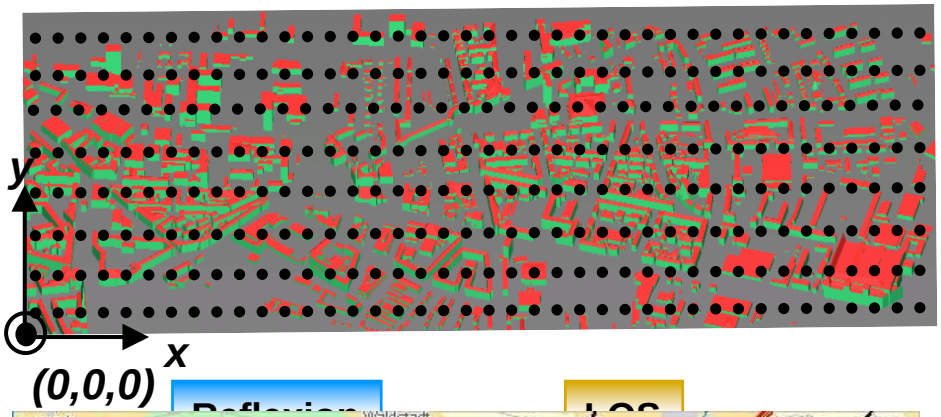
Example for Urban FM-Coverage Prediction

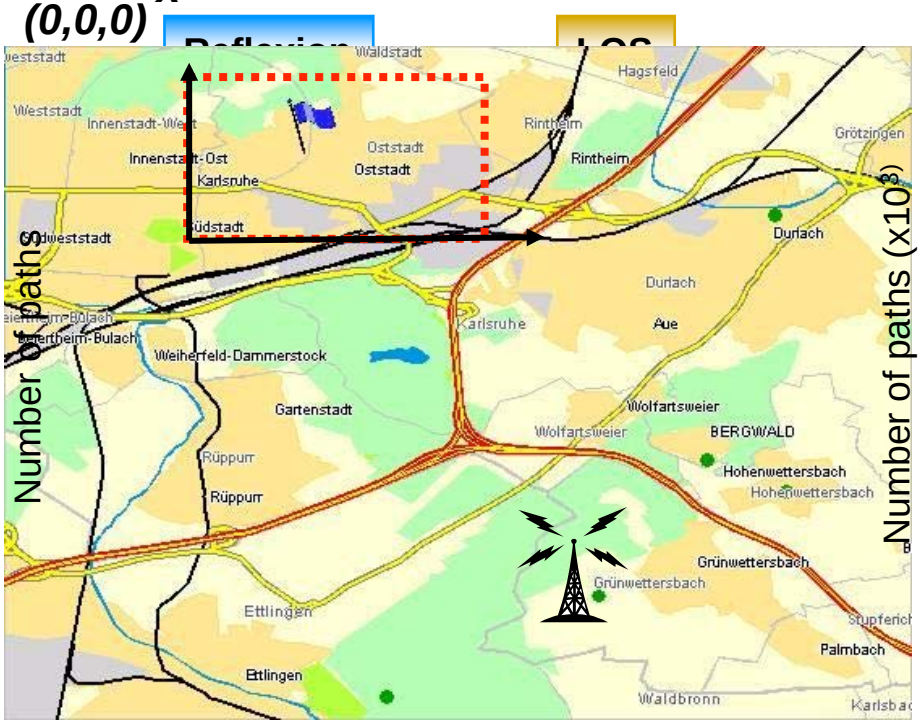


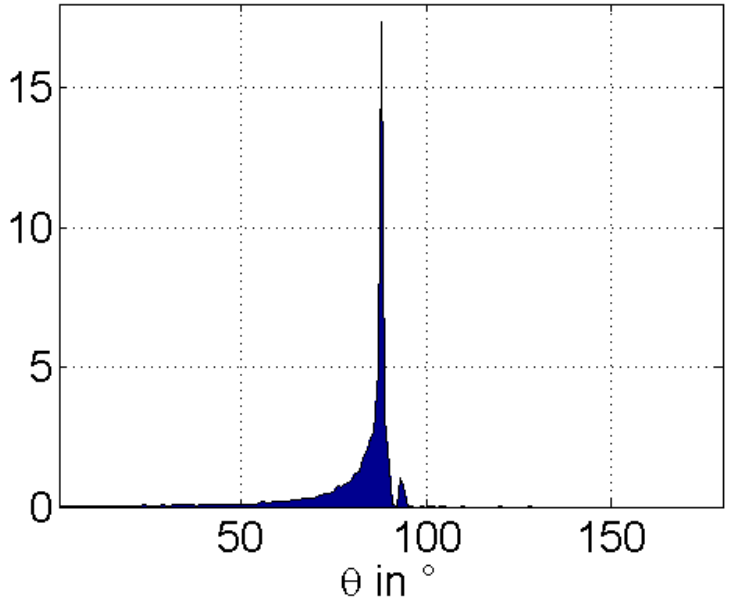
Urban coverage grid:

- ca. 2500 positions
- grid spacing 30 m (ca. 10λ)
- prediction height 1 m above ground

