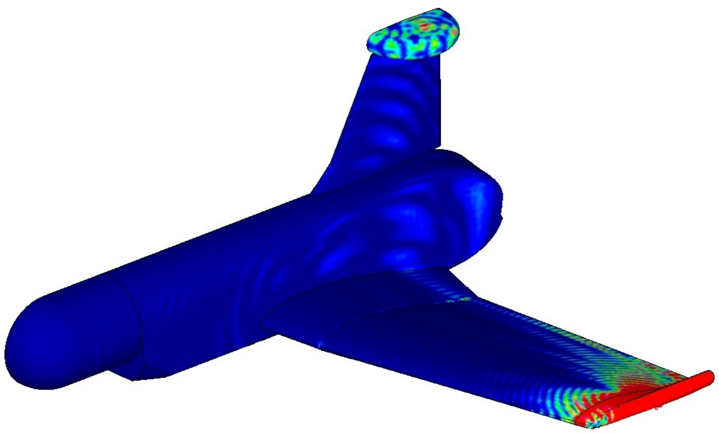
Simulation of Radar Signatures of Arbitrary Airborne Targets

Simulation of Scattered Fields, RCS and Installed Antenna Performance on Land, Aerial and Maritime Vehicles



Frank Weinmann

Antenna Technology and Electromagnetic Modelling

Fraunhofer Institute for High-Frequency Physics and Radar Techniques (FHR)

Wachtberg, GERMANY

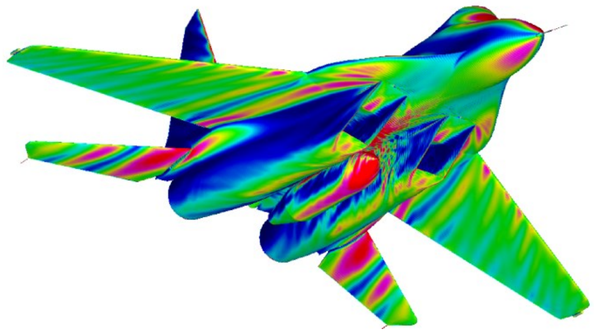
frank.weinmann@fhr.fraunhofer.de

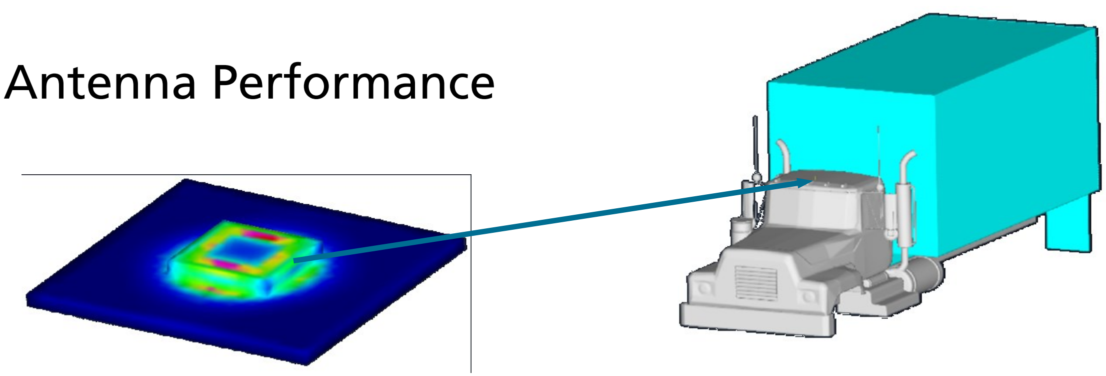
Fraunhofer FHR

Why Do We Need EM Modelling?

EM Field Predictions:

- Cheap and fast planning tools (e.g. for aircraft design, radar systems)
- Influence of different configurations
  (geometry, materials, loads)
- Databases (e.g. for identification purposes)
- Visualisation and understanding of
  propagation phenomena
- Prediction of Installed Antenna Performance
- ...



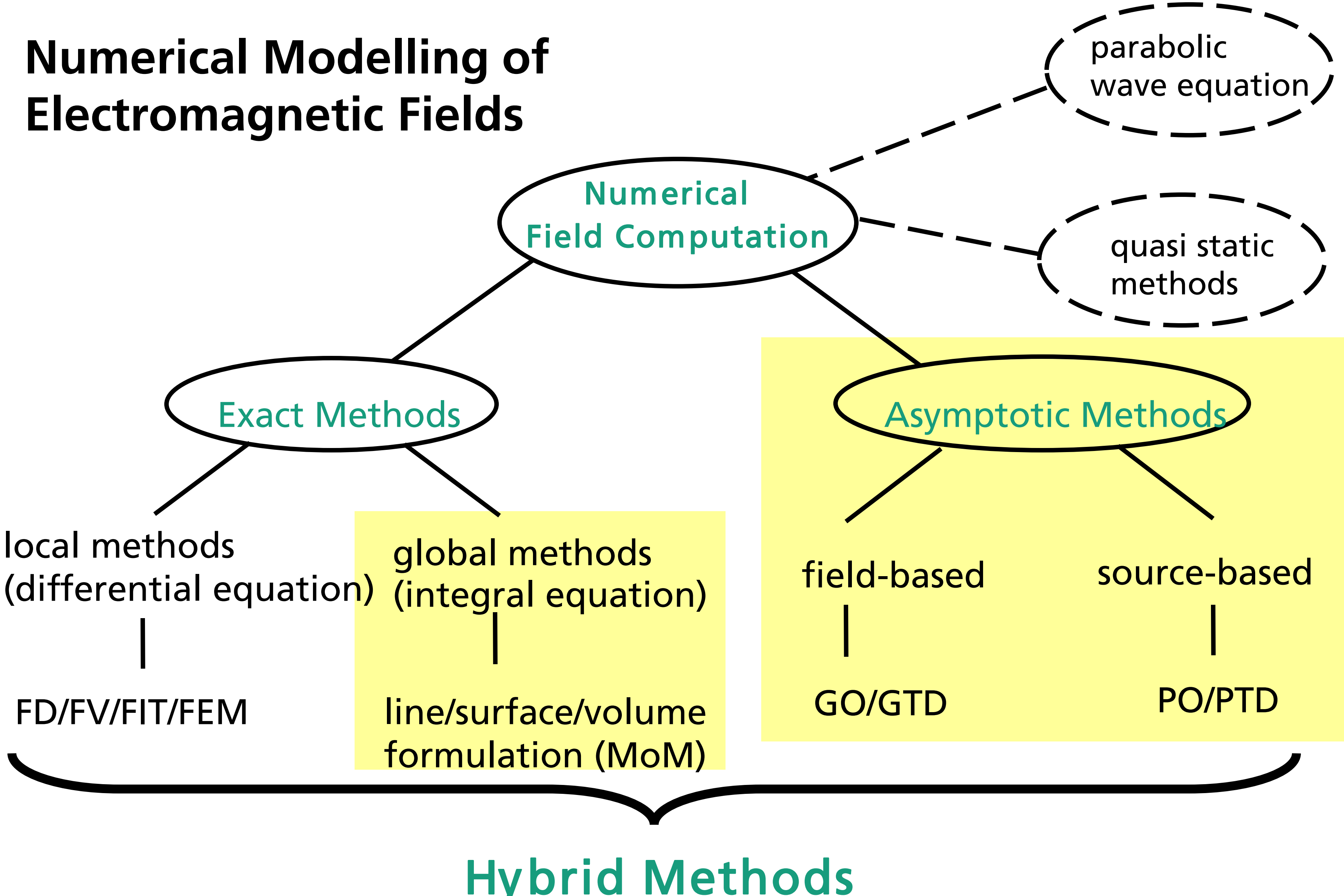


Fraunhofer FHR

Outline

- Introduction and Motivation
  - The Need for EM Modelling
  - Different Methods for EM Modelling
- EM Simulation Tools at Fraunhofer FHR
- Simulation Examples
- Current and Recent Projects
- NATO SET-200: “Electromagnetic scattering prediction of small complex aerial platforms for NCTI purposes“

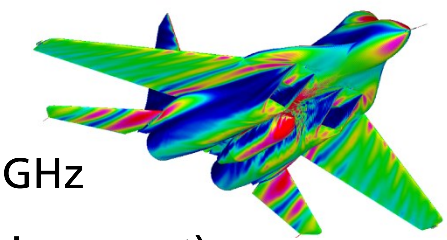
Numerical Modelling of Electromagnetic Fields



