We3E-1

Convergence of Simulation, Cloud Computing and Artificial Intelligence in Electromagnetics

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ALTAIR

Outline

- Introduction to Altair
- Mega Trends in Industry
- Evolution of Simulation and Data-Driven Design and Convergence
- Computational Electromagnetics (CEM) and Applications
- High Performance Computing
- Machine Learning for CEM
- Cloud on Demand
- Digital Twins
- Conclusions

Altair

1985
Founded & Headquartered in Troy, MI U.S.

13,000+
Customers Globally

$572M
FY22 Revenue

86
Offices in 25 Countries

3,000+
Engineers, Scientists, and Creative Thinkers

150+
Altair and Partner Software Products

"To transform enterprise decision-making by leveraging the convergence of simulation, high-performance computing, and artificial intelligence"

Mega Trends

Electrification

Electrification – EV's

AI Driven Simulation

Simulation and AI Driven Design and Innovation

Data Driven Enterprise

Decisioning driven by data - autonomous included here

Semi-Conductor

5G, Electronic System Design and PCB/Semiconductor

Cloud

The Move to the Cloud – Virtual workforce

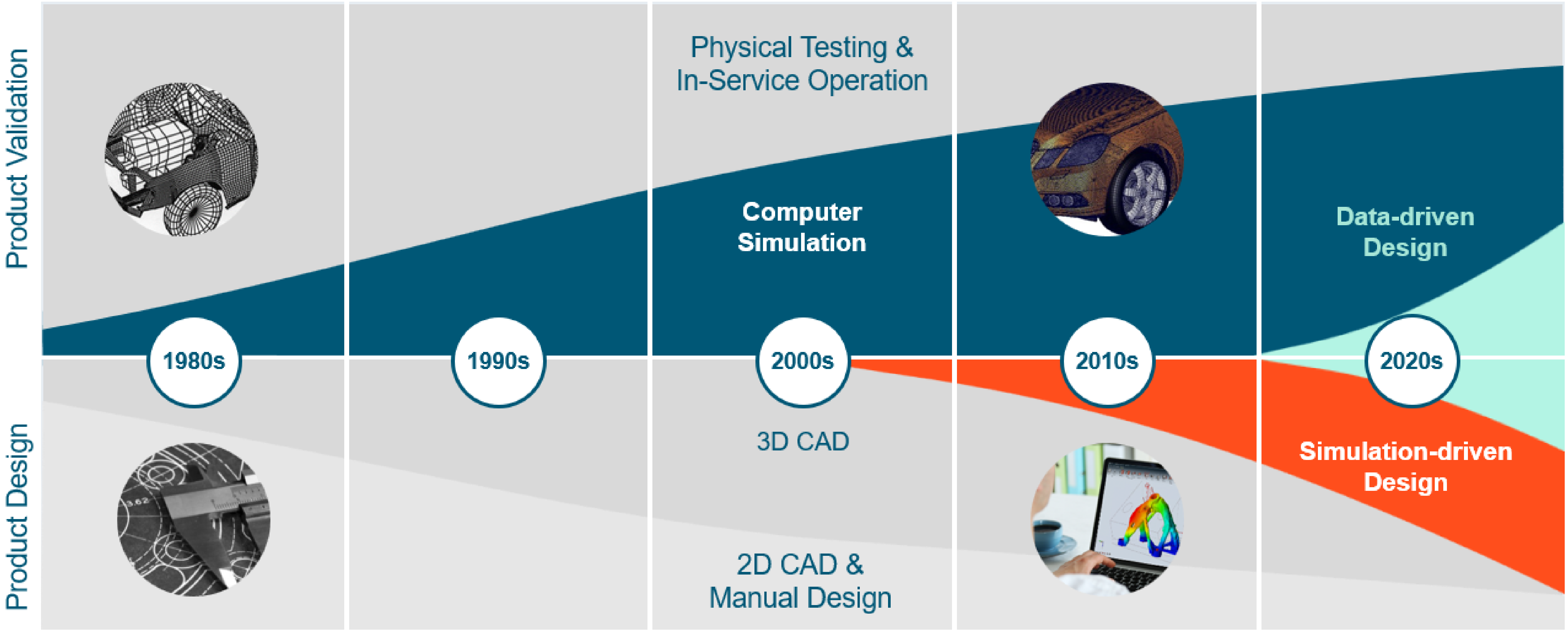
Compliance Risk & Fraud / AML

Compliance – Risk and Fraud – AML – Expertise/Solutions

De-carbonization

Decarbonization, Net-Zero commitments, ESG

Evolution of Simulation- and Data-Driven Design



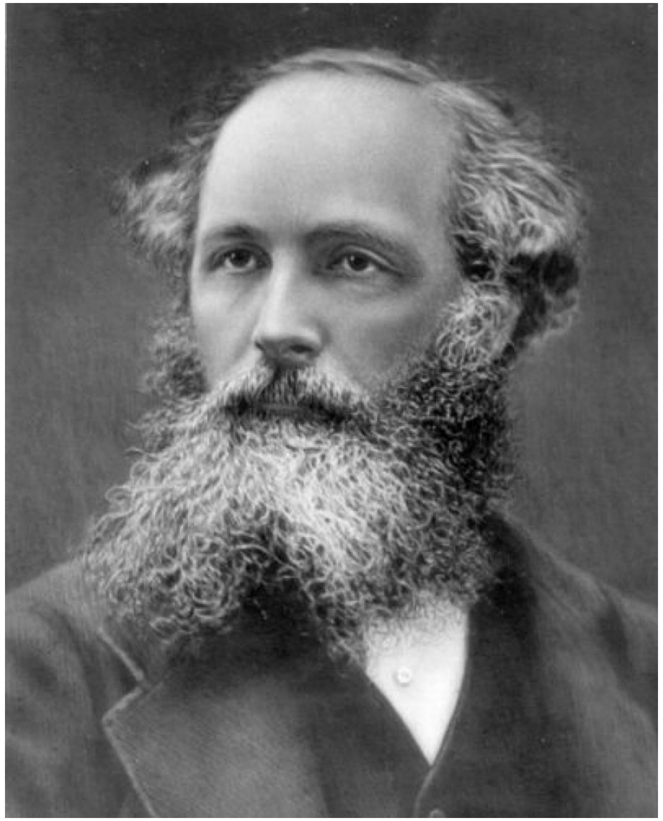
Convergence

- Global evolution toward smart, connected everything
- Simulation- and data-driven models will drive design and operational decisions
- Massive exploration of ideas is driving the need for advanced HPC and cloud

Computational Electromagnetics

Maxwell's equations for electromagnetism have been called the ***"second great unification in physics"*** after the first one realized by Isaac Newton.

James Clerk Maxwell
(1831-1879)



Maxwell's Equations

$$\vec{\nabla} \times \vec{H} = \vec{J}_v + \varepsilon \frac{d\vec{E}}{dt}$$

$$\vec{\nabla} \times \vec{E} = -\vec{M}_v - \mu \frac{d\vec{H}}{dt}$$

$$\vec{\nabla} \bullet \vec{H} = \frac{1}{\mu} \sigma_m$$

$$\vec{\nabla} \bullet \vec{E} = \frac{1}{\varepsilon} \sigma_e$$

$$\mathbf{E} = -j\omega\mu\mathbf{A} + \frac{1}{j\omega\epsilon}\nabla(\nabla\cdot\mathbf{A})$$

$$\mathbf{E} = -j\omega\mu \int_V d\mathbf{r}'\mathbf{G}(\mathbf{r},\mathbf{r}')\cdot\mathbf{J}(\mathbf{r}')$$

$$\mathbf{G}(\mathbf{r},\mathbf{r}') = \frac{1}{4\pi}\left[\mathbf{I} + \frac{\nabla\nabla}{k^2}\right] G(\mathbf{r},\mathbf{r}')$$

Computational Electromagnetics

- **CEM is the numerical solution of Maxwell's equations**
  - **CEM has become an indispensable industrial tool**

Computational cost (CPU time & memory) must be as low as possible

Computer modeling

$$\vec{\nabla} \times \vec{H} = \vec{J}_v + \varepsilon \frac{d\vec{E}}{dt}$$

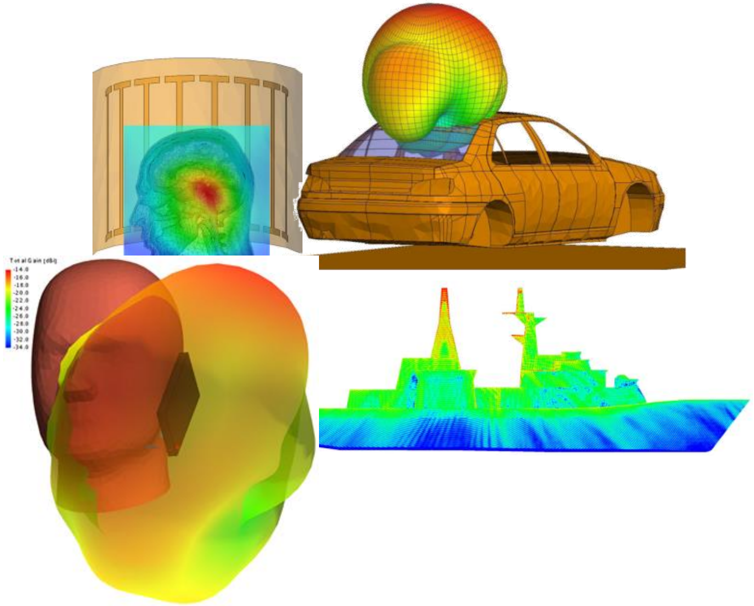
$$\vec{\nabla} \times \vec{E} = -\vec{M}_v - \mu \frac{d\vec{H}}{dt}$$

$$\vec{\nabla} \bullet \vec{H} = \frac{1}{\mu} \sigma_m$$

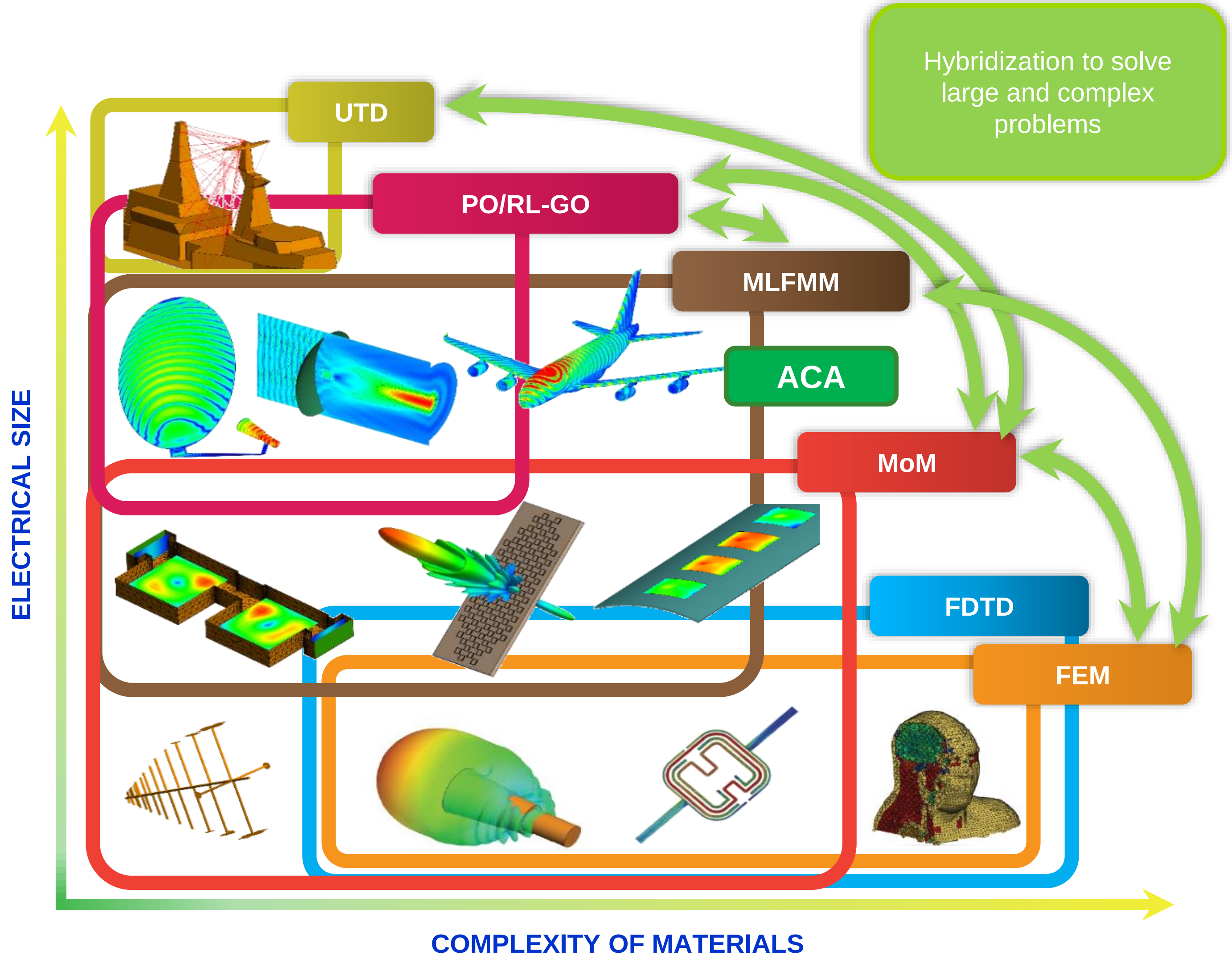
$$\vec{\nabla} \bullet \vec{E} = \frac{1}{\varepsilon} \sigma_e$$