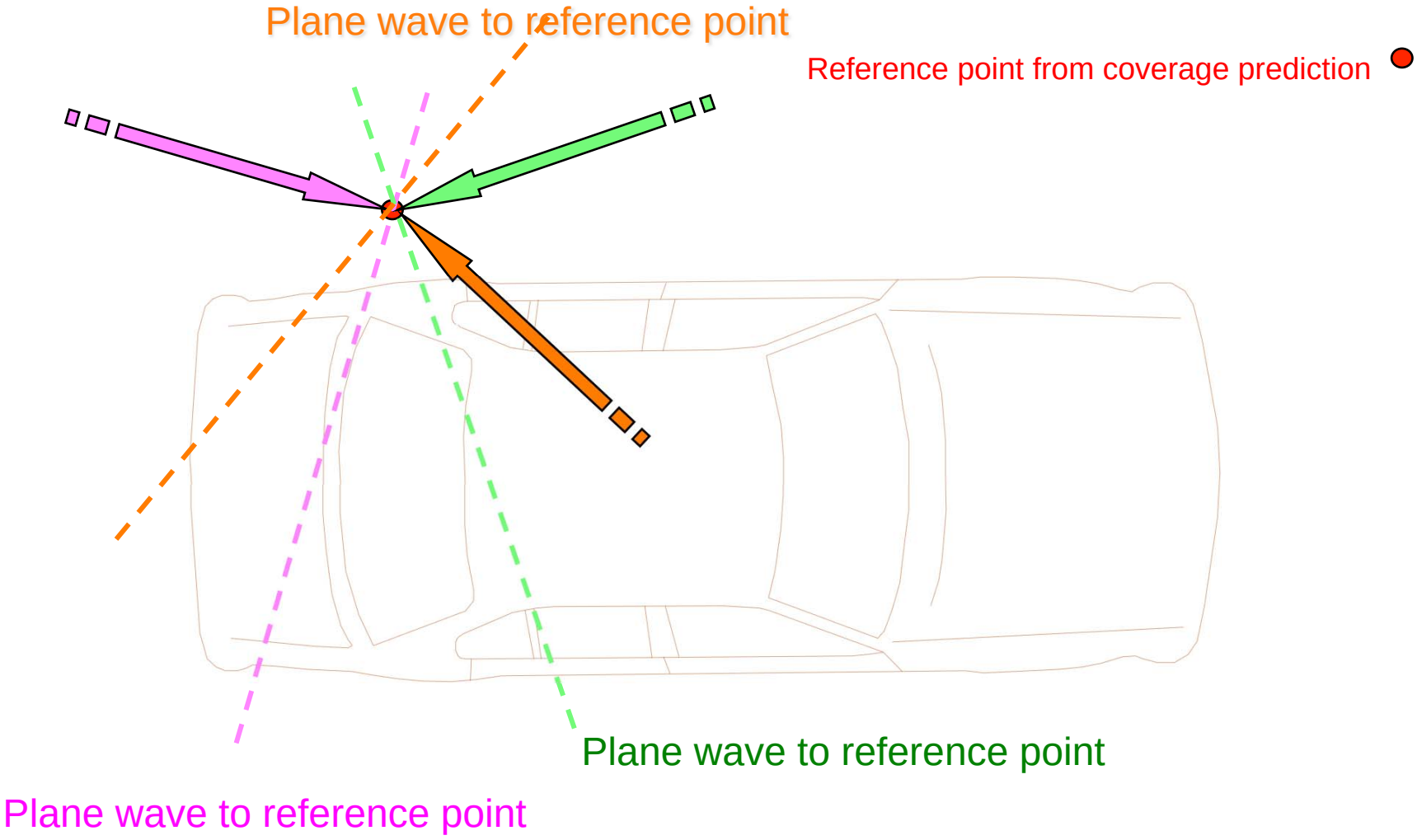
FM-Transmitter Grünwettersbach:

Position (2000, -6000, 445)





Wave Extension from Reference Point



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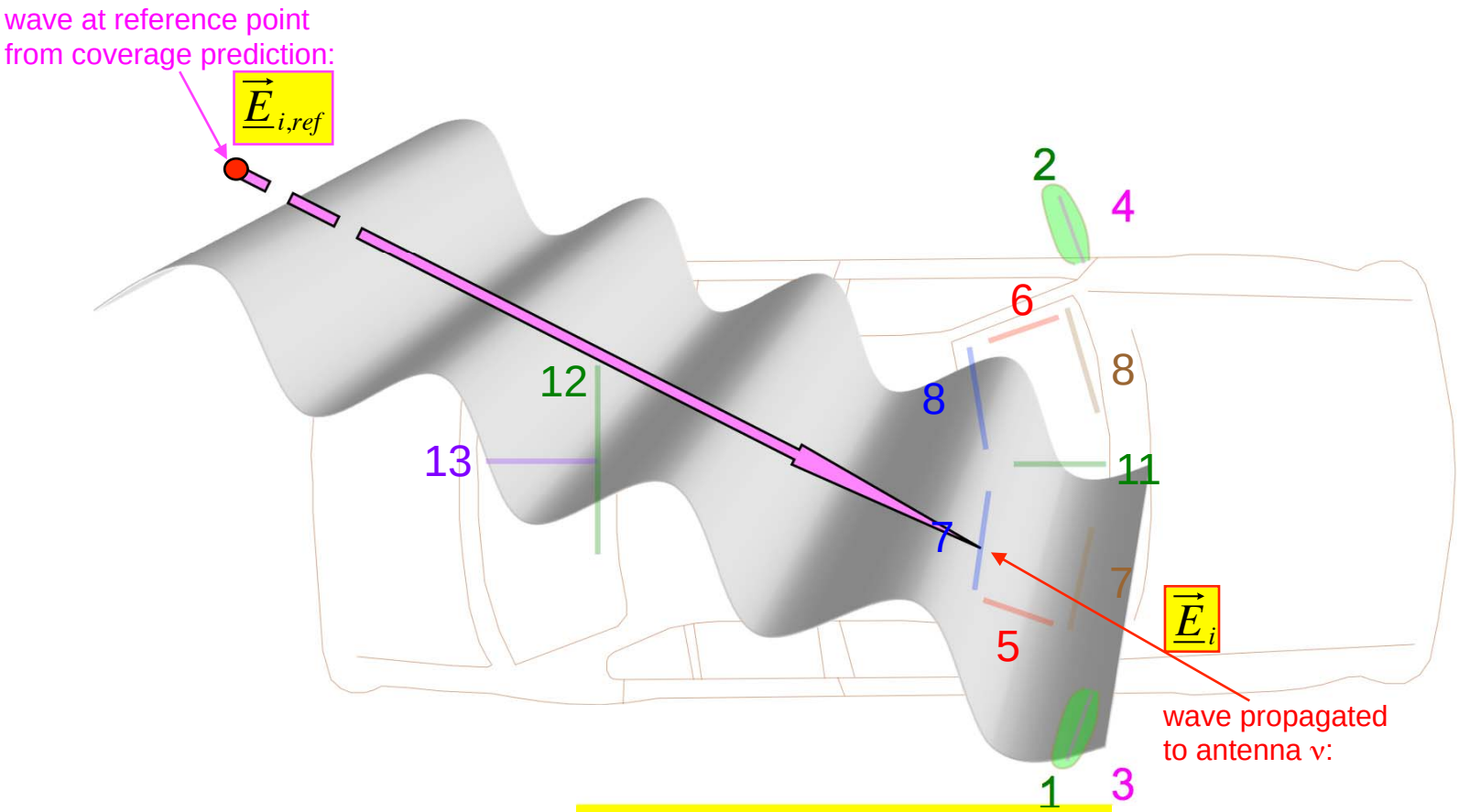
Calculation of the Antenna Output Signals



