



Study of the impact of a wind farm over the radio navigation systems of an airport by using the Method of Moments (MoM) and Physical Optics (PO)

José Maria Tamayo Palau, Pascal de Resseguier

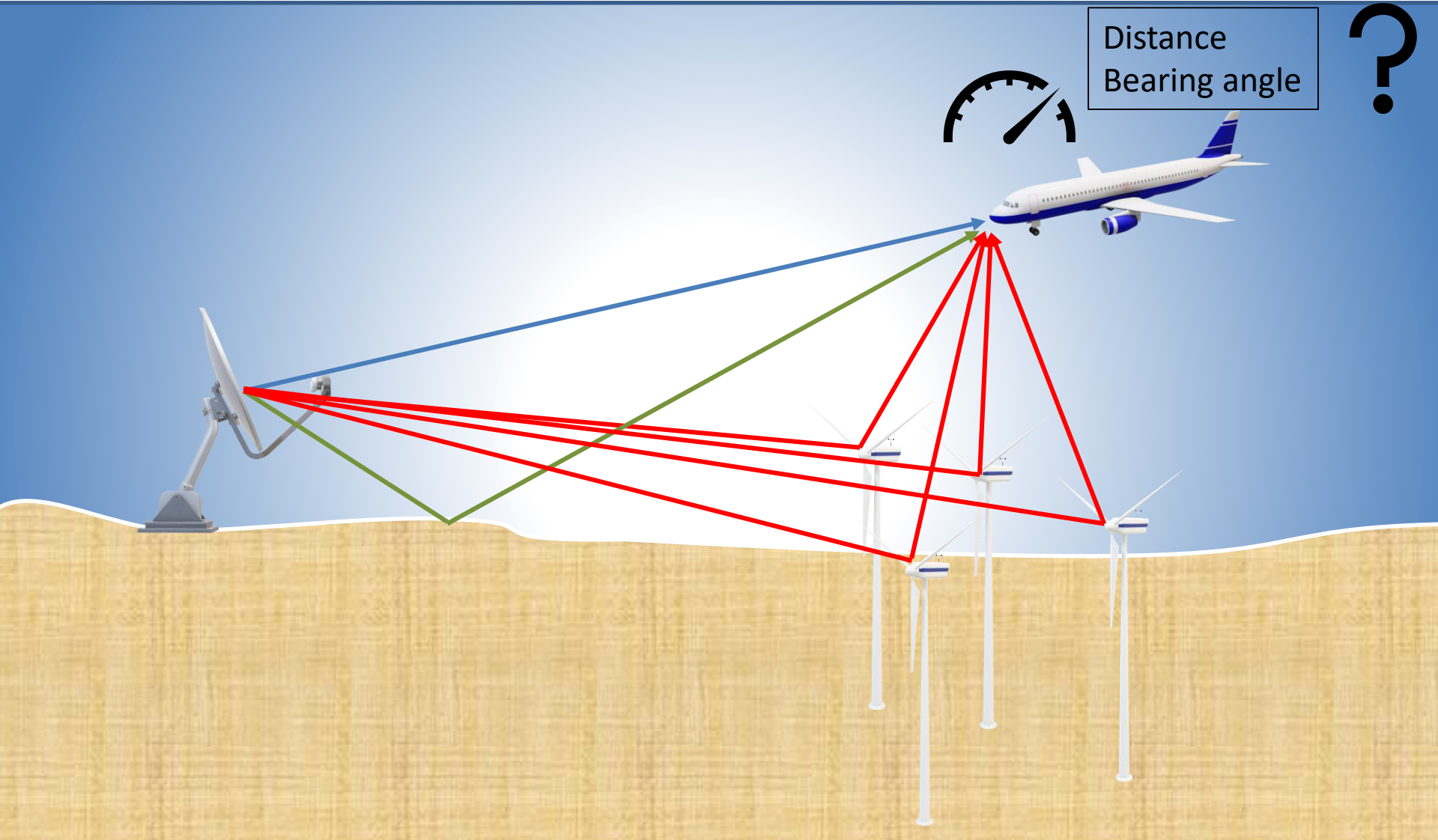


Outline

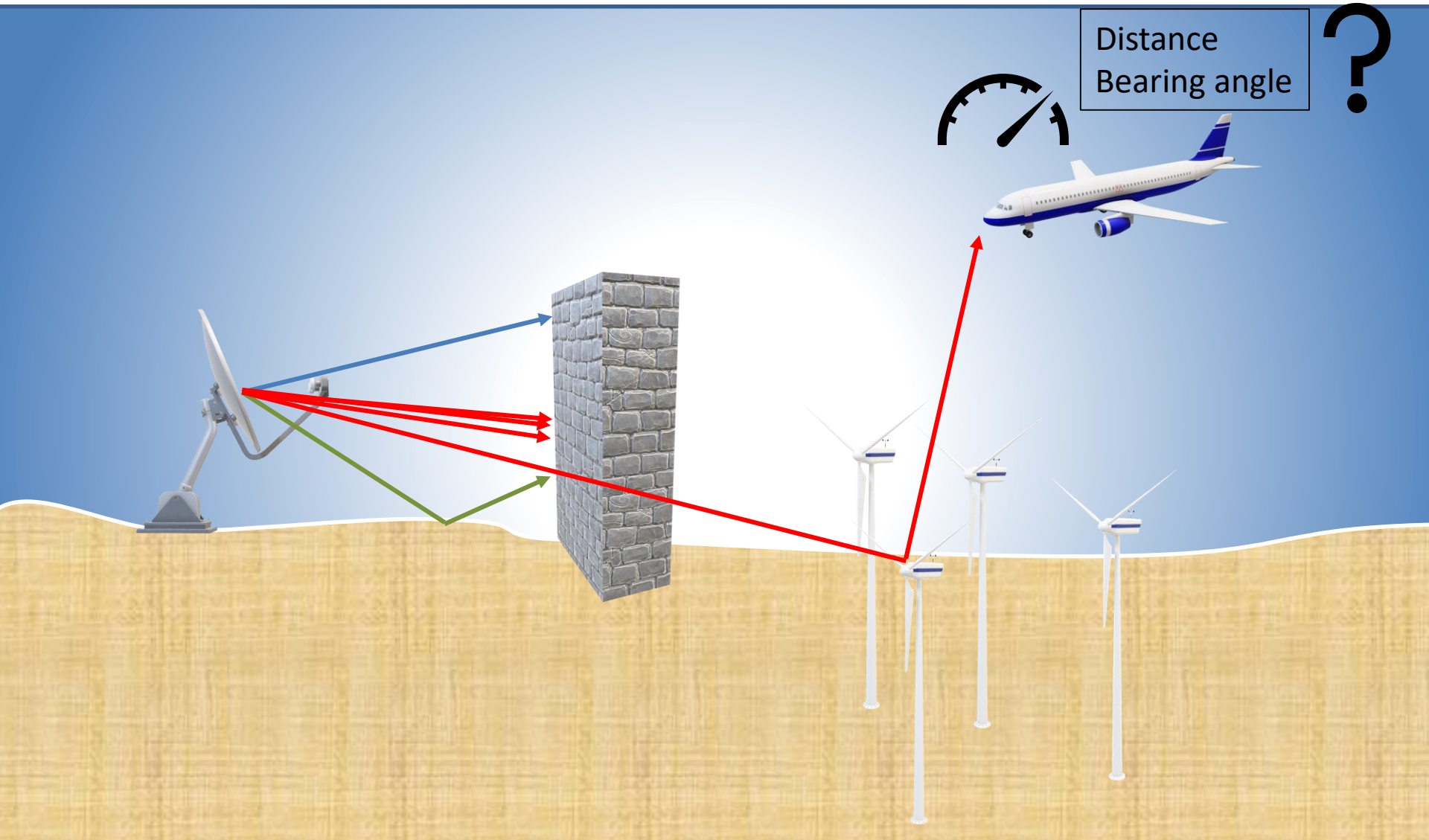
- Motivation
- Introduction
 - Bearing angle TACAN
- Comparison Frequency domain methods
 - MoM – MLACA
 - Physical Optics (PO)
- Numerical results
- Conclusion