CEM tool

Numerical analysis



CEM Solver Technologies

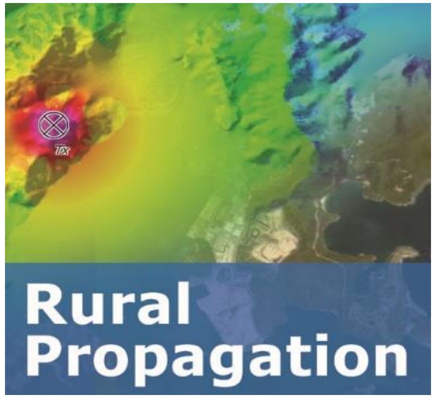


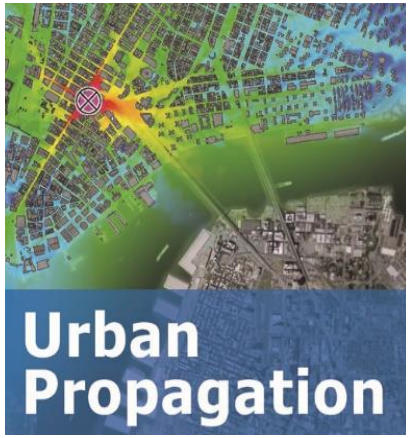
Asymptotic Methods
(high-frequency approximation)

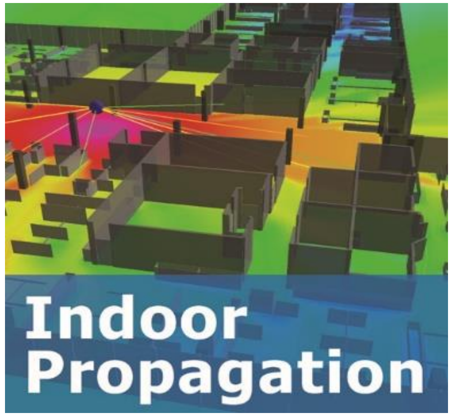
Full-wave Methods

(physically rigorous solution)

Propagation Models





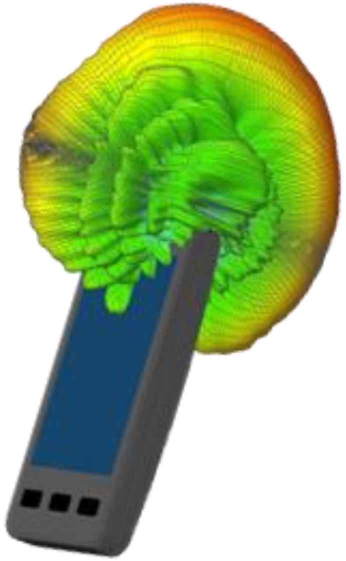


Map Data	Topography pixel data	2.5D building vector data	3D vector data
Optional Data	Clutter losses / heights Ground properties	Material properties Topography pixel data Vegetation objects	Material properties Subdivisions, furniture
Propagation Models	Empirical models (Hata, ITU,…) Vertical plane models **Dominant path model** ***3D Standard Ray Tracing (SRT)***	Vertical plane models (WI) **ITU-R P.1411 model** **Dominant path model** ***3D Intelligent Ray Tracing (IRT)***	Direct ray models (Multi-Wall) **Dominant path model** ***3D Ray Tracing SRT/IRT***

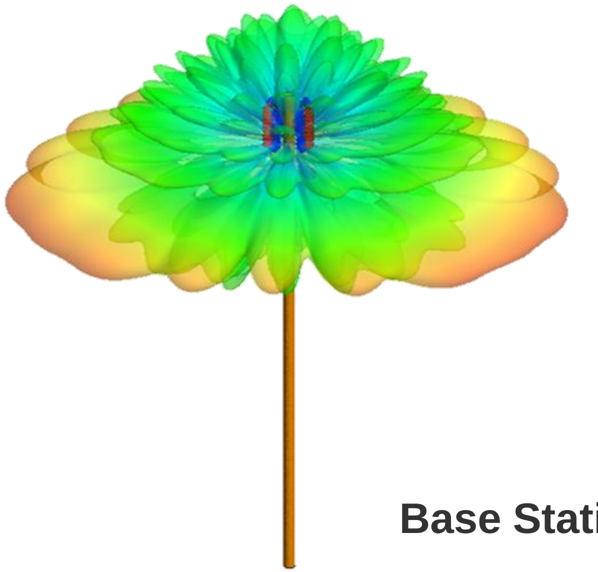
IMS
Connecting Minds. Exchanging Ideas.