Plane wave from reference point: $\underline{\vec{E}}_i(\vec{x}) = \underline{\vec{E}}_{i,ref} e^{-j\omega\tau_{i,ref}} e^{-jk_i\vec{x}_{i,ref}}$

Antenna receive voltage $V_{Rx\nu}$: $\underline{V}_{Rx\nu}(\vec{x}) \approx \underline{C}_\nu(\theta_i, \psi_i) \cdot \underline{\vec{E}}_i(\vec{x}) \cdot e^{-jk_i\vec{x}_\nu}$

Calculation of the Received Power P_{Rxi}

Calculation of the complex, polarimetric incident field-strenght by ray-tracing:

Wave:
- phase
- polarization
- ray vector

Rays:
- for each ray *n of N*
- for each antenna *i*
- for each car position *x*

Known:
- ✓ position of the BS
- ✓ position of the car
- ✓ position of antennas
- ✓ antenna characteristics

Calculation of the total received power P_{Rxi} for each antenna *i*:

$$P_{Rxi,coherent} = \frac{\left|\underline{V}_{Rx,i}\right|^2}{8\mathrm{Re}\left(\underline{Z}_{ARx,i}\right)} = \frac{\lambda^2}{8\pi} G_{Rx,i} \frac{1}{Z_{F0}} \left| \sum_{n-1}^{N} \underline{C}_{Rx,i}\left(\theta_{Rxn},\psi_{Rxn}\right) e^{j\Delta\phi_{in}} \underline{E}_{Rxn}\left(\theta_{Rxn},\psi_{Rxn}\right) \right|^2$$

$$P_{Rxi,incoherent} = \frac{\left|\underline{V}_{Rx,i}\right|^2}{8\mathrm{Re}\left(\underline{Z}_{ARx,i}\right)} = \frac{\lambda^2}{8\pi} G_{Rx,i} \frac{1}{Z_{F0}} \sum_{n=1}^{N} \left| \underline{C}_{Rx,i}\left(\theta_{Rxn},\psi_{Rxn}\right) e^{j\Delta\phi_{in}} \underline{E}_{Rxn}\left(\theta_{Rxn},\psi_{Rxn}\right) \right|^2$$

Calculation of the cumulative distributive function CDF of the received power P_{Rxi} →

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Calculation of the Antenna Correlation Coefficients

Voltage correlation coefficient:

$$\underline{\rho}_{V,\underline{v}_i,\underline{v}_j} = \frac{\sigma_{\underline{v}_i \underline{v}_j}}{\sigma_{\underline{v}_i}\sigma_{\underline{v}_j}}$$

***i, j* = 1...13**

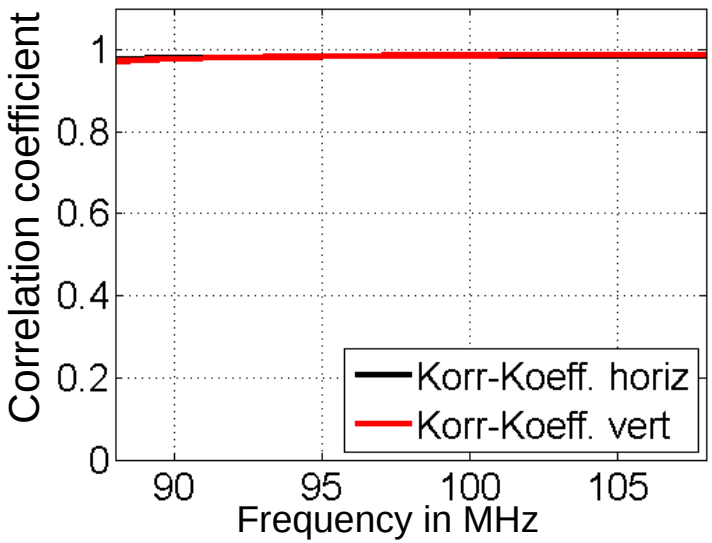
Power correlation coefficient

$$\rho_{P,\underline{v}_i,\underline{v}_j} \approx \left|\underline{\rho}_{V,\underline{v}_i,\underline{v}_j}\right|^2$$

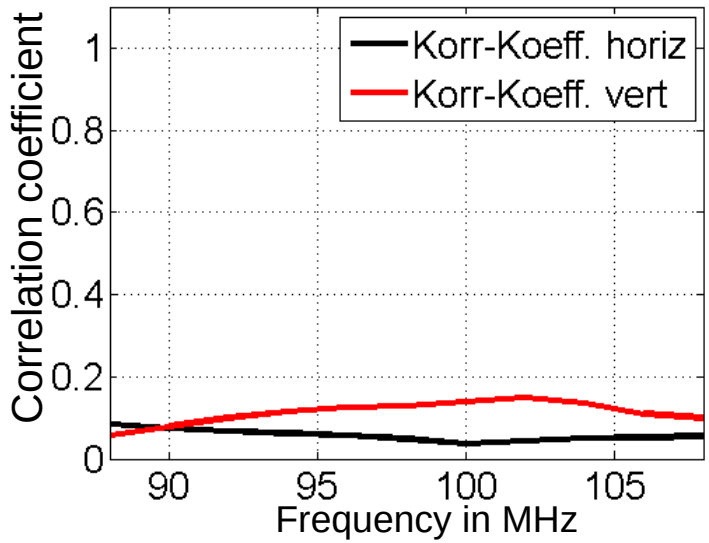
$0 \le \rho_P \le 1$

1/2: mirrors R/L	9/10: front window low R/L
3/4: mirror wires R/L	11: front window center
5/6: front window sides R/L	12: rear window horicontal
7/8: front window top R/L	13: rear window vertical