Motivation



Motivation



Introduction

Radio Navigation System	Working Frequency	Measurement
VOR	108-117.975 MHz	Bearing
DME	960-1215 MHz	Distance
NDB	190-1750 kHz	Bearing
ILS	108-111.975 MHz	Localiser
	328.6-335.4 MHz	Glide path
	75 MHz	Marker Beacon
MLS	5030.4-5150.0 MHz	Microwave Landing system
TACAN	960-1215 MHz	Bearing + distance



Introduction

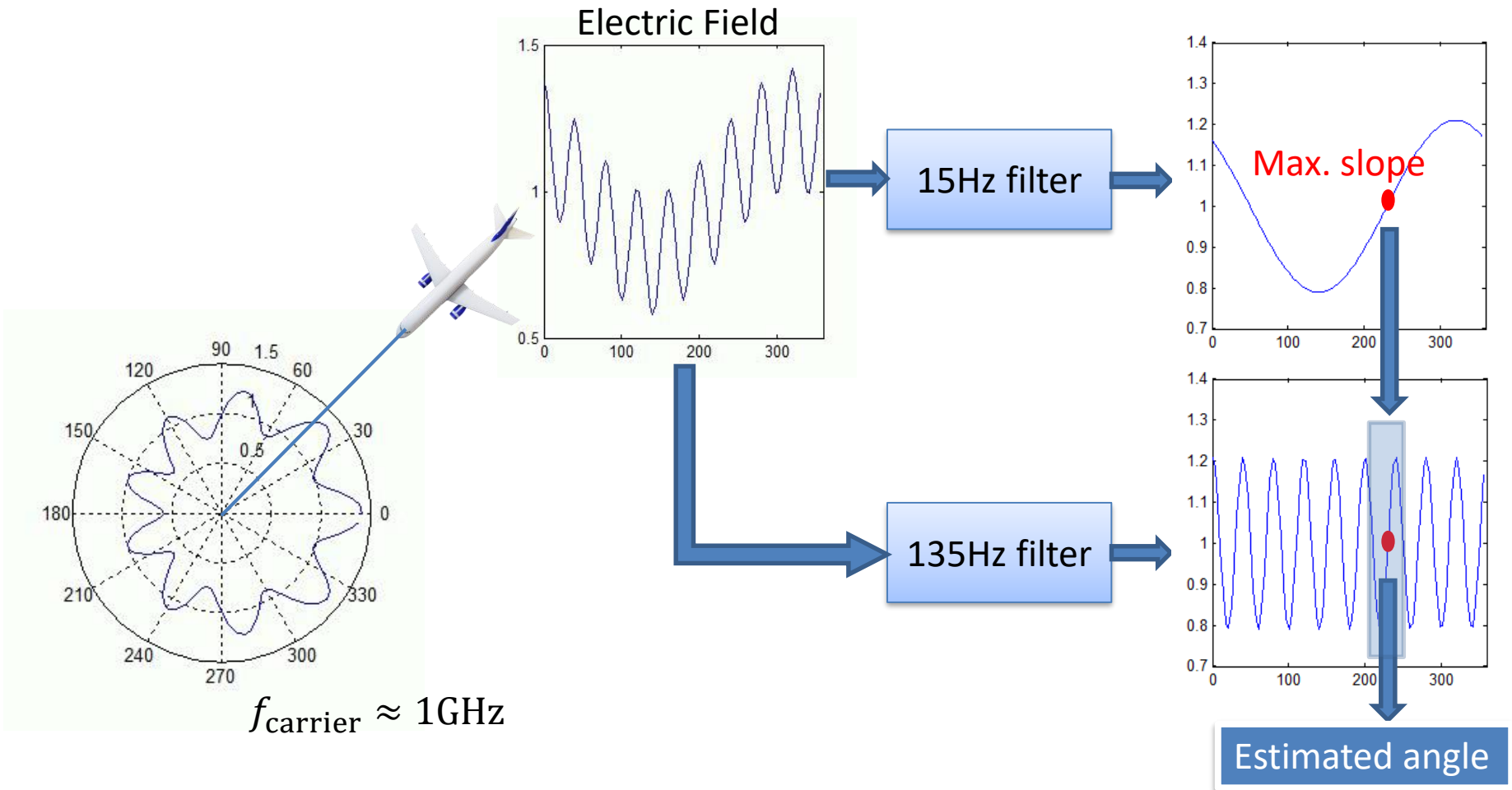
$$\vec{E}_{received} \neq \vec{E}_{free-space}$$