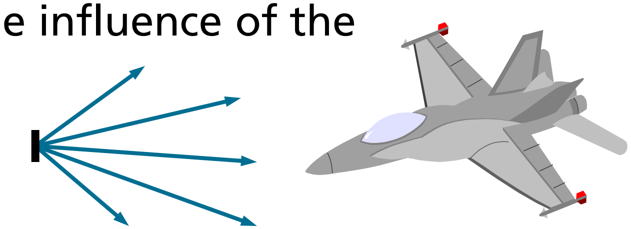
EM Simulation Tools at Fraunhofer FHR

Available Tools for Simulation of Installed Antenna Performance:

- Commercial Software Tools
- Special simulation tools developed for scenarios which are too large or too complex for standard treatment:
- Full wave tools (Boundary Integral Finite Element Method) - **FEBI**



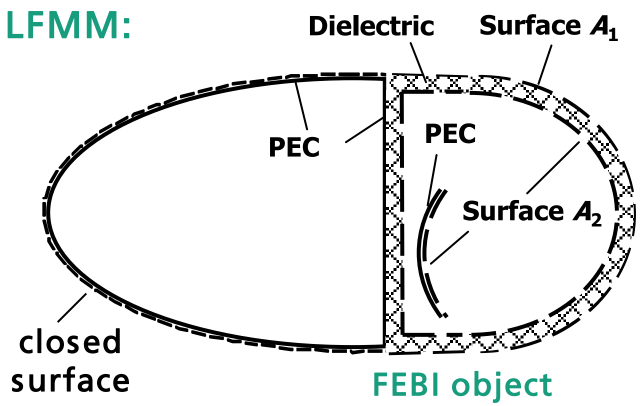
  - Maximum problem size up to now: RCS of fighter aircraft at 10 GHz
  - For larger problems (e.g. antennas on ships or vehicles in an environment) simulations only at lower frequencies or:
- High-frequency tools (Shooting-and-Bouncing SBR, Uniform Theory of Diffraction UTD, Physical Optics PO, Physical Theory of Diffraction PTD) - **FARAD**
  - Most commonly used for RCS predictions of arbitrary large targets
  - Drawbacks: Assumption of a point source; neglect of the influence of the surrounding environment on the source’s radiation
  - Method restricted to far field antenna problems



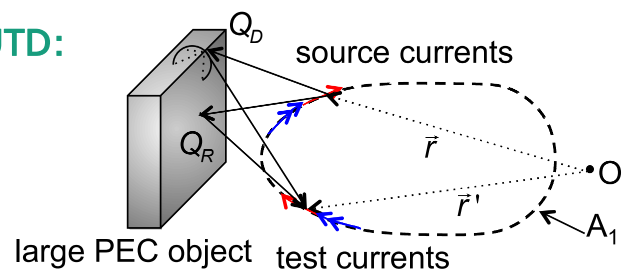
Fraunhofer FHR

The Hybrid FEBI-MLFMM-UTD Method

FEBI-MLFMM:



FEBI-MLFMM-UTD:



Mutual coupling between all objects through hybrid field formulations

GO/UTD at MLFMM level

A. Tzoulis, T.F. Eibert, "A Hybrid FEBI-MLFMM-UTD Method for Numerical Solutions of Electromagnetic Problems Including Arbitrarily Shaped and Electrically Large Objects", *IEEE Trans. Antennas Propagat.*, vol 53, no. 10, pp. 3358-3366, October 2005.

Finite Element Boundary Integral (FEBI) Technique

- Efficient modeling of arbitrarily shaped and complex metallic/dielectric structures

Multilevel Fast Multipole Method (MLFMM)

- Acceleration of matrix-vector products of BI part

Uniform Geometrical Theory of Diffraction (UTD)

- Efficient modeling of electrically very large objects with relatively simple shape in the same environment

Mutual coupling between all objects through hybrid field formulations

Fast Near Field Computations

Current Work:

- Development of a pure Surface Integral Equation (SIE) formulation for simulating composite metallic-dielectric objects

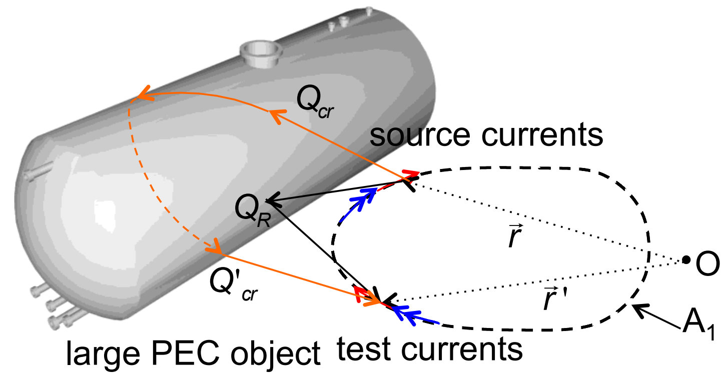
FEBI: Extension of UTD Formulation to NURBS Objects

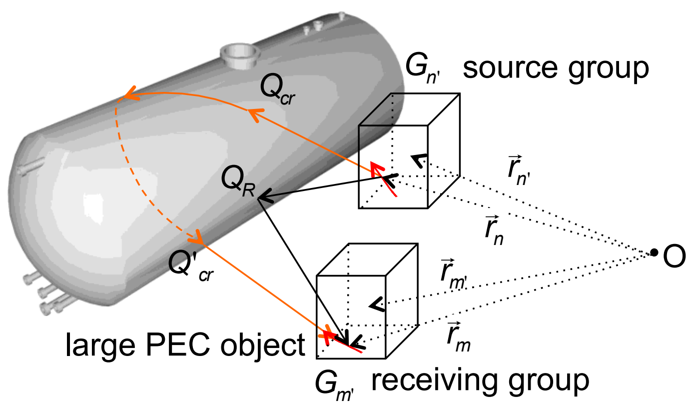
- Extension to reflections and diffractions from large curved surfaces described by Non-Uniform Rational B-splines (NURBS).

- Efficient calculation of reflection points

- Accurate tracing of creeping rays on NURBS curved surfaces

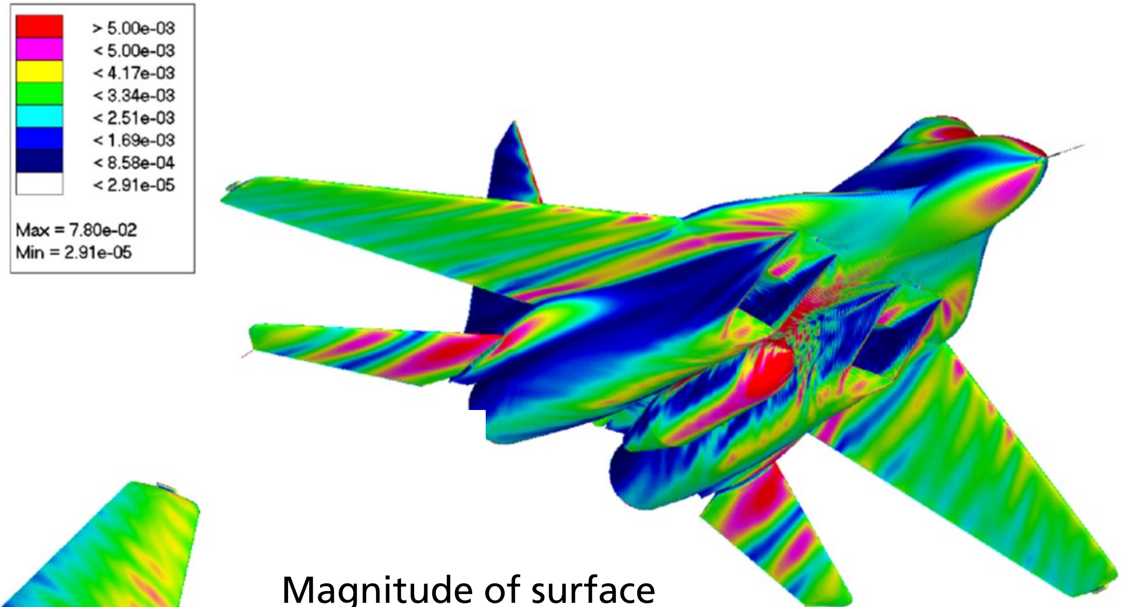
- Possible implementation using multithreaded parallel libraries or GPU acceleration