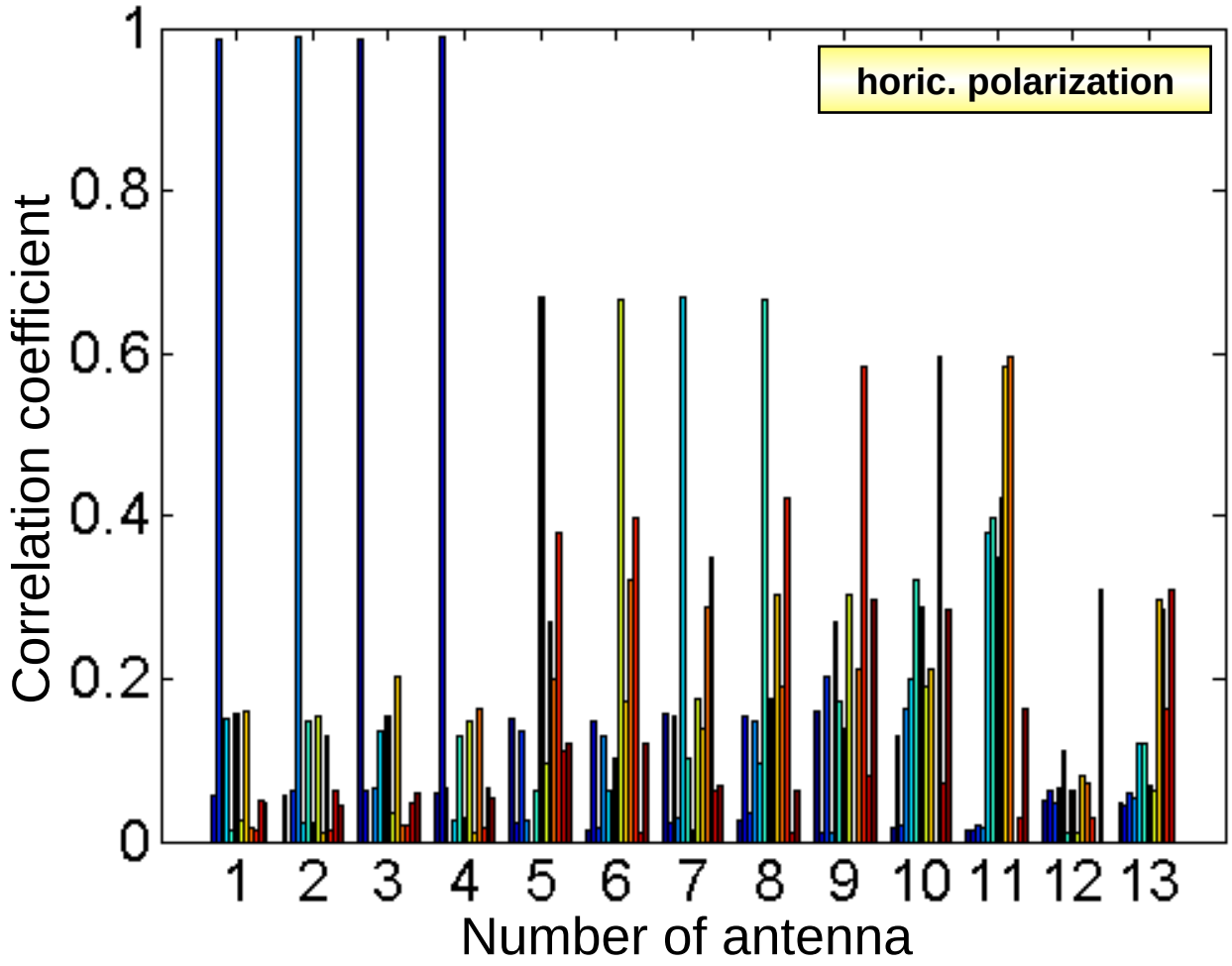
ρ_P mirror R & mirror wire R **$\rho_P \approx 1$**



ρ_P mirrors R & L **$\rho_P << 1$**



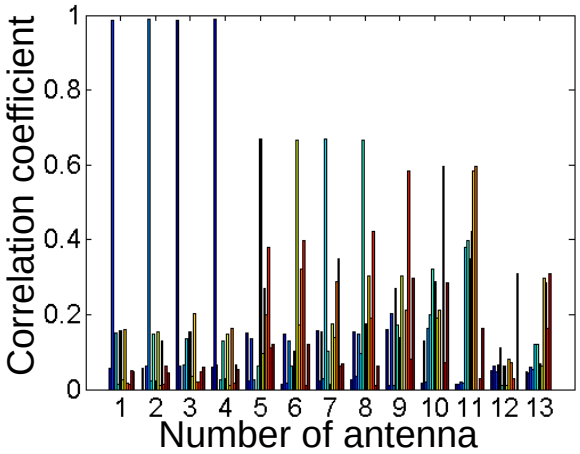
Power Correlation Coefficients ρ_P of all Antennas



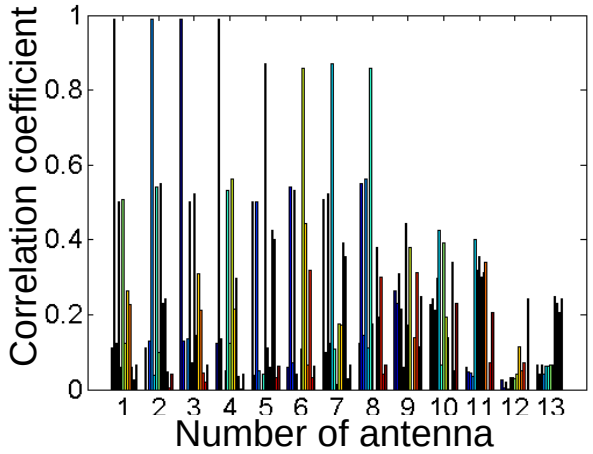
1/2: mirrors R/L
3/4: mirror wires R/L
5/6: front window sides R/L
7/8: front window top R/L
9/10: front window low R/L
11: front window center
12: rear window horic.
13: rear window vert.