Sources of error in the measured parameters :

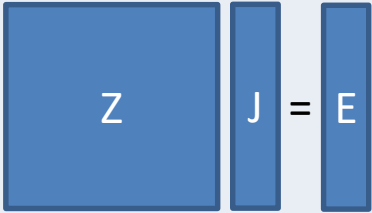
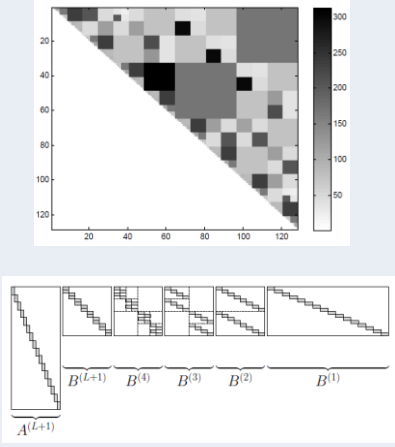
- Shadowing effects (Lost LOS).
- Multipath (ground + obstacles).
- Weather (atmospheric effects).
- Mountainous terrain.
- Electronic noise.
- Interference of other antennas.
- Doppler from moving obstacles.



Example - Bearing Angle TACAN



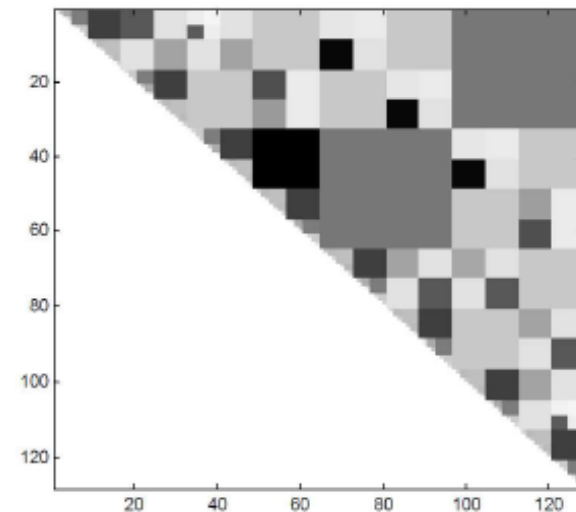
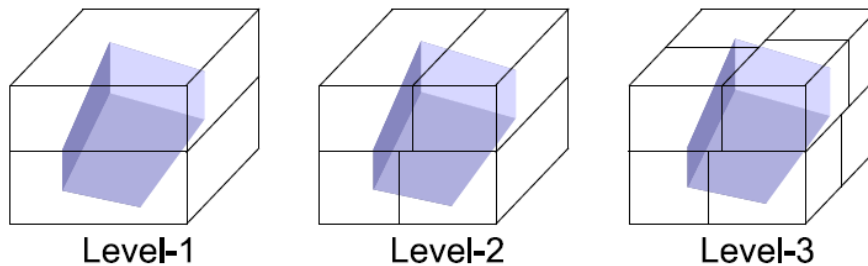
Comparison frequency domain methods

	MoM	MoM-MLACA	PO/PTD
Precision	★ ★ ★	★ ★ ★	★ ★
Memory Usage	★	★ ★	★ ★ ★
CPU time	★	★ ★	★ ★ ★
			<p>PEC</p> $\mathbf{J}(\mathbf{r}) = 2\hat{\mathbf{n}} \times \mathbf{H}(\mathbf{r})$ $\mathbf{M}(\mathbf{r}) = 0$



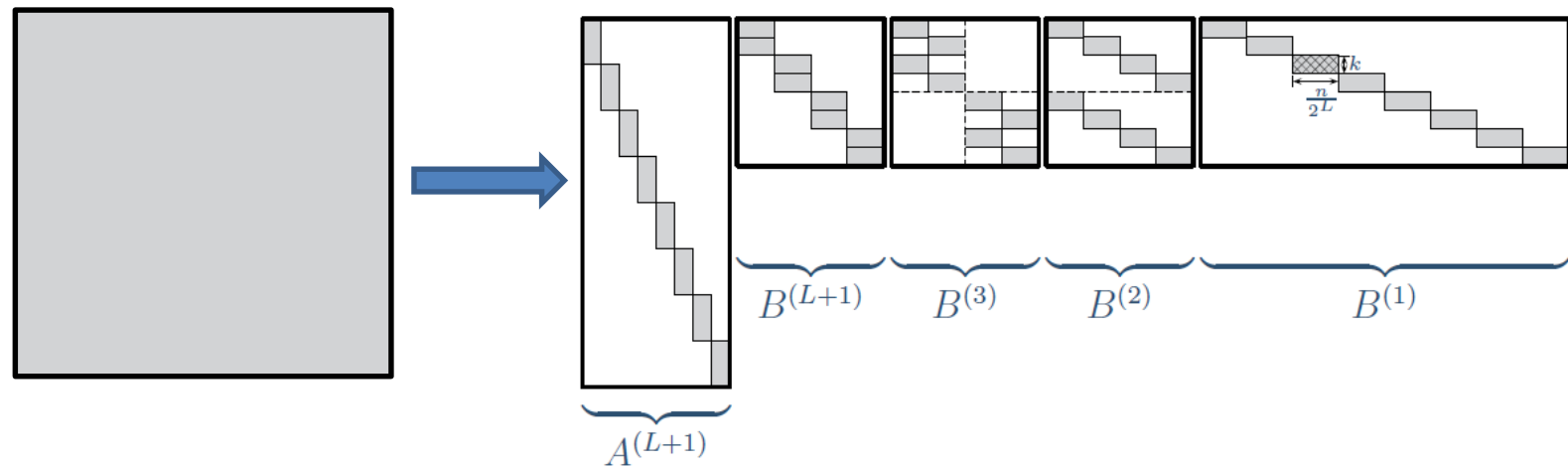
MoM - MLACA

- Computational complexity : $O(N^3) \rightarrow O(N^2 \log N)$
- Necessary memory : $O(N^2) \rightarrow O(N \log^2 N)$
- Object split hierarchically into near and far interactions