Connected Devices

The Coolest Ideas Under the Sun
SAN DIEGO 2023

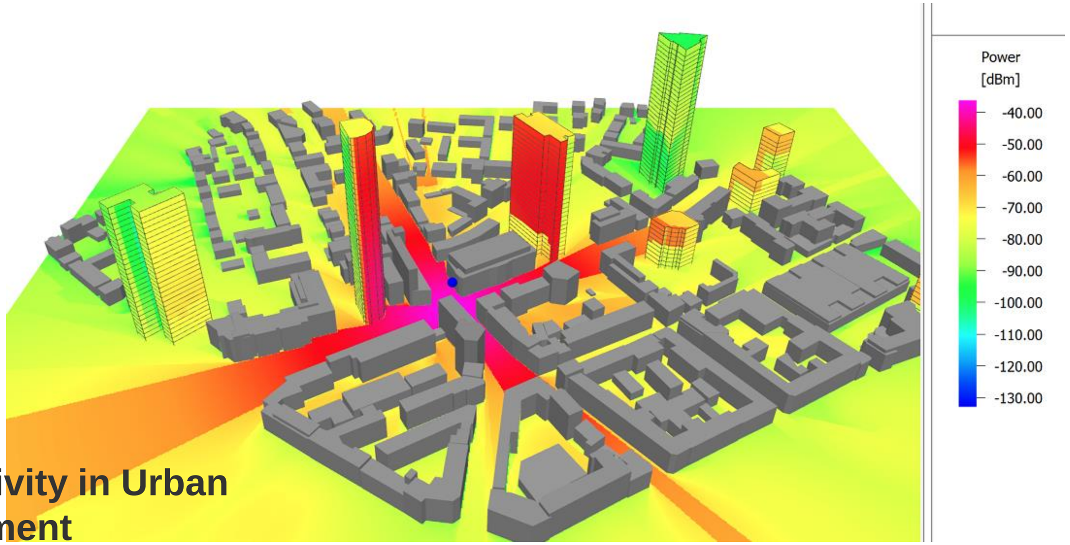


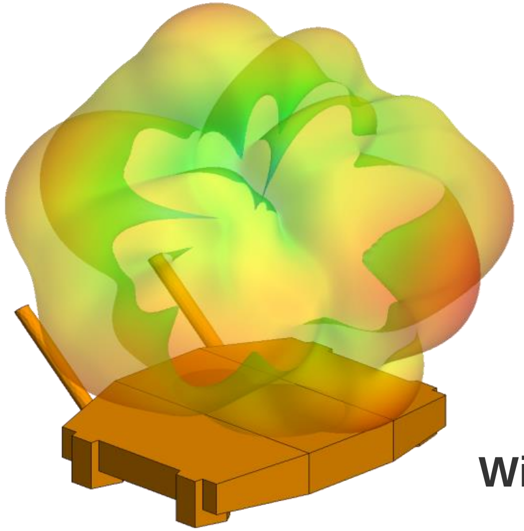
Mobile Device



Base Station

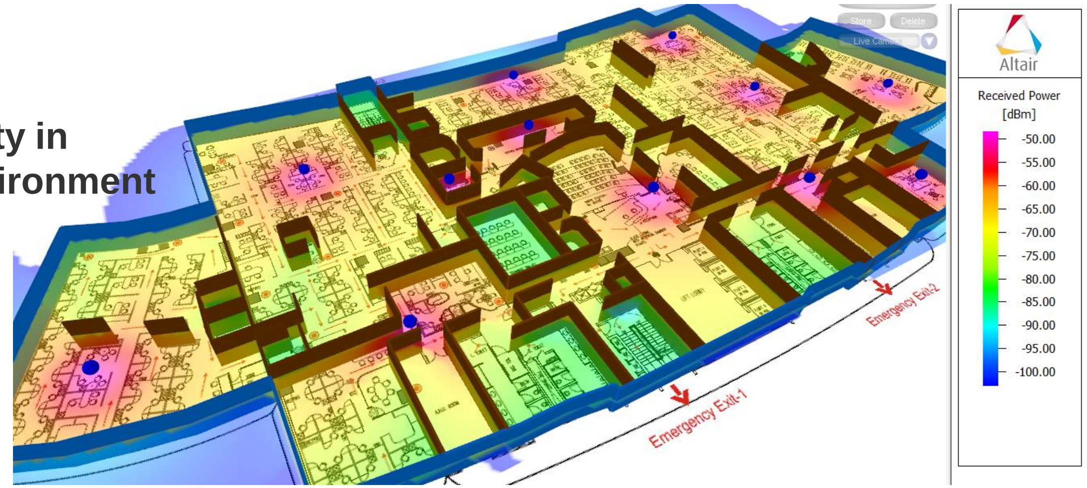
Connectivity in Urban Environment



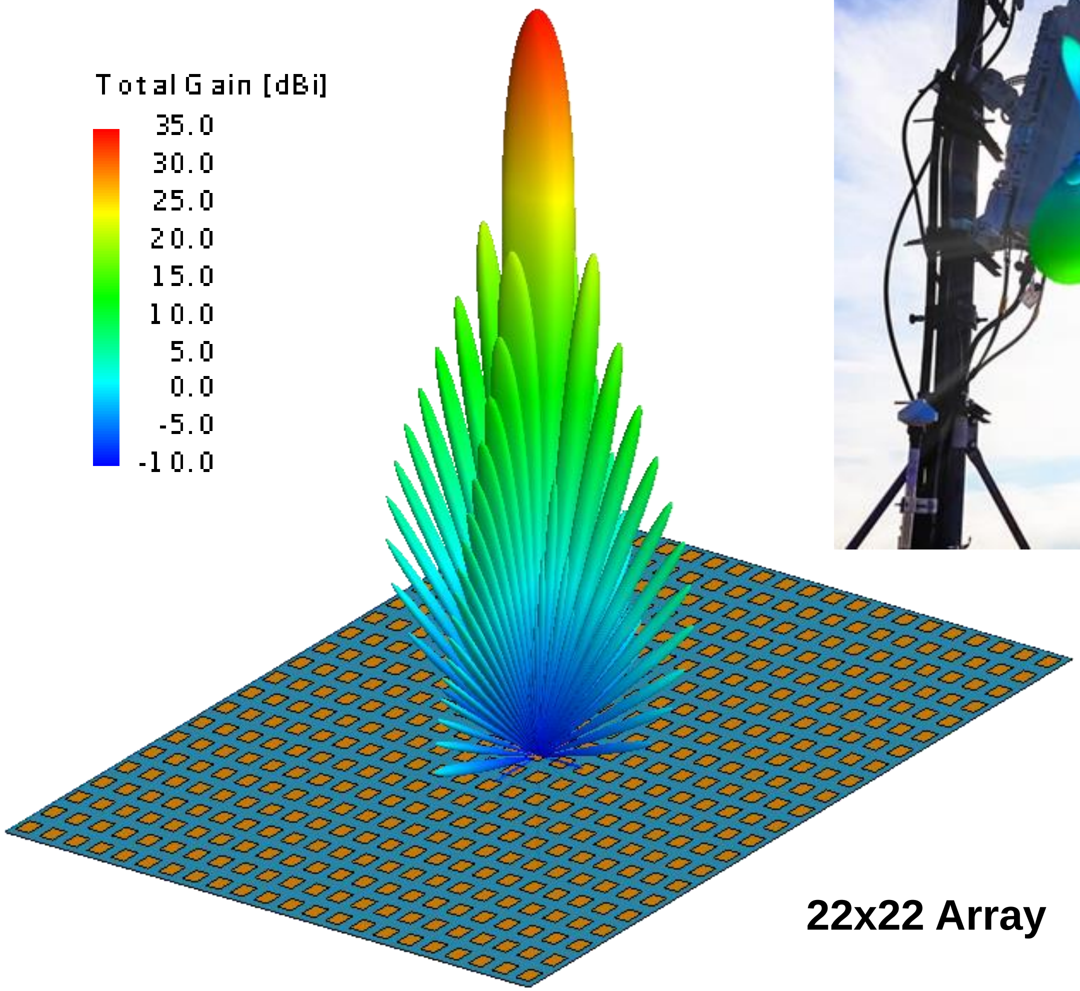


WiFi Router

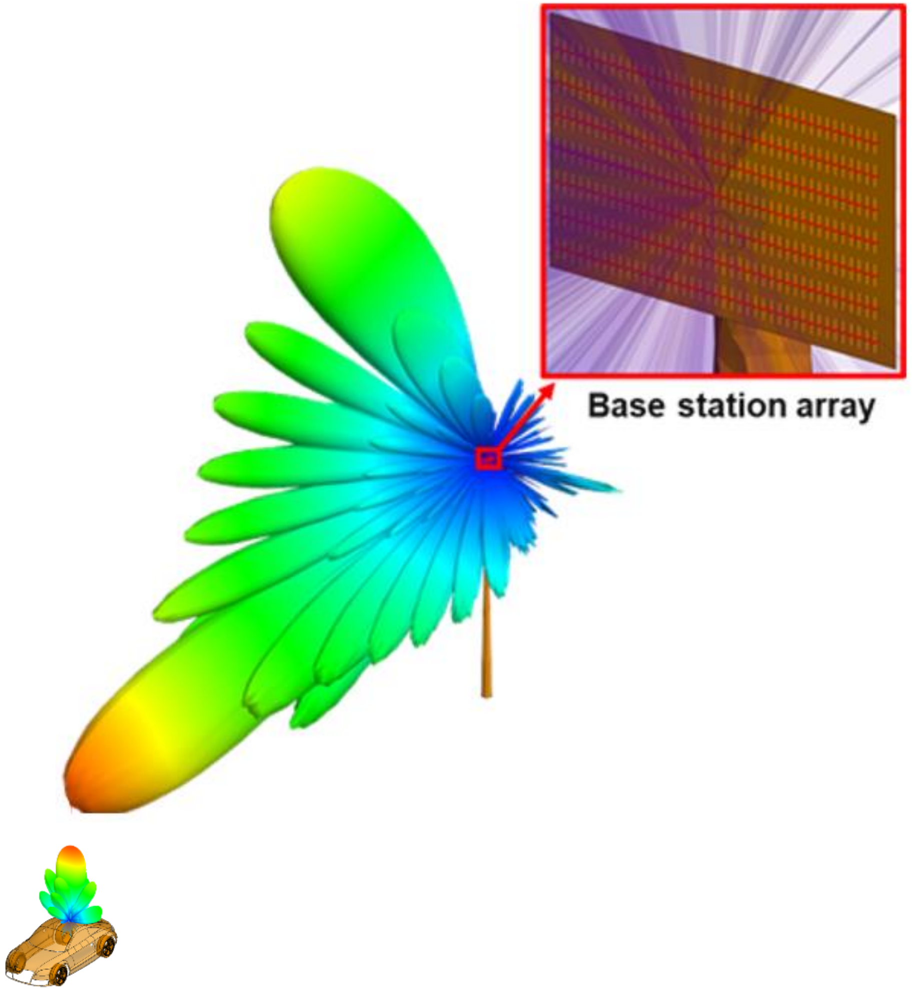
Connectivity in Indoor Environment



Antenna Arrays for 5G

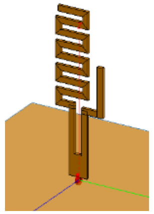


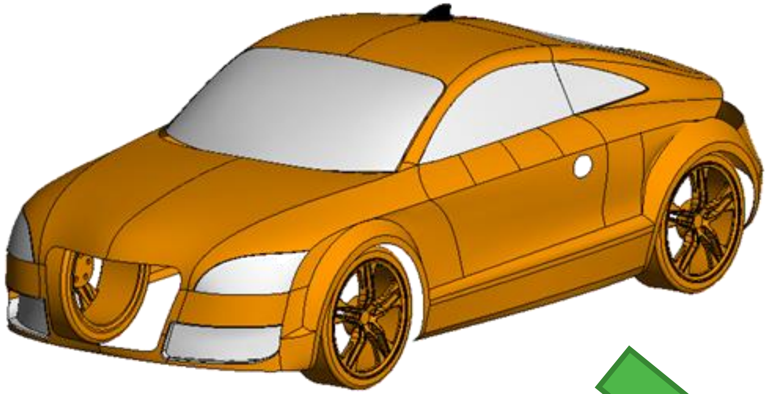
22x22 Array



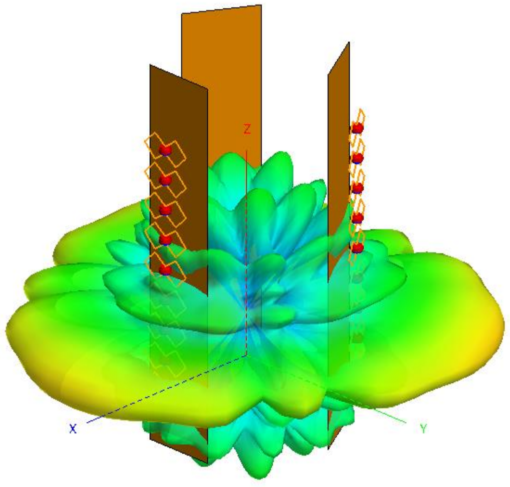
CV2X

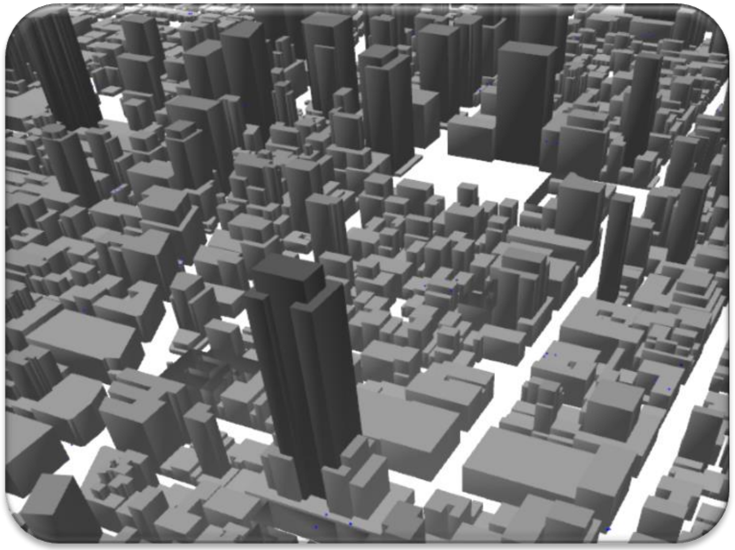