Power Correlation Coefficients ρ_P of all Antennas

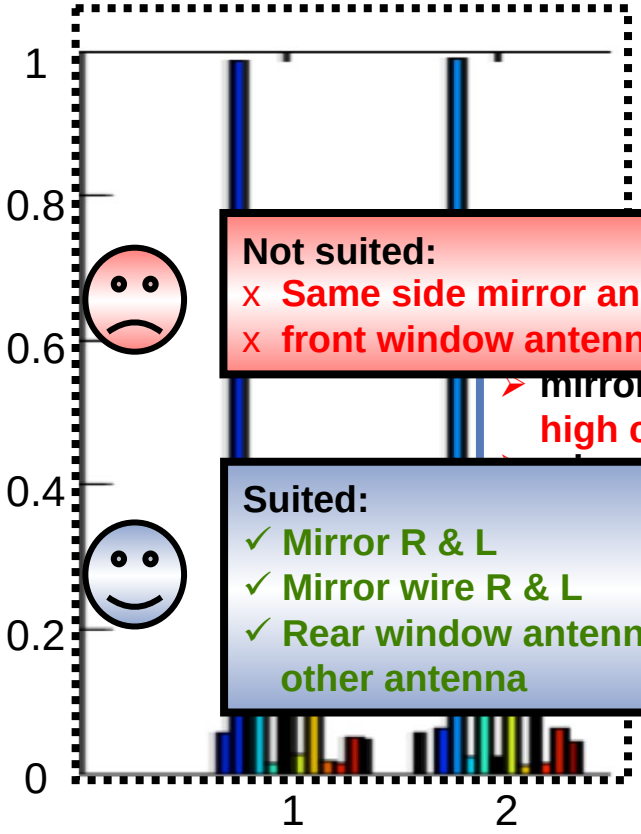
Horic. polarization



Vert. polarization



1/2: mirrors R/L	9/10: front window low R/L
3/4: mirror wires R/L	11: front window center
5/6: front window sides R/L	12: rear window horic.
7/8: front window top R/L	13: rear window vert.



Not suited:
- x Same side mirror and wire 2
- x front window antennas co-pol

wire R :

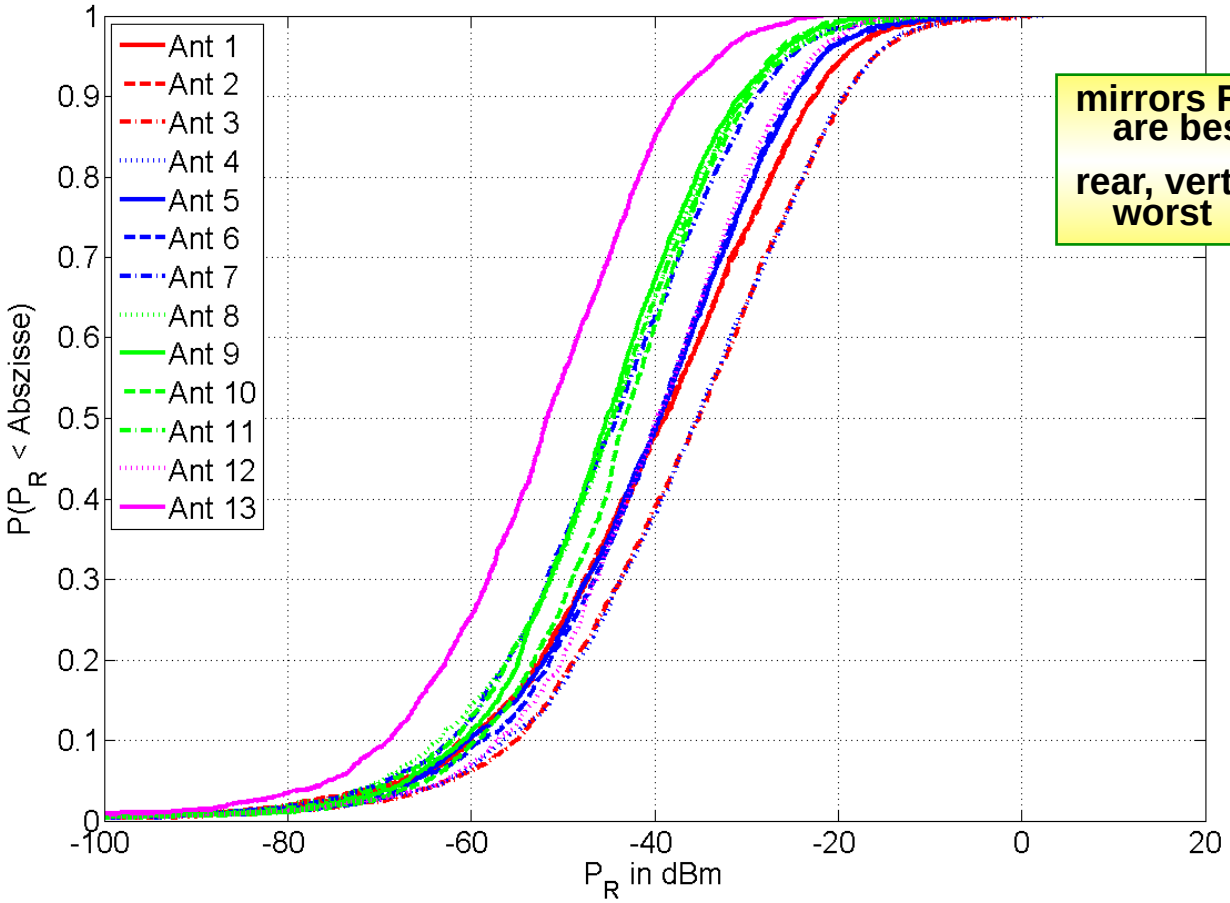
- ➢ mirror L and mirror wire L : high correlation

all other

Suited:
- ✓ Mirror R & L
- ✓ Mirror wire R & L
- ✓ Rear window antenna & each other antenna

CDF of the Received Power P_{Rxi}

- **Transmitter: omni antenna, transmit power P_{Tx}= 60 dBm**
- **no attenuation by trees, people, cars etc.**
- ***f* = 100 MHz, polarization horizontal**



mirrors R/L and mirror wires R/L are best

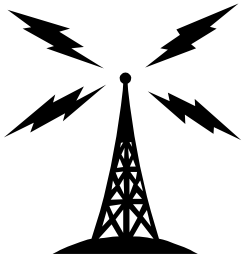
rear, vertical window antenna is worst

Antennas:

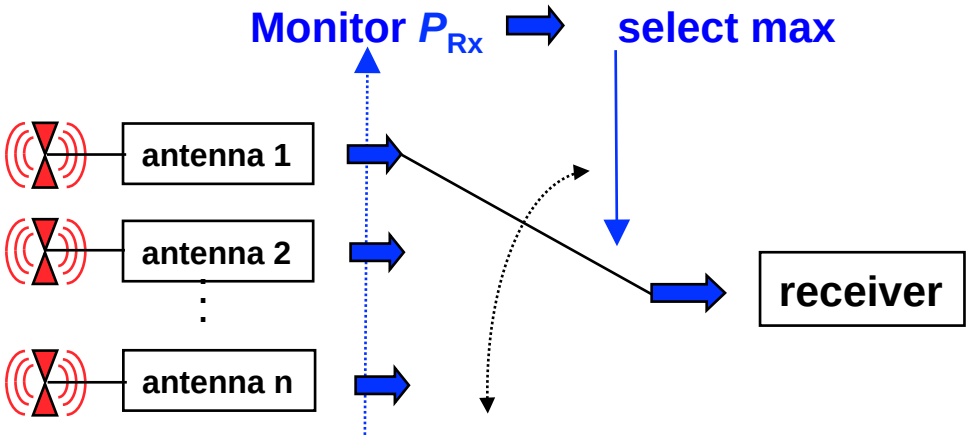
1/2: mirrors R/L
3/4: mirror wires R/L
5/6: front window sides R/L
7/8: front window top R/L
9/10: front window low R/L
11: front window center
12: rear window horizontal
13: rear window vertical

