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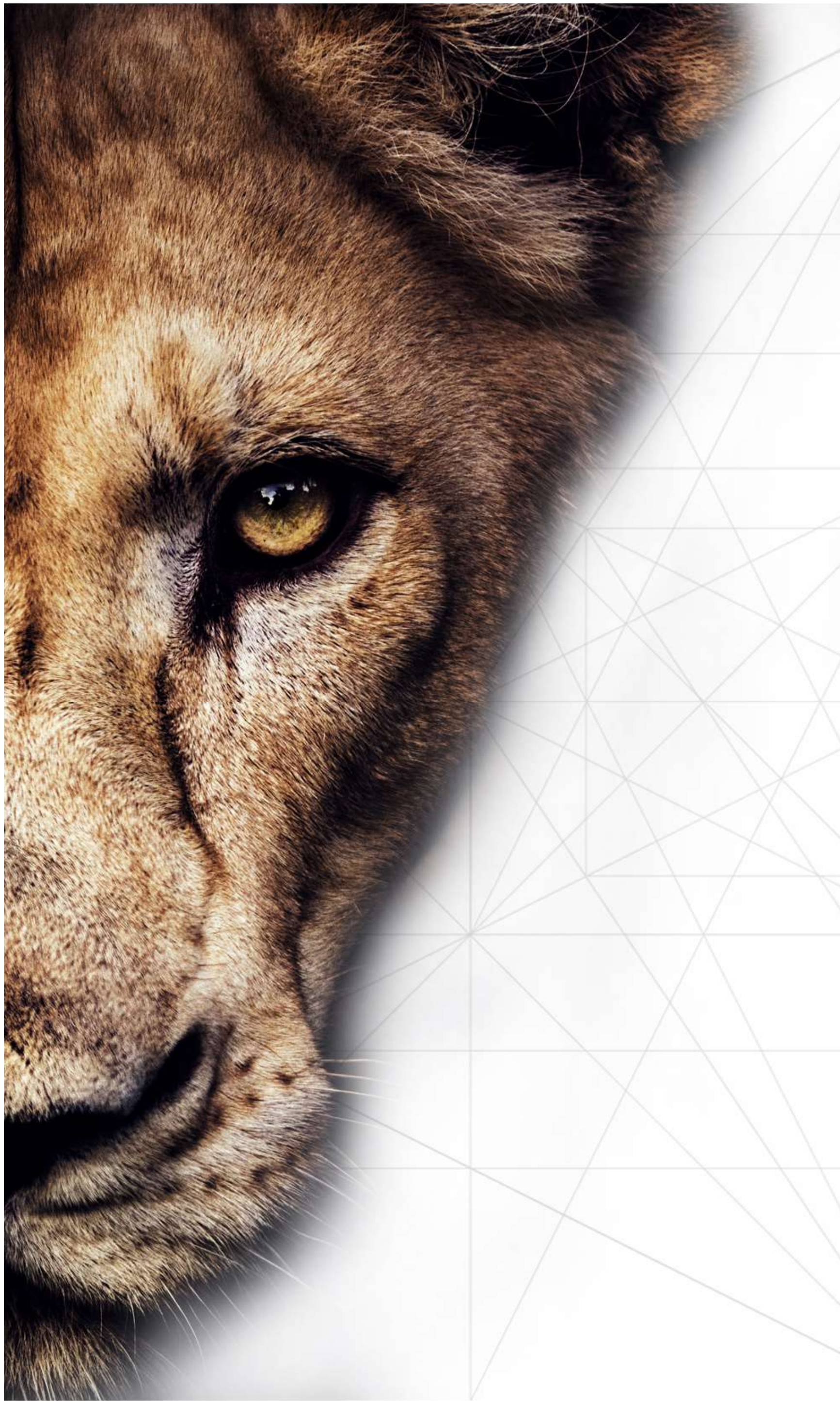
Vision of the Next Generation Propagation Tool in a “Fast and Furious” Three-Dimensional World