Dual band LTE Antenna





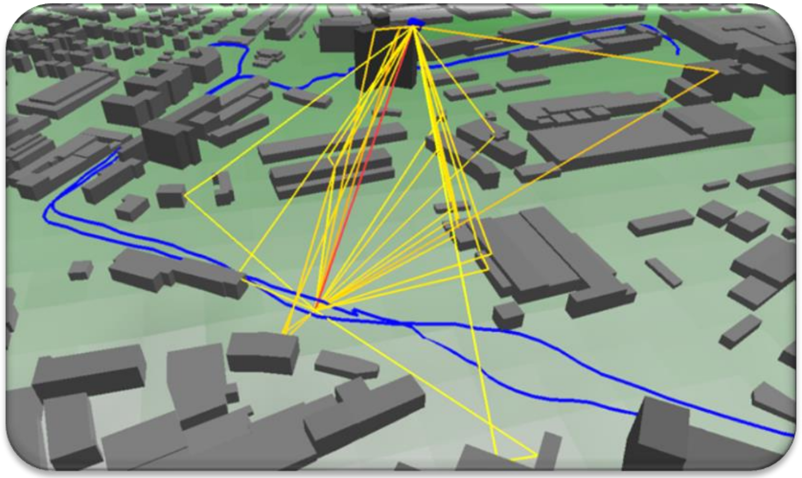
Base station sectors





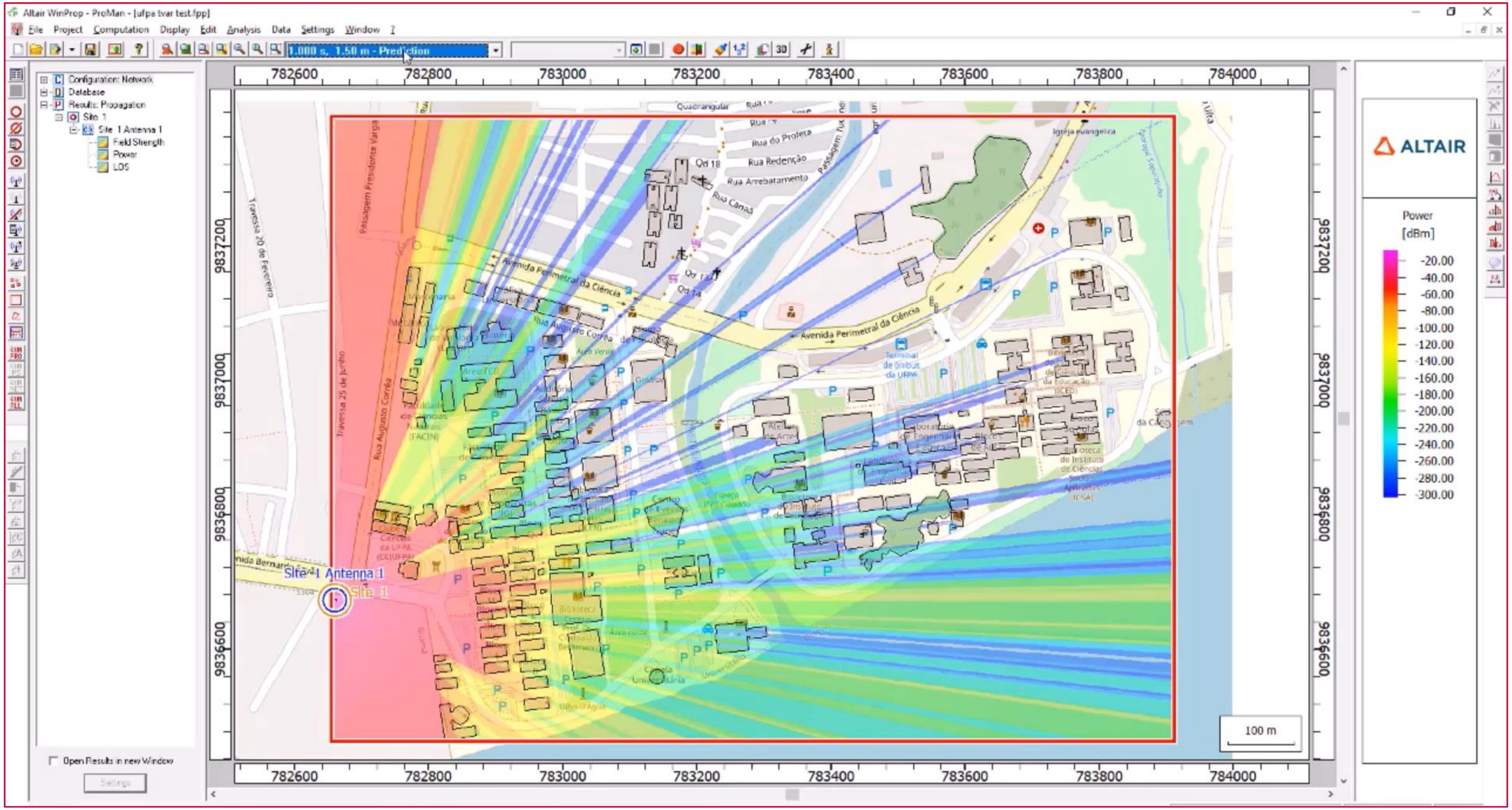
Urban Scenario

Virtual Drive Test

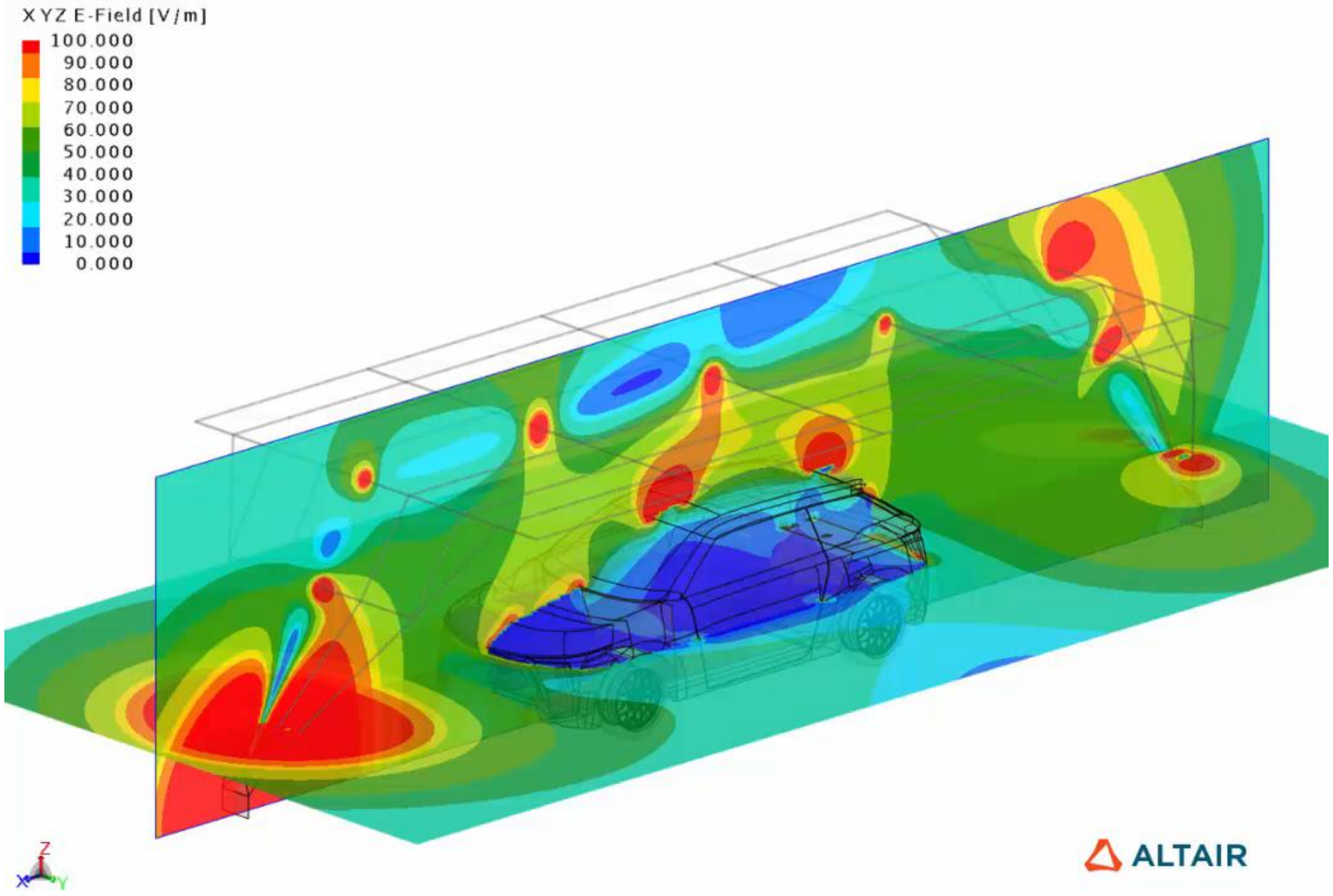


3D Ray Tracing

Virtual Drive Test

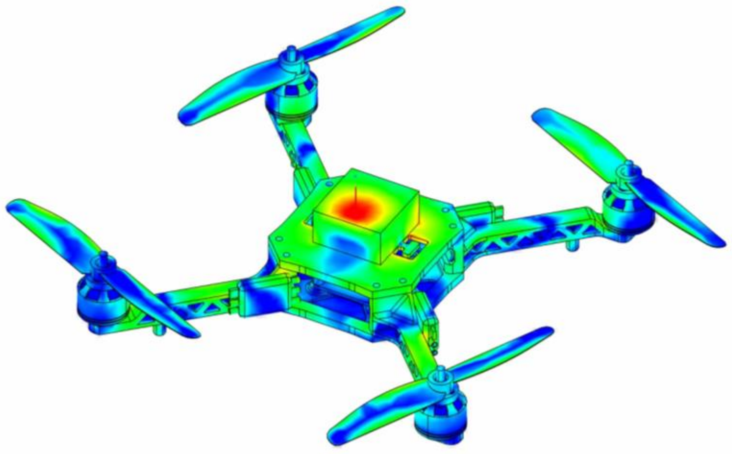


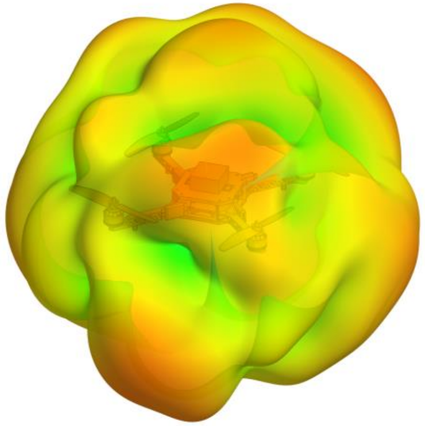
Virtual EMC Test

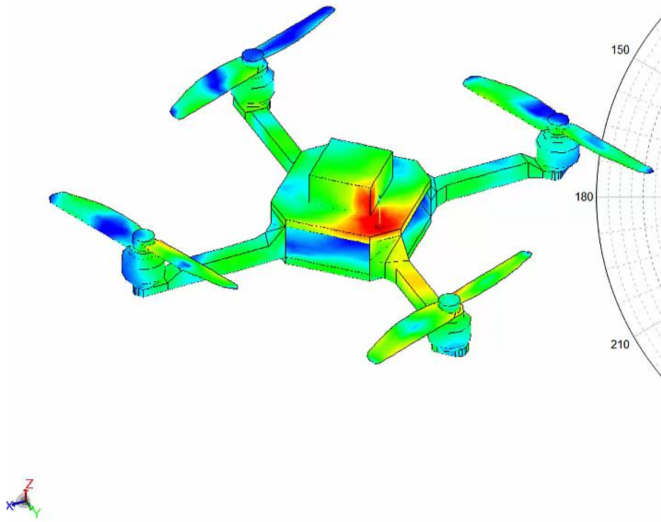


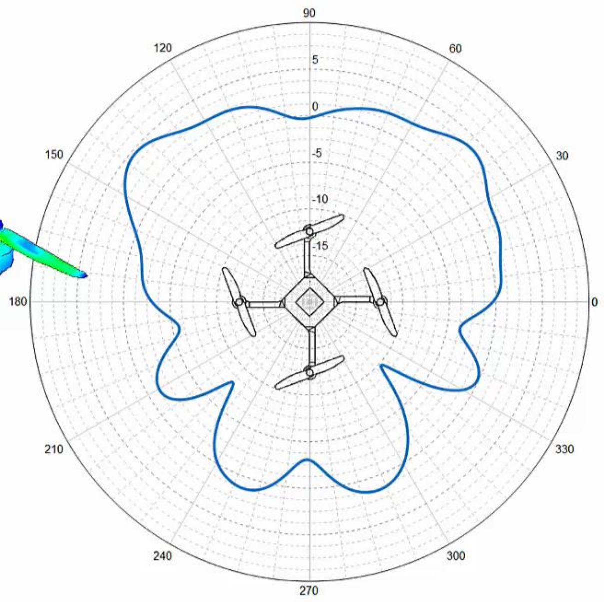
Virtual Flight Test

Virtual Flight Test

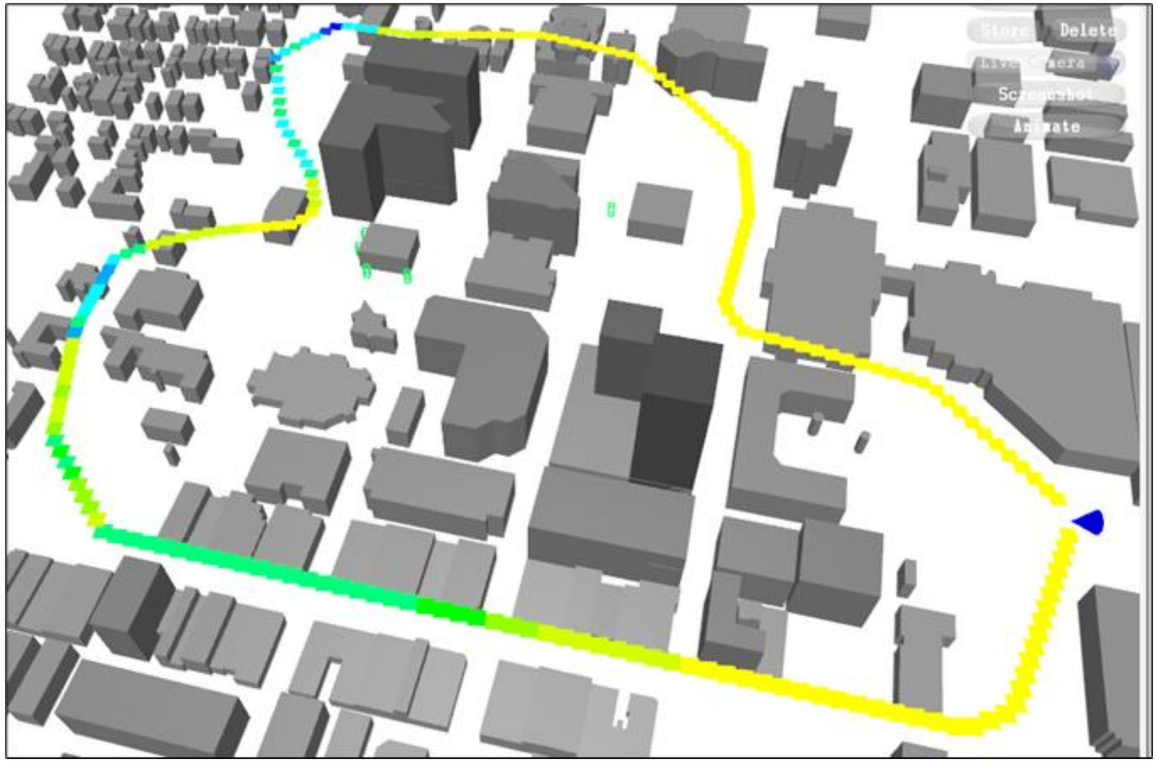








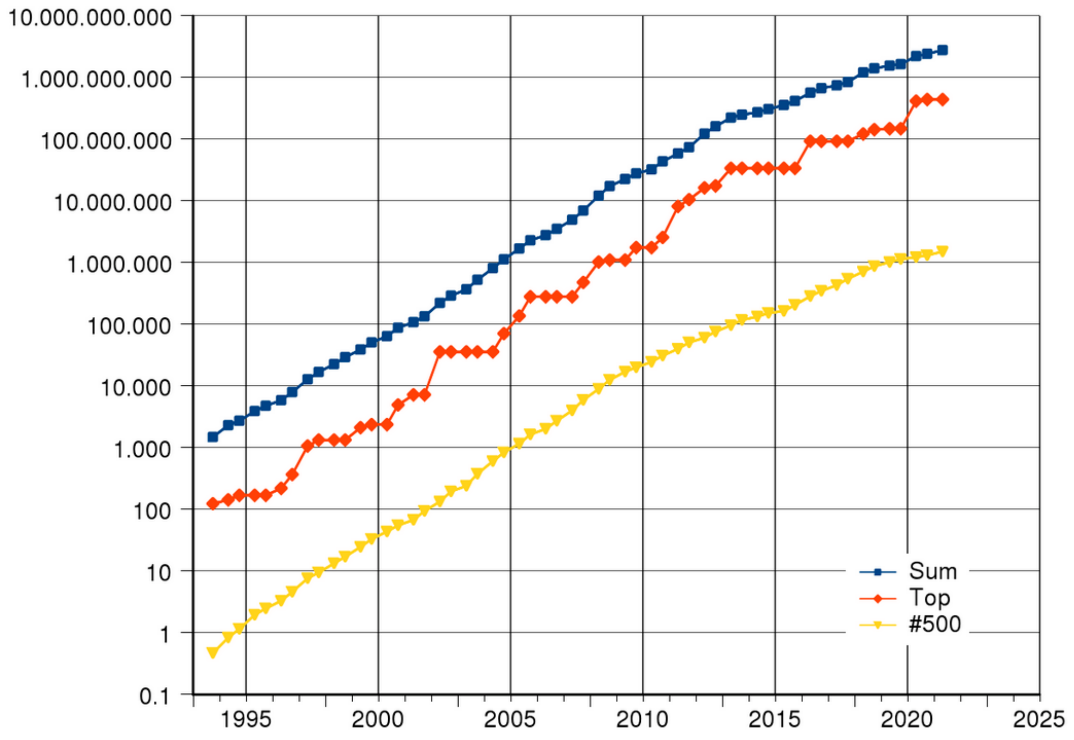
Total Gain [dBi] for f = 2.45 GHz at θ = 90°