Diversity for Combination of Antennas

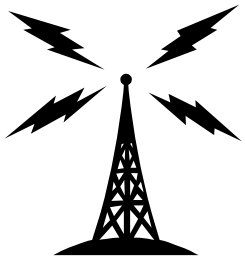
Selection Combining:



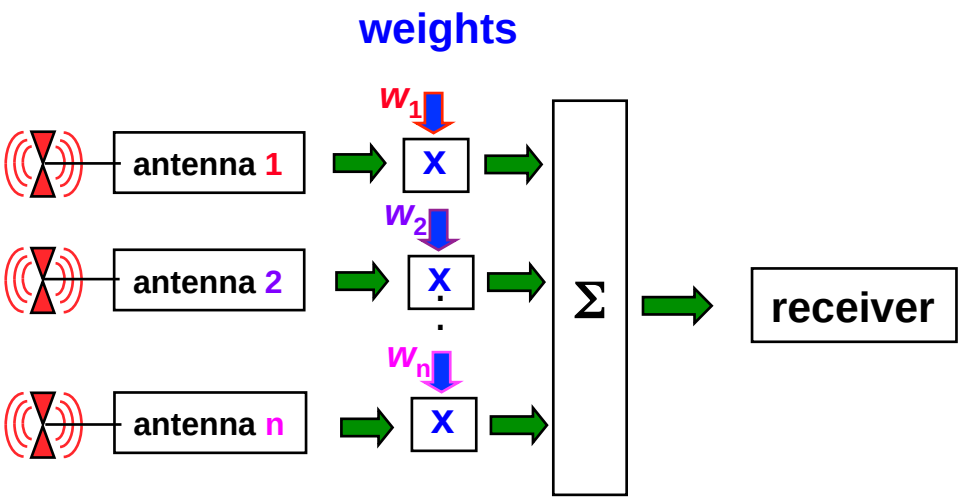
only 1 signal used



Maximum Ratio Combining:

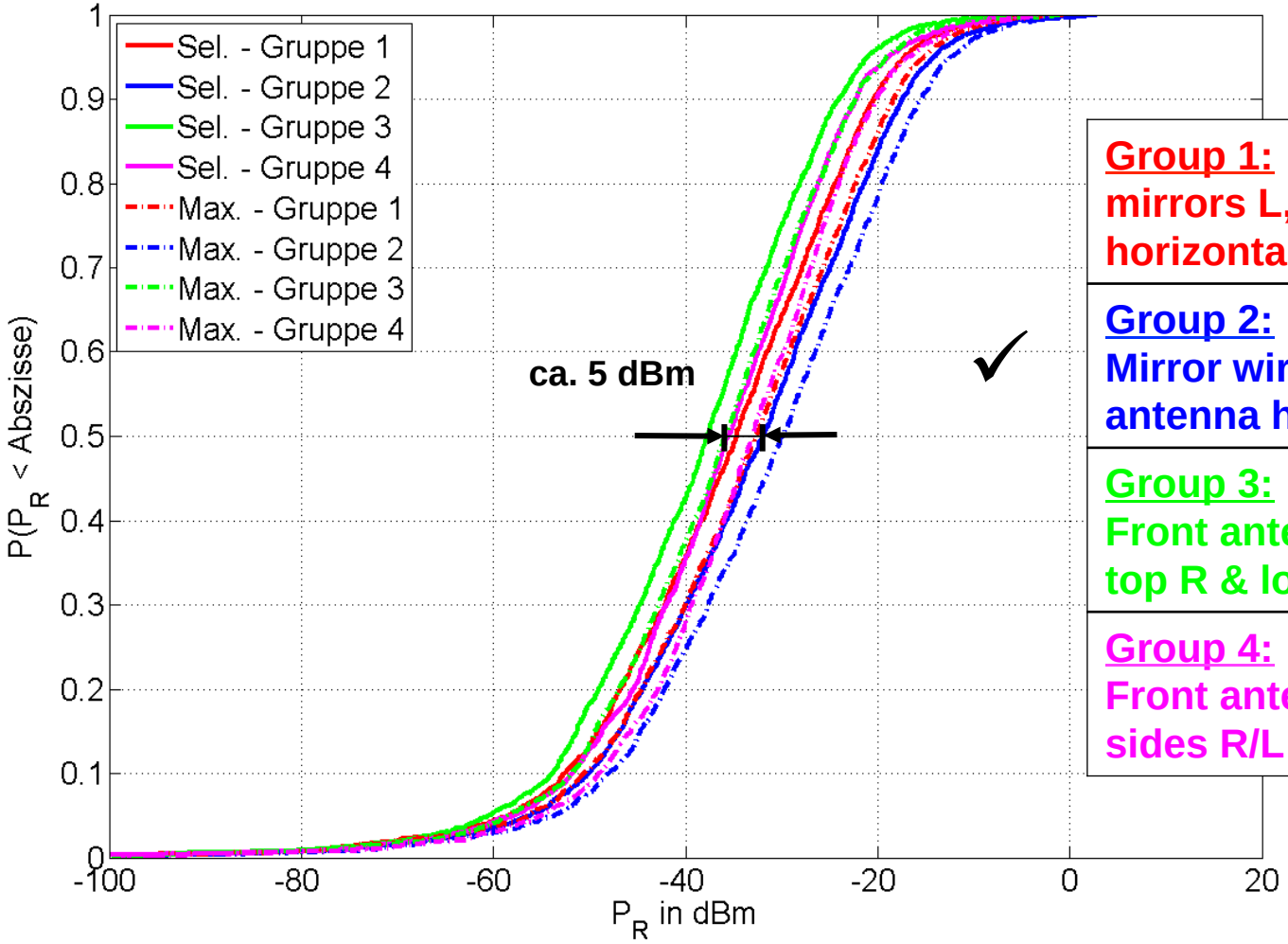


Good antennas are better weighted



P_{Rxi}-Comparison of 4 Antenna Groups, 3 Ant. Each

Selection Combining Sel.; Max. Ratio Combining Max. (all weights 1 (Equal Gain Combining)



