EMWT 2017

WERAN-Numerische Simulationen

FKZ: 0325644A-D

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  - modeling DVOR antenna
  - modeling the ground
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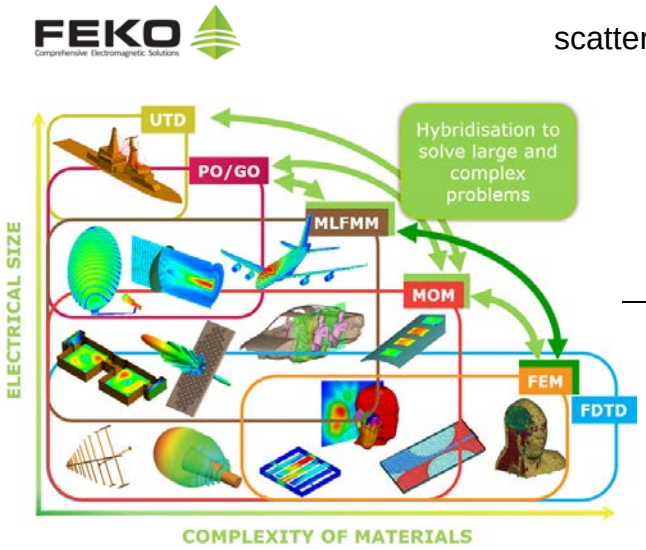
- **Conclusion & Outlook**

Calculation Workflow



antenna, terrain, scattering objects, WT, ..