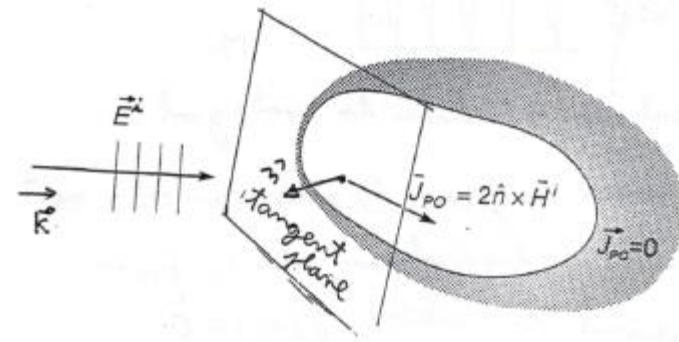
MoM - MLACA

- Computational complexity : $O(N^3) \rightarrow O(N^2 \log N)$
- Necessary memory : $O(N^2) \rightarrow O(N \log^2 N)$
- Far interactions compressed with MLACA



- Iterative method : Need for GMRES + preconditioner

Physical Optics (PO)



- The induced currents \vec{J}_S are approximated by the currents that would exist in a point of the surface if it was located in an infinite plane tangent to the surface in that point.

- $$\vec{J}_{PO} = \hat{n} \times \vec{H} = \begin{cases} 2\hat{n} \times \vec{H}^i & \text{in lit region} \\ 0 & \text{in shadowed region} \end{cases}$$

- Local approximation: \vec{J}_S depends only on \hat{n} and \vec{H}^i .
- Equivalent currents: $\vec{J}_{eq} = \vec{J}_S \approx \vec{J}_{PO}$ and we compute \vec{E}^S radiated by \vec{J}_{eq} as the radiation of \vec{J}_{PO} in free space.
- In the far field:

$$\vec{E}^S = -j\omega\mu \frac{e^{-jkr}}{4\pi r} \vec{r} \times \vec{r} \times \iint_{Slit} 2\hat{n} \times \vec{H}^i e^{jk\hat{r} \cdot \vec{r}'} ds'$$



Limitations of PO

- Fails when R curvature $< \lambda$.
- Fails in wedges : use edge diffraction (PTD).
- Assumes $\vec{J}_S \approx 0$ in the shade region. Does not account for creeping waves.
- Does not account for surface wave diffraction at surface discontinuities.



- Artificial discontinuity in \vec{J}_{PO} at the limit between lit and shadow regions produces an error term.
- Not multibouncing.

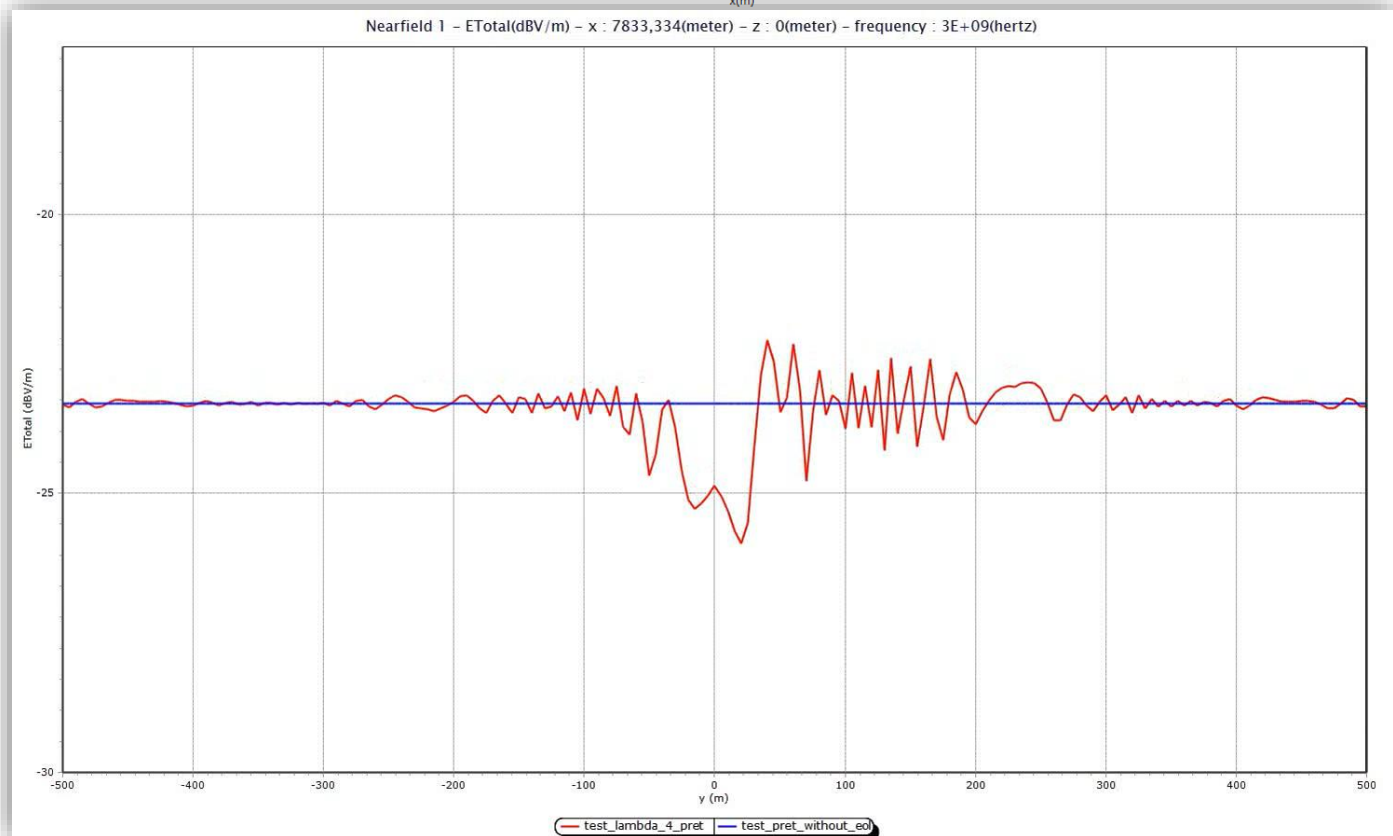
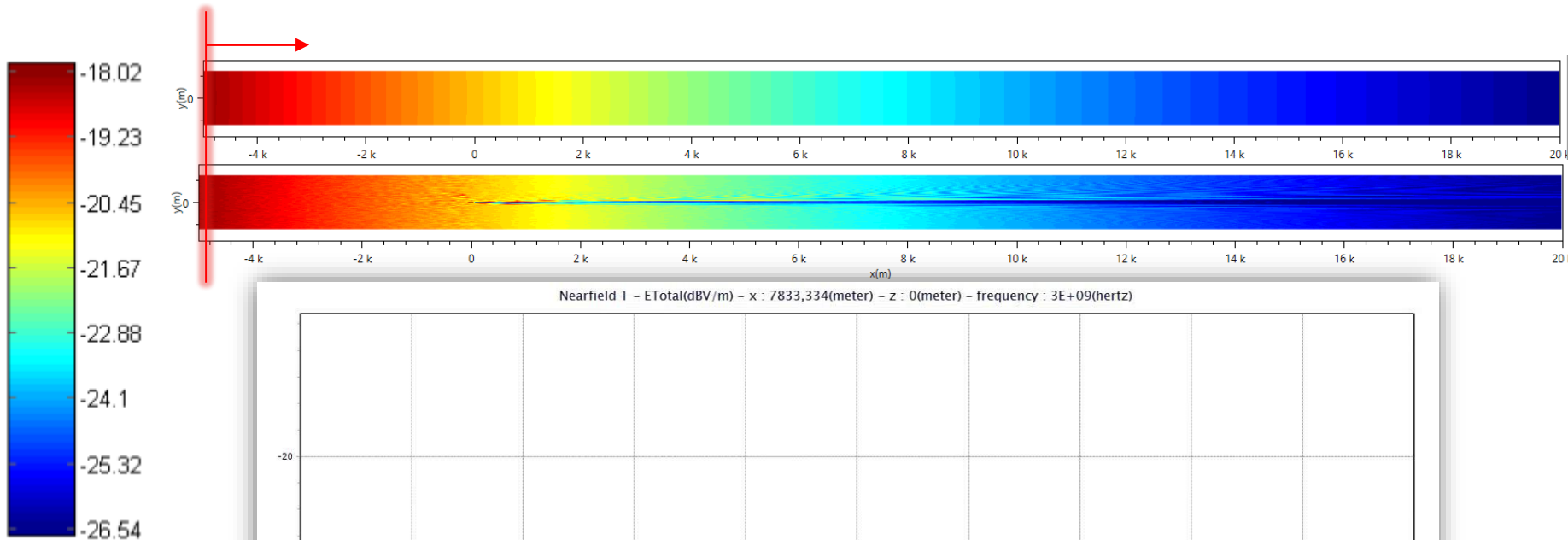