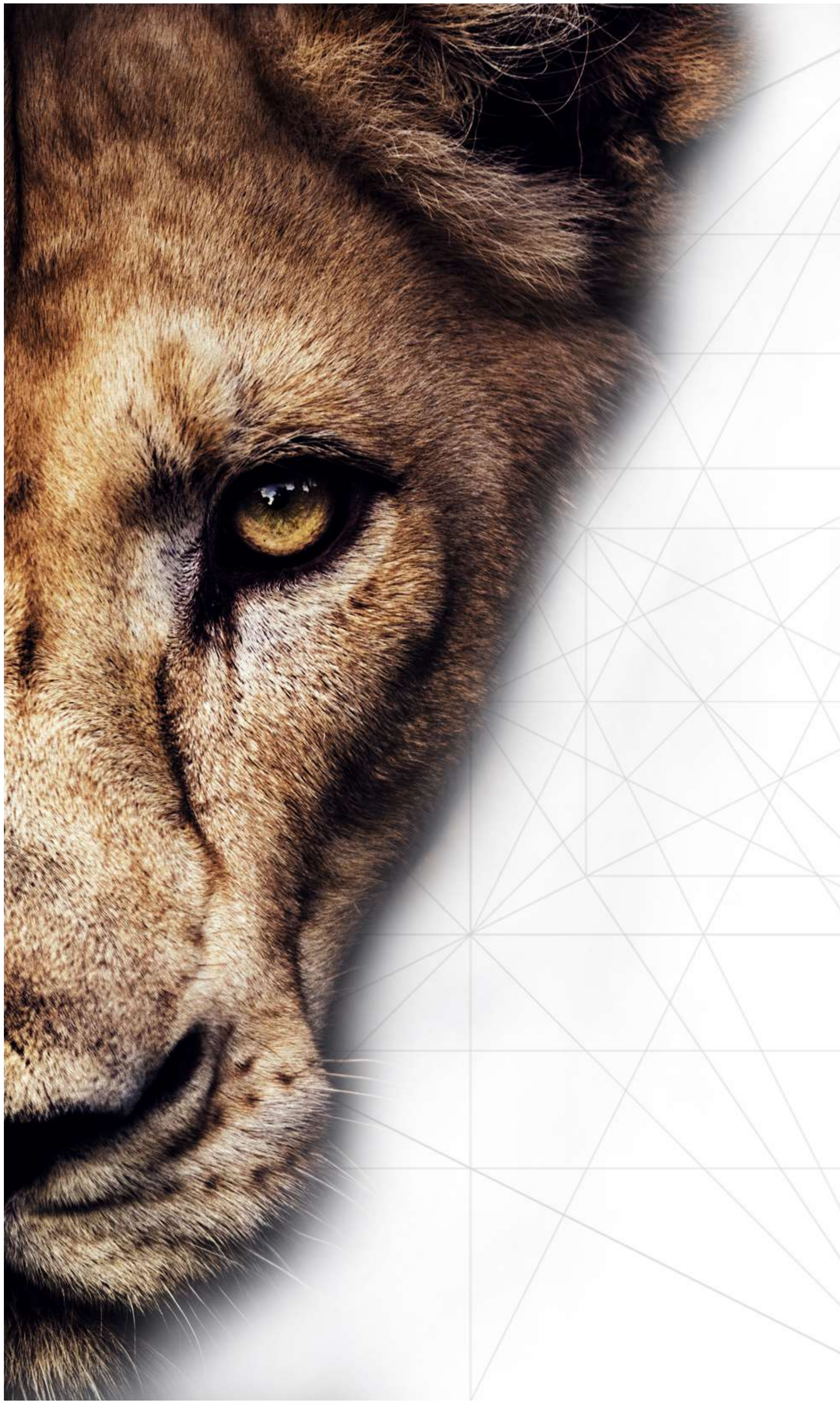
Presented by Alion Science and Technology
Emma Morgenstern
(and VIPER Team)

December 16, 2020



Agenda

- Needs and Challenges
- Vision
- Technologies and Theories
- Math and Physics
- Demo



Needs and Challenges

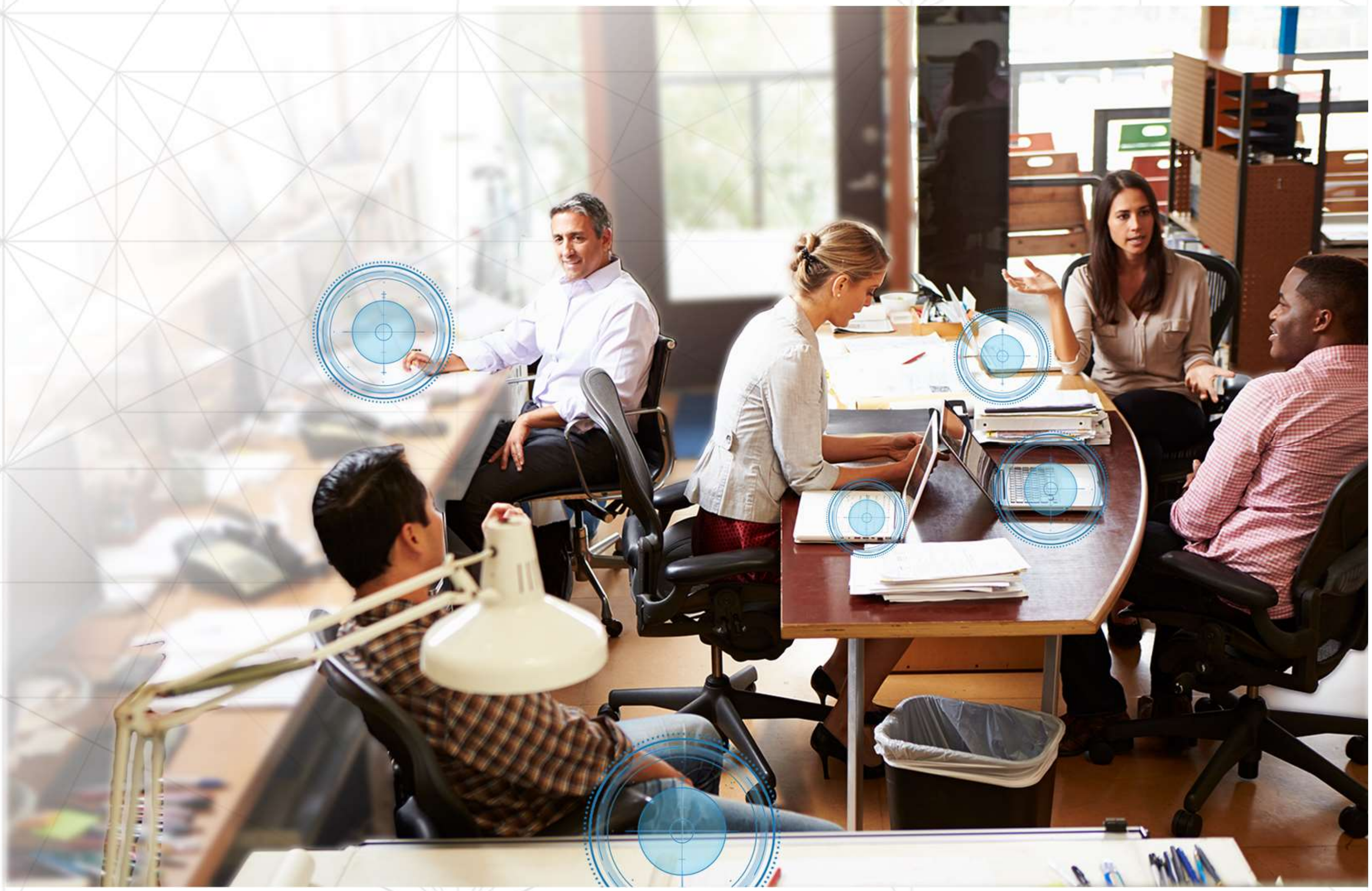
- ***Flexibility***
  - Urban clutter
  - Complex indoor network
  - Indoor to/from outdoor transition
  - Irregular terrain
- ***Accuracy***
  - Building and environmental materials
  - Weather
- ***Speed*** (lacking from existing tools)
  - True full 3D modeling in near-real time
- ***5G***
  - Millimeter-wave