modeling

CAD model

EM simulation

[amplitude, phase] @ f_x

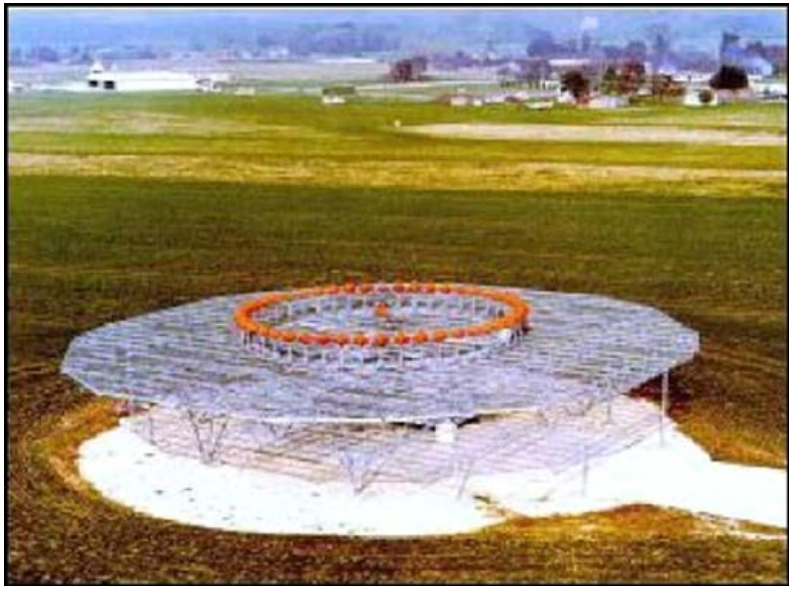
postprocessing

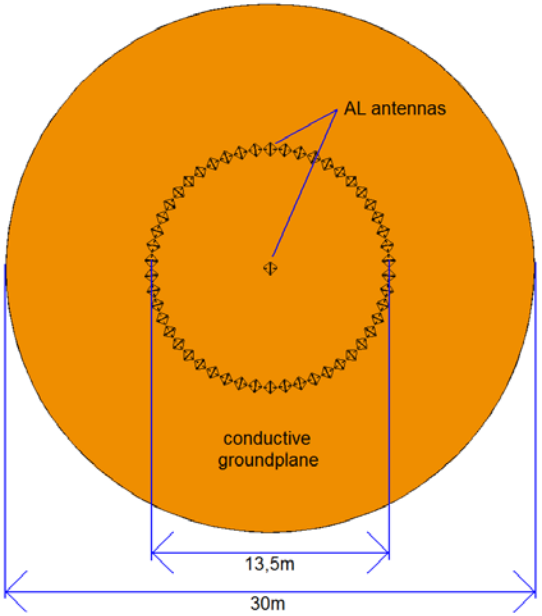
t_{pulse}, A_{pulse}, P_D, .. @ RADAR

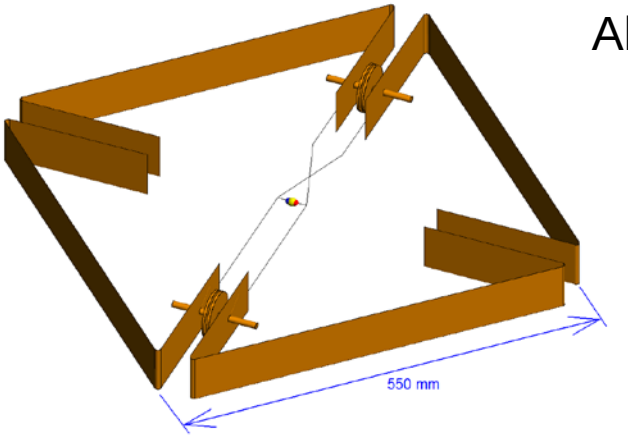
bearing @ VOR, DVOR

validation with measurements

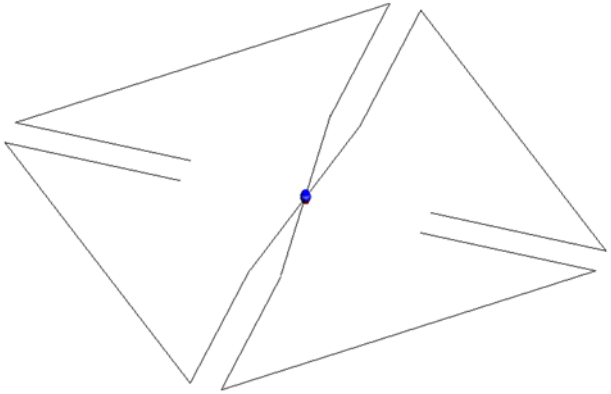
Modeling DVOR Antenna



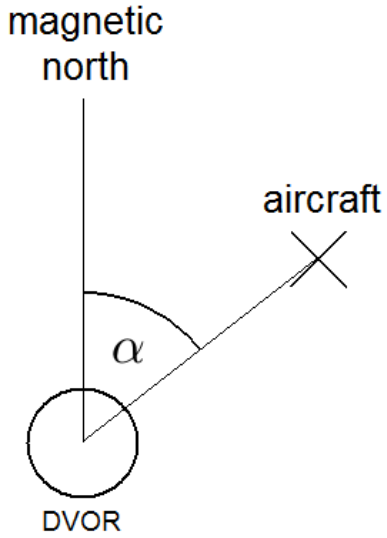


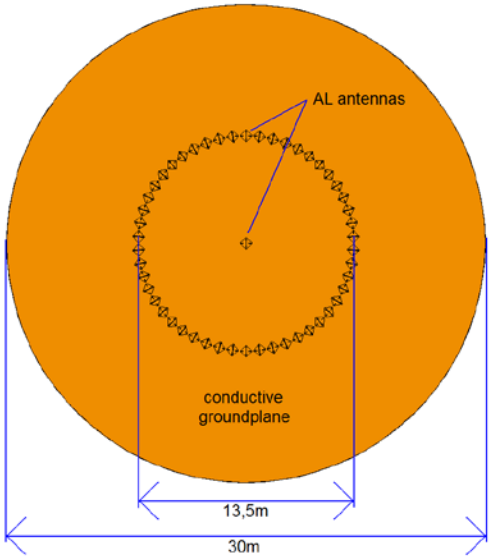


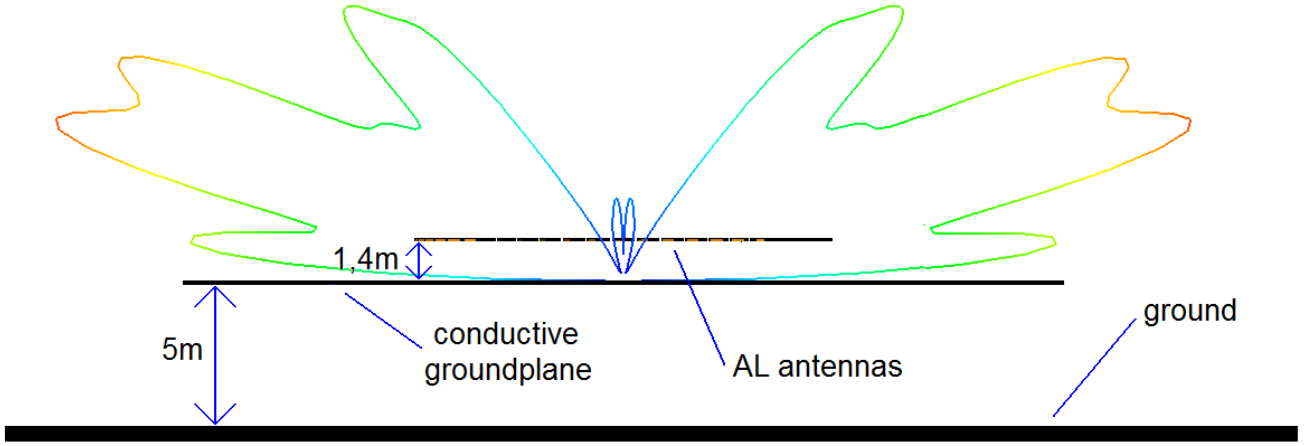
Alford Loop antenna



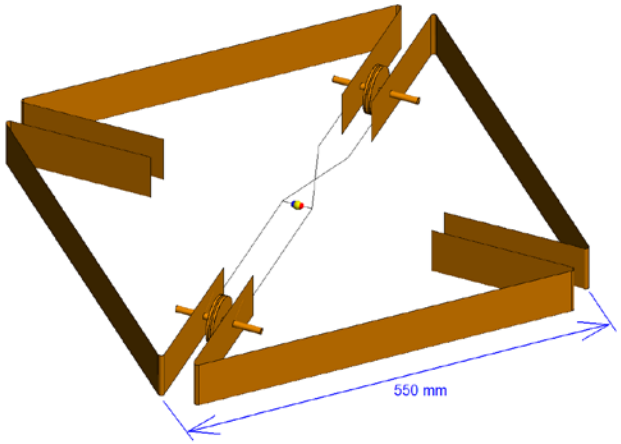
Modeling DVOR Antenna

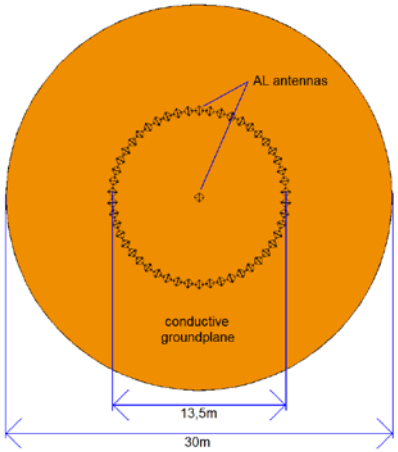


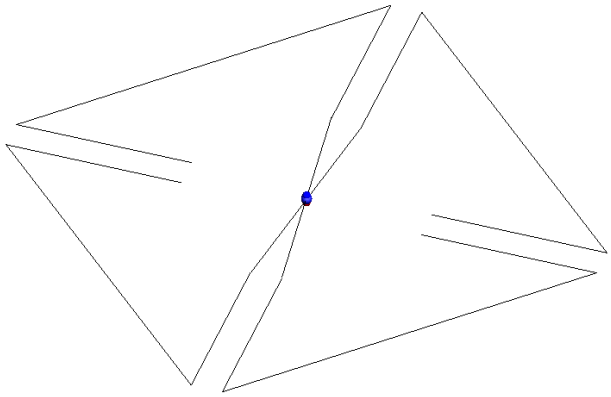


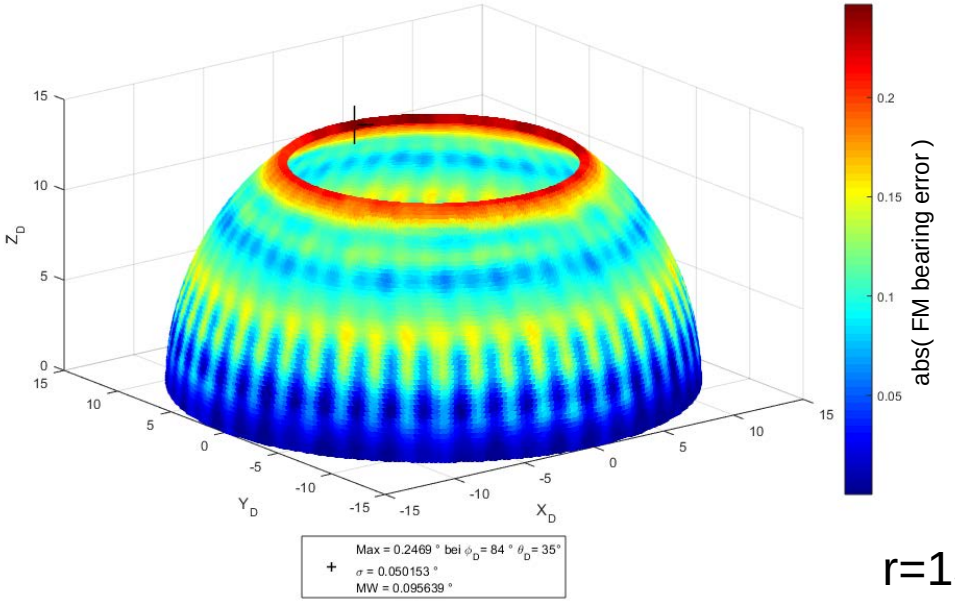


Modeling DVOR Antenna

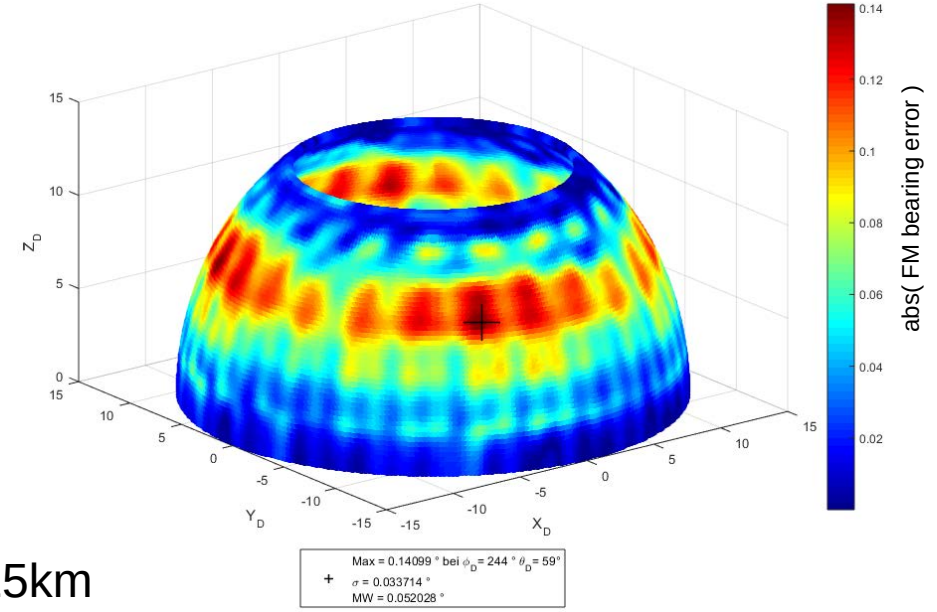




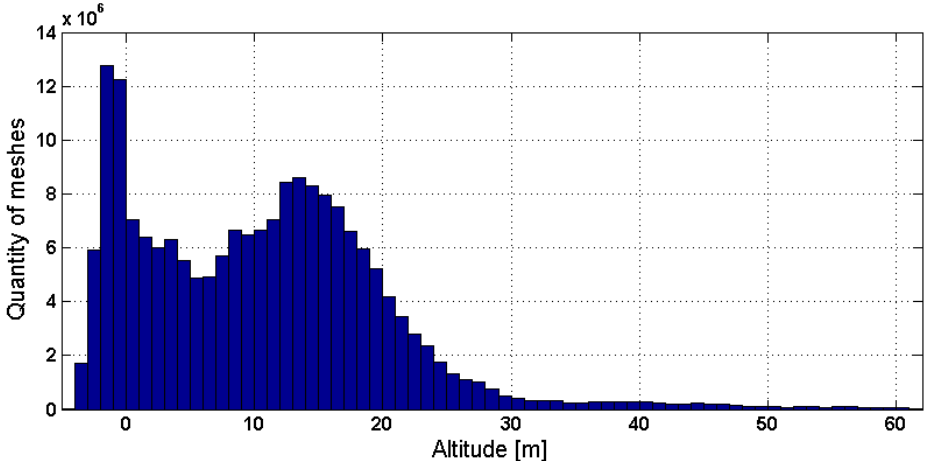




r=15km

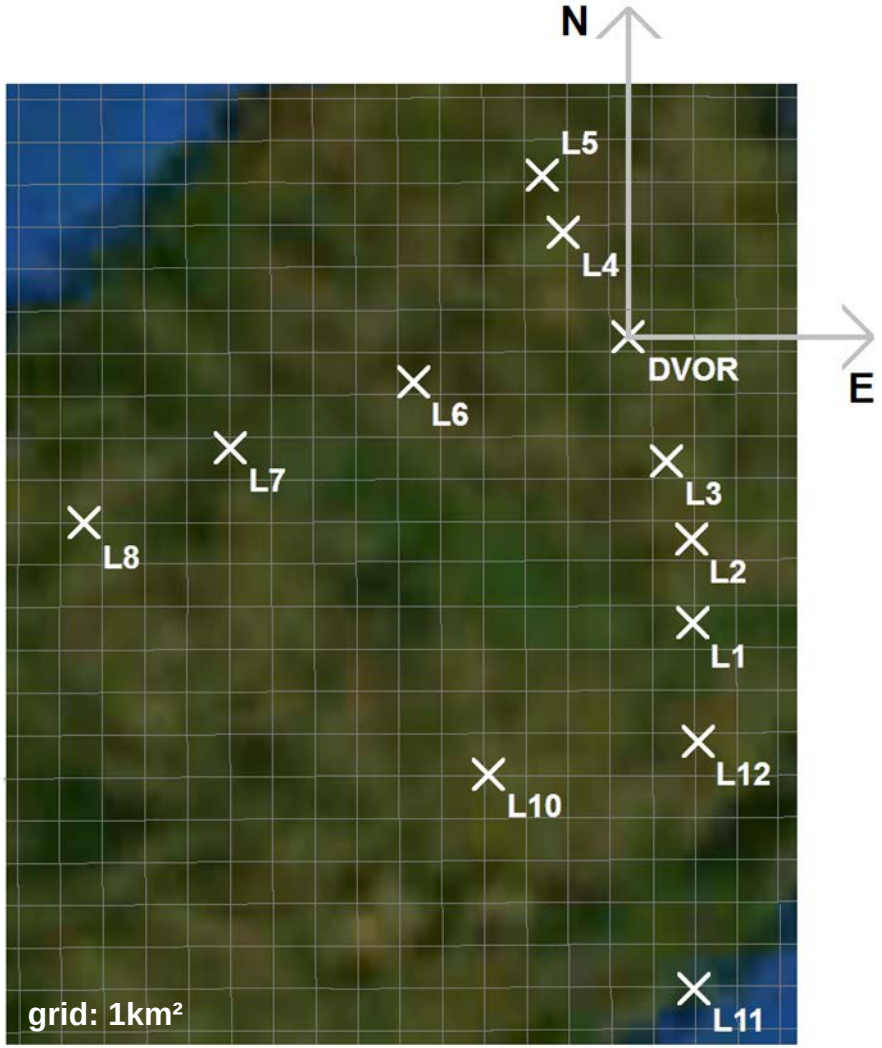


Modeling the Ground

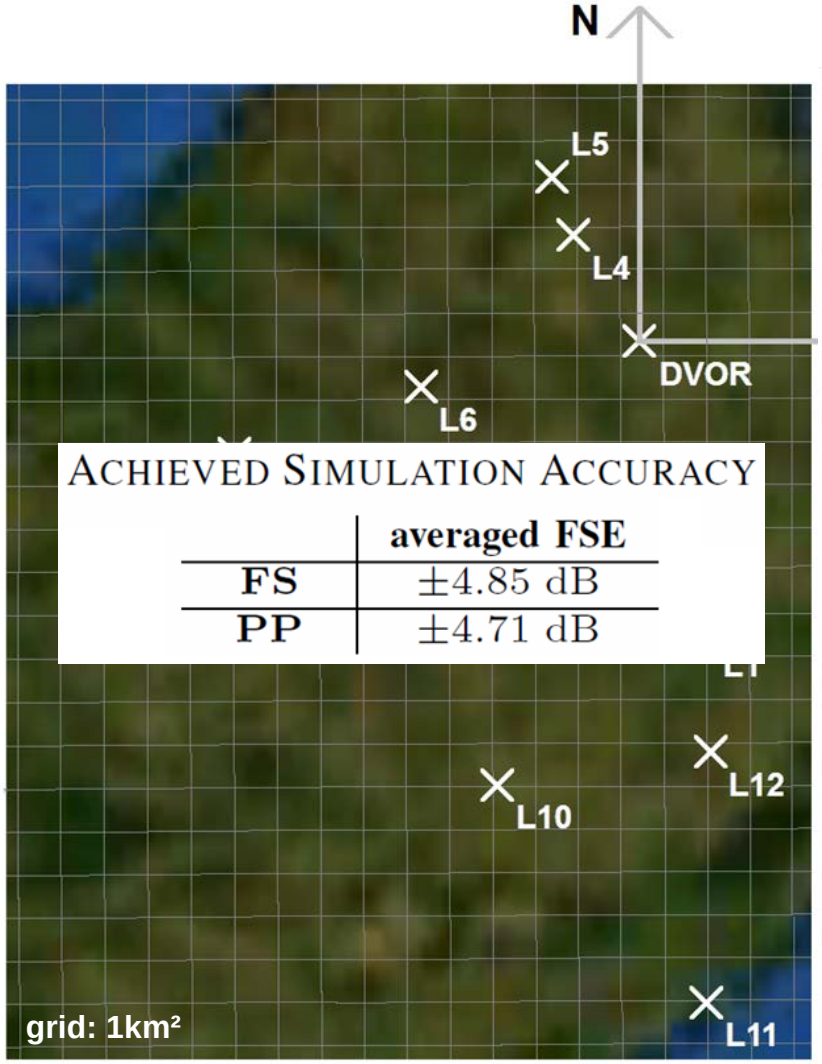


GEOMETRICAL DATA OF OBSERVATION POINTS IN m

	E	N	H_1	H_2	H_3	H_4
L1	1527,8	-6761,9	45,7	92,6	139,5	163,4
L2	1494,9	-4761,9	45,7	141,6	–	–
L3	895,0	-2917,0	85,5	132,1	173,4	–
L4	-1519,4	2464,3	51,8	86,5	147,2	–
L5	-2033,8	3817,6	53,8	93,4	–	–
L6	-5084,3	-1058,2	48,7	88,8	131,9	–
L7	-9433,6	-2579,4	52,5	110,5	–	–
L8	-12892,1	-4355,5	98,0	131,9	–	–
L9	-3318,3	-4520,5	–	–	–	–
L10	-3343,0	-10306,7	59,5	104,6	165,0	–
L11	1523,9	-15390,7	77,2	119,5	–	–
L12	1629,4	-9551,0	53,4	88,8	128,8	153,4