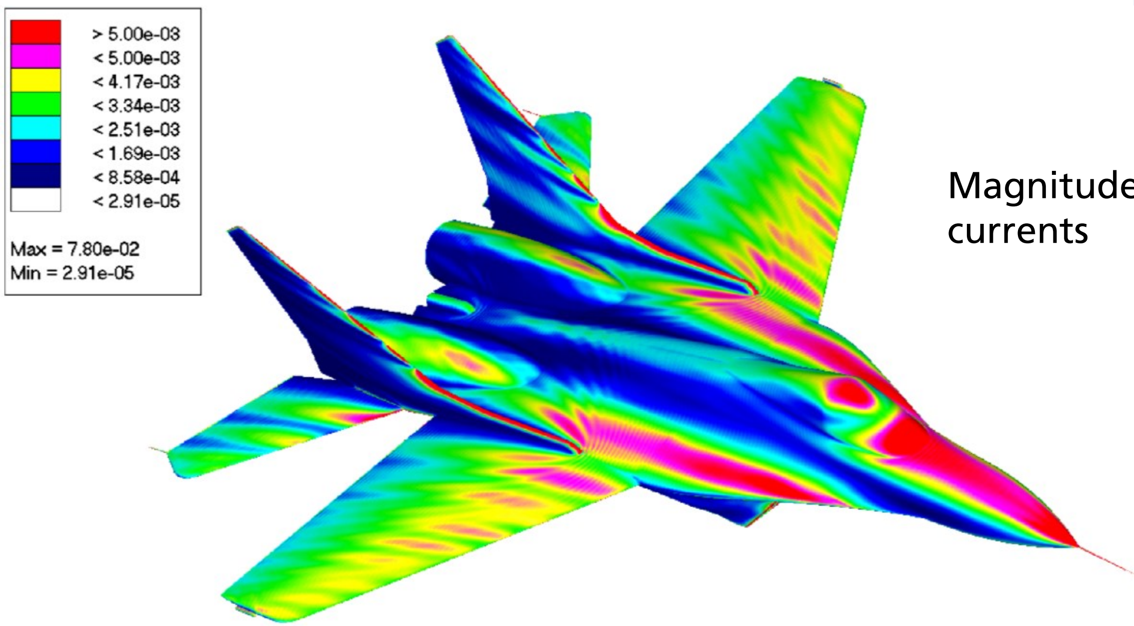




FEBI Example: Surface Currents on Aircraft

- f = 2.024 GHz
- Nose-on incidence
- V-Polarisation





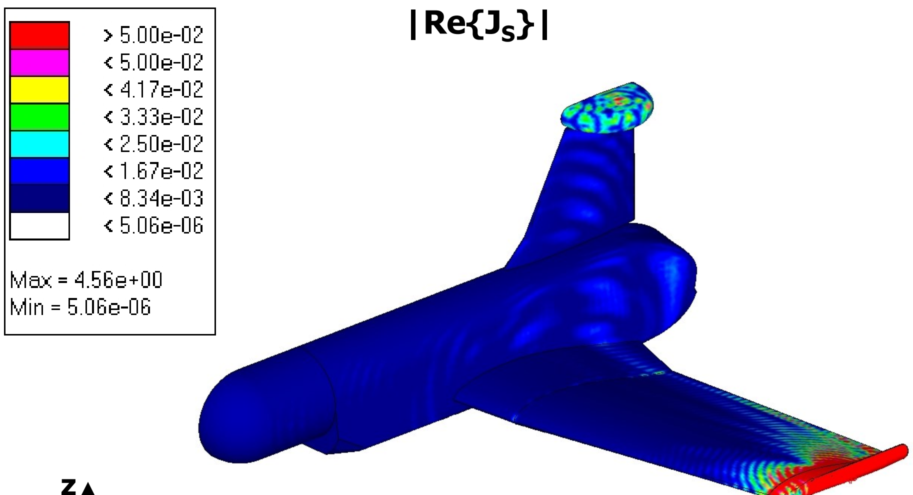
Magnitude of surface currents

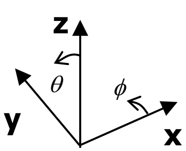
- 3 million unknowns
- ~ 8 GB RAM

FEBI Example: Antenna on Platform (Installed Performance of UAV Antenna)

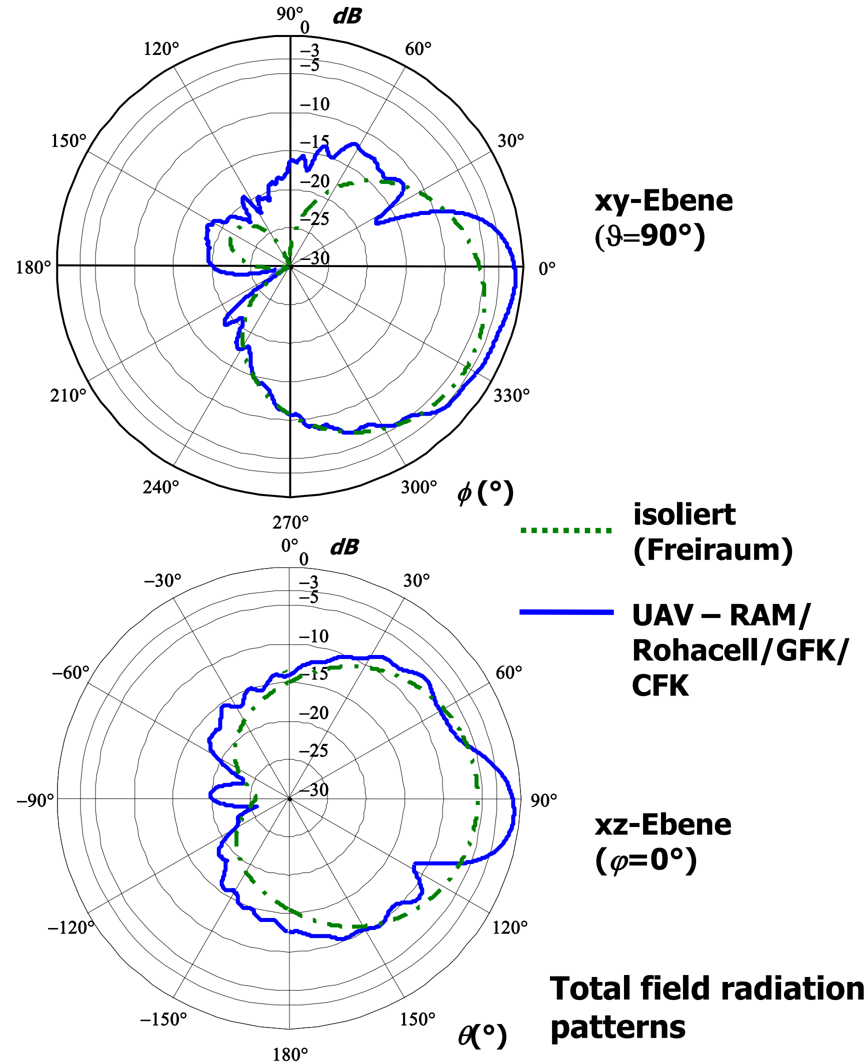
- Patch antenna on UAV
- f = 4,7 GHz
- Far field calculated from CAD model
- Antenna integrated into wing tip

|Re{J_S}|





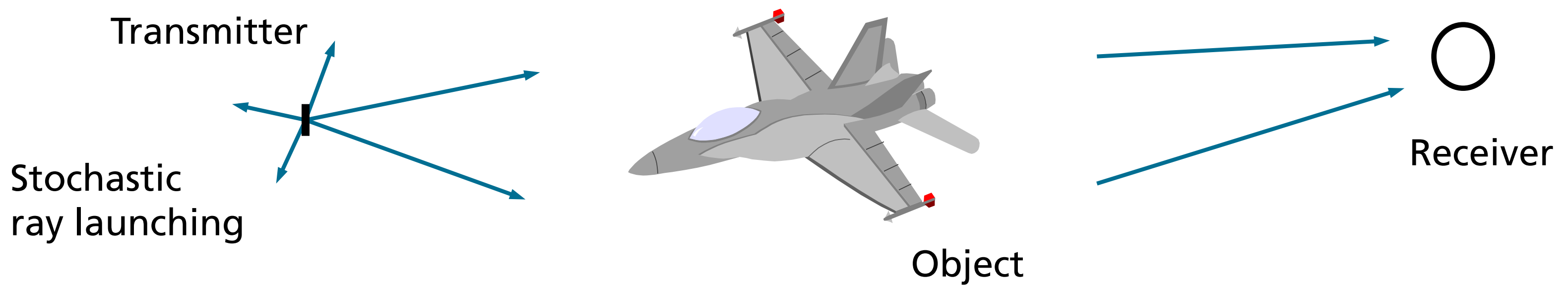
Equivalent Surface Current Density



Total field radiation patterns

Fraunhofer FHR

FARAD - EM Fields Calculation with SBR Ray Tracing



Ray Tracing Method:

(Geometrical Calculation of Propagation Paths)

Shooting-and-Bouncing Rays (SBR), number of reflections practically unlimited

Discrete rays as representatives of ray tubes

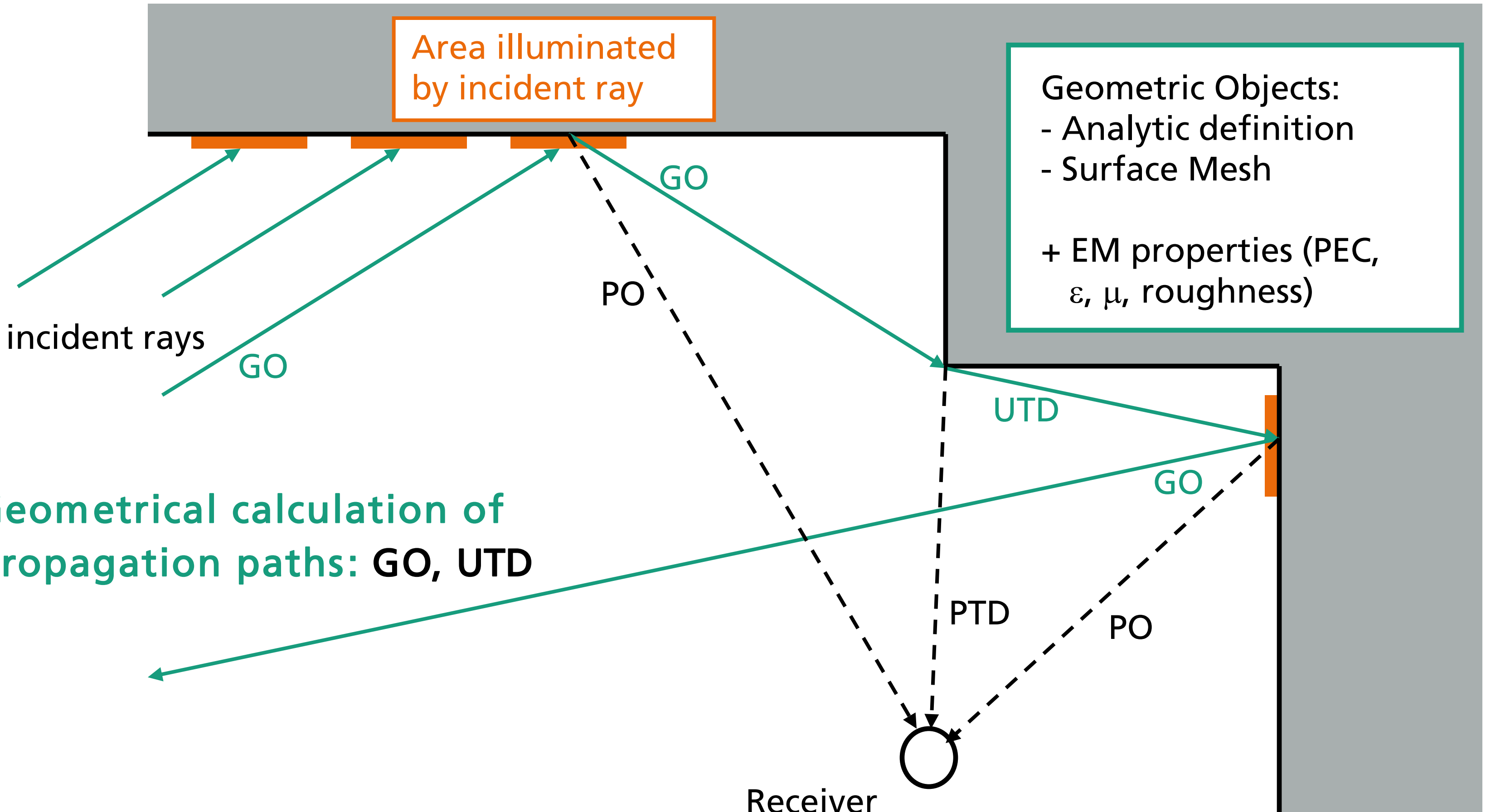
Ray-Density Normalisation (RDN) states the “distance” between rays

Calculation of Field Strength Contributions to Receiver:

(each time a ray hits the object)

Physical Optics (PO) + Physical Theory of Diffraction (PTD)

FARAD - Combination of GO/UTD-PO/PTD



Geometrical calculation of propagation paths: GO, UTD

Calculation of field contributions:
(each time a ray hits the object) **PO, PTD**

GO and PO also implemented for dielectric objects

FARAD - Enhancements for Improved Accuracy

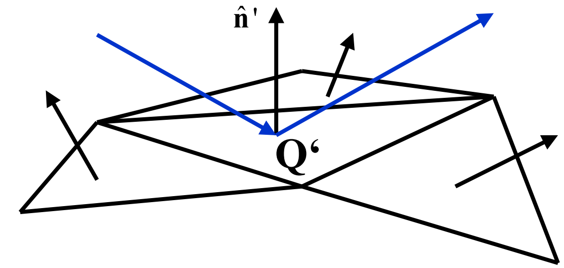
- Curvature Interpolation for facetted surfaces

  → Interpolation of normal vector

  → Deformation of reflected wave front

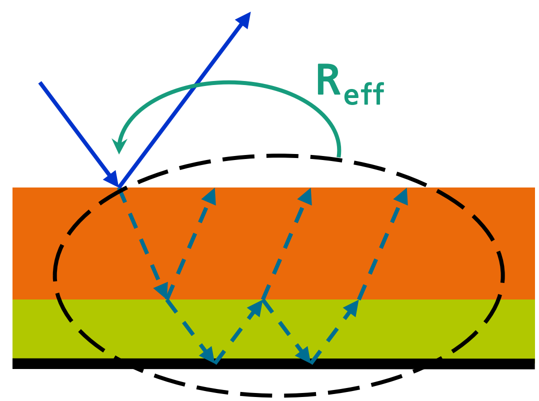
  Required for multiple reflections on curved surfaces

  (e.g. inside cavities, such as jet engines)