Challenge in Flexibility – Urban Clutter

- Skyscrapers
- Small buildings
- Urban canyon
- **Bridges**
- Towers

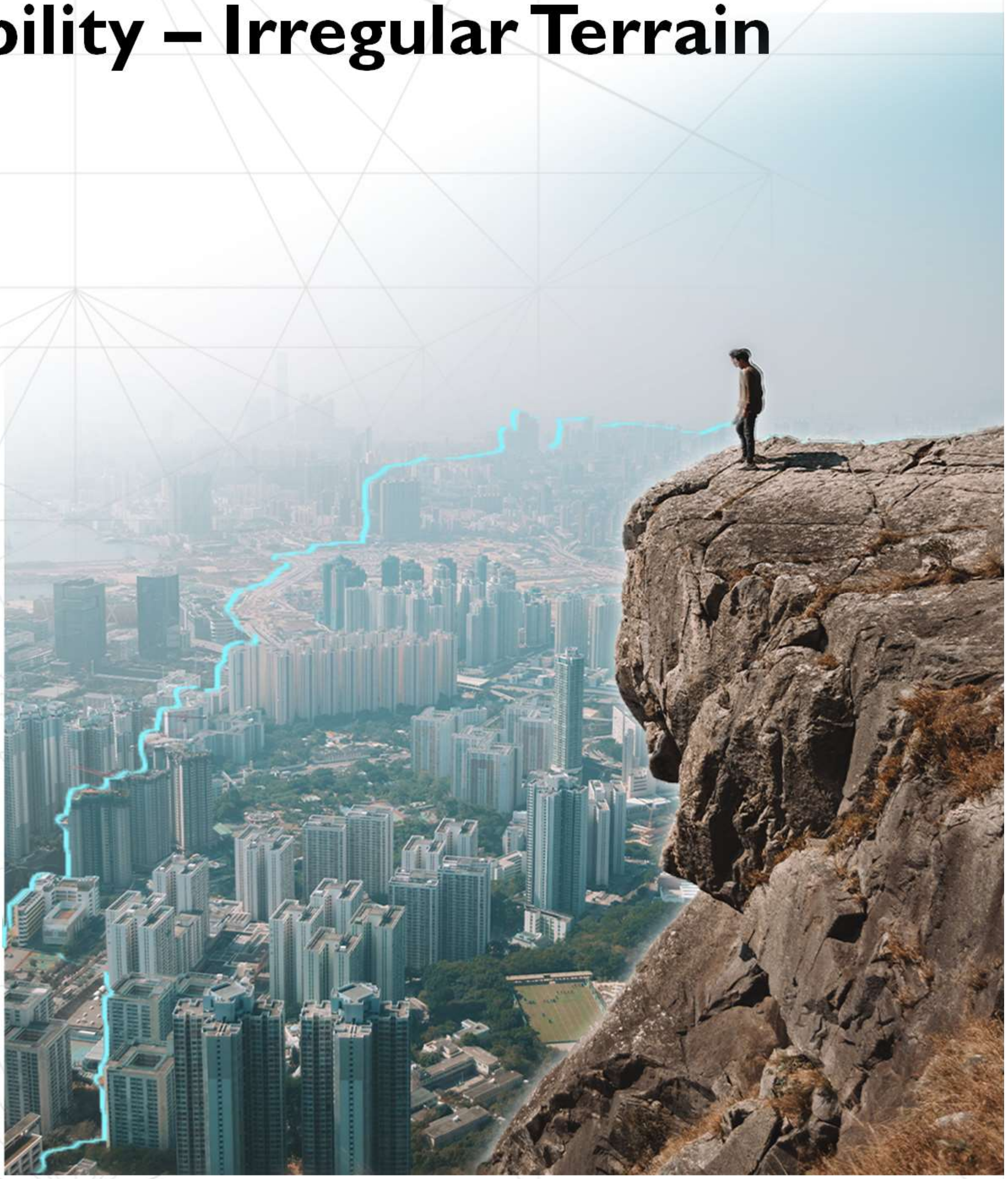
Challenge in Flexibility – Complex Indoor Networks