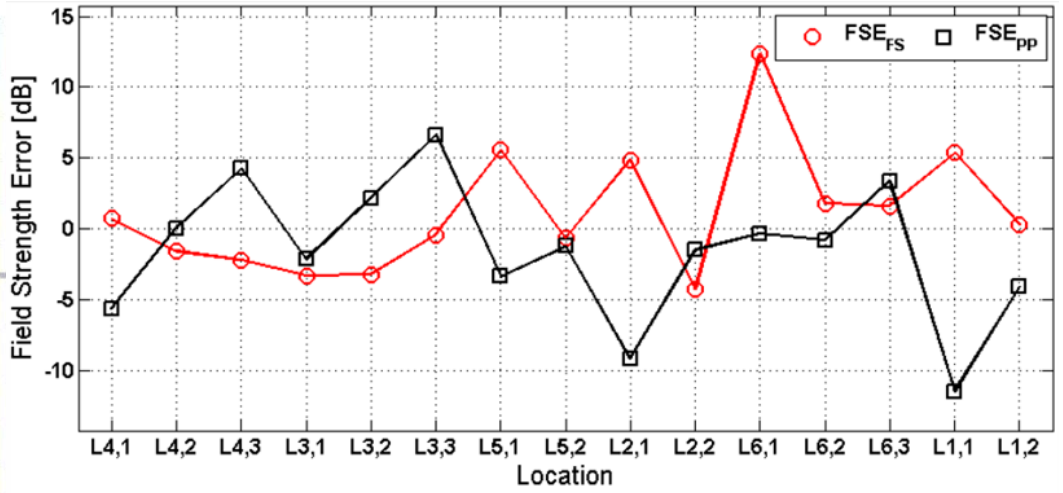


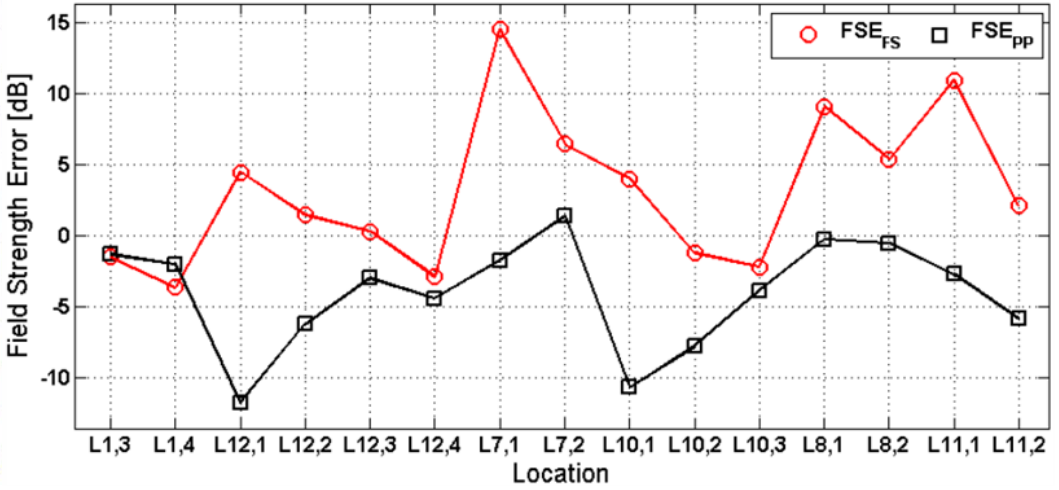
Modeling the Ground



ACHIEVED SIMULATION ACCURACY

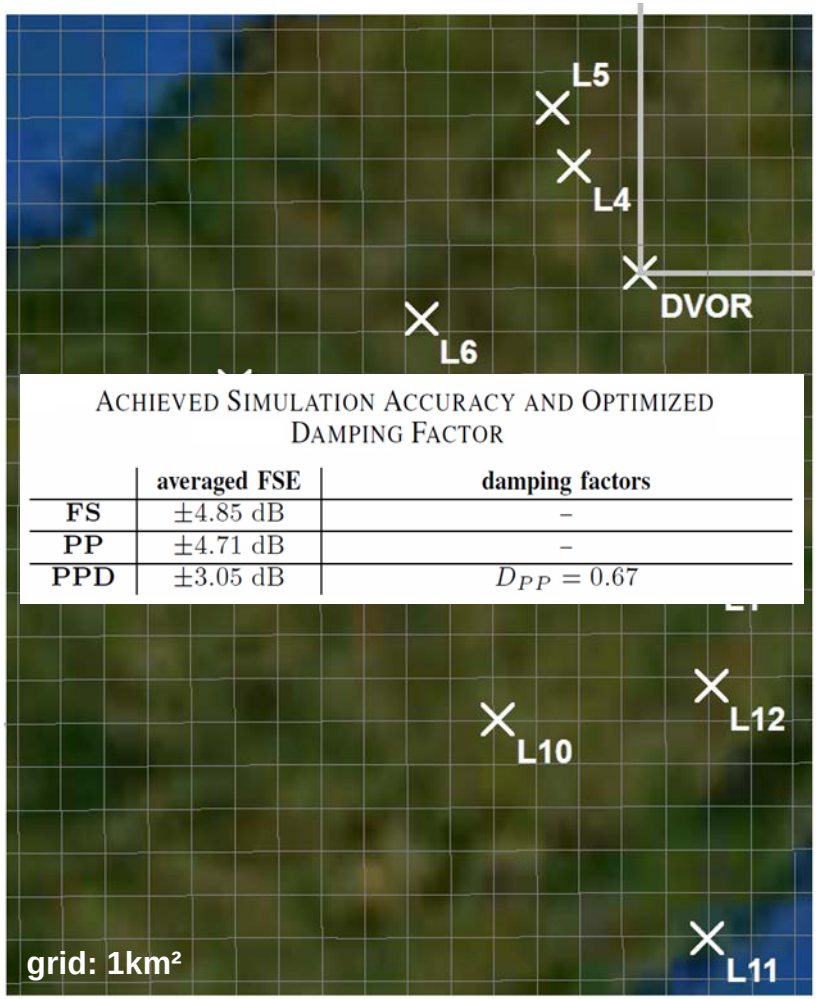
	averaged FSE
FS	±4.85 dB
PP	±4.71 dB





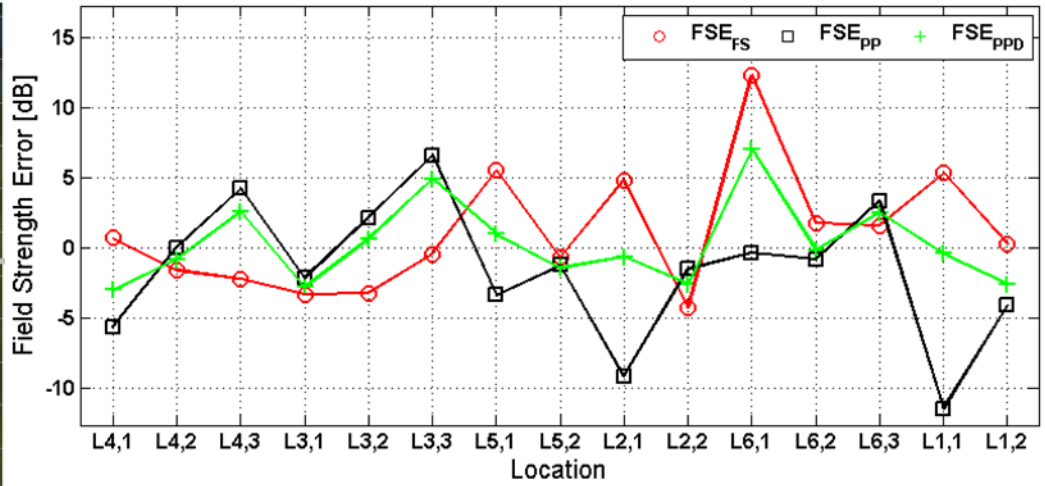
Modeling the Ground

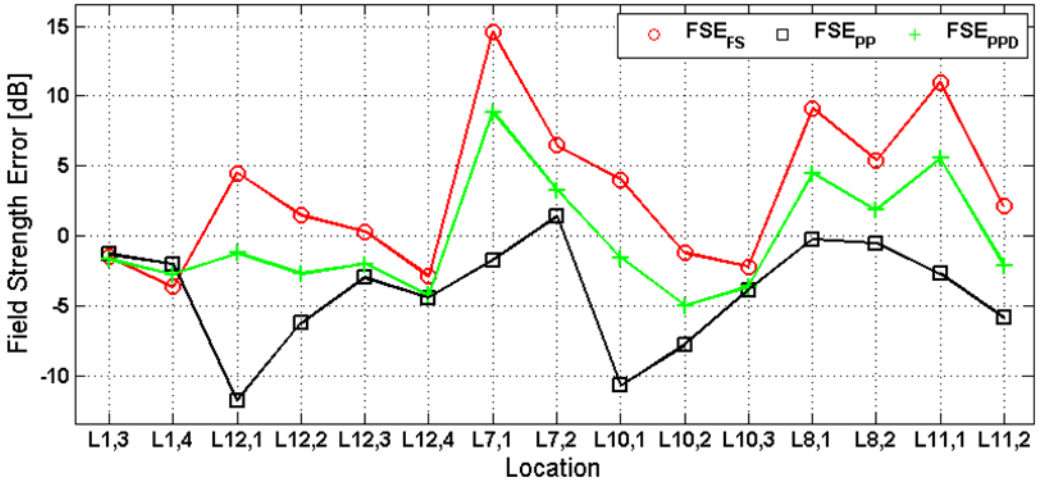
$$\underline{E}_{PPD,i} = \underline{E}_{FS,i} + D_{PP} \cdot (\underline{E}_{PP,i} - \underline{E}_{FS,i})$$



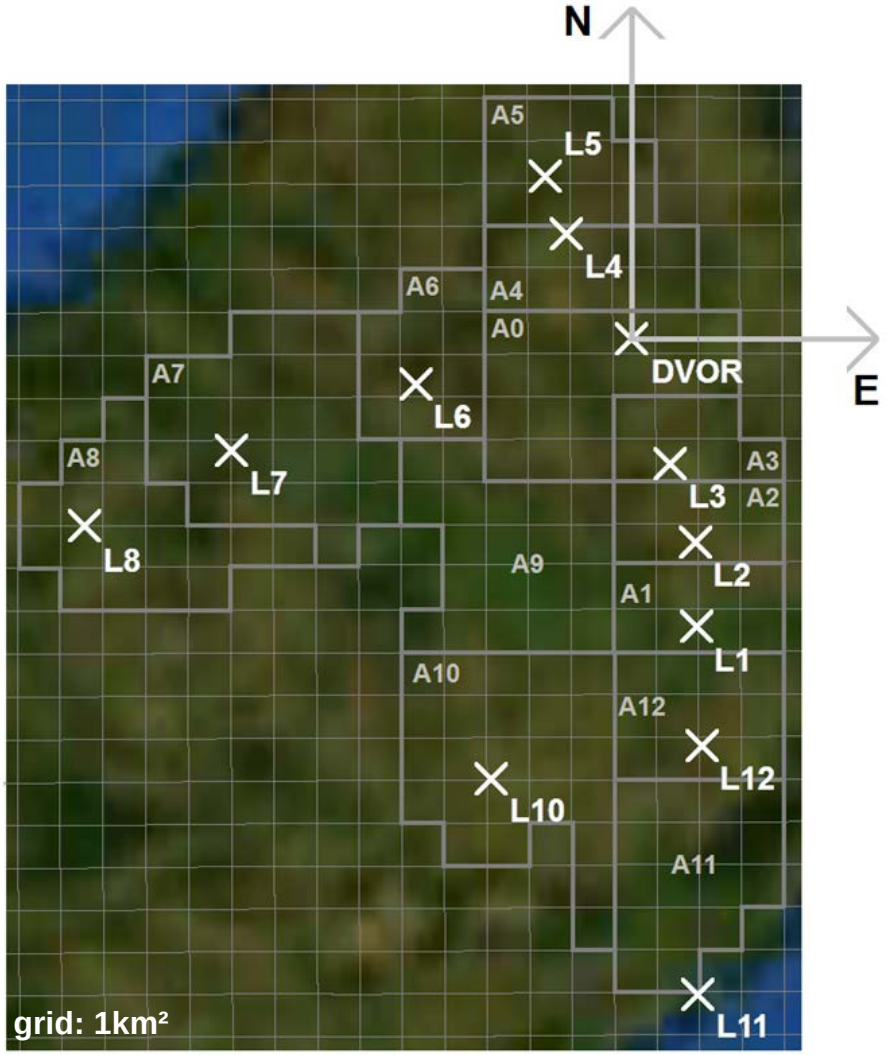
ACHIEVED SIMULATION ACCURACY AND OPTIMIZED DAMPING FACTOR

	averaged FSE	damping factors
FS	±4.85 dB	–
PP	±4.71 dB	–
PPD	±3.05 dB	$D_{PP} = 0.67$





Modeling the Ground



-splitting terrain data
in 1km² sized patches & meshing

>>> consideration of „real“ terrain texture and earth curvature

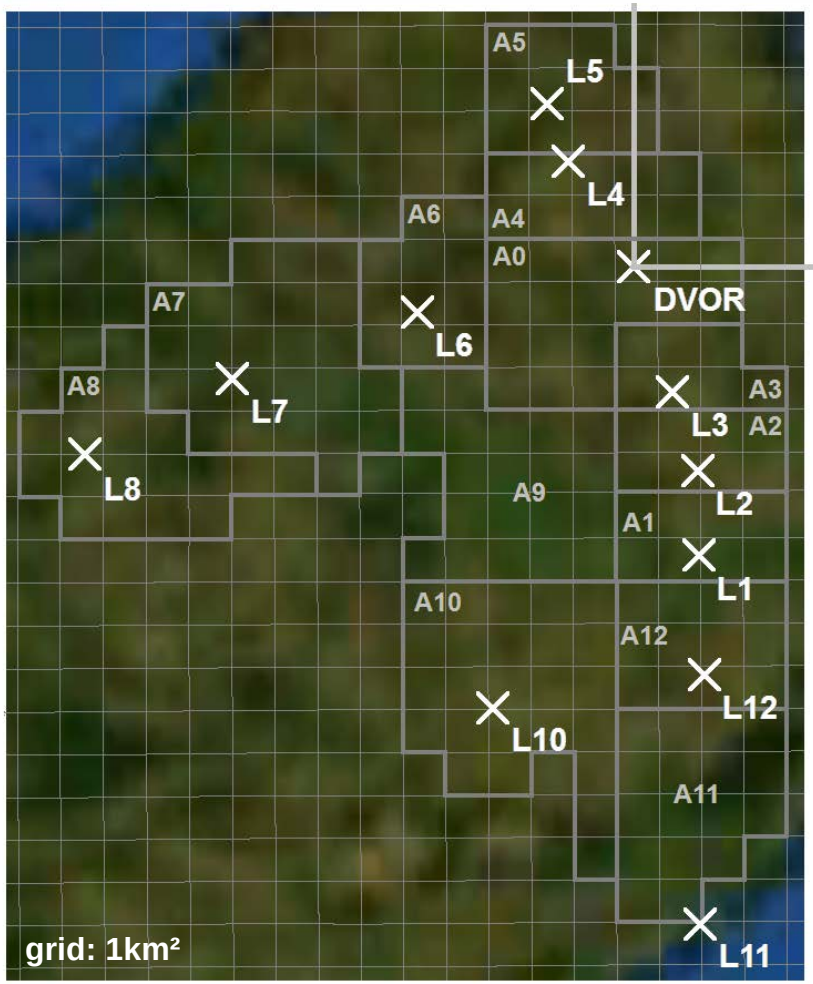
-Large Element Physical Optics FEKO

-average mesh edge size 2.8m @ 112 MHz

-separated simulations of all patches
(3 GB RAM, ~ 200 cpu hours)

Modeling the Ground

$$\underline{E}_{TPD,i} = \underline{E}_{FS,i} + D_{SS} \cdot \underline{E}_{SS,i} + D_{IS} \cdot \underline{E}_{IS,i} + D_{OS} \cdot \underline{E}_{OS,i}$$



E

-combining individual patches to areas

$$\underline{E}_{Am,i} = \sum_{AREA\ m} (\underline{E}_{TP,i,n} - \underline{E}_{FS,i})$$

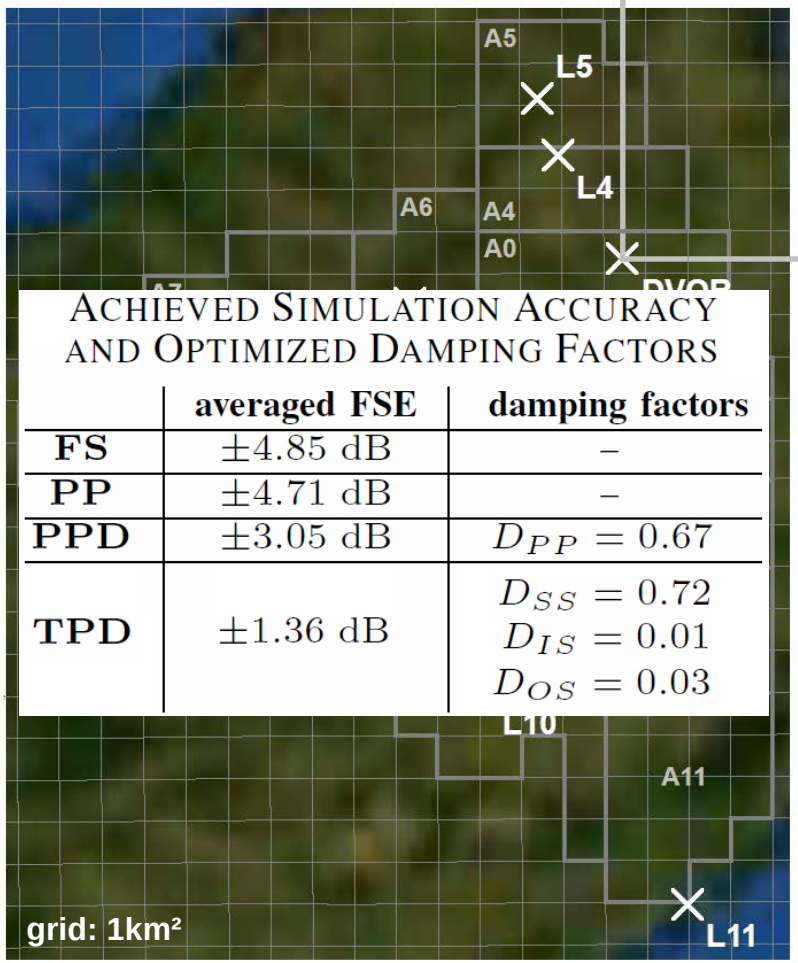
-defining 3 different sectors for each location
- source sector (SS)
- interspace sector (IS)
- observation sector (OS)

	$\mathbf{E}_{SS} =$	$\mathbf{E}_{IS} =$	$\mathbf{E}_{OS} =$
L1	$\underline{E}_{A0}$	$\underline{E}_{A2} + \underline{E}_{A3}$	$\underline{E}_{A1}$
L2	$\underline{E}_{A0}$	$\underline{E}_{A3}$	$\underline{E}_{A2}$
L3	$\underline{E}_{A0}$	–	$\underline{E}_{A3}$
L4	$\underline{E}_{A0}$	–	$\underline{E}_{A4}$
L5	$\underline{E}_{A0}$	$\underline{E}_{A4}$	$\underline{E}_{A5}$
L6	$\underline{E}_{A0}$	–	$\underline{E}_{A6}$
L7	$\underline{E}_{A0}$	$\underline{E}_{A6} + \underline{E}_{A9}$	$\underline{E}_{A7}$
L8	$\underline{E}_{A0}$	$\underline{E}_{A6} + \underline{E}_{A7} + \underline{E}_{A9}$	$\underline{E}_{A8}$
L9	–	–	–
L10	$\underline{E}_{A0} + \underline{E}_{A3}$	$\underline{E}_{A1} + \underline{E}_{A2} + \underline{E}_{A9}$	$\underline{E}_{A10}$
L11	$\underline{E}_{A0} + \underline{E}_{A3}$	$\underline{E}_{A1} + \underline{E}_{A2} + \underline{E}_{A9} + \underline{E}_{A10} + \underline{E}_{A12}$	$\underline{E}_{A11}$
L12	$\underline{E}_{A0} + \underline{E}_{A3}$	$\underline{E}_{A1} + \underline{E}_{A2} + \underline{E}_{A9} + \underline{E}_{A10}$	$\underline{E}_{A12}$