Group 1:
mirrors L, R & rear ant. horizontal

Group 2:
Mirror wires L, R & rear antenna horizontal

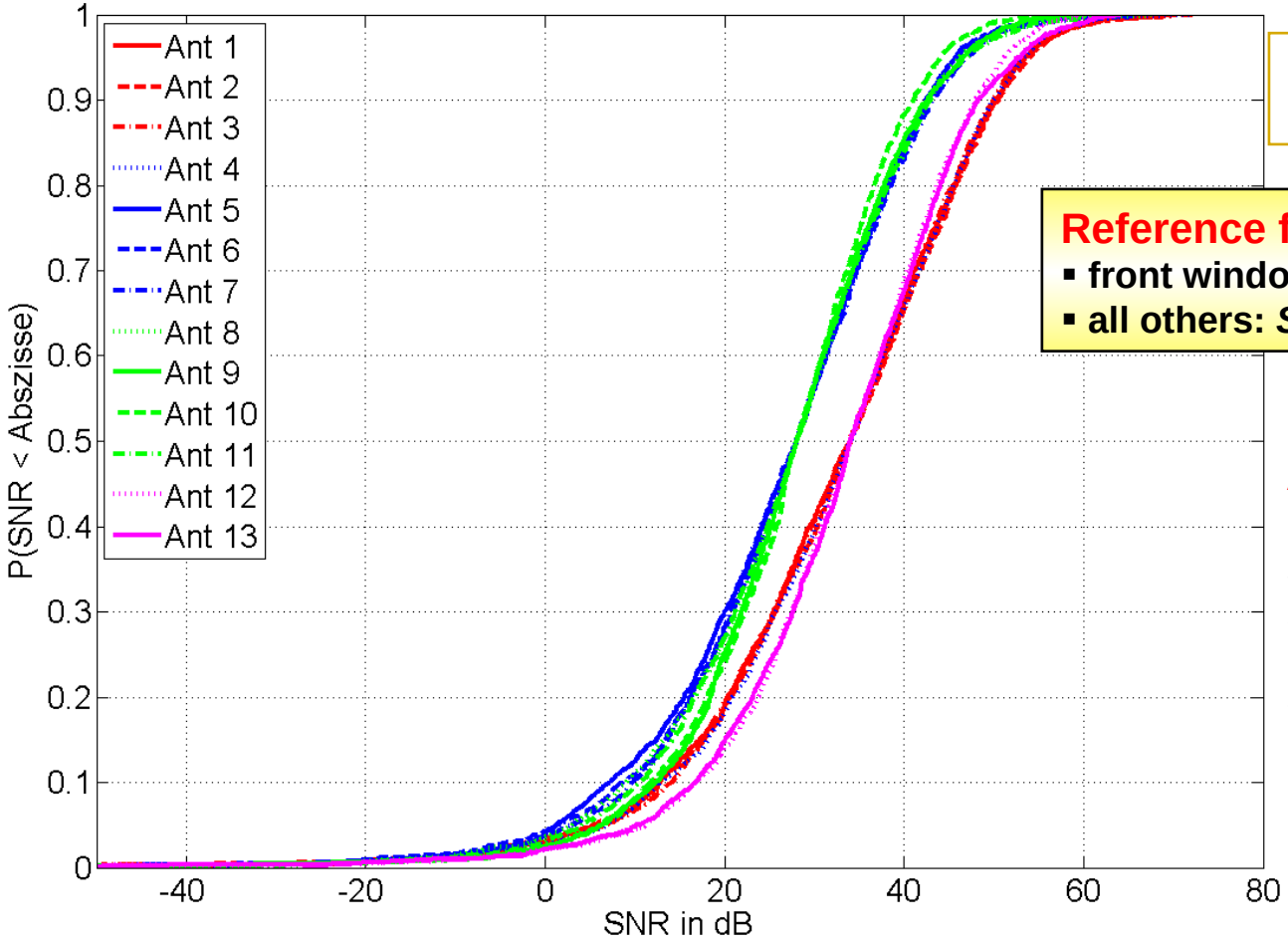
Group 3:
Front antennas side R, top R & low R