High Performance Computing

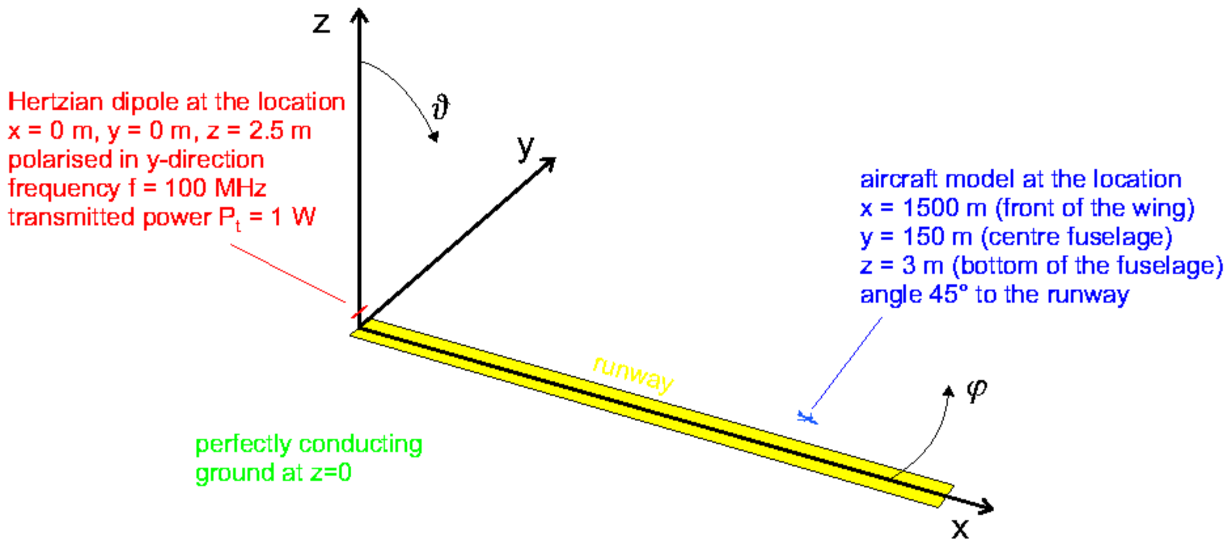
- Start with smart algorithms (N log N versus N^2 etc.) and best options (AI/ML) in the first place instead of brute-force HPC
- Evolution of CPUs in terms of clock rate, no. of cores and instruction sets (SSE, AVX512, …)
- Massively parallel computing (fast interconnects for MPI, hybrid MPI / OpenMP, shared MPI-3 memory windows, …)
- Use HPC enabled libraries (MKL, AOCL, Magma, StarPU, Mumps, …)
- GPU accelerations (NVIDIA CUDA, OpenCL)
- Intelligent job scheduling systems supporting farming out multiple concurrent runs
- Constant process of profiling / performance testing / tuning

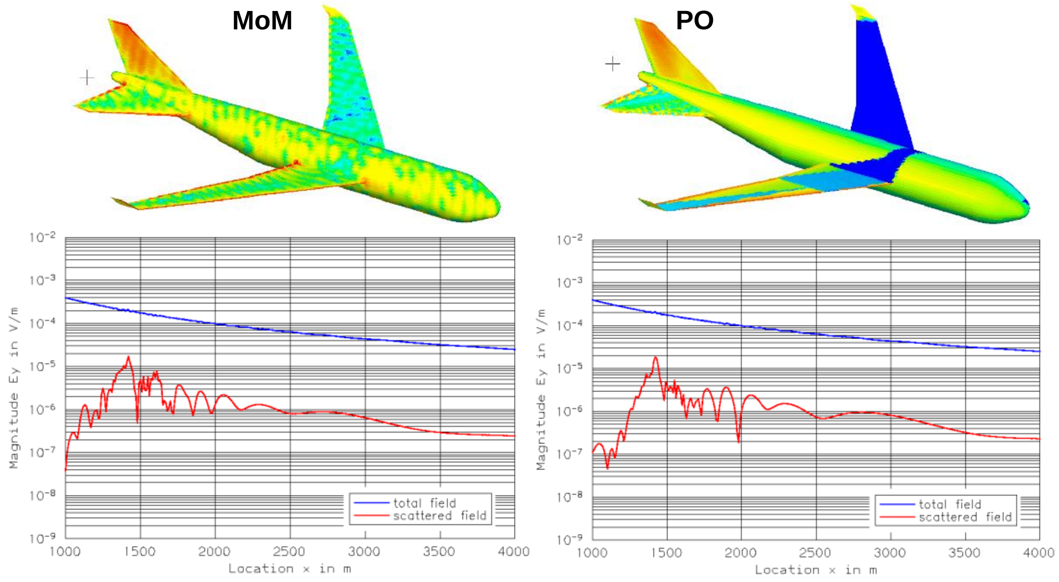
FLOPS (Floating Point Operations per Second) for the top 500 supercomputers in the world



Progress in Computational Power

Aviation: Disturbance of Localizer by Aircraft





Computational effort in 1997:

method	machine	memory	CPU–time
MoM (36358 basis fct.)	CRAY T3E, 384 nodes (incore, iterative solver)	19.7 GByte	384×1.7 h $= 27$ days
PO	Pentium II 400 MHz (seq.)	10.2 MByte	25 min

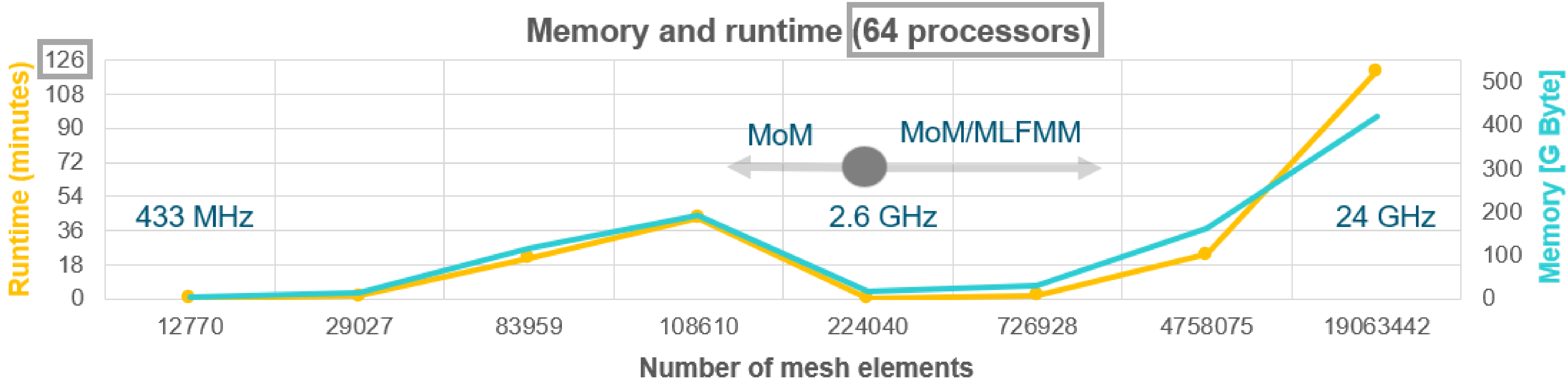
Laptop Computer today (2023):

Intel i7-9850H 2.6 GHz
with 6 cores 32 GByte RAM

MoM **351 sec**
MLFMM **19 sec**

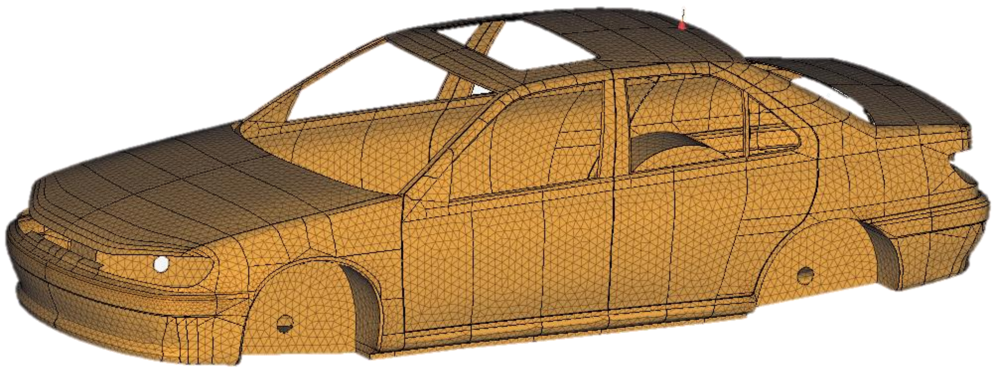
PO **0.4 sec**

Progress in Computational Power



Feko version 2022.2.0

CPU: Intel Xeon Gold 6338 CPU @ 2 GHz
Dual CPU, 32 cores per CPU
Total cores: 64
Memory available: 1 TByte

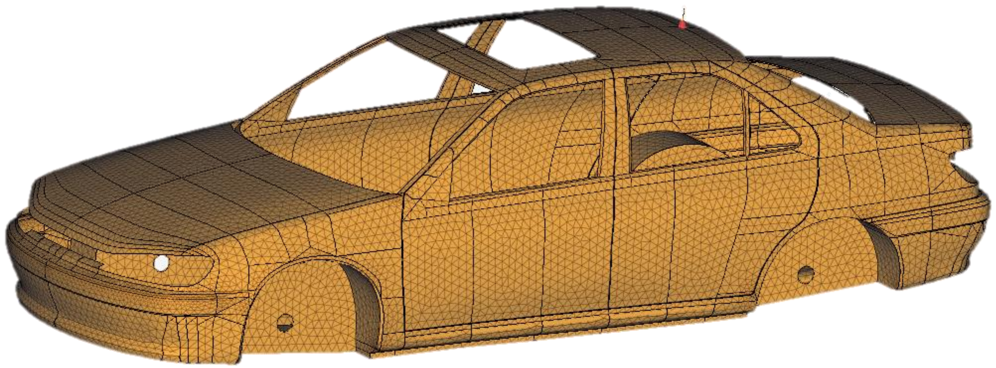


Dimensions (approximate)

Length: 4.4 meters
Width: 1.8 meters
Height: 1.3 meters

Surface area: 20 m^2

Progress in Computational Power



Dimensions (approximate)
- Length: 4.4 meters
- Width: 1.8 meters
- Height: 1.3 meters

Surface area: 20 m^2

Feko version 2022.2.0

CPU: Intel Xeon Gold 6338 CPU @ 2 GHz
Dual CPU, 32 cores per CPU
Total cores: 64
Memory available: 1 TByte

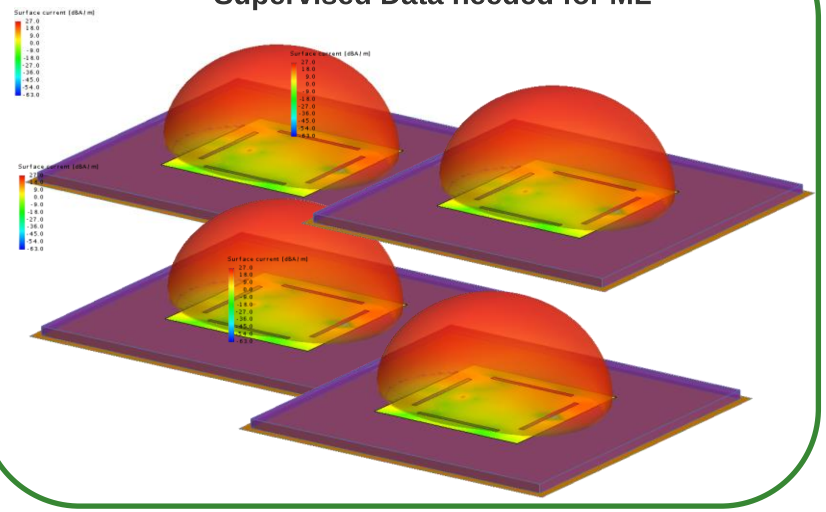
No of processes = 64					
Frequency	Unknowns	No. of mesh triangles	Runtime [s]	Memory [GB]	Solver
433 MHz	18,460	12,770	16	2.6	MoM
868 MHz	42,568	29,027	88	13.5	MoM
1.575 GHz	124,724	83,959	1,296	115	MoM
1.8 GHz	161,025	108,610	2,569	193	MoM
2.6 GHz	333,360	224,040	33	16.6	MLFMM
4.7 GHz	1,085,,519	726,928	110	30.7	MLFMM
12 GHz	7,124,696	475,8075	1413	163	MLFMM
24 GHz	28,570,302	19,063,442	7,222	421	MLFMM
37 GHz	67,998,870	45,358,146	18,206*	925*	MLFMM

* excludes far field request

68 million unknowns in 5 hours on 64 processors !!