-using individual damping factors for each sector

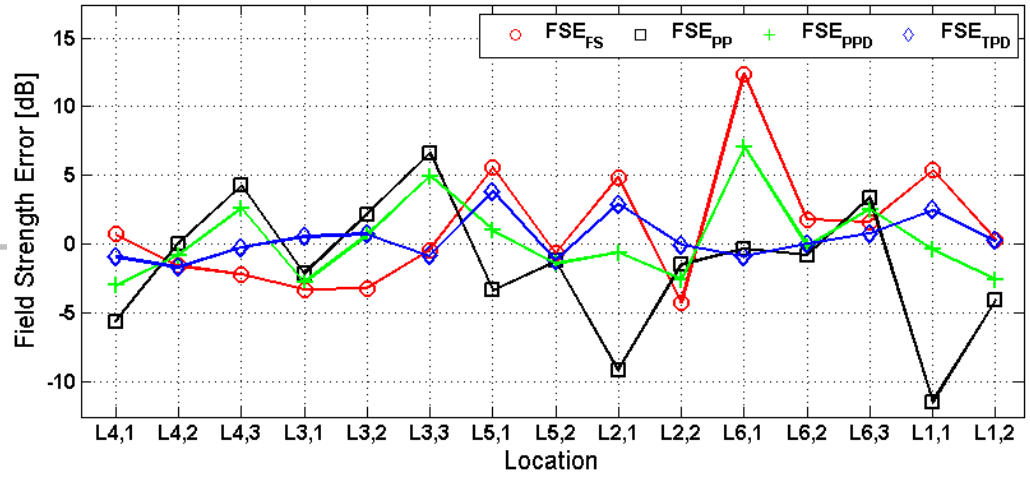
Modeling the Ground

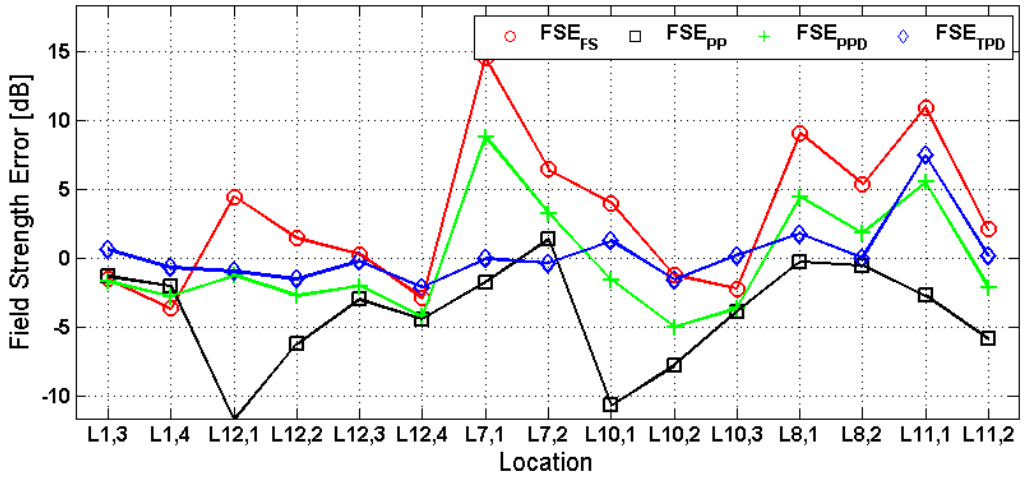
$$\underline{E}_{TPD,i} = \underline{E}_{FS,i} + D_{SS} \cdot \underline{E}_{SS,i} + D_{IS} \cdot \underline{E}_{IS,i} + D_{OS} \cdot \underline{E}_{OS,i}$$



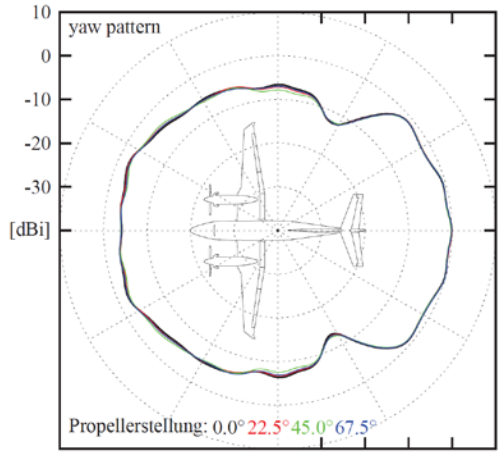
ACHIEVED SIMULATION ACCURACY AND OPTIMIZED DAMPING FACTORS

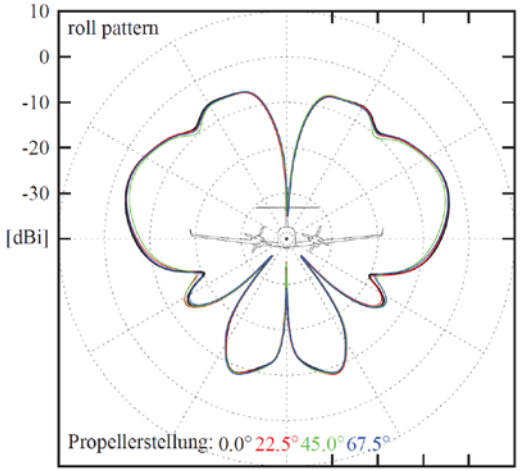
	averaged FSE	damping factors
FS	±4.85 dB	–
PP	±4.71 dB	–
PPD	±3.05 dB	$D_{PP} = 0.67$
TPD	±1.36 dB	$D_{SS} = 0.72$ $D_{IS} = 0.01$ $D_{OS} = 0.03$