Numerical Results

- EDA-Workshop »Radar Signatures & EM Benchmarks« 2017
- Test case 3: Rotating Wind Turbine.
- Rotor diameter: 96m.
- Height : 150m.
- Source at (-20km,0,0).
- Frequency : 3Ghz.
- Unknowns at $\lambda/4$: 12.5M
- Output : Nearfield at $x=[-5\text{km},20\text{km}]$
 $y=[-0.5\text{km},0.5\text{km}]$
 $z=0\text{m}$
- Simulated with PO (justified by the results at smallest frequencies).

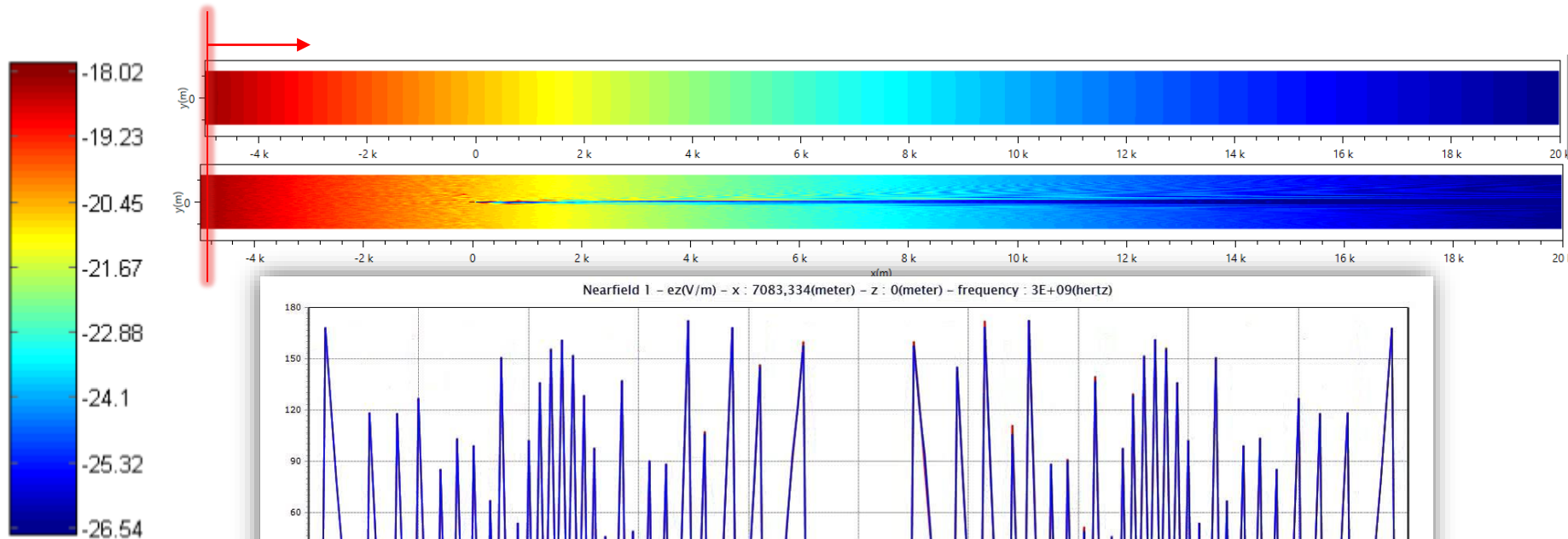


Numerical Results – 3GHz

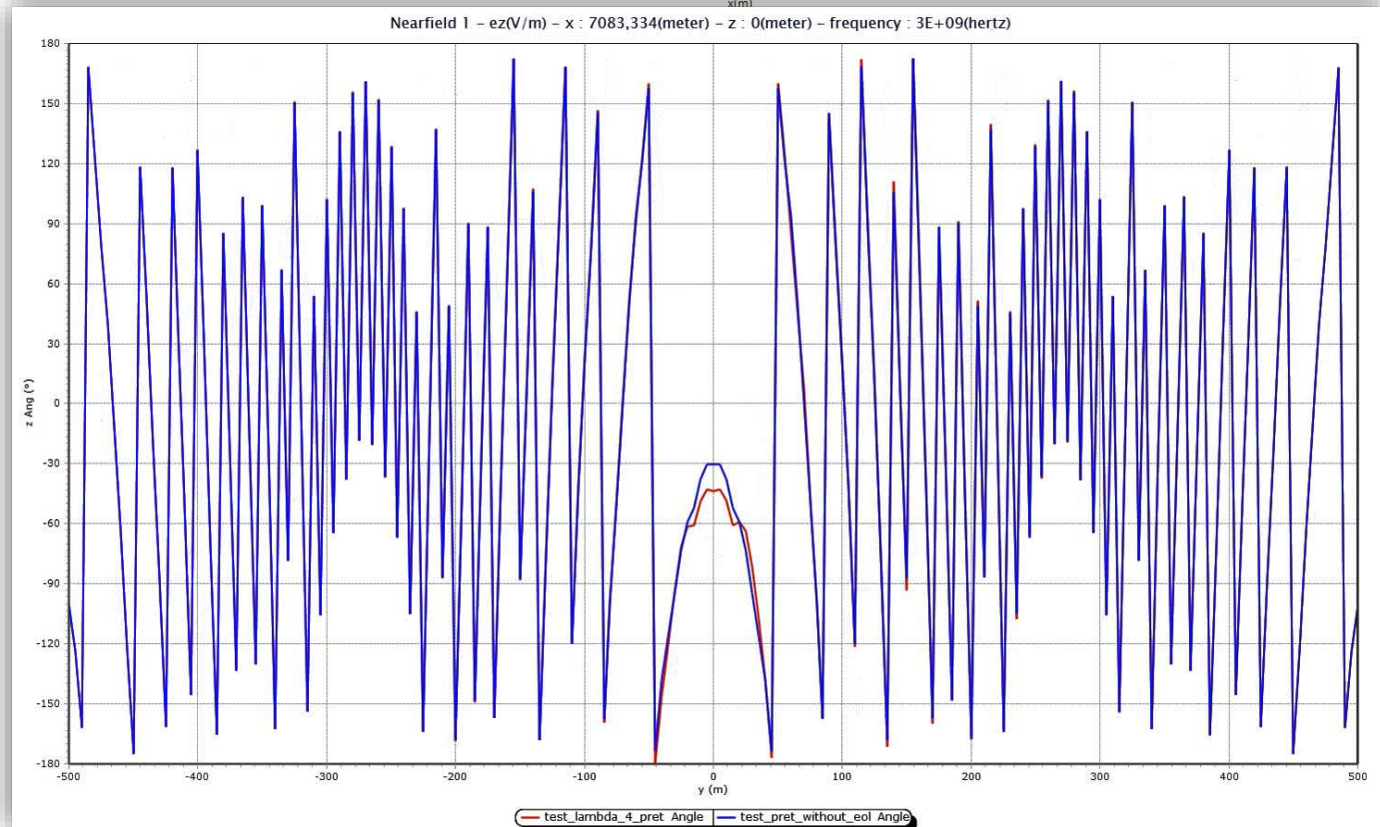


Module

Numerical Results - 3GHz

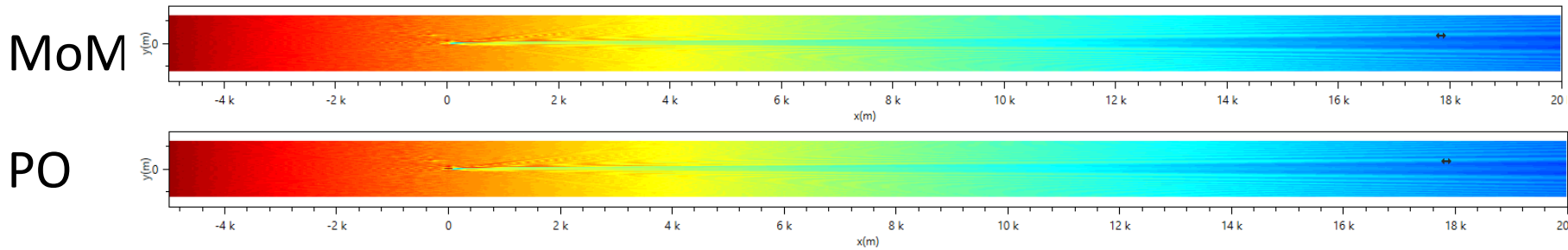


Phase

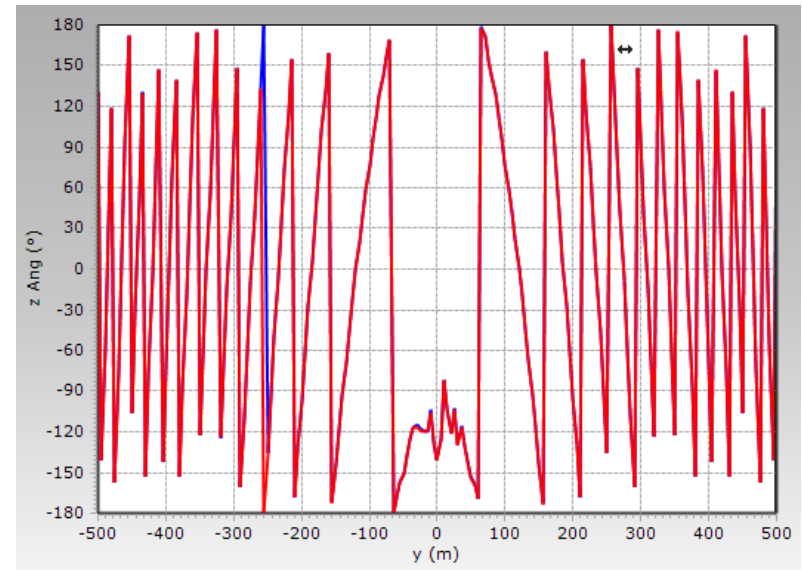
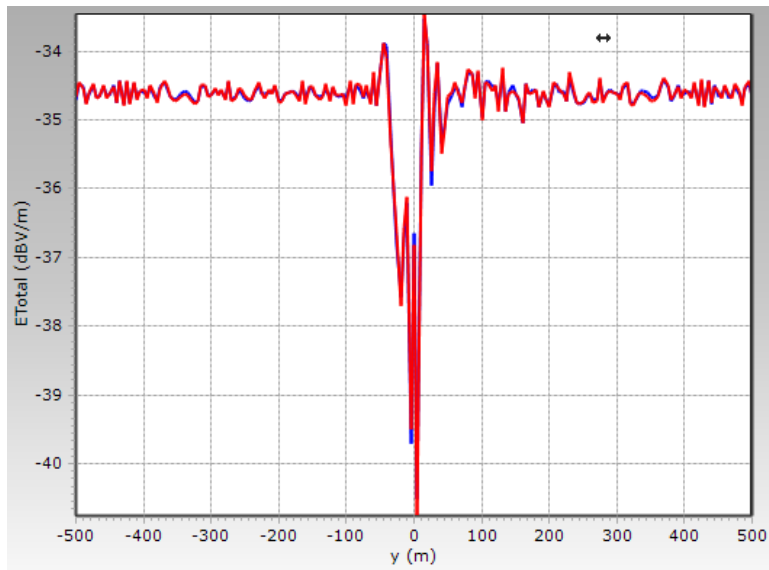