- Desktops
- Laptops
- Tablets
- Handheld devices
- Routers
- VoIP



Challenge in Flexibility – Irregular Terrain

- Mountains
- Caves
- Ocean
- Forest
- Glacier



Challenge in Accuracy – Building and Environmental Materials

- Concrete
- Glass
- Wood
- Clay
- Trees
- Foliage

Challenge in Accuracy – Weather

- Rain
- Snow
- Dust
- Fog

- Stats from past
- Locations and rates
- NOAA.gov

Needs in Speed – True Full 3D Modeling in Near-Real Time

- Current struggle
  - Slow rendering
  - Run analysis for days

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Limitation of Existing Tools

Tool	3D	Materials	Diffraction Mechanism	Frequency Range	Weather
Tool1 (T)	✗	✗	✗	✓	✓
Tool2 (U)	✗	✓	✗	✓	✓
Tool3 (A)	✓	✓	✓	✗	✗

Vision

- The next generation propagation tool will replace the legacy tools to better predict signal loss in accuracy in full-3D simulation. The GPU-based propagation modeling tool is capable of efficiently simulating complex wave interactions, such as wedge diffraction, curved surface diffraction, etc.

- Implements
  - Wider range of frequency use (low, mid, high)
  - Millimeter-wave path analysis
  - Micro-cell and pico-cell deployments
  - Beamforming and phased array
  - Massively MIMO networks
- Full 3D modeling and GPU-based
  - Building materials
  - Clutter geometry
  - Atmospheric conditions and weather
  - Wedge/surface diffraction, reflection
  - Volumetric/voxelization
  - Ray-tracing

- Can address (with RF expertise)
  - Complex clutter morphologies/dense urban deployments
  - Co-site analysis/interference avoidance analysis
  - Line-of-sight & BLOS calculations
  - Aggregate coverage from multiple locations
- True 3D modeling in near-real time
- Runs at a revolutionary speed (1: 3000)
- Supports 5G deployment

Technologies and Theories

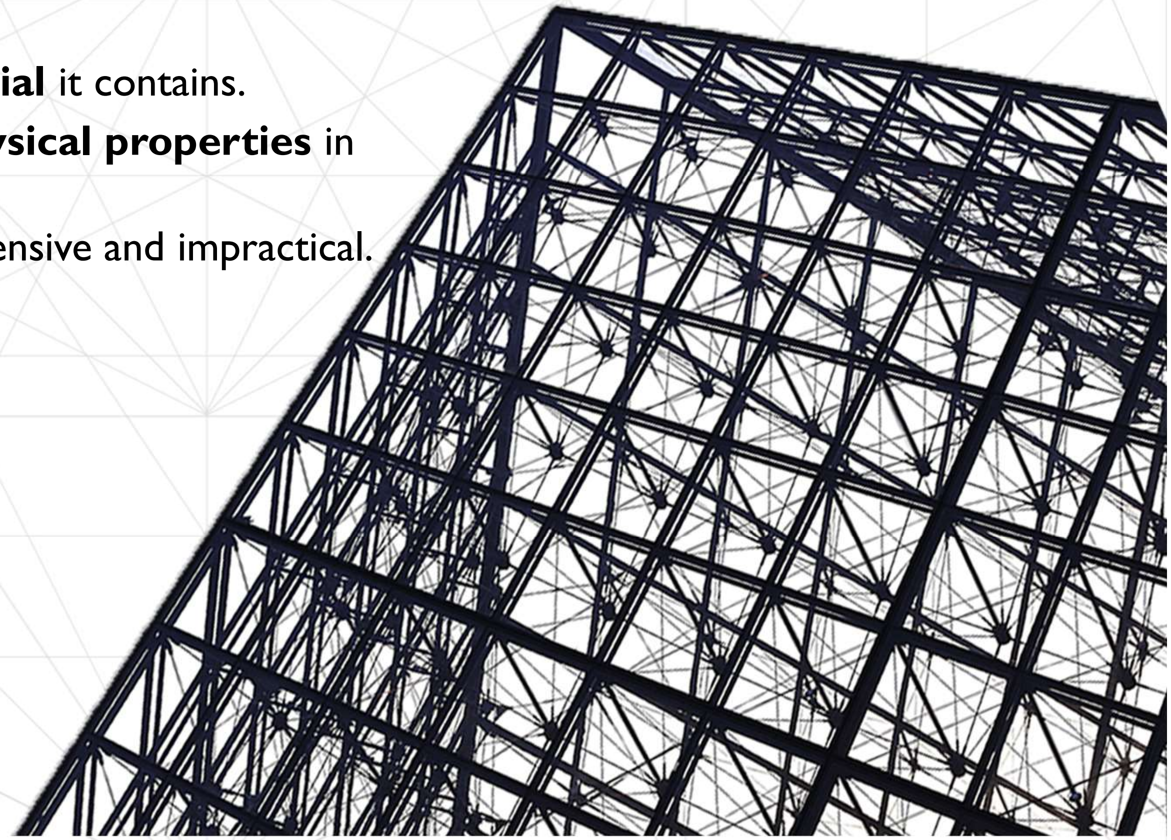
- Volumetric
- Voxelization
- Sparse voxel tree
- Ray-tracing
- GPU

Technologies and Theories – Volumetric

- The system does not merely calculate received power along a path from Tx to Rx but calculates the **entire volume** filled by the **RF** field inside a **3D space**.
- Volumetric geometry representation is a 3D volumetric model composed of nested “volumetric elements” (**voxels**).
- A voxel is the **invisible unit** of physical space in the simulation like the **pixel** in a digital image, an unit of display space.