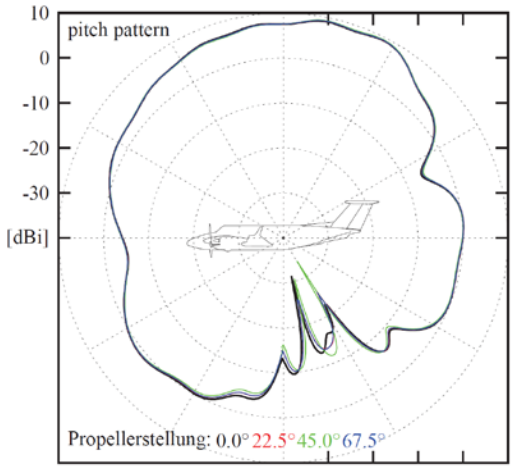


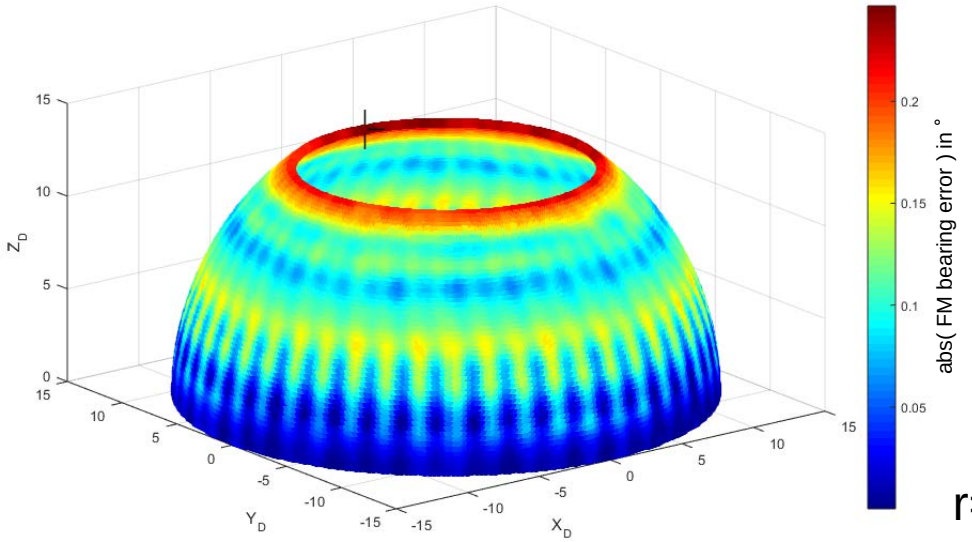


Aircraft Antenna Characteristics

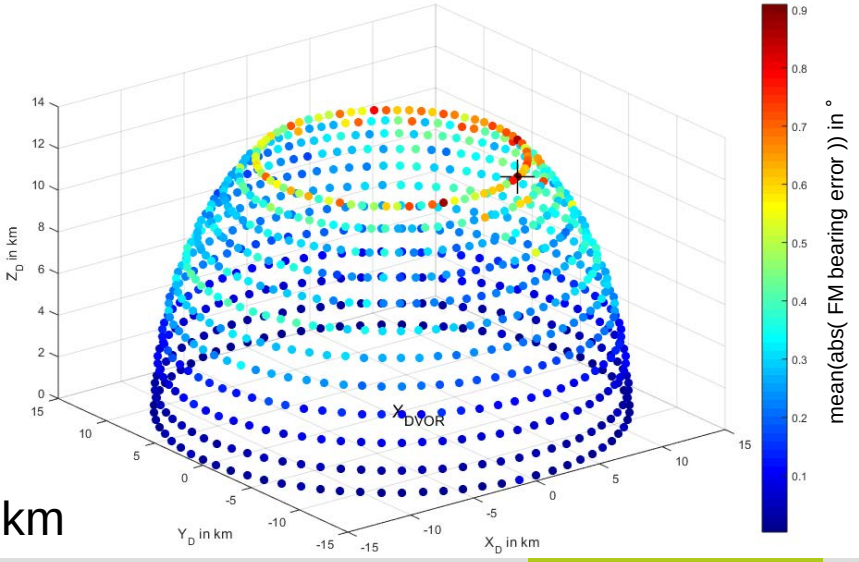




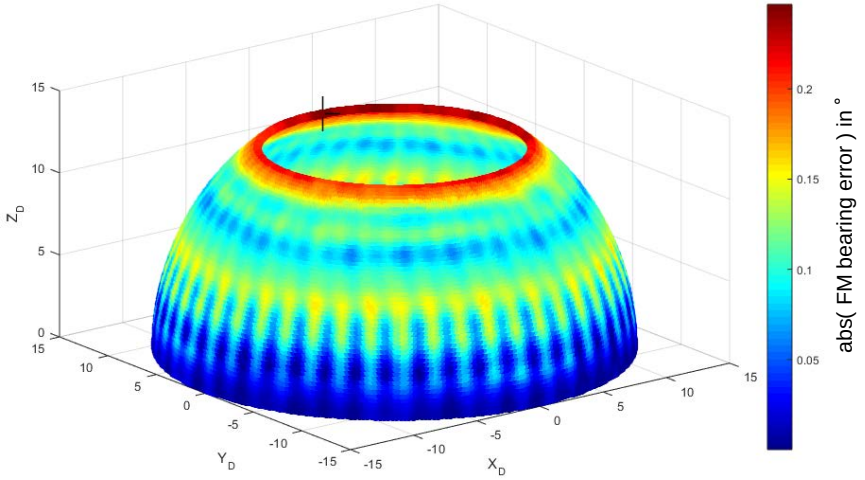


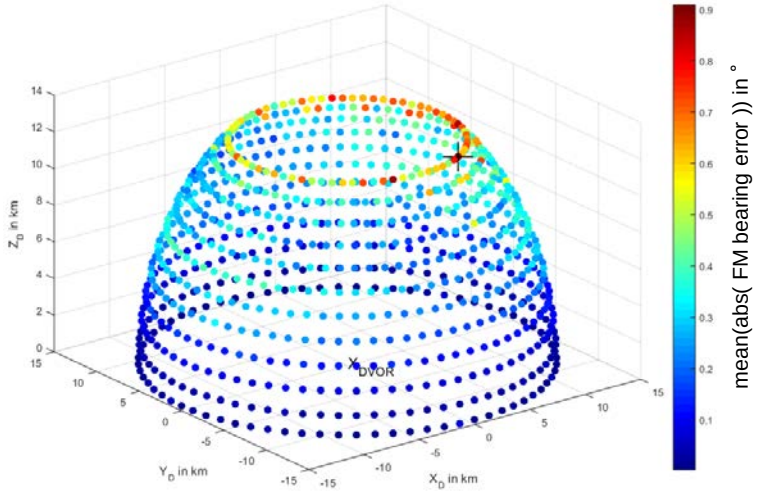


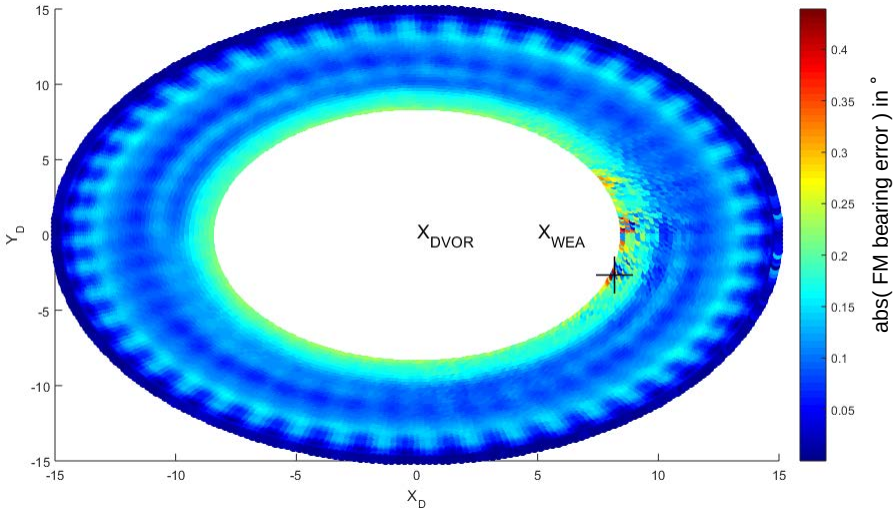
r=15km

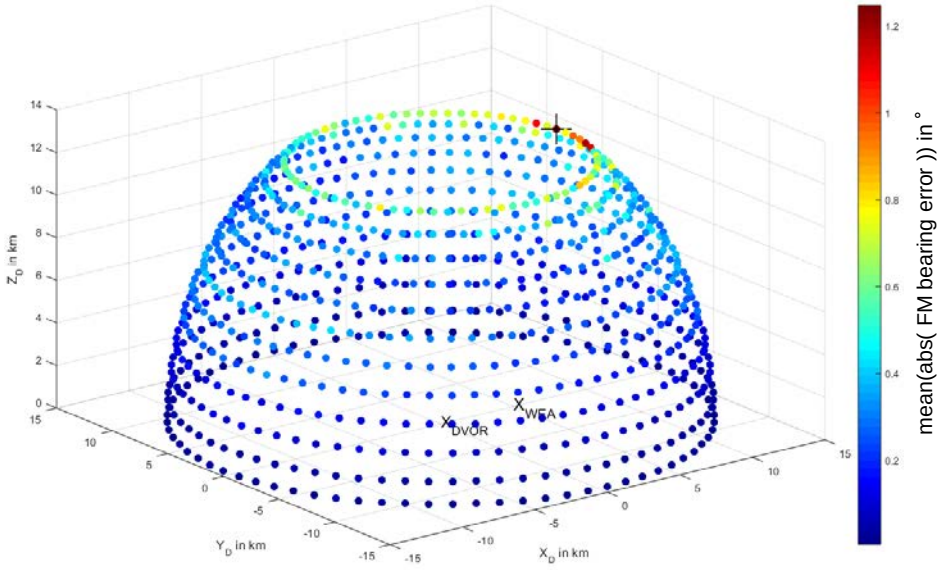


Aircraft Antenna Characteristics

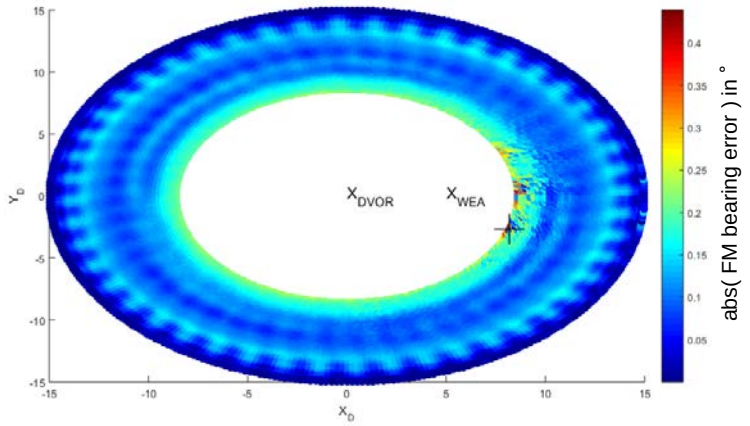


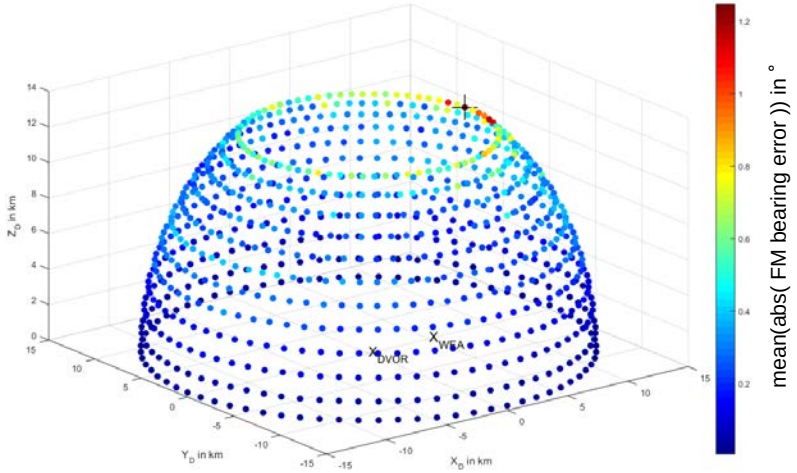


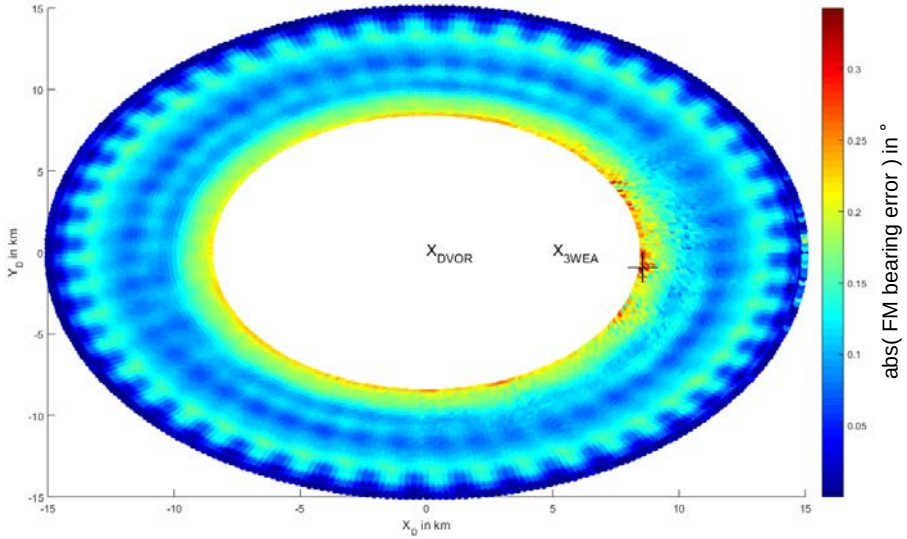


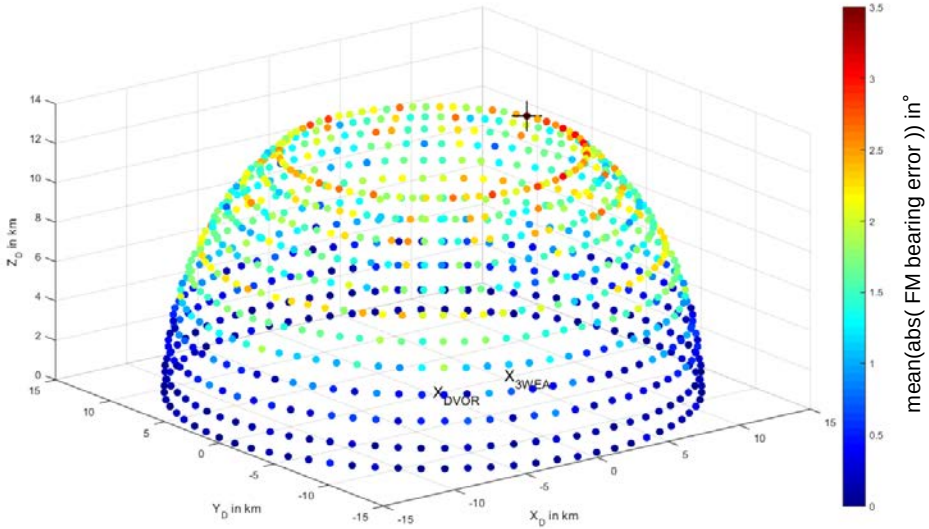


Aircraft Antenna Characteristics

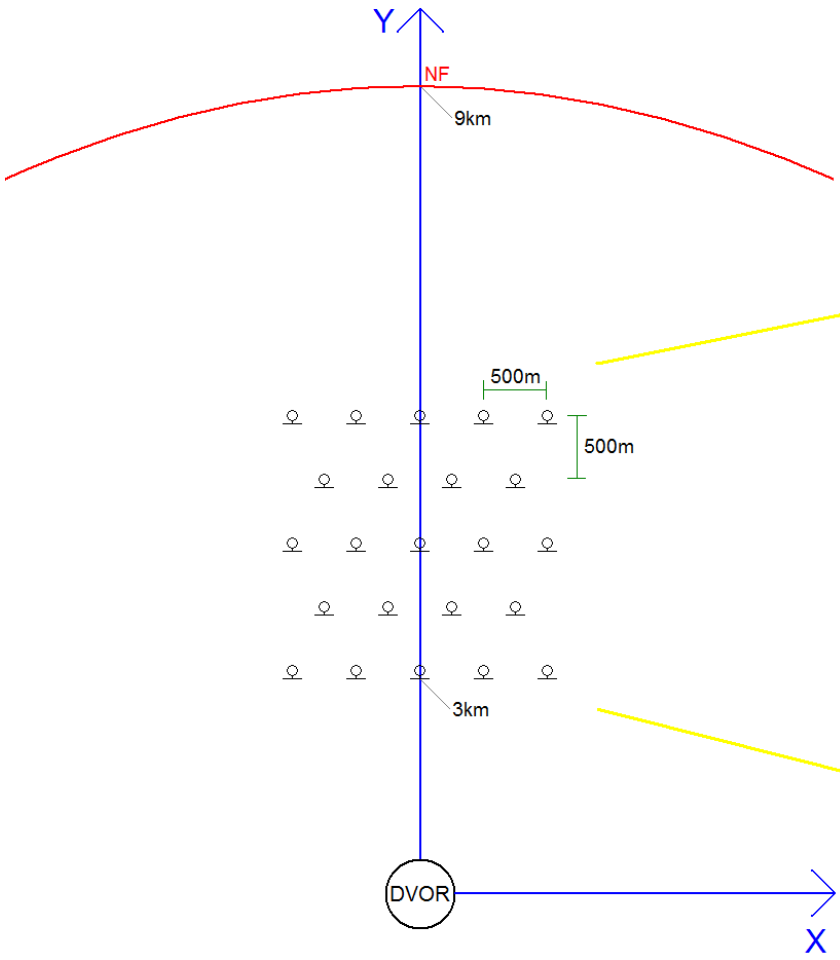






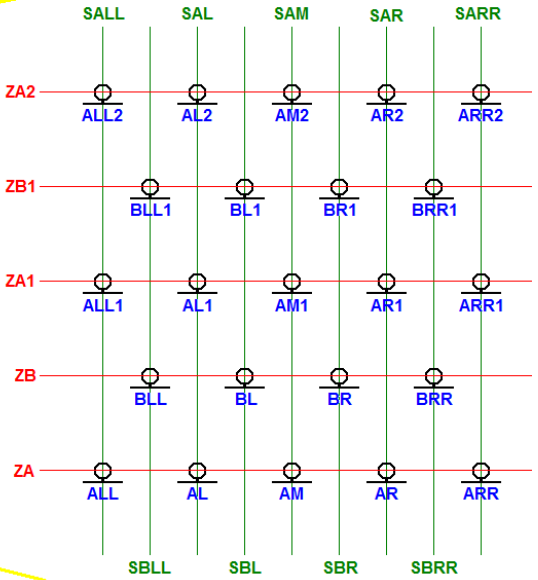


Superposition of DVOR Bearing Error

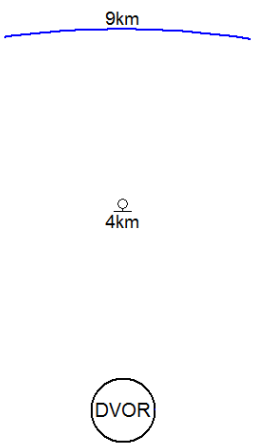


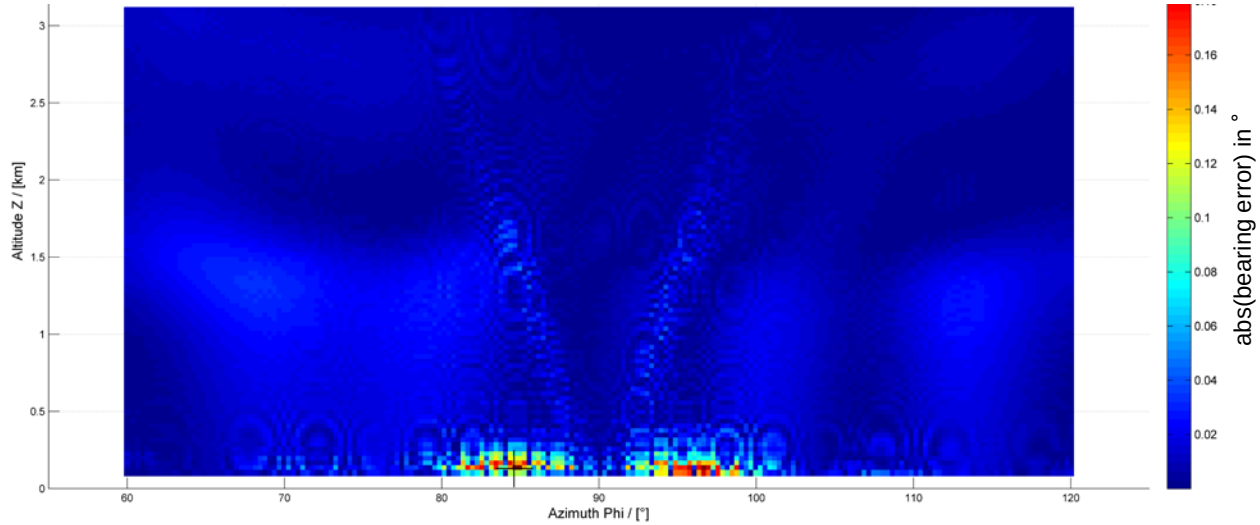
Weitere Gruppierungen von WEA

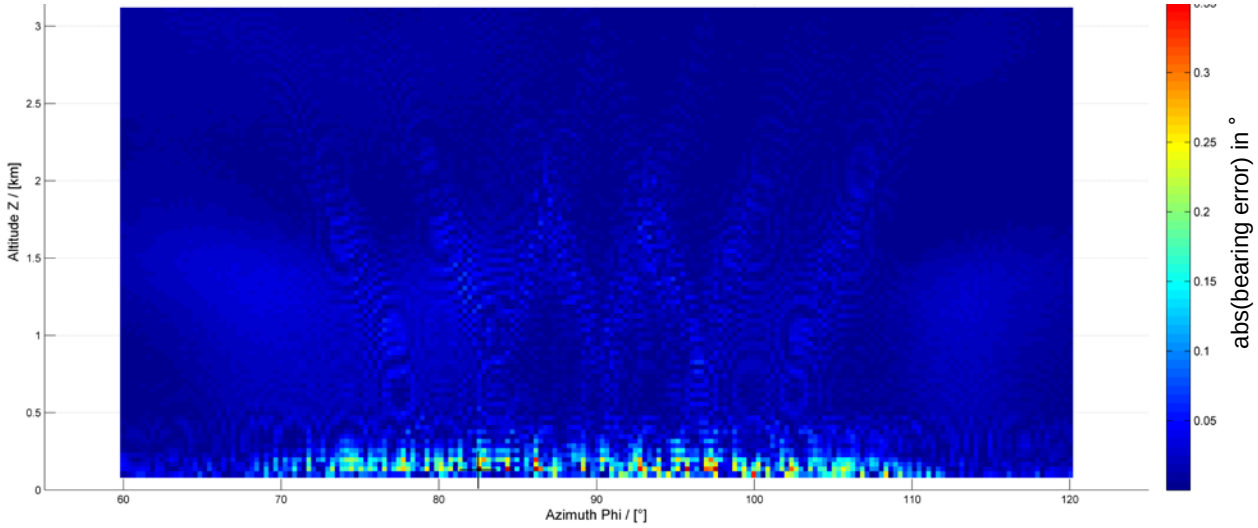
Bezeichnung	beteiligte WEA
DF	ALL, BLL, AM1, BRR1, ARR2
DB	ARR, BRR, AM1, BLL1, ALL2
SQ	SALL, SAM, SARR
ZSAB	ZA2, ZB1, ZA1, ZB, ZA