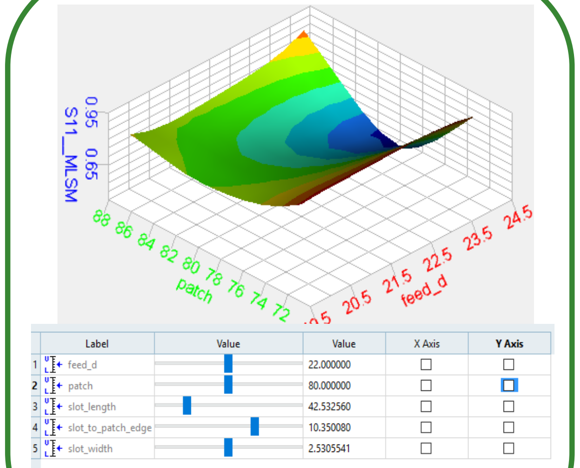
Optimization via Machine Learning

Simulation data with multiple variables
Supervised Data needed for ML



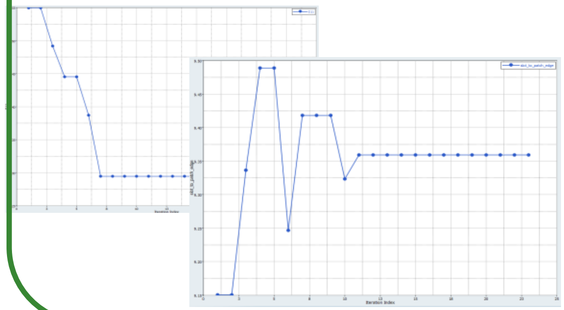
Machine Learning with Regression

Build a mathematical model that defines the goal (Return Loss of the Antenna etc.) as function of geometry variables



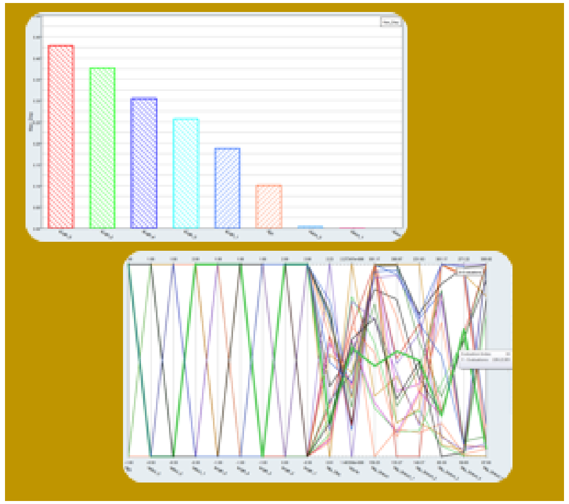
Mathematical Model

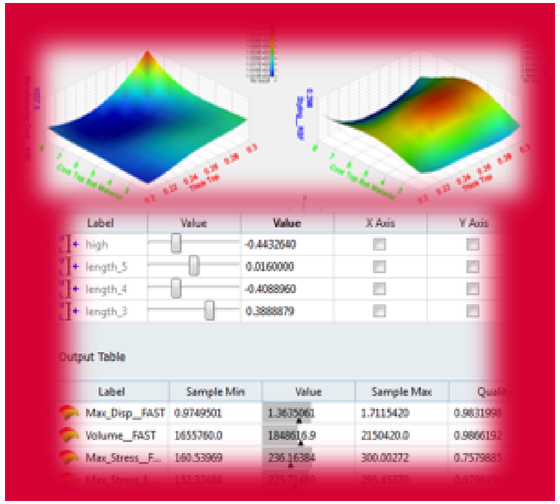
Optimization using Mathematical Model

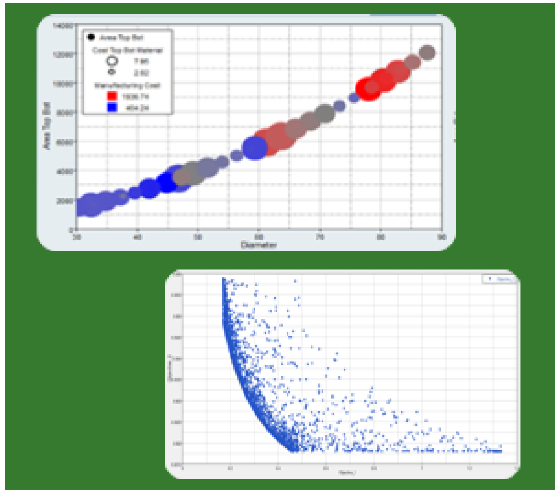


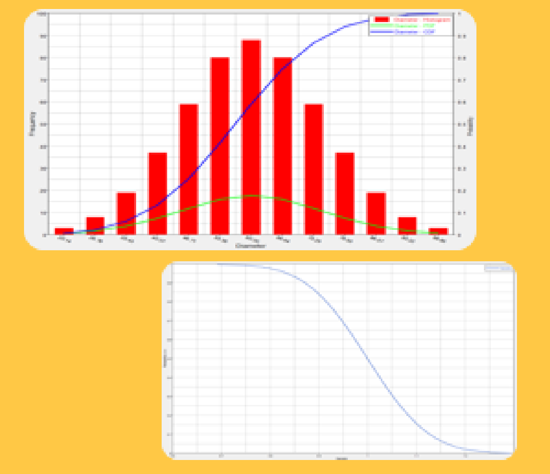
Optimization via Machine Learning

Investigate relationships	Make predictions	Identify best design	Assess reliability









Data Collection	Mathematical Model	Optimization	Stochastic

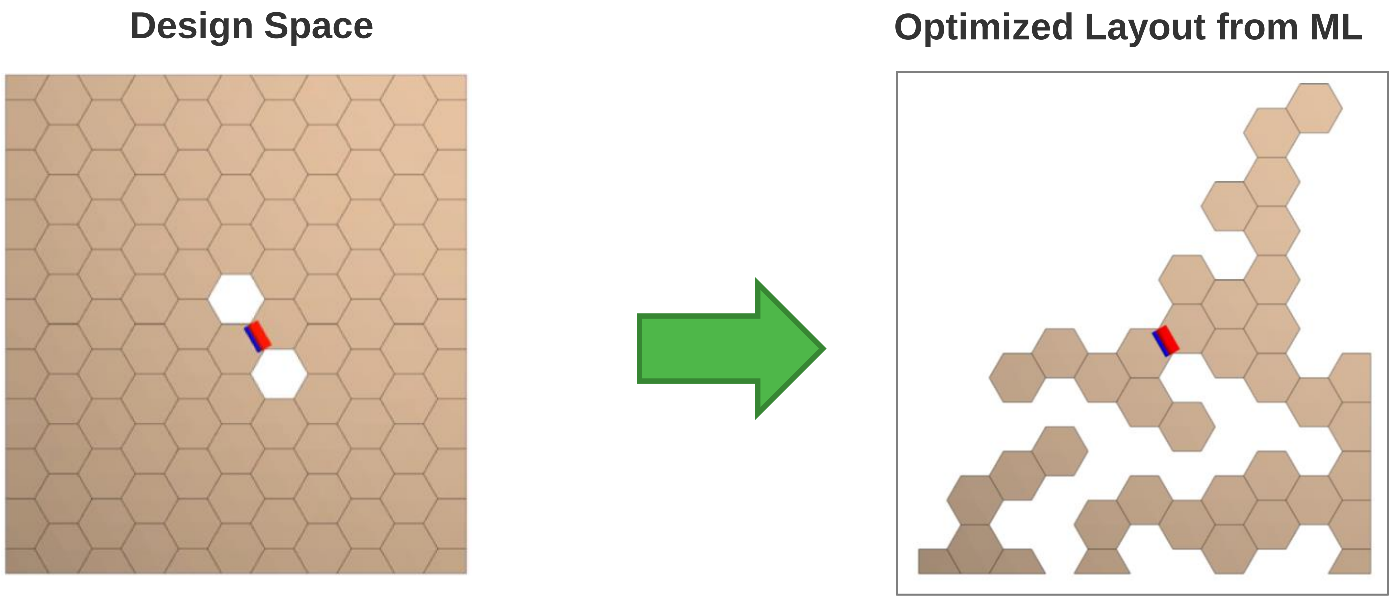
Machine Learning

Altair® HyperStudy®

Powerful Design Exploration and Optimization

Optimization With Evolutionary Learning

WLAN Antenna



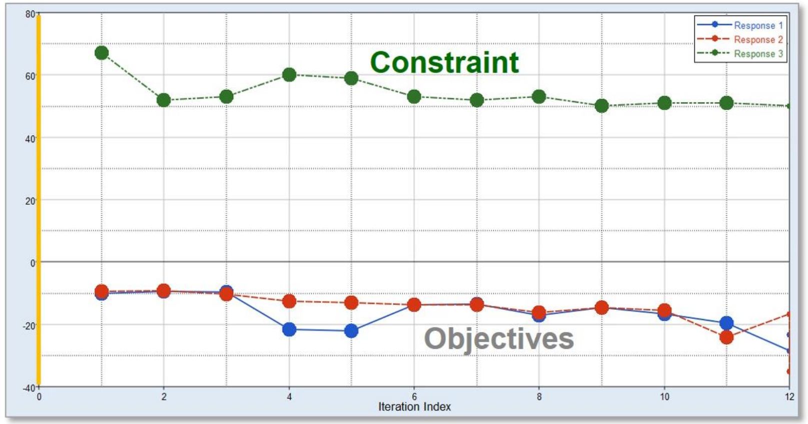
- **Topology Optimization**
- **112 binary input variables:** s_i - *Number of possible design combinations:* $2^{112} \approx 5.2 \cdot 10^{33}$ *!!*
- **3 Output variables: S_{11}(2.44 GHz), S_{11}(5.22 GHz), sum of conductive honeycomb elements**
- **Training data:** New data generated in each generation of genetic algorithm