Group 4:
Front antennas low L, sides R/L & center

SNR -Comparison of the Antennas

$$[SNR]^{dB} = [P_{Rx}]^{dBm} - [P_N]^{dBm}$$

- ***SNR***: **Signal-to-Noise-Ratio**
- P_N: **Noise power**



Assumption:
no motor or vehicle noise

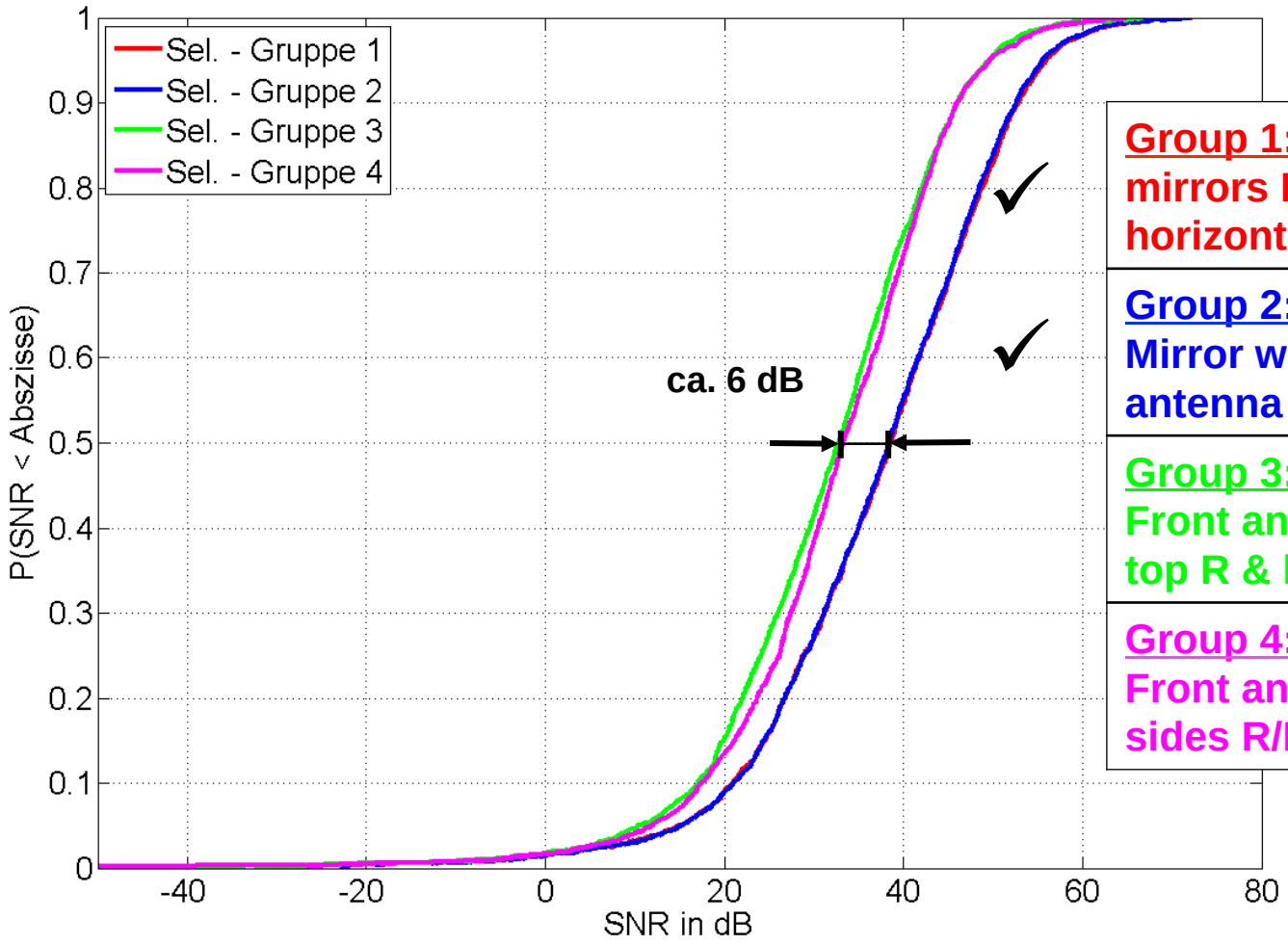
Reference from measurements:
- **front window ant.: SNR_{mean}= 28dB**
- **all others: SNR_{mean}= 34dB**

Antennas:

1/2: mirrors R/L
3/4: mirror wires R/L
5/6: front window sides R/L
7/8: front window top R/L
9/10: front window low R/L
11: front window center
12: rear window horizontal
13: rear window vertical

SNR -Comparison of the 4 Antenna Groups

Requirement for Maximum Ratio Combining: uncorrelated noise not satisfied ➔ Sel. Combining



Group 1:
mirrors R, L & rear ant. horizontal

Group 2:
Mirror wires R, L & rear antenna horizontal

Group 3:
Front antennas side R, top R & low R

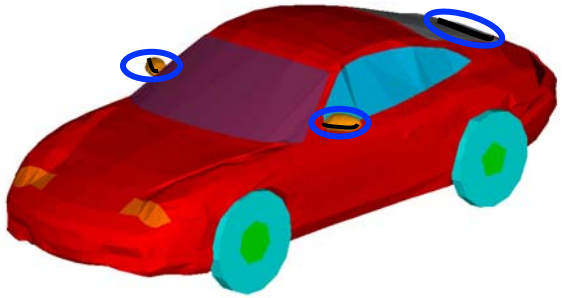
Group 4:
Front antennas low L, sides R/L & center

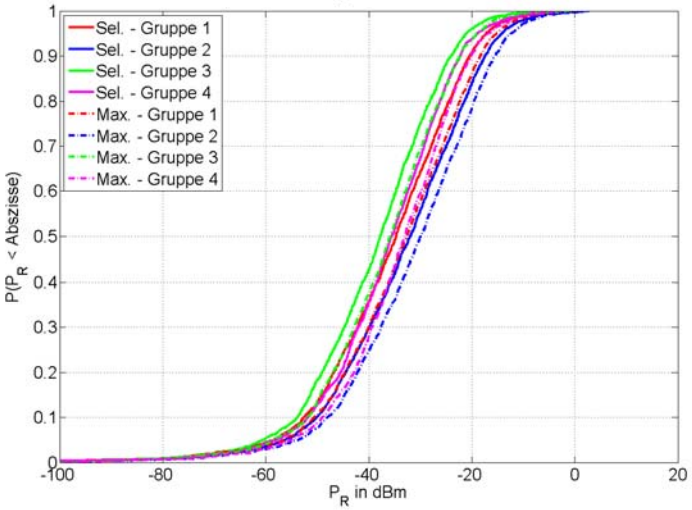
Summary

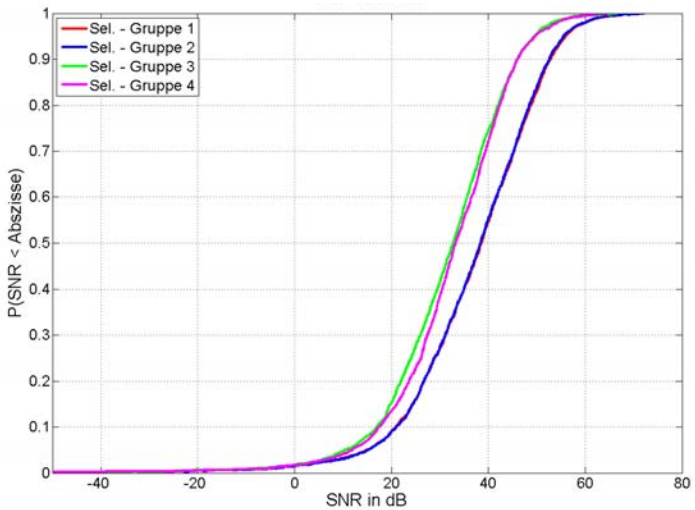
Best antenna combination with 3 elements:

Group 2:
Mirror wires R, L & rear antenna horizontal

- ✓ **pattern suited for terr. transmission**
- ✓ **all correlation coefficients below 0.2**
- ✓ **receives more power than all others**
- ✓ **high *SNR***







Summary Virtual Drive

All tools are available for Virtual Drive

vehicle EM-modeling

coverage prediction

During the vehicle R&D phase the antennas and antenna positions can be optimized as soon as the shape and materials are known

Enormous advantages:

- optimization of Diversity and MIMO systems
- significant cost reduction
- significant time savings