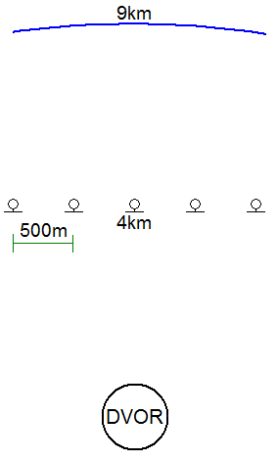


Superposition of DVOR Bearing Error





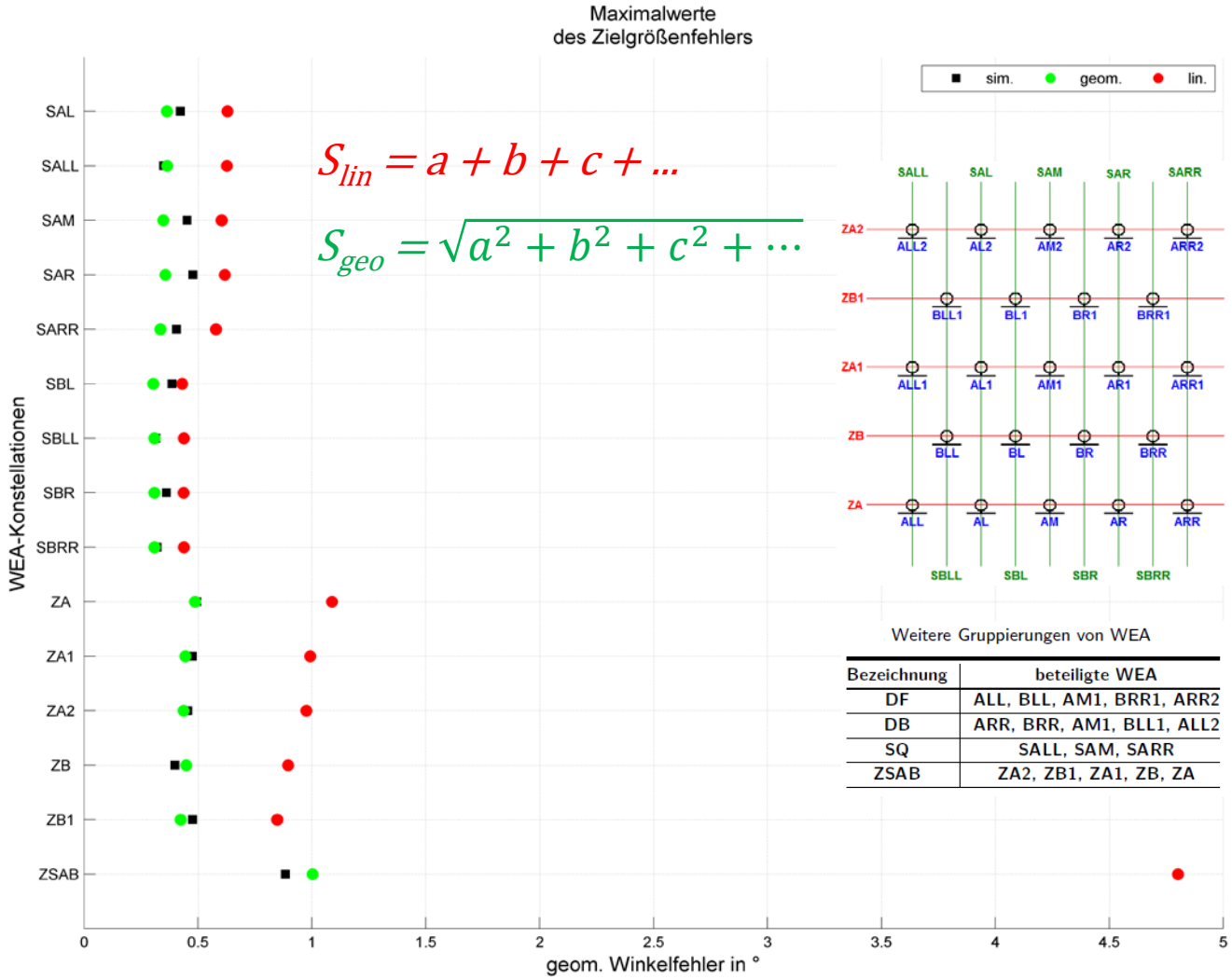




Superposition of DVOR Bearing Error

Zielgrößenabweichungen für alle WEA-Standorte in °

WEA	Maximalwert
AL	0.2146
AL1	0.2134
AL2	0.2017
ALL	0.2433
ALL1	0.1892
ALL2	0.1949
AM1	0.2049
AM2	0.1932
AM	0.2057
AR	0.2190
AR1	0.1917
AR2	0.2070
ARR	0.2058
ARR1	0.1934
ARR2	0.1799
BL	0.2197
BL1	0.2106
BLL	0.2268
BLL1	0.2114
BR	0.2292
BR1	0.2085
BRR	0.2209
BRR1	0.2174

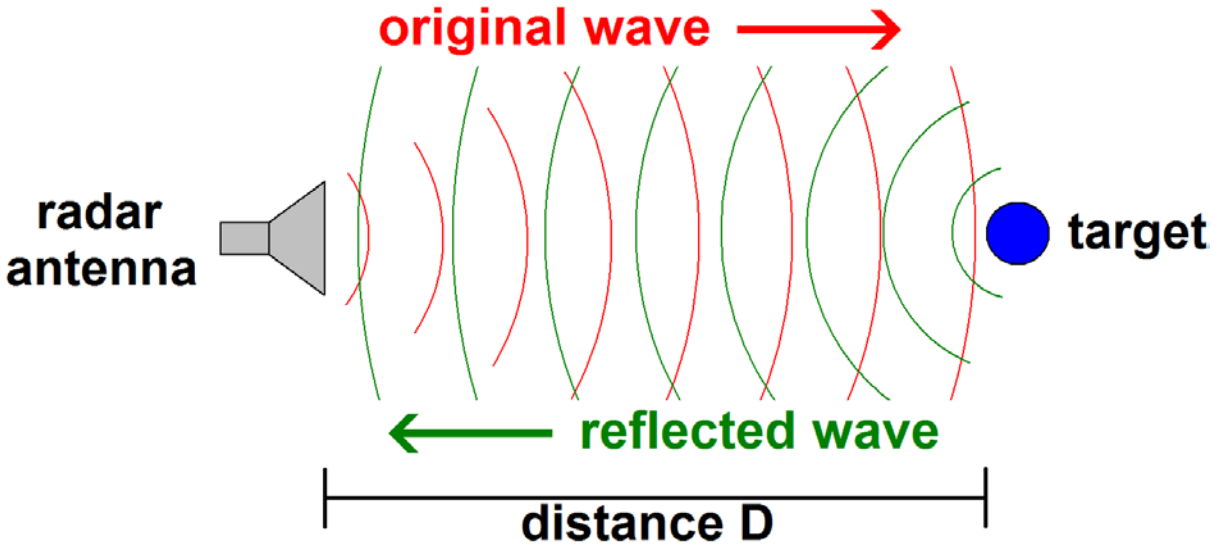


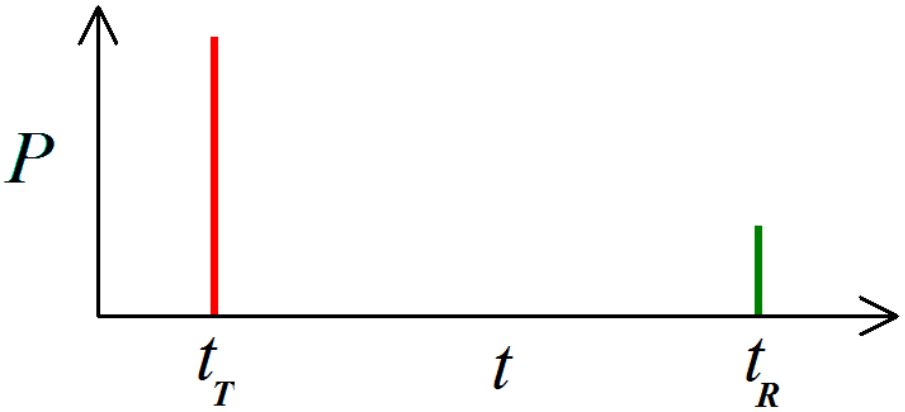
Weitere Gruppierungen von WEA

Bezeichnung	beteiligte WEA
DF	ALL, BLL, AM1, BRR1, ARR2
DB	ARR, BRR, AM1, BLL1, ALL2
SQ	SALL, SAM, SARR
ZSAB	ZA2, ZB1, ZA1, ZB, ZA

Numerical Calculation of RADAR Response

Operational Radar Theory



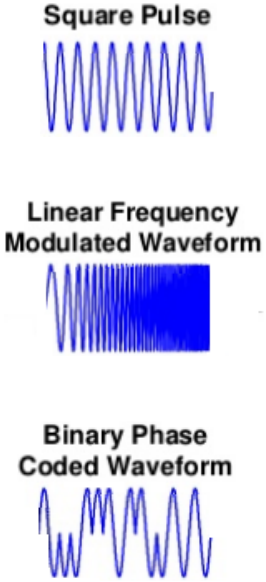


$$P_R = \frac{P_T \cdot G^2 \cdot \sigma \cdot \lambda^2}{(4 \cdot \pi)^3 \cdot D^4}$$

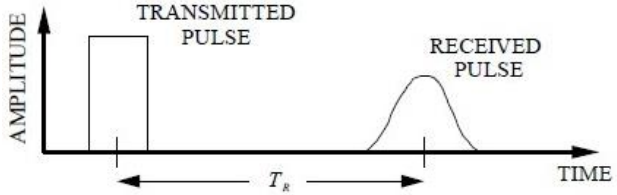
$$t_R - t_T = \frac{2D}{c_0}$$

Difficulties using Analytical Approach

defined pulse shape



puls distortion



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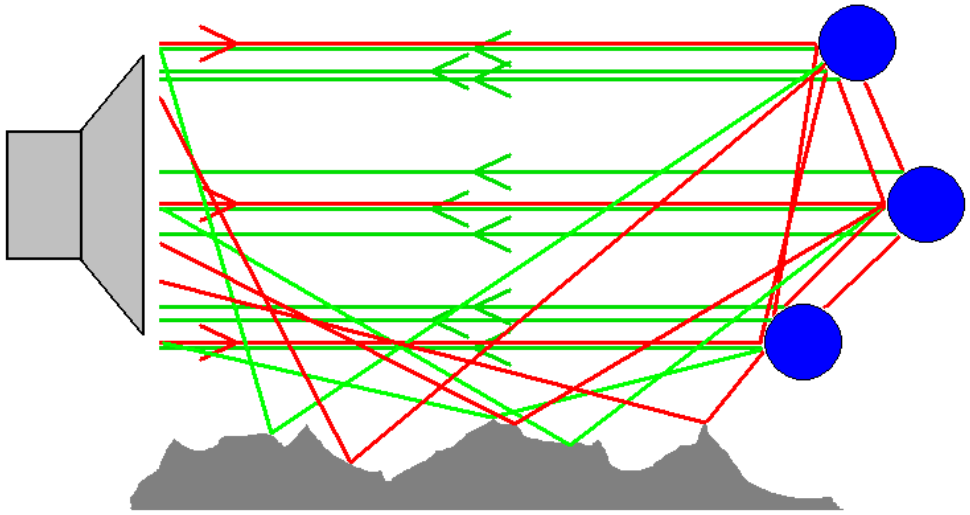


ground / landscape

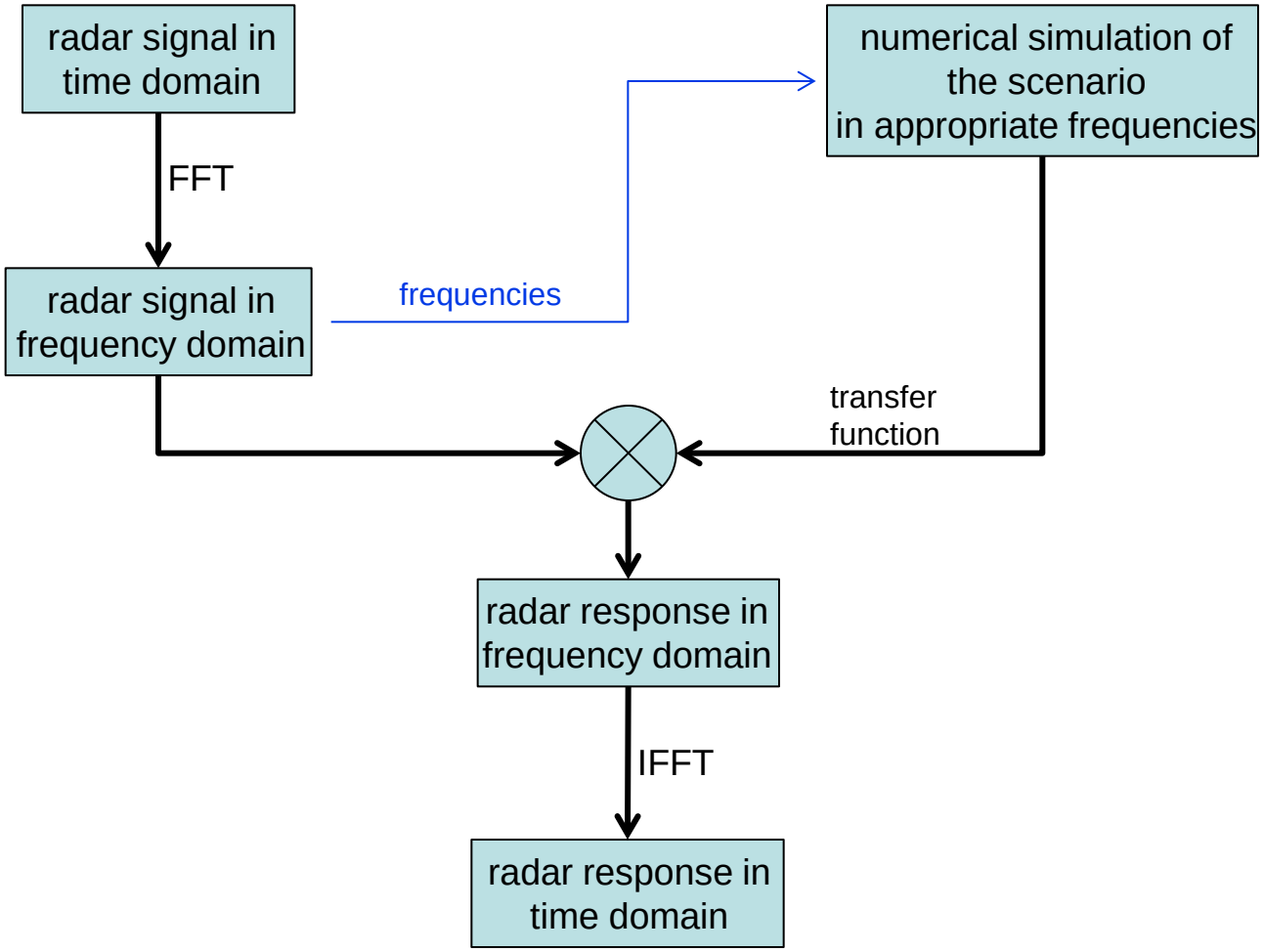
multiple objects
- multiple (overlapping) echoes