- Reflection Factors from External Files

  Efficient modelling of multi-layer or coated surfaces

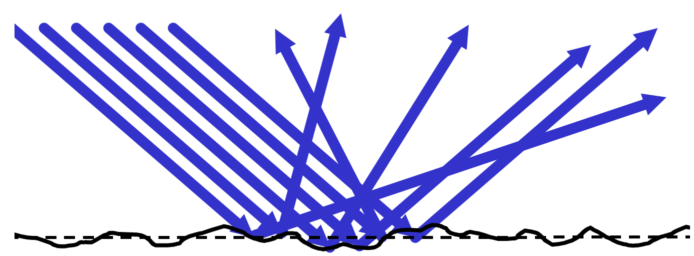


- Antenna Diagrams

  Coverage predictions for antennas in larger environment

- Stochastic Scattering Model for Rough Surfaces

  Needed for higher frequencies

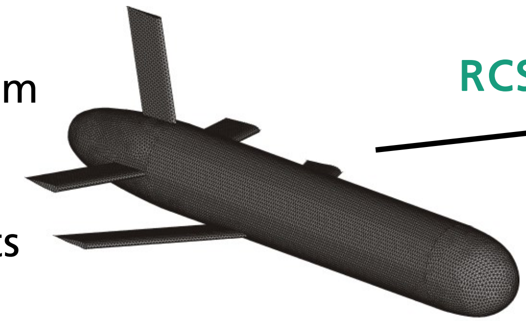


- NURBS for Curved Surfaces

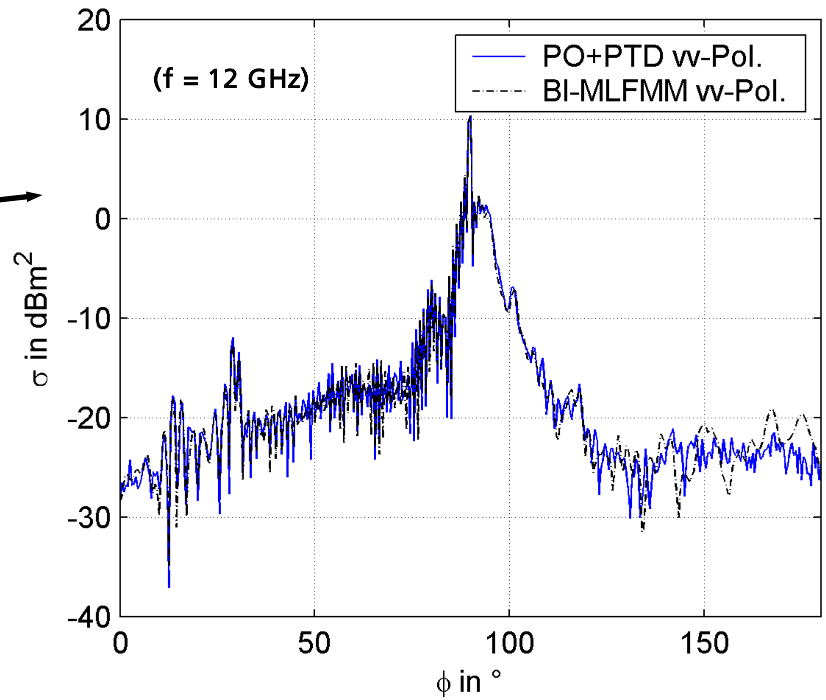
Simulation Examples

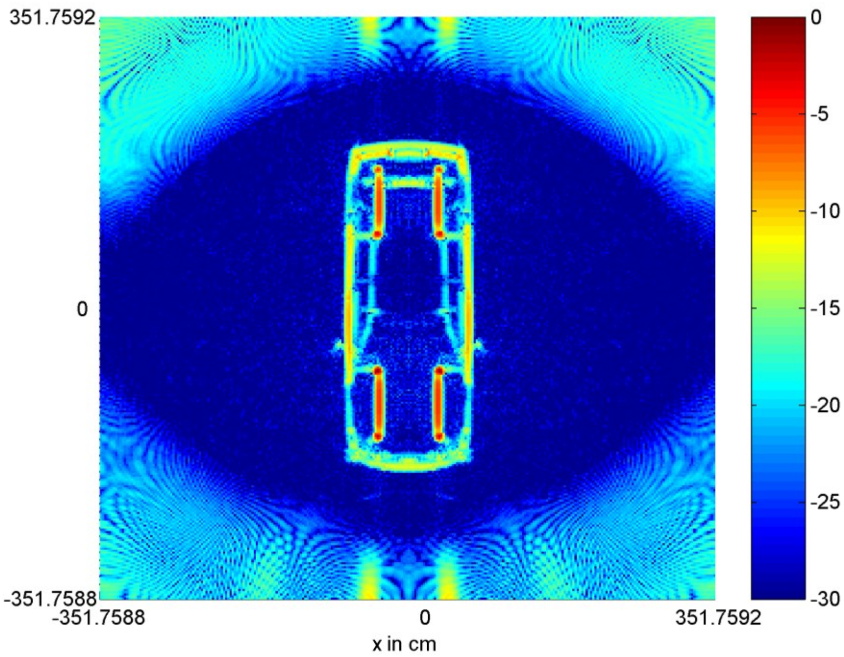
length approx. 1 m

Triangular mesh with 44,000 facets



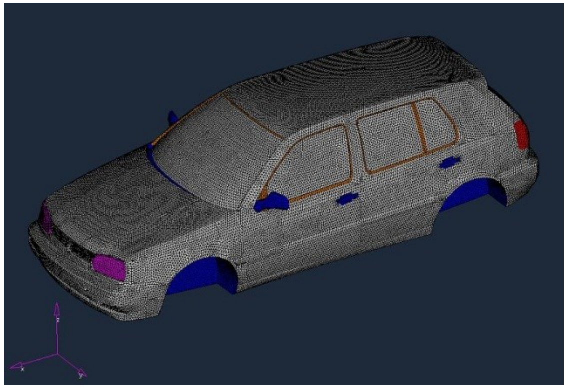
RCS





Analysis of scattering centers

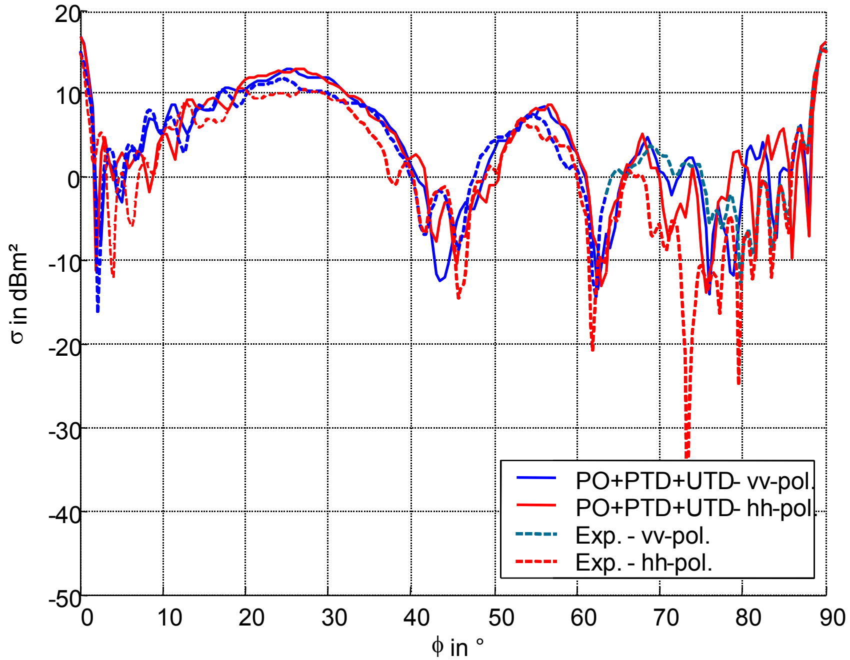
(f = 6-10 GHz)



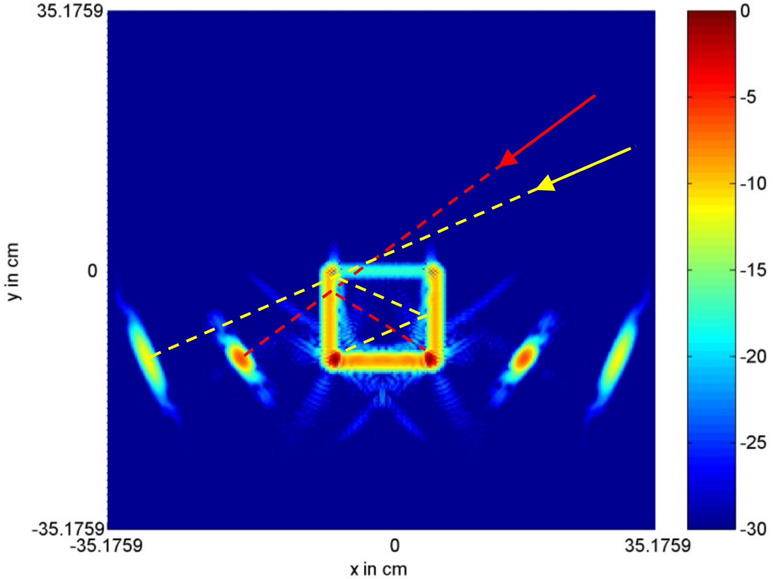
Fraunhofer FHR

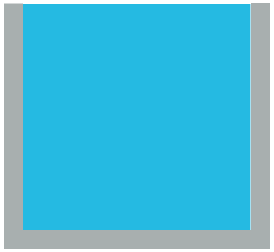
Cavity with Dielectric Material

Empty Cavity

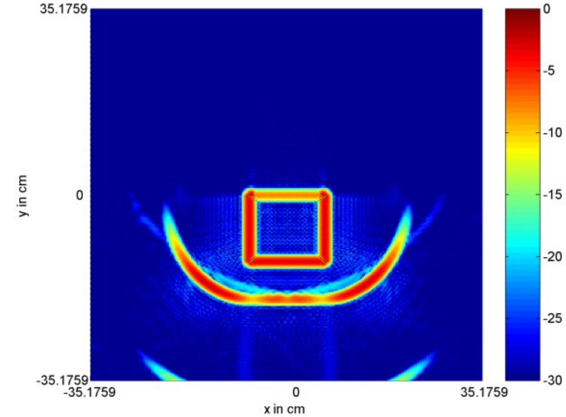


Scattering center analysis (20-40 GHz) (from calculated data)