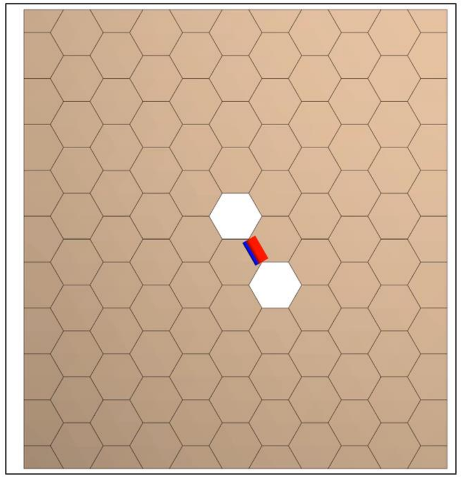
Optimization With Evolutionary Learning

WLAN Antenna

- **Learning Process over 12 generations:**

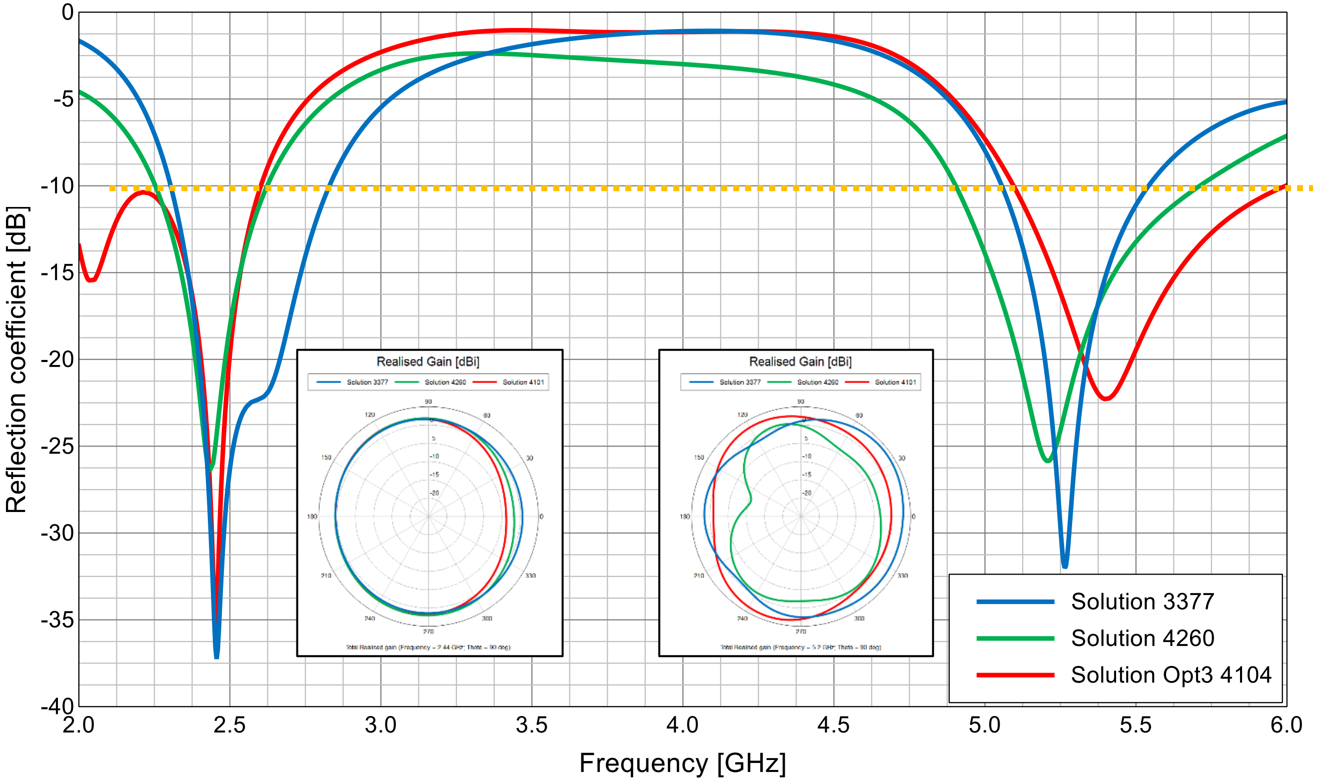
  - **Objective:** Minimize S_{11} at **2.44 GHz** and **5.2 GHz** (better than -15 dB)
  - **Constraint:** Sum of honeycomb elements **< 50**
  - **After 4,300 iterations and 12 generations the multi-objective genetic algorithm has identified a set of Pareto-optimal solutions (*far less than $2^{112} \approx 5.2 \cdot 10^{33}$ Combinations !!*)**

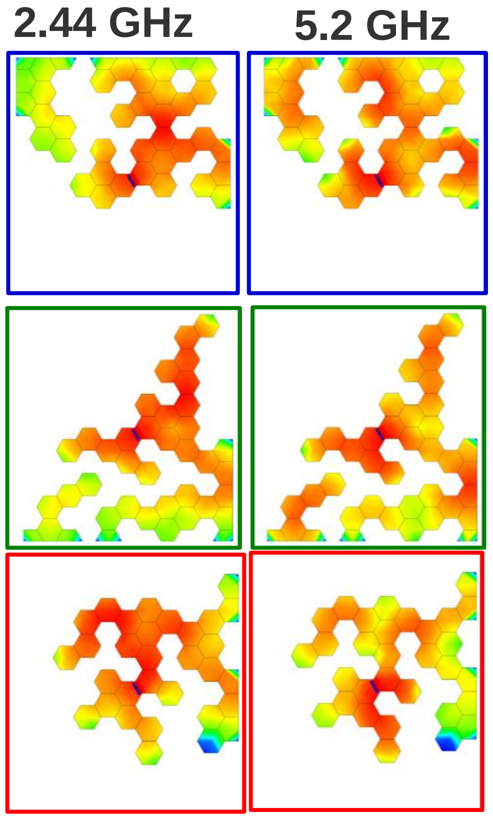




Optimization With Evolutionary Learning

WLAN Antenna - Reflection Coefficient for Different Solutions





Christoph Mäurer, Peter Futter and Gopinath Gampala, "Antenna Design Exploration and Optimization using Machine Learning," European Conference on Antennas and Propagation (EuCAP 2020) Online, April 2020.

ML assisted Reliability Analysis for Radar Antenna Tolerances

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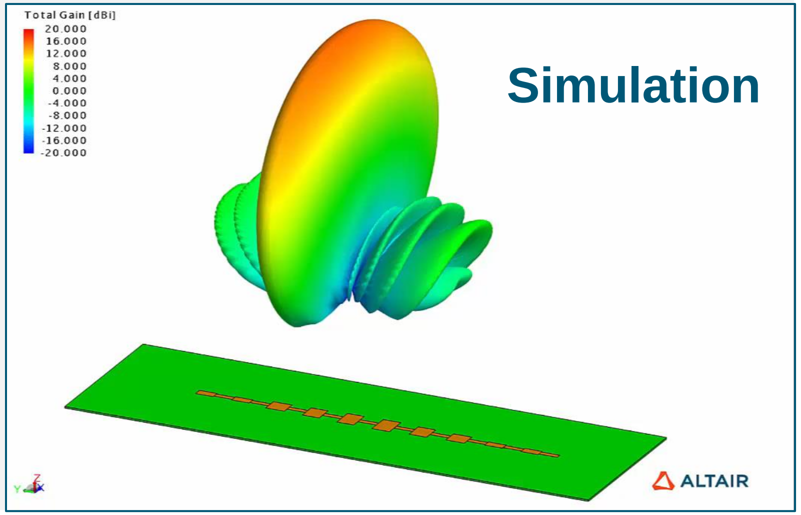
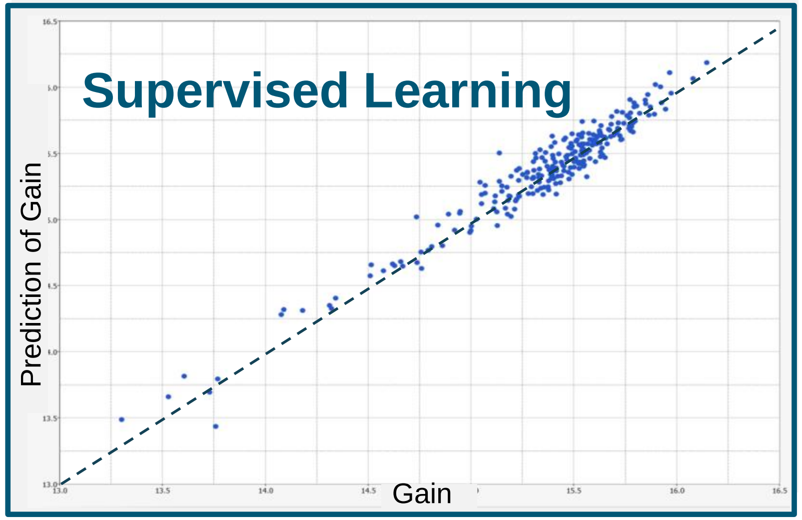
The Coolest Ideas Under the Sun
SAN DIEGO 2023

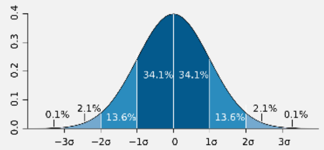
- **Radar Antenna Model at 76.5 GHz**
- How is the antenna gain affected by **fabrication tolerances**?
- How reliable is the solution?
- Parametrized **Feko** model
- Couple **Feko** with Altair **HyperStudy**

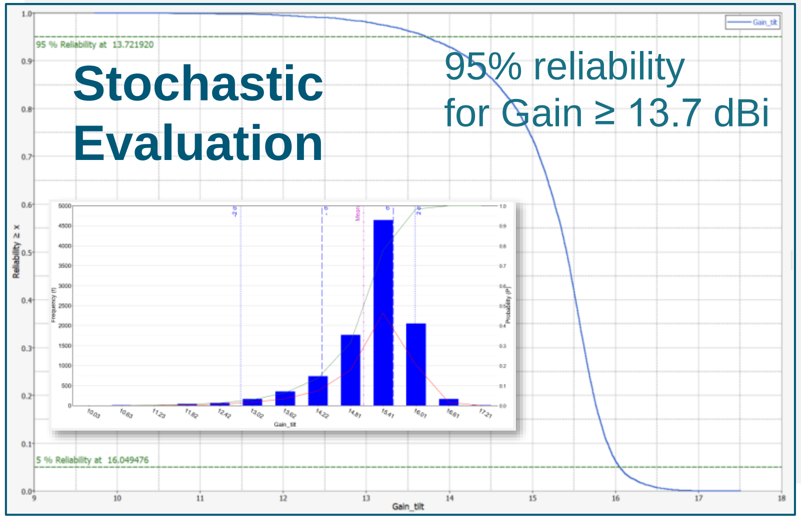


- Use Design of Experiments (DoE) to create data for **supervised learning**
- Build **regression model** for prediction of the antenna gain
- Validate ML model with test data or cross validation
- Use validated model for stochastic reliability analysis



- Define distribution of input variables
- **Stochastic DoE with 10,000 runs** using fast ML model
- Evaluate distribution of responses and assess the reliability with cumulative distribution function



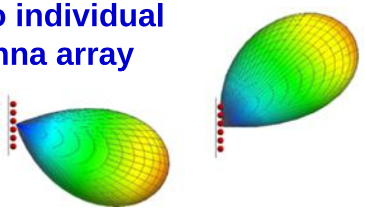


5G Network Planning Optimization

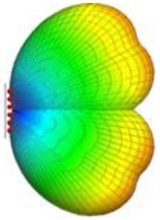
Downtown Munich (1000 m × 600 m)

- 5G at 3.6 GHz with envelope patterns
- Result of interest is Received Power from all active antennas together.
- Four antennas (1, 4, 5, 8) are always enabled and the rest can be either off or on.
- Input Variables
  - (x, y, z) coordinates for ten antennas
  - Azimuth orientation of ten antennas
  - OFF or ON for six antennas (four are always ON)
  - ***Total 46 variables!***