unknown RCS

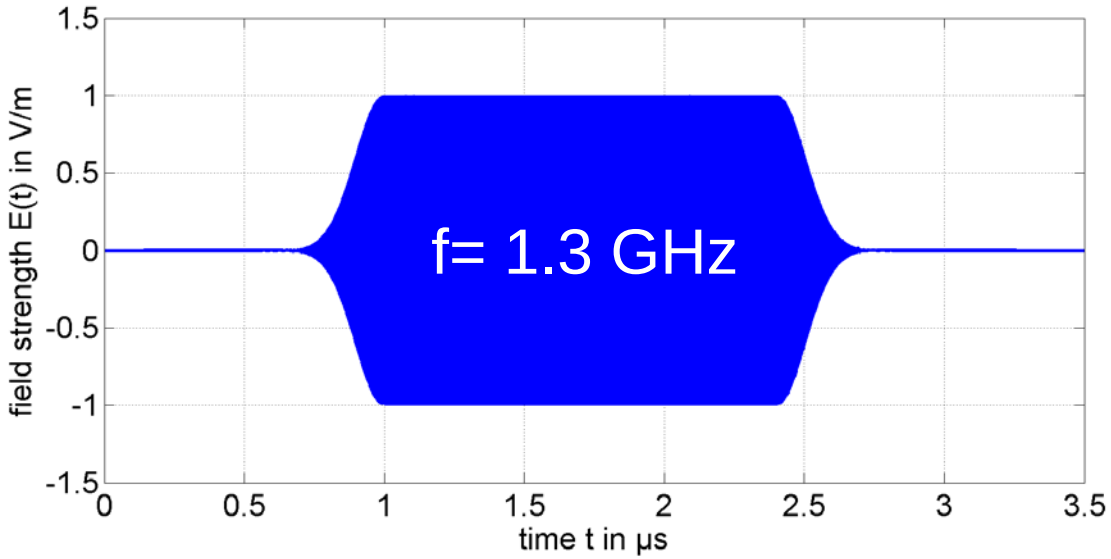
(overlapping) interacting reflections

analytical calculation not possible
- calculation using numerical simulation

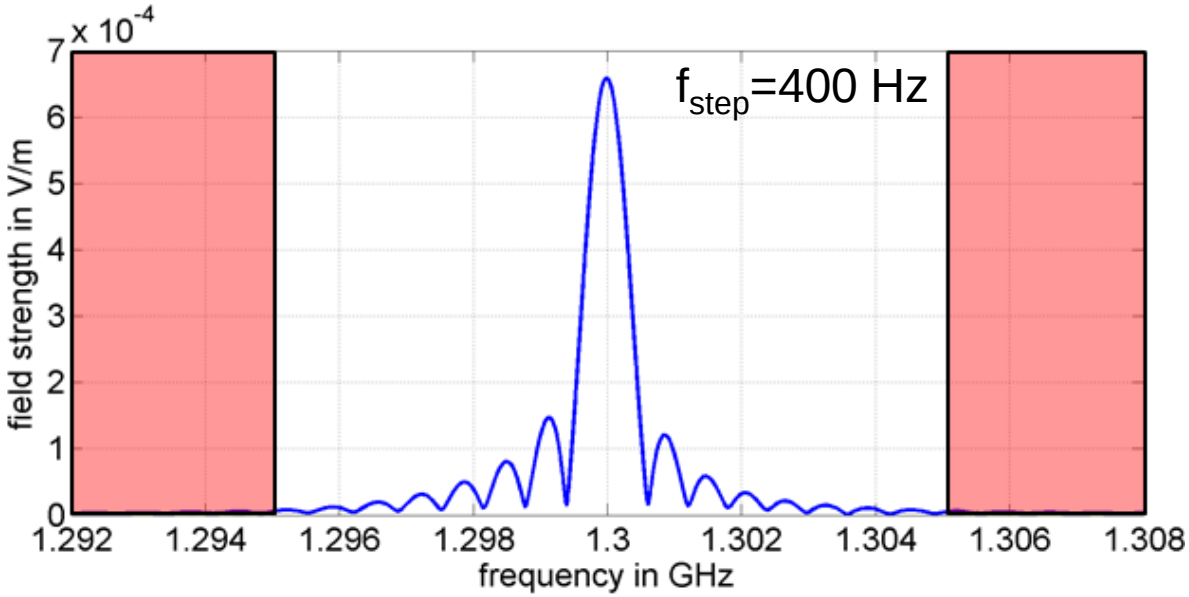
Basic Approach of Calculation



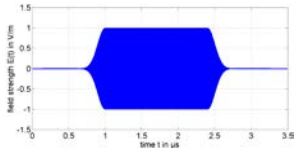
Basic Approach of Calculation



Basic Approach of Calculation



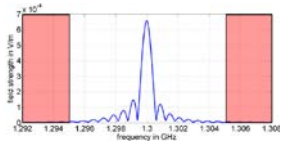
Basic Approach of Calculation



radar signal in time domain

FFT

BPF



radar signal in frequency domain

25,000 frequencies:
BW = 10 MHz
f_{step} = 400 Hz

numerical simulation of the scenario **with GO** in appropriate frequencies

426 MB RAM
16 h CPU
per step

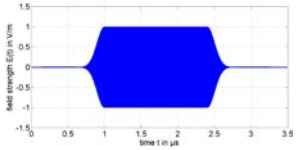
transfer function

radar response in frequency domain

IFFT

radar response in time domain

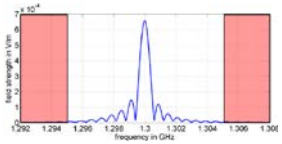
Basic Approach of Calculation



radar signal in time domain

FFT

BPF



radar signal in frequency domain

25,000 frequencies:
BW = 10 MHz
f_{step} = 400 Hz

numerical simulation of the scenario **with GO** in appropriate frequencies

426 MB RAM
16 h CPU
per step

1,000 Simulations:
BW = 10 MHz
f_{step} = 10 kHz

interpolation

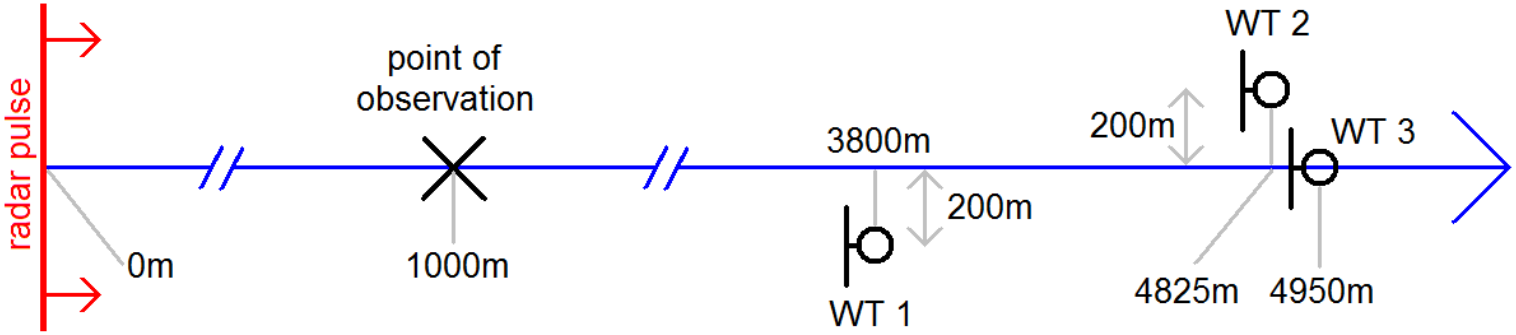
transfer function

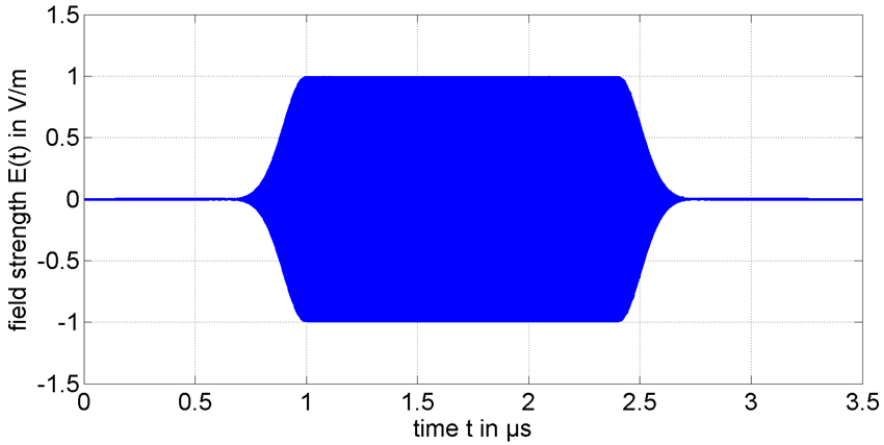
radar response in frequency domain

