Antenna Modeling for Virtual Drive
Criteria for the Selection of the Position

Single antennas:
- sufficient antenna height
- hemispherical coverage
- ground plane/balun
- no vehicle interfering signals
- polarization purity (SDARS)

Multiple antenna systems:
- decoupling
- diversity
  - pattern diversity
  - polarization diversity
  - spatial diversity

Multi-band antennas:
- decoupling of the bands
Requirements for the Antenna Position

- no shielding of the $E$-field!
- no displacement of the $H$-field!
- no capacitive coupling antenna - vehicle!
- no inductive coupling antenna - vehicle!
- no parasitic currents on the cables!
- no radiation inside the vehicle
Examples for Elevation Coverage

- Sat Radio, GPS ...
- Radio, TV, MobCom ....
- Car to infrastructure
- C2C, C2X
Advantageous Vehicle Antenna Integration

Low interference, good V2V links
Example Automotive Antenna System

- Back window: AM + FM1
- Back window: FM2 + TV
- Back window: DAB
- Roof antenna for GPS, GSM, SDARS
- DSRC Antenna in Dashboard (only Japan)
- VICS/DSSS Antenna in front window (only Japan)
- Keyless entry antennas

Source: Audi AG
Cabrio: Pattern-, Polarization-, Spatial-Diversity
Cabrio: Pattern-, Polarization-, Spatial-Diversity
Raodstar and Cabrio

bad place

good place
Heigh Vehicles
SUV: Pattern-, Polarization- and Spatial-Diversity
SUV: Pattern-, Polarization- and Spatial-Diversity
Corbon Fiber Roof

VW Golf

Shilded integration

spoiler

mirrors
Corbon Fiber Car

Be aware of cables, radiation inside, sensitive matching...

BMW i3
Carbon Fiber Problems – Required Research

- Losses of the compound material
- Radiation inside the car
- Influence from inside on the antenna radiation characteristics
- Influence of cables and power supply
- Polarization sensitivity
# AM/FM Antenna Comparison

<table>
<thead>
<tr>
<th>Antenna Attribute</th>
<th>Fixed Mast</th>
<th>Power Mast</th>
<th>Wire Windshield</th>
<th>Film Windshield</th>
<th>Roof Slot</th>
<th>Decklid Slot</th>
<th>Rear Window</th>
<th>Active Rear Window</th>
<th>Active Diversity Window</th>
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<tbody>
<tr>
<td>AM Gain</td>
<td>Good</td>
<td>Good</td>
<td>Fair</td>
<td>Good</td>
<td>Good</td>
<td>Good</td>
<td>Fair/Poor</td>
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<tr>
<td>FM Gain</td>
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<td>Good</td>
<td>Fair</td>
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<td>EMC Immunity</td>
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<td>Fair/Poor</td>
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<td>Fair</td>
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<td>Signal Overload Resistance</td>
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<td>Good</td>
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</table>

Antenna Engineering Handbook; Ch. 39, Luis L. Nagy
Assessment of Antennas in Diversity/MIMO Systems

Antenna selection by:
- antenna correlation coefficients
- antenna Signal to Noise Ratio (SNR)
- system capacity $C = \log_2(1 + SNR)$

System performance evaluation:
- Diversity or MIMO capacity
- Mean Effective Array Gain

$$\text{MEAG} = \frac{\bar{P}_{\text{DUT}}}{\bar{P}_{\text{reference}}}$$

where $\bar{P}_{\text{DUT}}$ is the power of the test signal on the same channel and same transmit antenna.
Objective: Optimization of Antenna Configurations.

Diagram showing different antenna configurations with symbols for BF, MR, ML, and B, along with a graph plotting path loss in dB over time in s.
C2X Communications Optimisation

- Selection of antenna types
- Selection of antenna positions
- Number of antennas
- Number of receive channels
- Diversity or MIMO

Optimisation
Commercial 3D Digital Car Models

Data conversion, Material assignment

Models for Ray-Tracing and EM-Simulation
Car - Full Model

Courtesy EMSS
Car and Car-Integrated Antenna Modeling Features

- 3D-models available
- adjustable resolution
- flexible material assignment
- interior-modeling for in-vehicle propagation
- import to FEKO, CST, HFSS...
- implementation of antennas
- import to Ray-Tracing
Car EM Modeling Verification

Verification:
- antenna characteristic $C(\theta, \psi)$
- antenna gain $G$
Measurement Audi Integrated DSRC Antenna

Freq: 5.900 GHz

Relative Gain (V-Pol/DB)

Driving Direction

AudiA6_MIMO_1st_Mode
Coherent/Incoherent Path Combination $h = 60$ cm

**Coherent**

- Cross range $y$ in m
- Distance $d$ from transmitter in m
- Path loss in dB

**Incoherent**

- Cross range $y$ in m
- Distance $d$ from transmitter in m
- Path loss in dB

$h = 60$ cm