An example of two individual beams of 5G antenna array



Envelop pattern of all possible beams

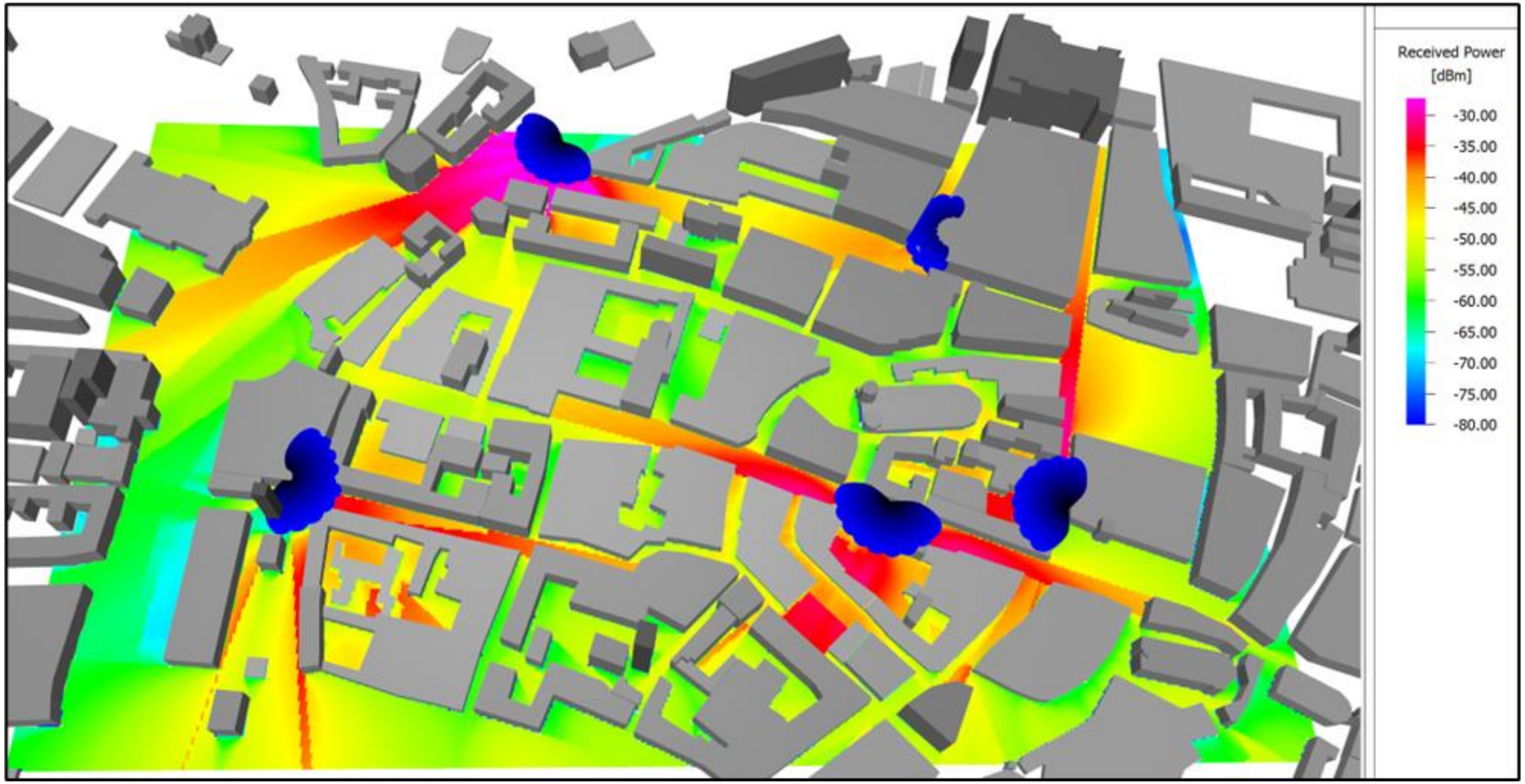


Goal:
"Good coverage" = power above ***-80 dBm*** in a large percentage of the area.

5G Network Planning Optimization

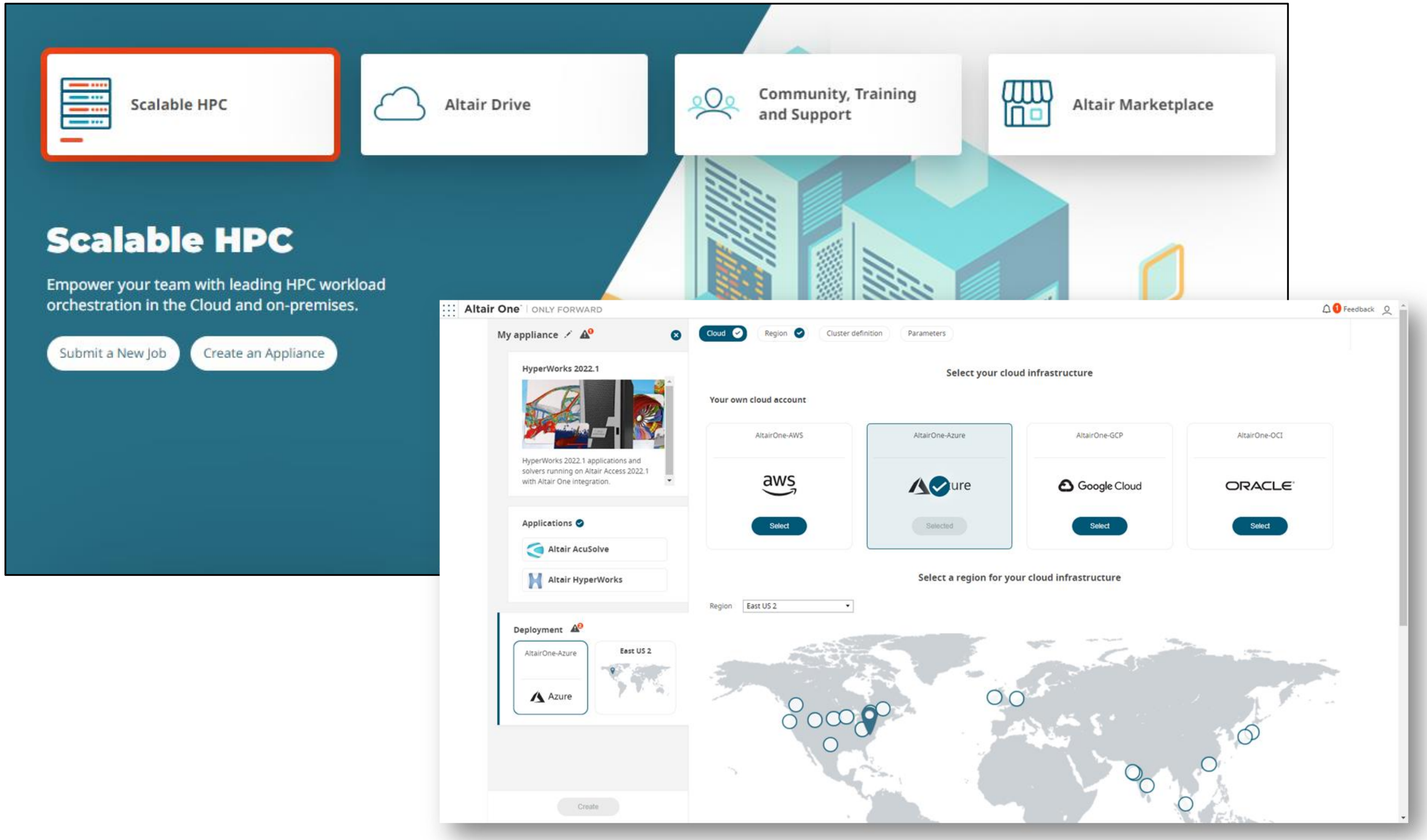
Downtown Munich (1000 m × 600 m)

Optimized with GRSM using ML - Coverage above **-80 dBm** = **93.8%** of area **With 5 Antennas**



CLOUD ON DEMAND

ALTAIR | Altair One™
ONLY FORWARD



Create Scalable HPC Clusters

- ✓ Multi-Cloud
- ✓ Multi-Region
- ✓ Applications
- ✓ Access Controls

Jobs as service

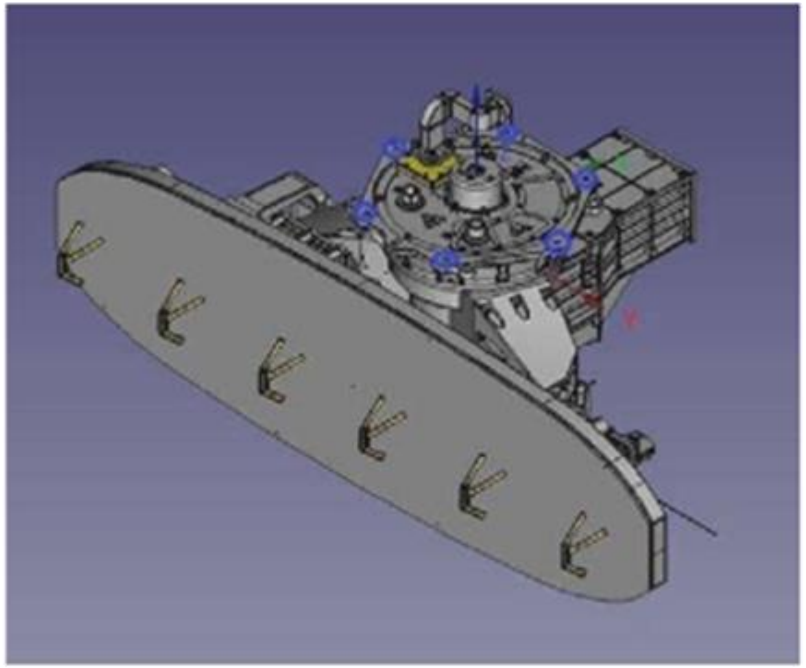
- ✓ Multi-tenant compute cluster
- ✓ No need for a dedicated cluster

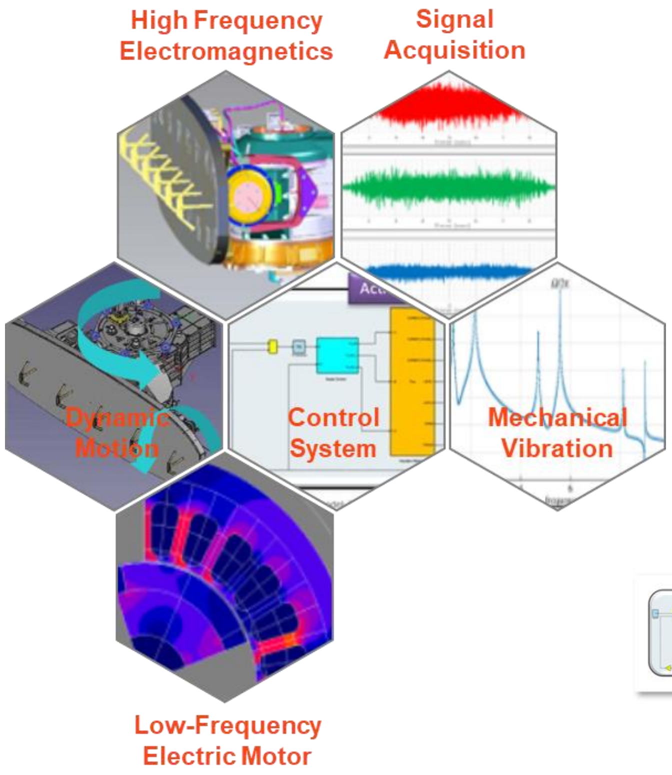
DIGITAL TWIN

LEONARDO Airborne Radar Digital Twin

Challenge

Ensure reliable performance of complex, mechatronic scan radar systems experiencing realistic environmental conditions

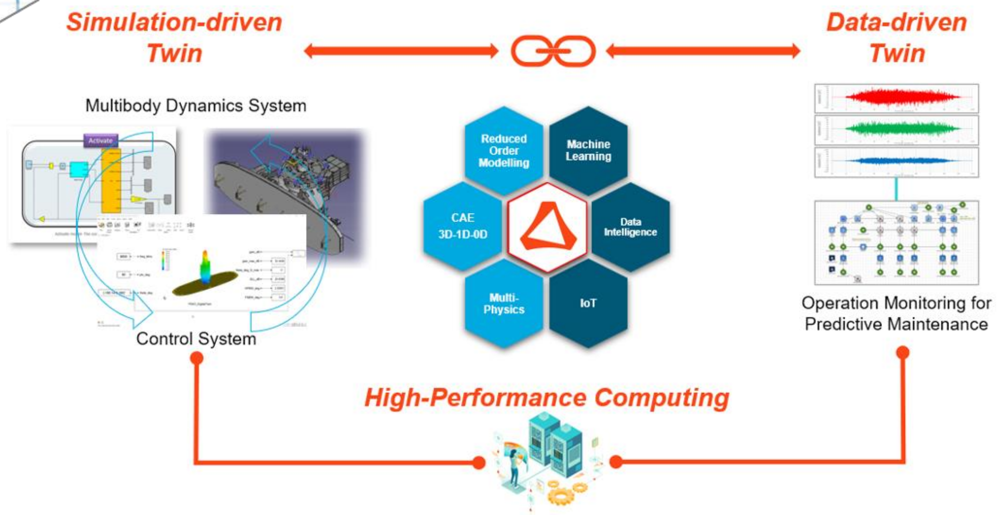




"To verify the performance of our radar units in virtual flights, it's fundamental that our Digital Twin condenses all physics, plus machine learning models based on real-world data, into one single environment.

Together, we built a process to define where and which sensors to include in our products to benefit from Predictive Maintenance."

– Romano Lazurlo, CTO Leonardo Electronics



Conclusions

- CEM Simulations are becoming dominant player in product design and Connectivity.
- Cloud Computing is becoming affordable with "Cloud On Demand."
- Data Driven Design backed by powerful simulation techniques, Cloud Computing and AI/ML brings faster and better innovative products with reduced time to market.
- Convergence of Simulation, Cloud Computing and AI/ML is key to making Digital Twins possible.