Numerical Results – MoM vs PO

600 MHz

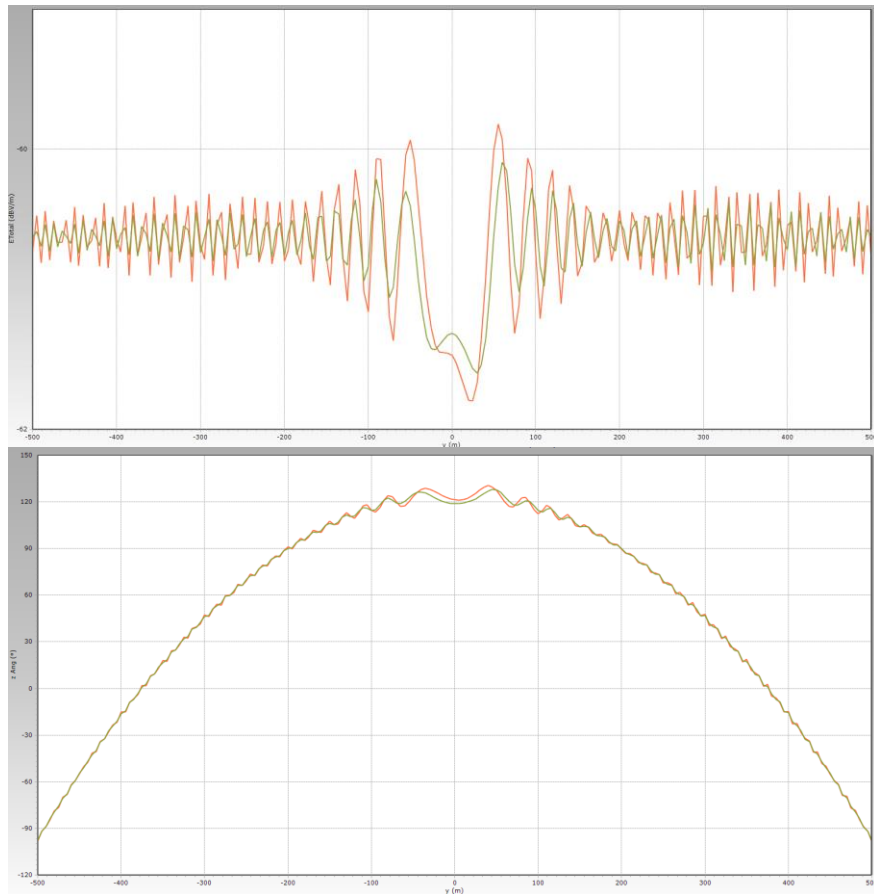


600MHz – x=250m

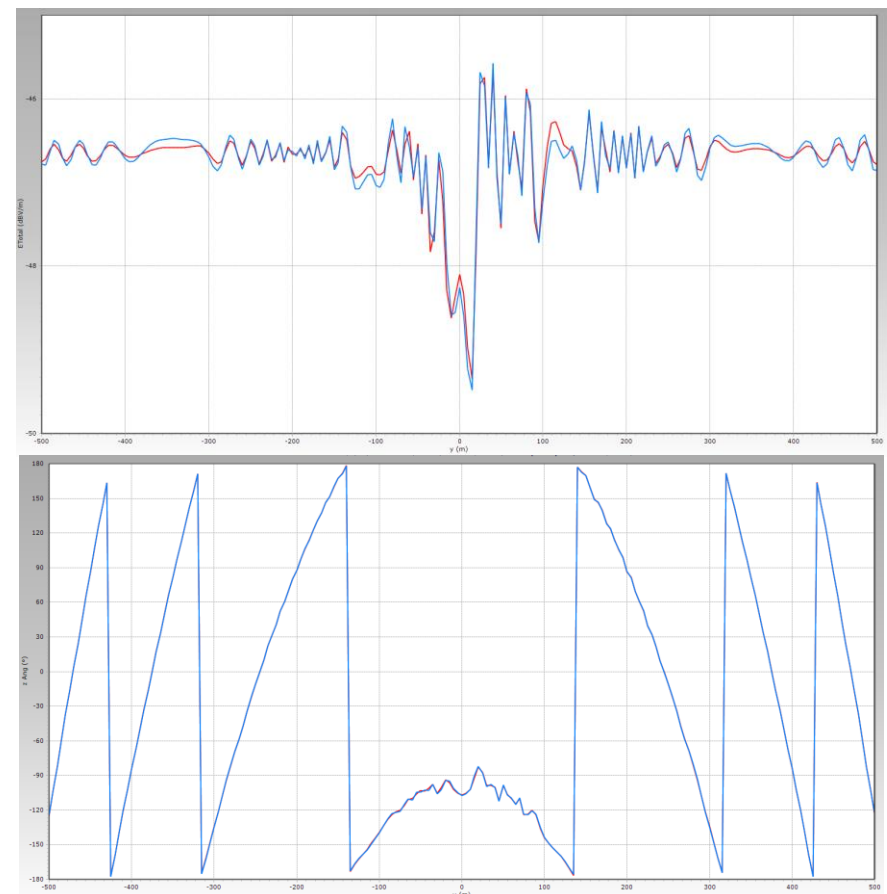


Numerical Results – MoM vs PO

30MHz – x=250m



150MHz – x=250m

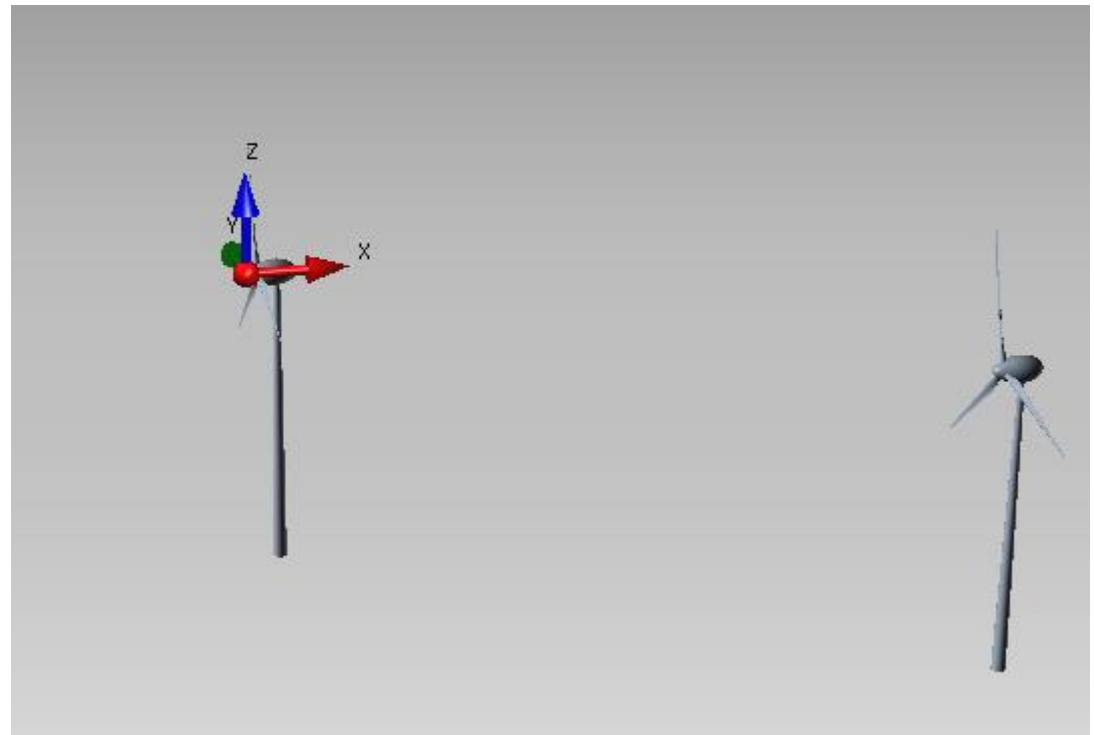
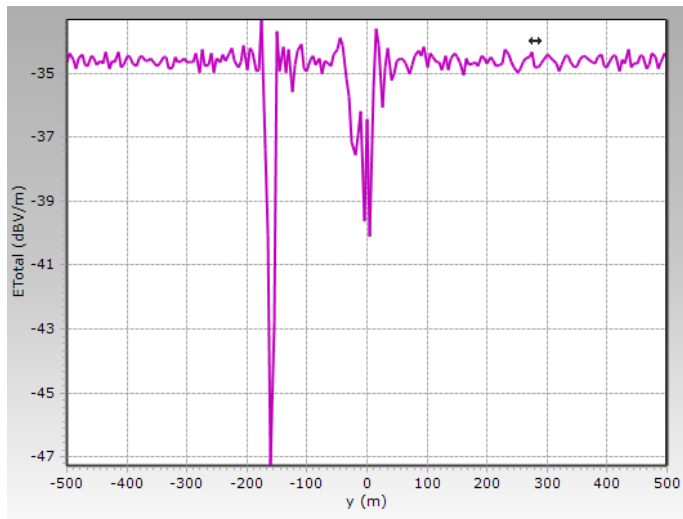


Numerical Results – 600MHz

- Two wind turbines at 600MHz



- $N = 4M$



Conclusion

- We have shown the interest of frequency domain simulation methods in the study of the impact of a wind farm over a radio navigation system.
- The choice of simulation technique depends on the complexity of the problem and the carrier frequency of the system.
- We advise to use a high precision method such as the MoM for a simplified problem to use it as reference. It allows to justify the use of a high frequency approximation method such as PO or GTD.
- The performed simulations to reproduce the system behavior depend on the system itself. In particular, we have shown the procedure for the bearing angle estimation of a TACAN radio navigation system.
- The impact of the shadowing effects of a wind turbine on the received electric field has been presented.