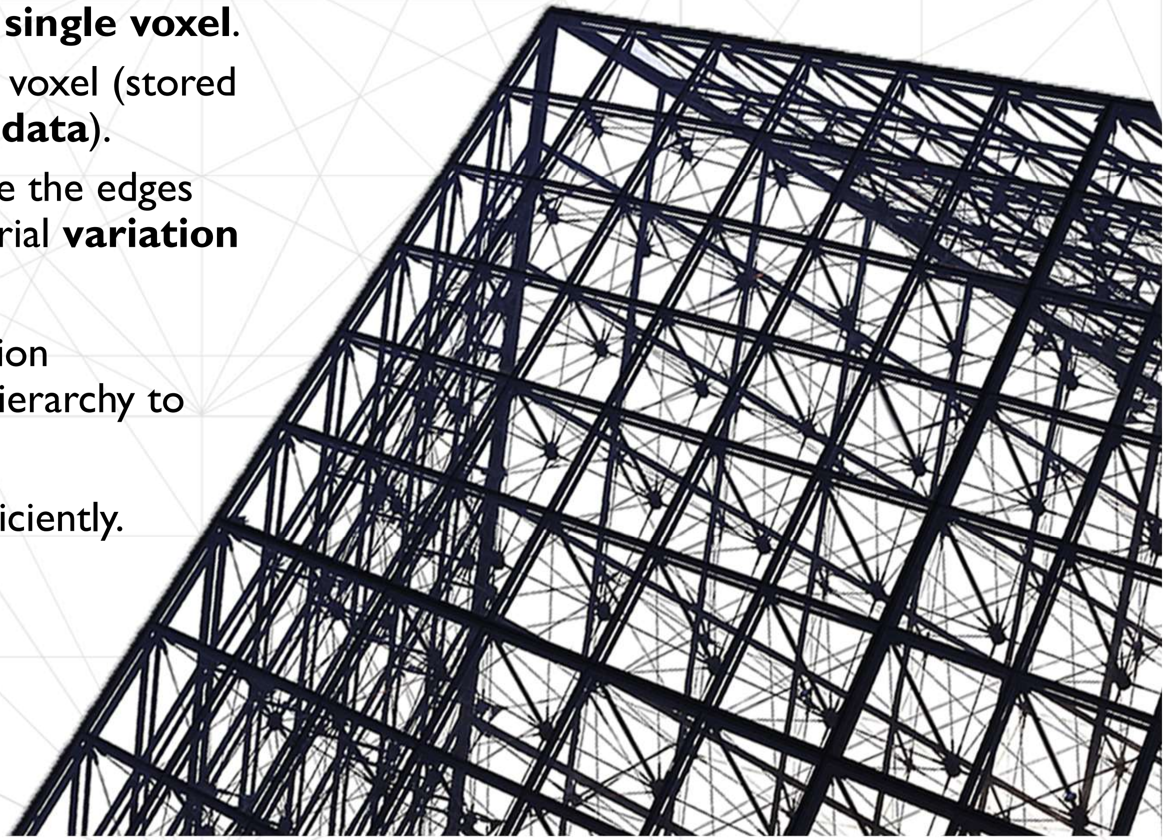
Technologies and Theories – Voxelization

- Each voxel will contain the attributes of its bounded space:
  - Model-specific information (**surface normals and geometric hints**).
  - A reference to the **material** it contains.
  - Can store all localized **physical properties** in the material definitions.
  - This quickly becomes expensive and impractical.



Technologies and Theories – Voxelization

- To overcome this difficulty:
  - Contiguous, homogenous structures, such as mountain ranges, buildings, or open-air spaces, can be treated as a **single voxel**.
  - Represented using a larger voxel (stored with material and location **data**).
  - Smaller voxels will populate the edges where geometry and material **variation** may increase.
- We envisioned the next generation propagation tool to use a tree hierarchy to organize this division: "**Octree**".
- Deals with very large models efficiently.