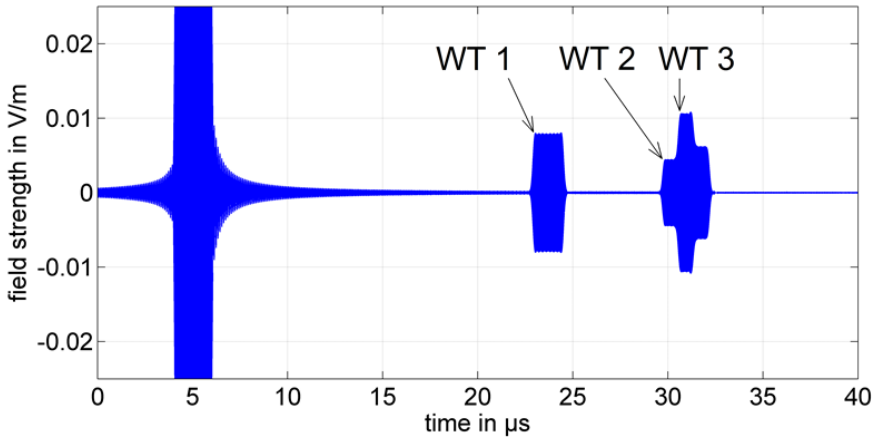
IFFT

radar response in time domain

Calculation of RADAR Response



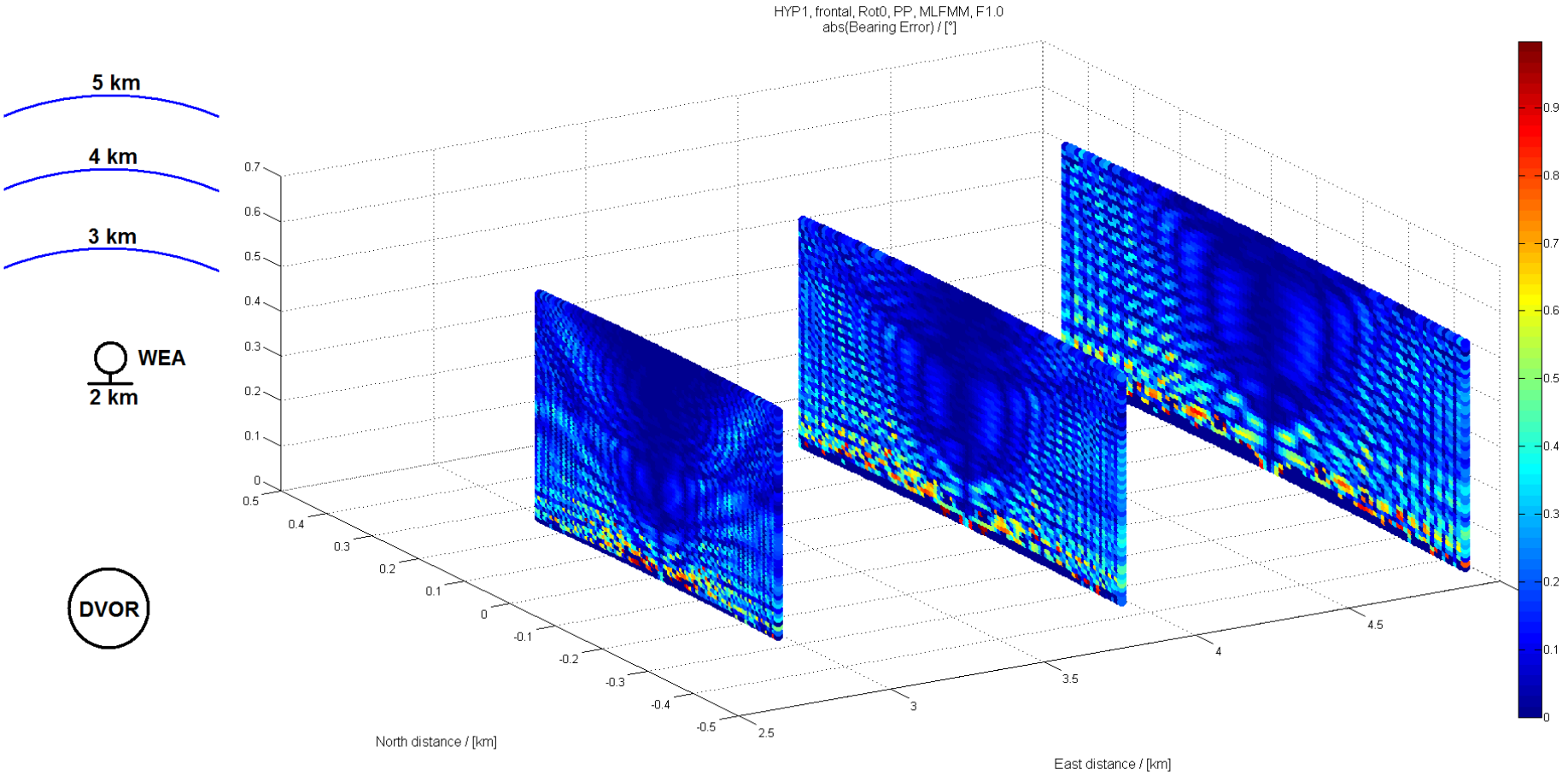




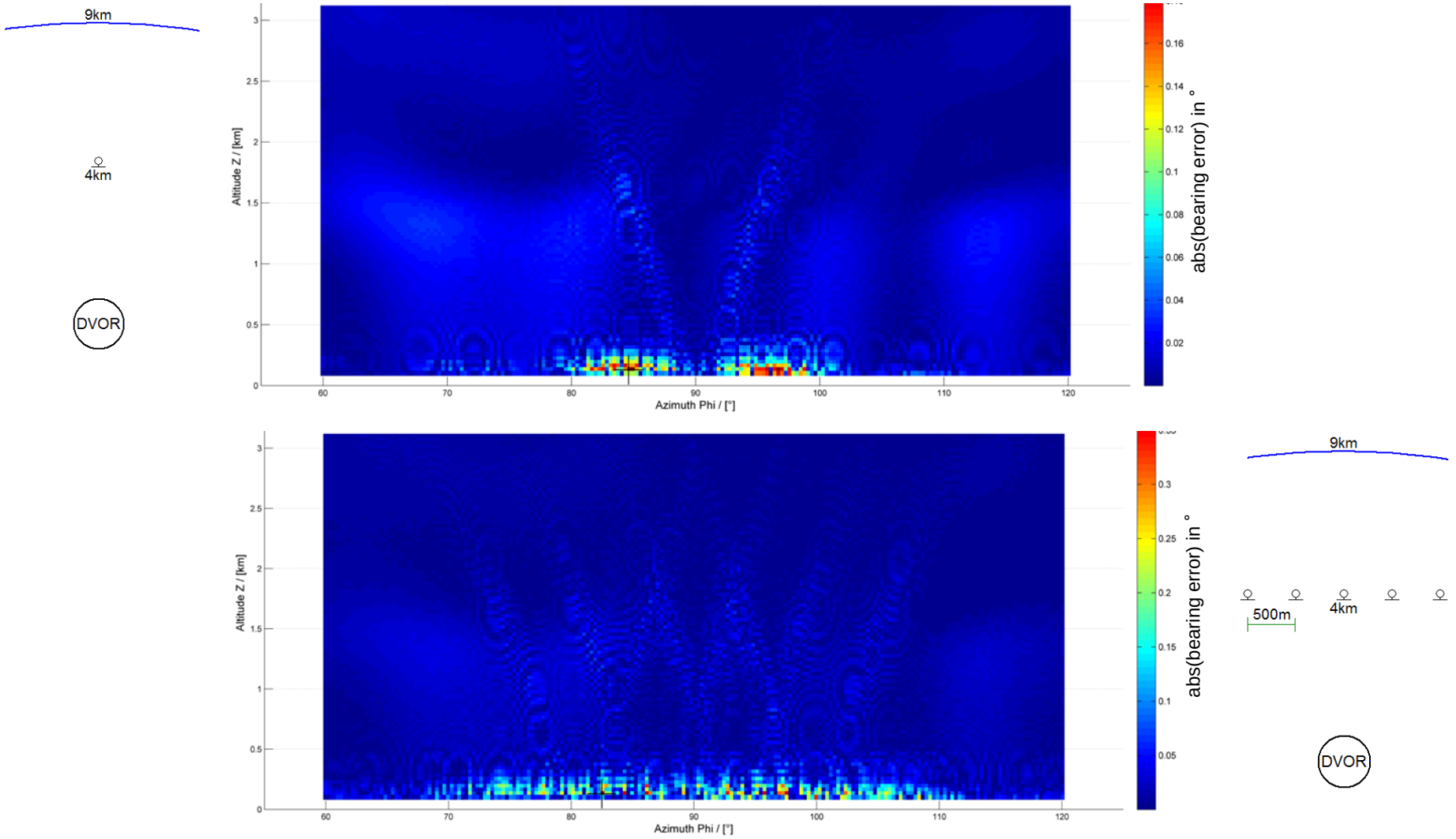
Summary & Outlook

- RADAR:
  - ✓ numerical calculation of **stationary RADAR** response
  - numerical calculation of **dynamical RADAR** response
- DVOR:
  - ✓ numerical calculation of **stationary FM** bearing contribution
  - numerical calculation of **dynamic FM** bearing contribution
  - numerical calculation of **dynamic AM** bearing contribution
  - **analytical approximating bearing calculation approach**

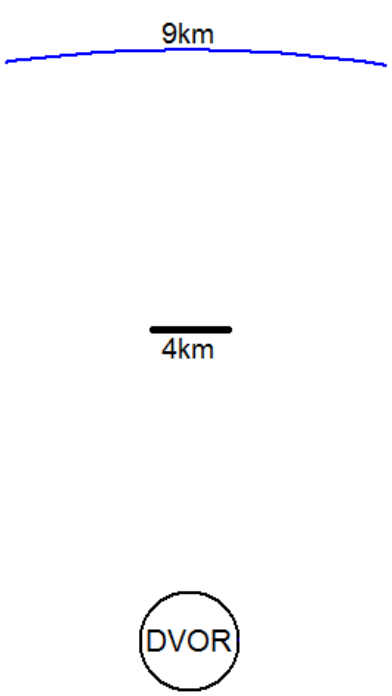
DVOR FM Bearing Pattern

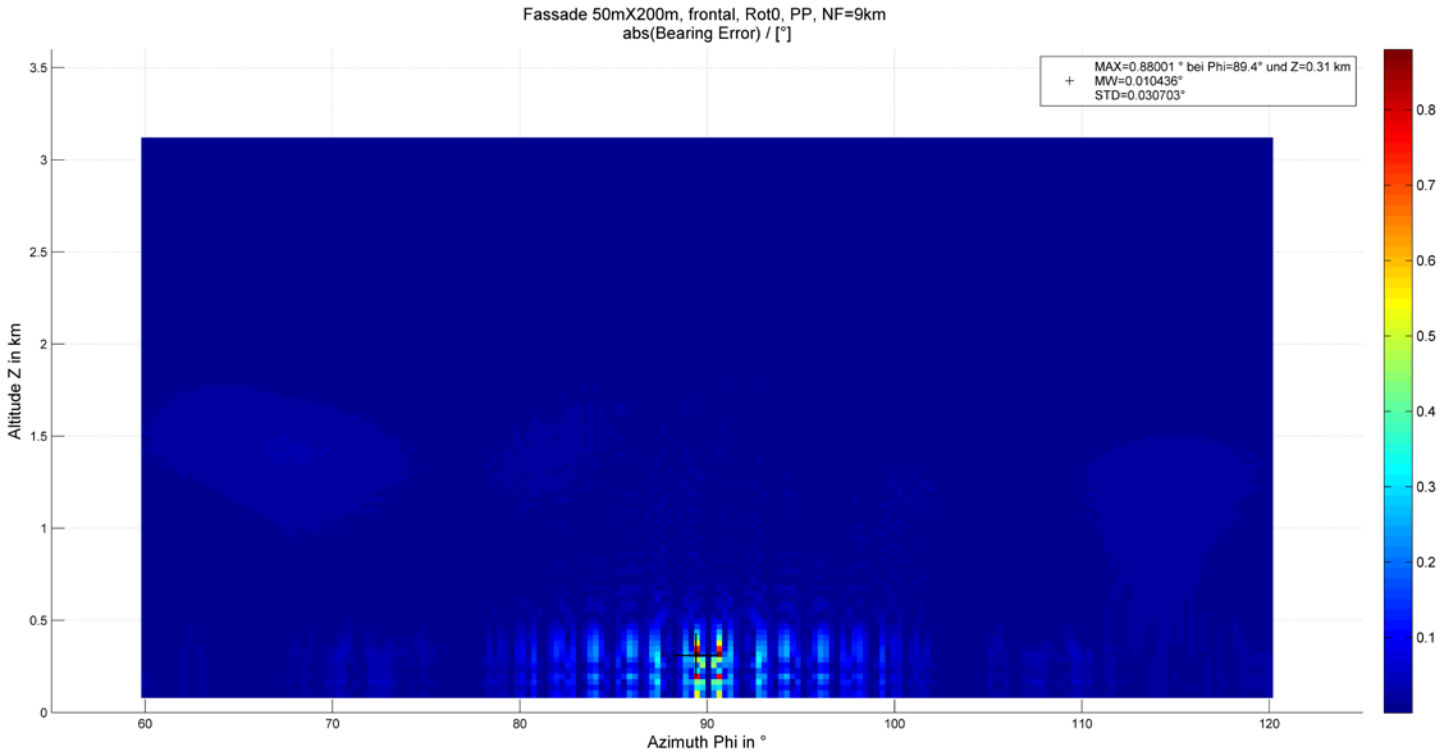


DVOR FM Bearing Pattern

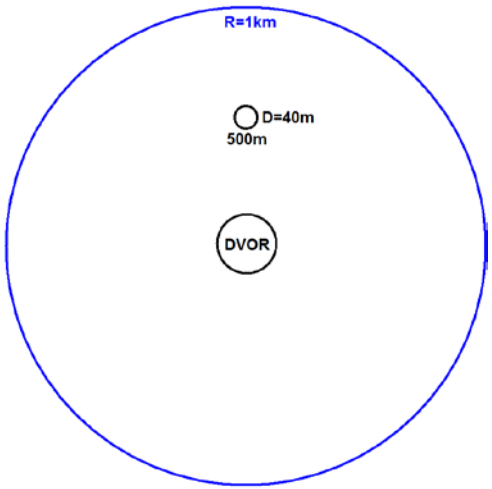


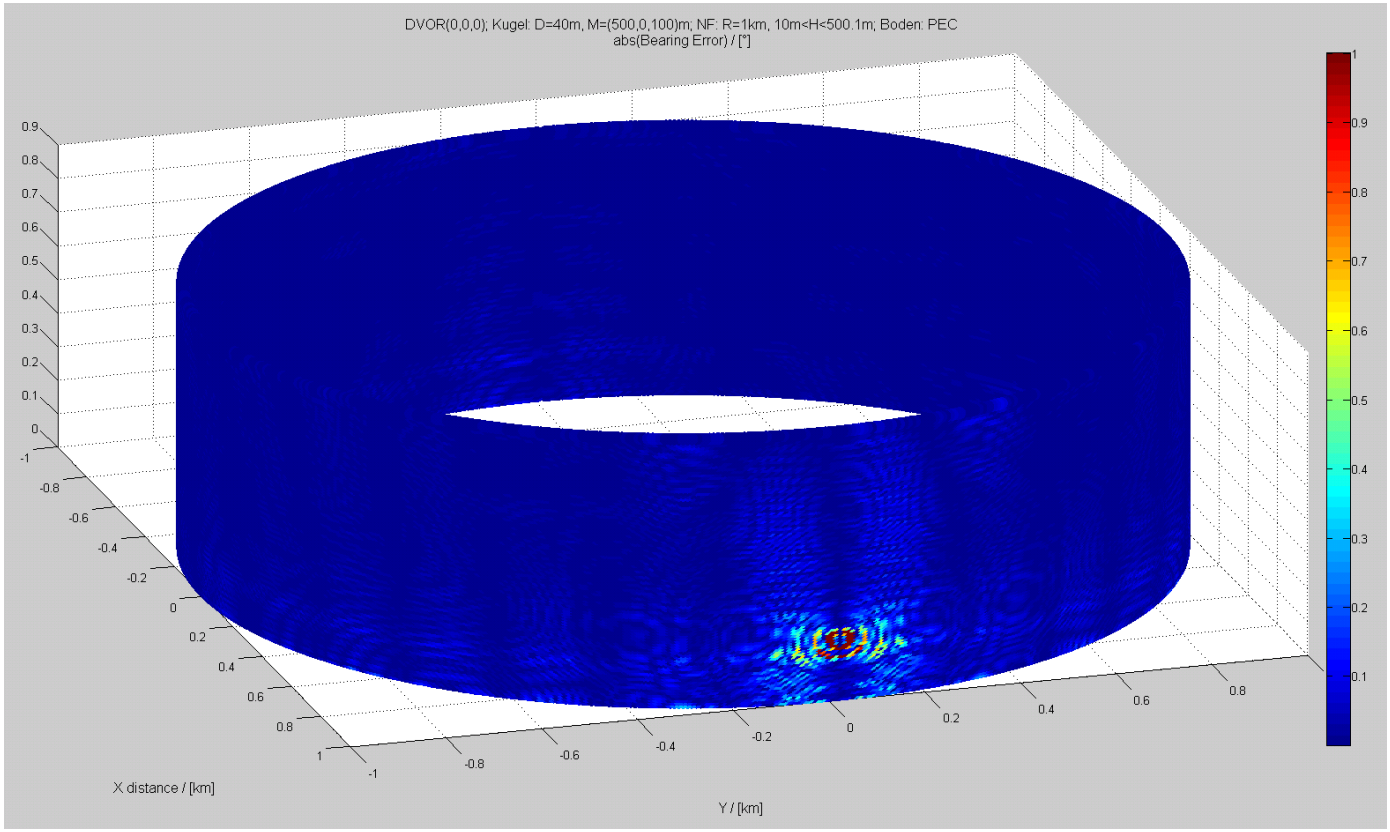
DVOR FM Bearing Pattern





DVOR FM Bearing Pattern





Summary & Outlook

- RADAR:
  - ✓ numerical calculation of **stationary RADAR** response
  - numerical calculation of **dynamical RADAR** response
- DVOR:
  - ✓ numerical calculation of **stationary FM** bearing contribution
  - numerical calculation of **dynamic FM** bearing contribution
  - numerical calculation of **dynamic AM** bearing contribution
  - **analytical approximating bearing calculation approach**

Thank you for your attention!