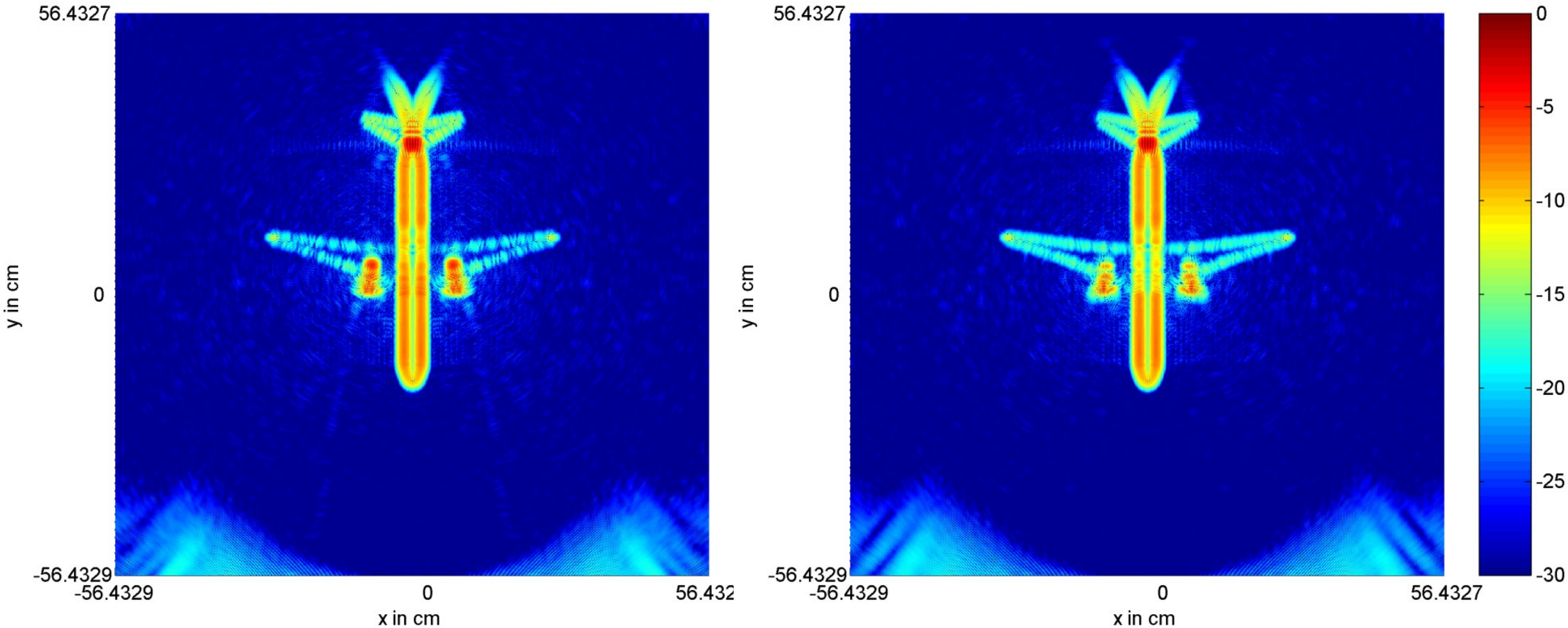


Cavity filled with PVC Cube



FARAD Example: „Boeing 767 like“ 1:100 scaled Model

Analysis of Scattering Centers



vertical polarisation

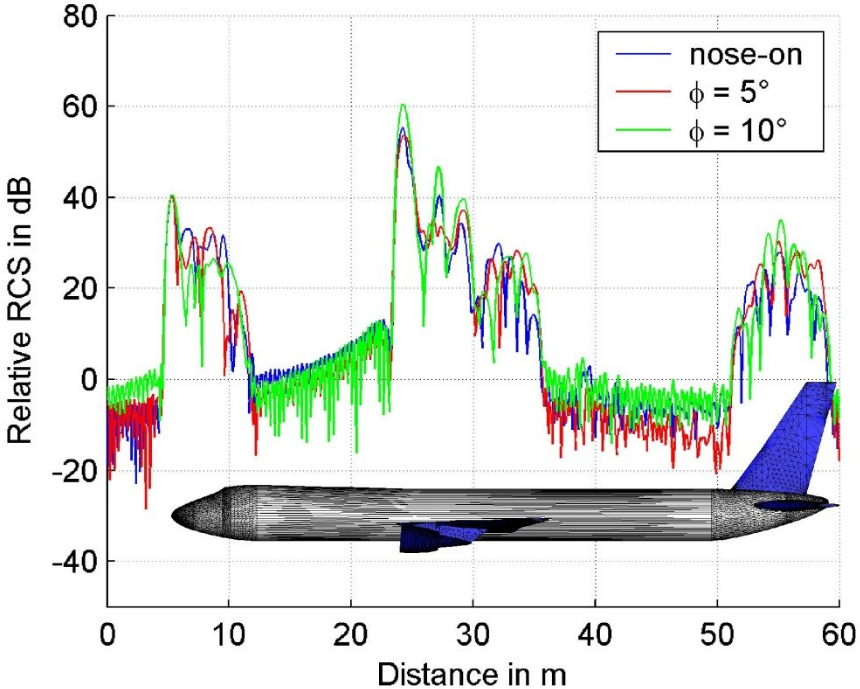
horizontal polarisation

$\phi = 0° \text{-} 360°$

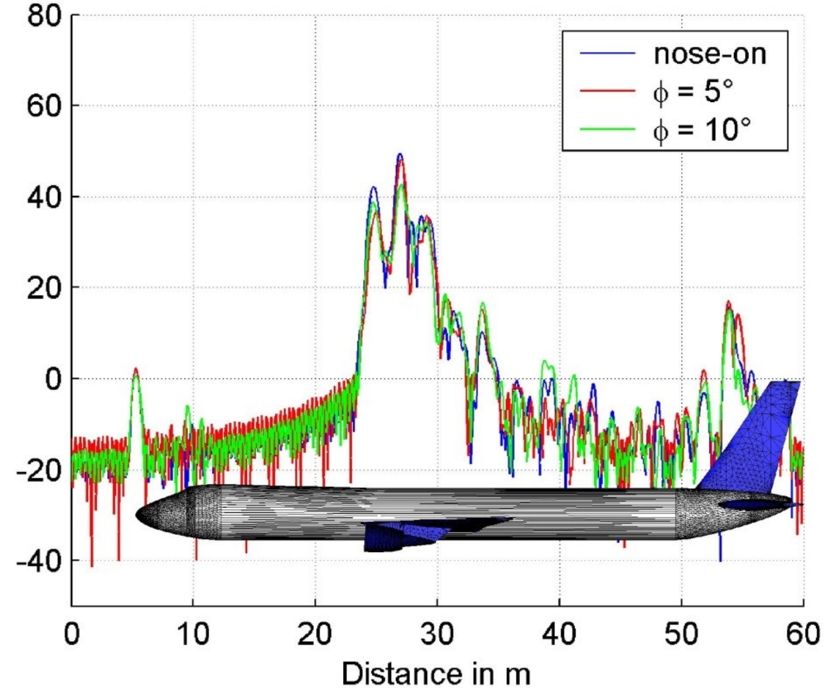
Engines show significant contribution to scattering behaviour of the target