Technologies and Theories – Sparse Voxel Tree

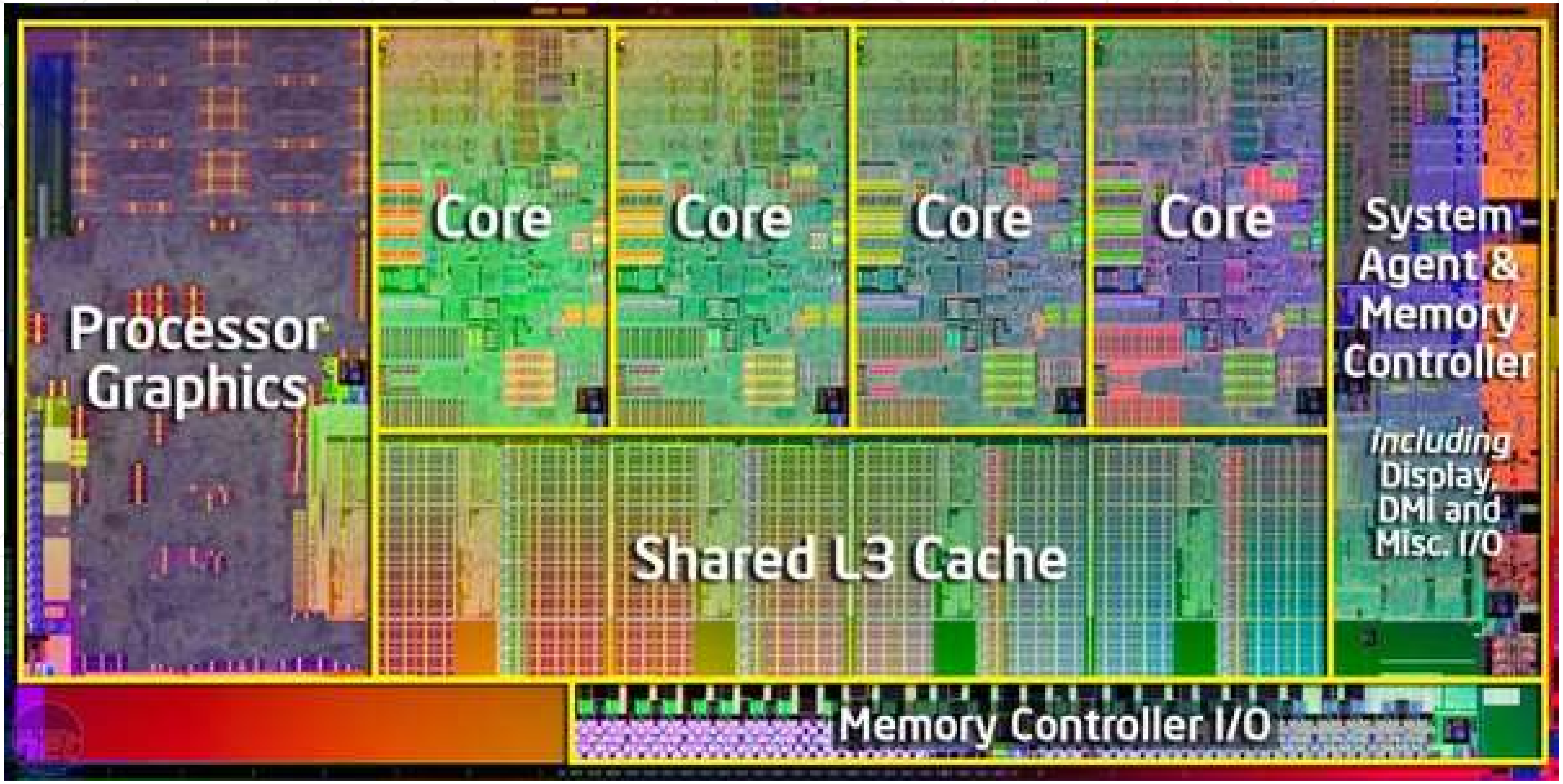
- Sparse voxel tree (extension of Octree)
  - A very compact pointer-based structure
  - Is "sparse": homogeneous space (node) is **not subdivided**.
  - All the details of an object in the simulation are connected and subordinated to the **main** node and stored with the **minimum** amount of **data redundancy**.
  - The benefit of the sparse voxel tree: no need to investigate every voxel within the system; increased analysis **speed**.

Technologies and Theories – Ray Tracing

- Ray-tracing is a way of drawing 3D picture.
- A fundamentally different rendering process than rasterization, it simulates real light more accurately.
- Where a signal has **actually gone**: **not guesswork** but actual 3D calculation.
- Film industry.

Technologies and Theories – GPU

- GPU-based parallel computation: high speed
- Turn a laptop into a supercomputer
- NVIDIA chip (RTX3000 09/2020)



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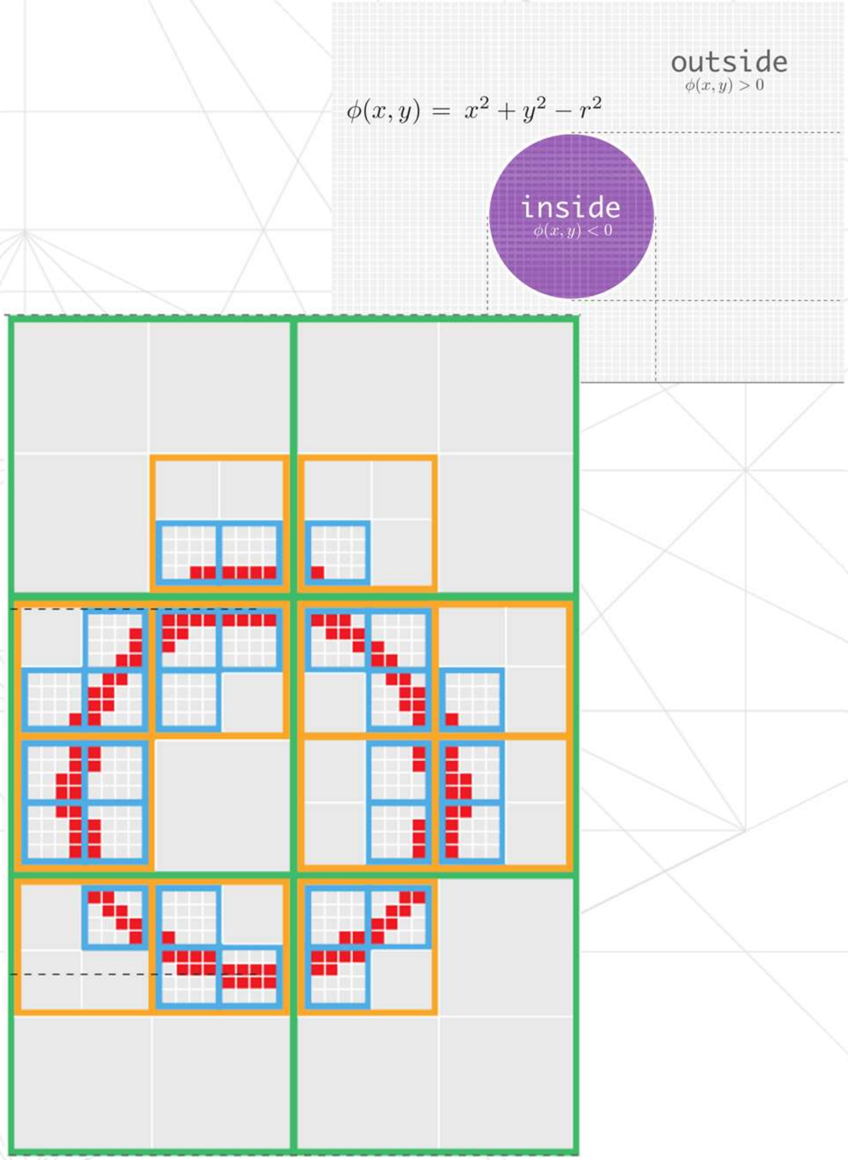
PUTTING IT ALL TOGETHER

The Science Behind:

Math and Physics

Propagation Model Architecture

- GPU - accelerated graphics
  - Turn a laptop into a supercomputer
- Voxelized hierarchical data structures
  - Speed geometry traversal
  - Solve the model repair problem – no stitching of facets
- Electromagnetic field solutions
  - Uniform theory of diffraction
  - Incremental length diffraction coefficients + physical optics
- Materials database
- Antenna database
- Platform and geographic database



Propagation Physics – Uniform Theory of Diffraction

- UTD – uniform theory of diffraction
- Wedge diffraction coefficients
  - Energy bending
  - Building corners
  - Aircraft wing edges
- Scattering mechanisms
- Reflection
- Surface diffraction

$$\mathbf{D} = -\hat{\beta}_0'\hat{\beta}_0 D_s - \hat{\phi}'\hat{\phi} D_h$$

$$D_{s,h} = (D_1 + D_2) + R_{s,h}(D_3 + D_4)$$

$$D_1 = H \cot\left(\frac{\pi + (\phi - \phi')}{2n}\right) F\left[kL^i a^+(\phi - \phi')\right]$$

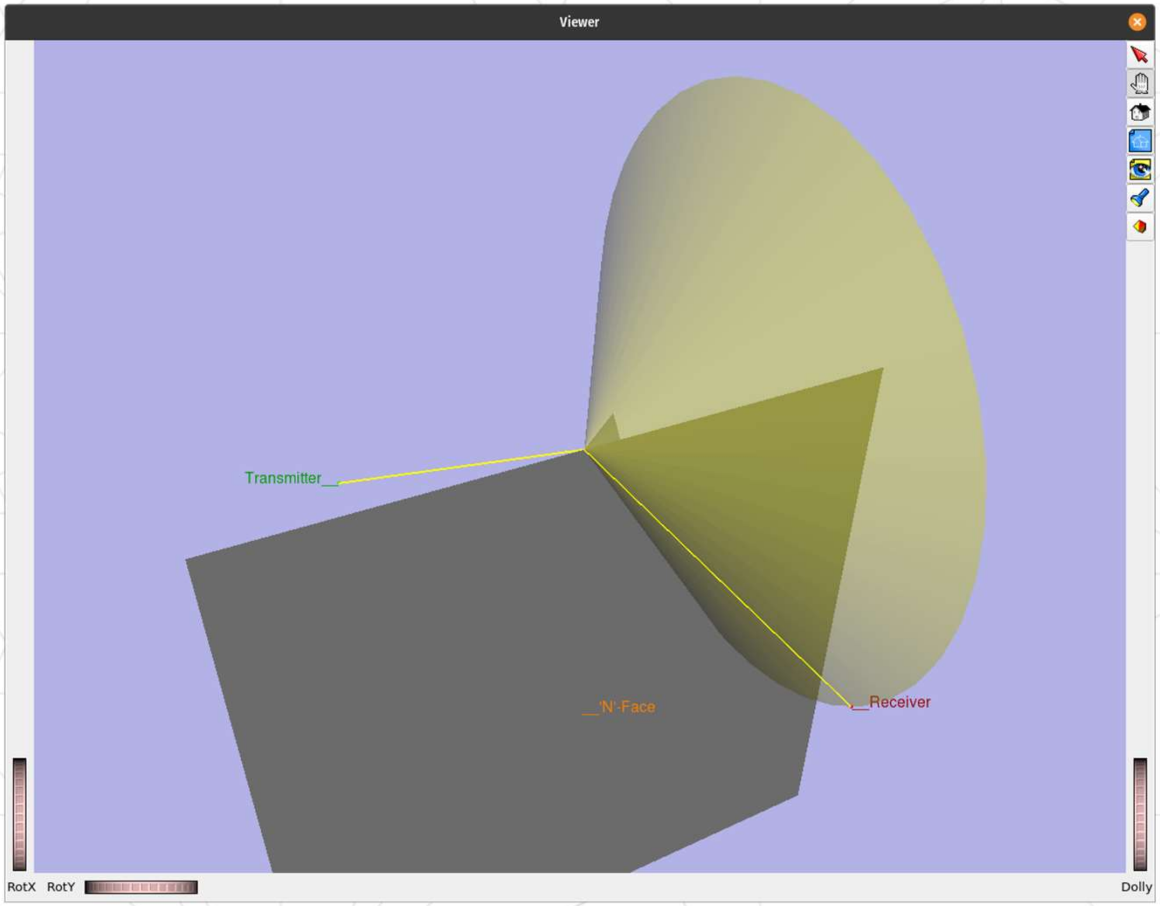
$$D_2 = H \cot\left(\frac{\pi - (\phi - \phi')}{2n}\right) F\left[kL^i a^-(\phi - \phi')\right]$$