„Boeing 767 like“ Aircraft: HRRPs in the K_u-Band

vertical polarisation



cross polarisation



Significant contributions from nose, wings, and tail fin

Main peak corresponds to engine, also large cross polar contributions from engine

→ Accurate CAD model required for accurate results

Fraunhofer FHR

Workshop EM ISAE "Radar Signatures" (Toulouse)

http://websites.isae.fr/workshop-em-isae-2014

- "Initiated by DGA and Industrials Societies in 1990, the Workshop is reserved to Industrials, Defence organizations, Public and Private Laboratories involved in the design of Radar and Targets."
- "The themes are Defence and Civilian topics: RCS, Targets and antennas designs, EMC …"
- "The idea is to highlight predictive and validated computational tools to compare and federate current works on reference problems."
- FHR participates in the workshop since 2006

TEST CASE 6: Metallic cavity filled with PVC

Monostatic RCS and ISAR images

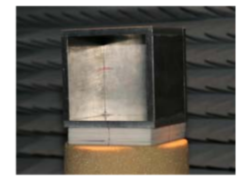
Chairmen : Jérôme SIMON, Frank WEINMANN

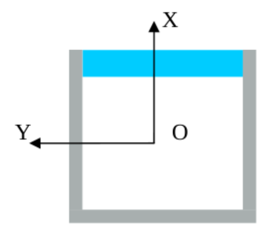
Contacts: jerome.simon@onera.fr, frank.weinmann@fhr.fraunhofer.de,

1. Definition of the Geometry

The target is a metallic cavity filled with a PVC Plate (2cm)):

- Thickness of plates: 1 cm
- Internal dimensions: 12x12x12 cm
- PVC Plate = 2cm





The centre of the interior cube and the phase centre are assumed to be located at $(x,y,z) = (0,0,0)$.

2. Simulation Parameters

The time dependency is assumed to be $\exp(j\omega t)$.

The object described above shall be studied at the frequency $f = 30$ GHz. At this frequency, the relative permittivity of the material is approximately $\varepsilon_r = 2.7$. For all simulations, $\varepsilon_r = 2.7 - j\,0.02$ shall be assumed.

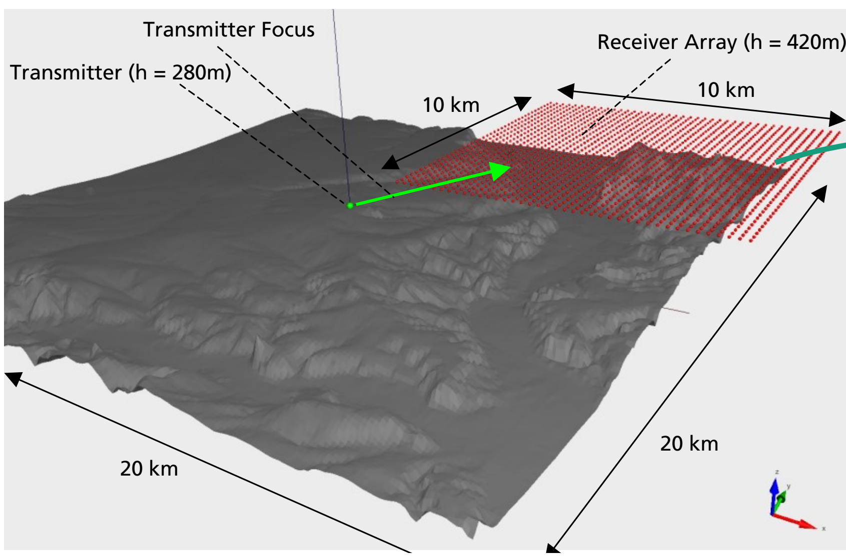
2.1. Case (a): Monostatic RCS of the target

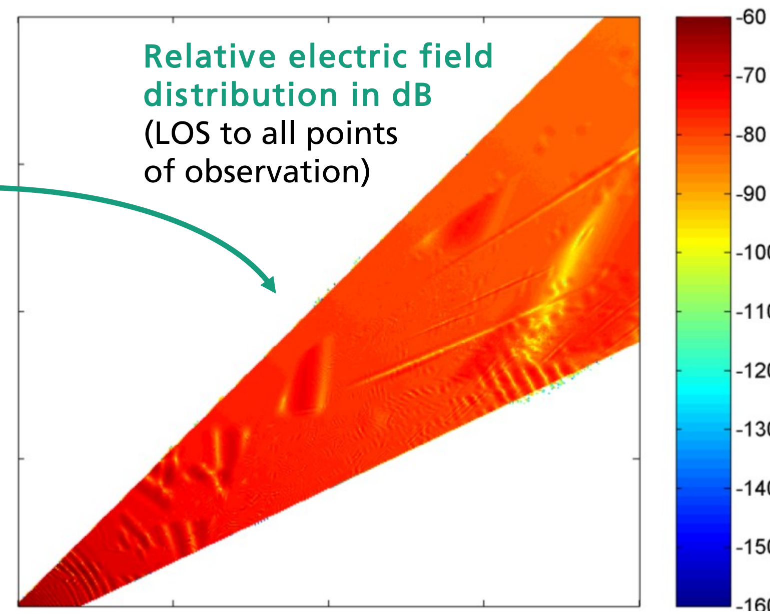
The monostatic RCS shall be simulated at the frequency $f = 30$ GHz in the azimuth plane ($z = 0$, $\phi = 0°…180°$, $\Delta\phi = 0.5°$) for both vertical polarisation ($\theta\theta$-polarisation, i.e. **E**

Fraunhofer FHR

EM Simulation of Three-Dimensional Propagation Scenarios

- Example: Radiation of an antenna system over terrain possibly containing various obstacles, such as buildings, wind turbines, etc.
- Obstacles might significantly influence the functionality of the antenna system
- Effects might become crucial, e.g., for air traffic radar systems or air surveillance systems because a significant risk might arise from malfunctioning of such systems
- Use of ray tracing approaches (size of scenario)





Fraunhofer FHR

Einfluss von Windenergieanlagen (WEAs) auf Radaranlagen des Einsatzführungsdienstes der Luftwaffe

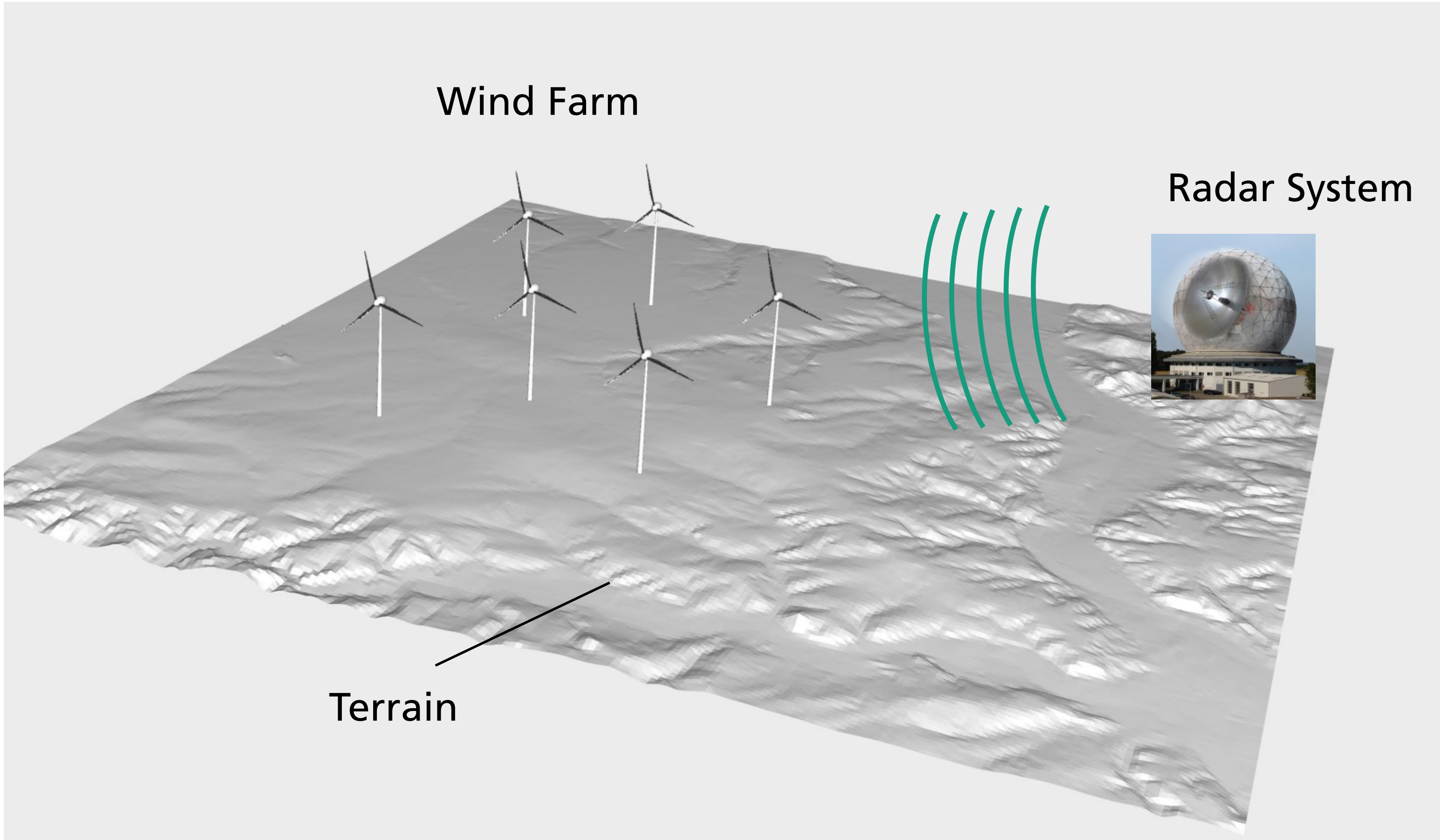
Background:

- Operation of air surveillance radars may be degraded by wind turbines / wind parks (e.g. shadowing, reduction of operating distance)

Project (09/2012-02/2015):

- Study of attenuation of fields by wind turbines
- Simulation environment for studying selected radar positions
- Take into account site specific properties (terrain etc.)

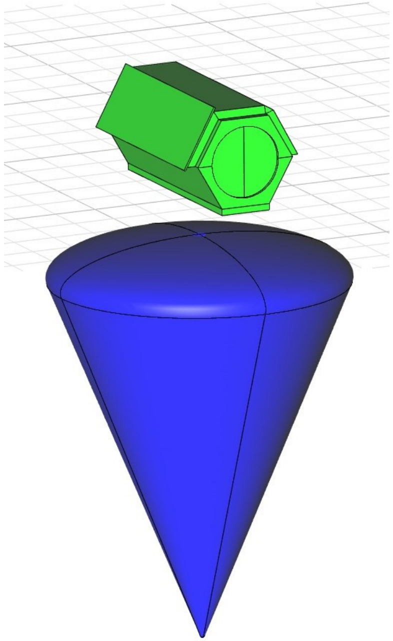
Typical Wind Farm Simulation Scenario



RCS/Signature Suppression of Satellites

Work Programme of Current Project with WTD 52, Oberjettenberg:

- Definition of generic CAD models
- Simulation of frequency/angle dependence of scattering properties
- Effect of cone signature suppression
- Variation of cone geometry
- Fabrication of scaled model
- RCS measurements on scaled model
- Comparison with simulations
- Development of alternative antenna concepts



Project Duration: Mar-Dec 2015

NATO SET-200: “Electromagnetic scattering prediction of small complex aerial platforms for NCTI purposes“

Overview of Work Programme:

1. Optimization of the already existing mathematical methods and/or development of new ones
2. Study of cavities effects
3. Definition of a small set of UAVs
4. Accurate prediction of full metallic UAVs
5. Accurate prediction of full UAVs with metallic, non-metallic and/or RAM/RAS parts
6. Simulation of HRRPs and/or ISAR images
7. Parametric studies
8. Close cooperation with SET-180

Duration:

2013-2015 (probably extended until 2016)

Participating Nations:

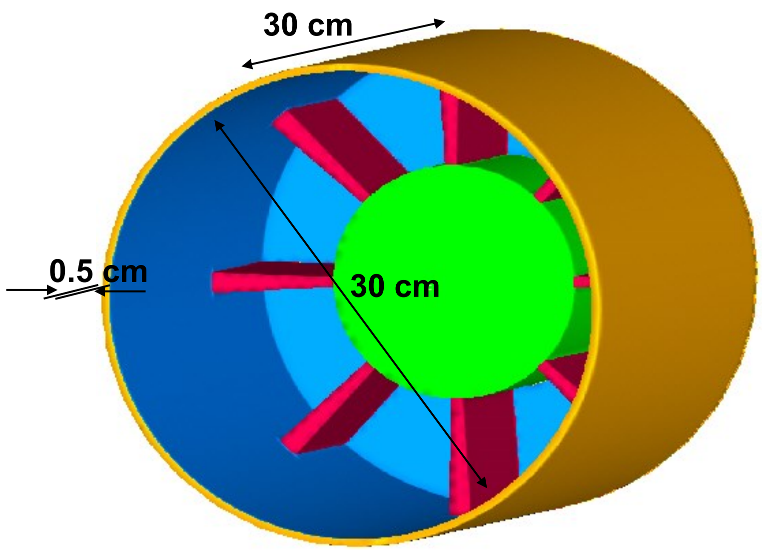
ESP, FRA, NLD, ITA, SWE, DEU

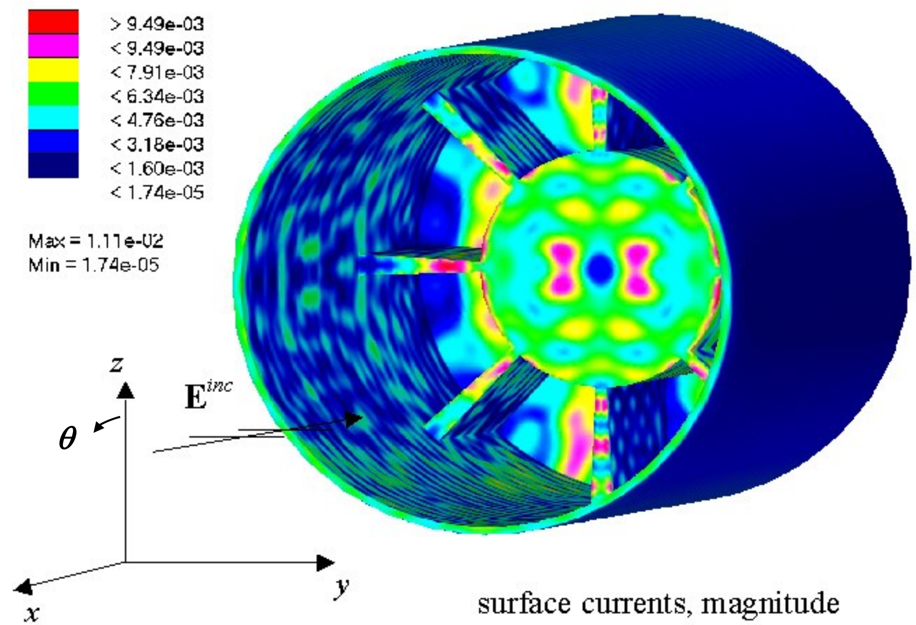
Fraunhofer FHR

EM Scattering Analysis of Jet Engines (NATO SET-200 Group, formerly SET-138)

Simplified Inlet Model with Straight Blades

f = 12 GHz (λ = 2.5 cm)
BI-MLFMM as reference solution





Magnitude of equivalent surface current density at 12 GHz

BI-MLFMM solution
h-polarized plane wave incidence

Fraunhofer FHR

Numerical Modelling of Antennas and Scattered Fields

Summary:

- FHR develops both full-wave and high-frequency simulation tools
- Metallic and dielectric materials, arbitrary shapes and sizes
- Modelling of time-variant scenarios, e.g. rotating wind turbine blades, rotating jet engine blades, objects moving along a straight trajectory

Applications:

- Signature prediction of airborne targets (HRRP, distribution of scattering centers)
- Radar imaging / target classification
- Low observability (LO)
- Modelling of wind turbine scenarios (propagation over terrain)
- Installed Antenna Performance (antennas on platforms)