$$D_3 = H \cot\left(\frac{\pi + (\phi + \phi')}{2n}\right) F\left[kL^{rn} a^+(\phi + \phi')\right]$$

$$D_4 = H \cot\left(\frac{\pi - (\phi + \phi')}{2n}\right) F\left[kL^{ro} a^-(\phi + \phi')\right]$$

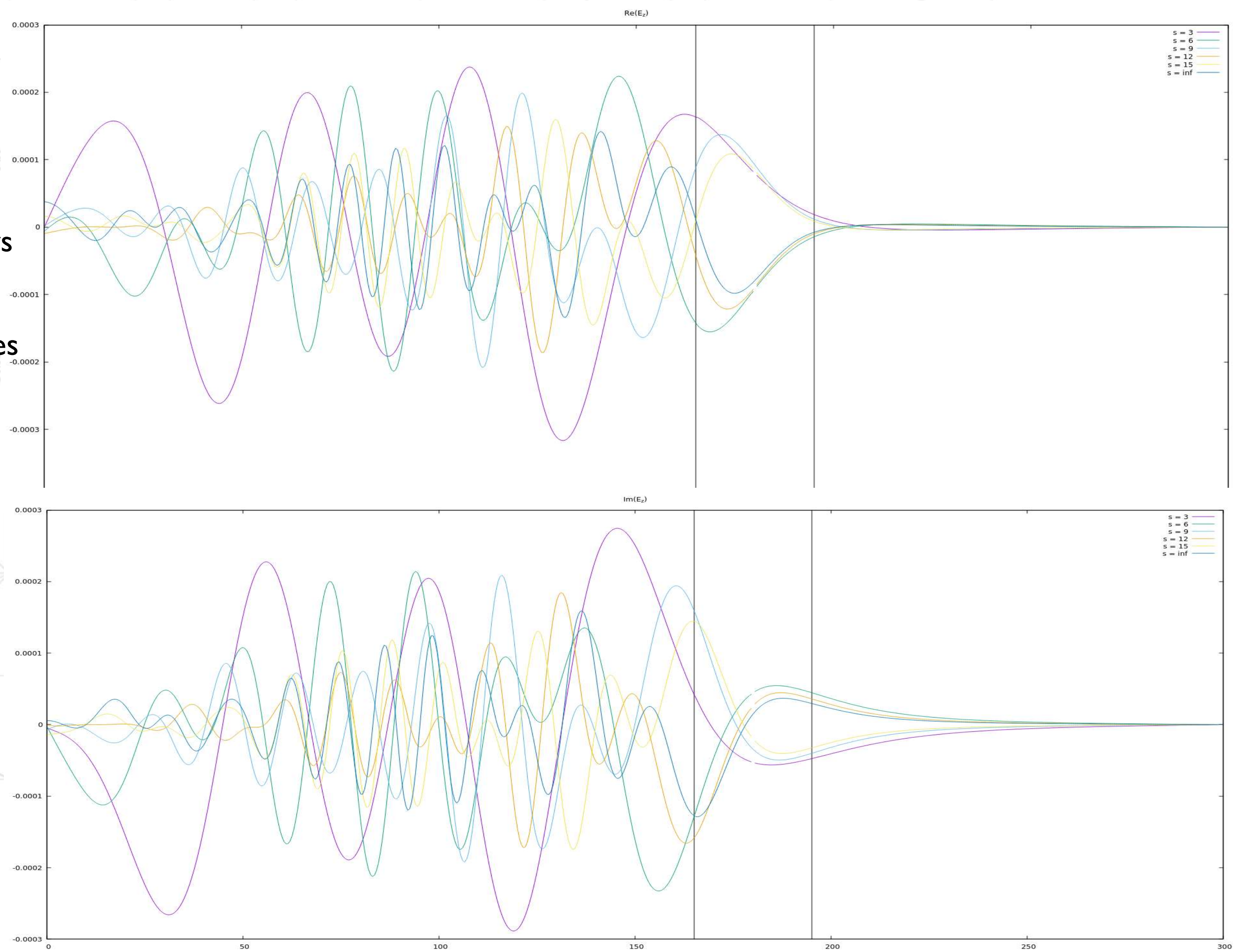
Propagation Physics – Wedge Diffraction

- Wedge diffraction
- Tx above wedge left
- Ray diffracts
- Rx lower right
- Keller cone



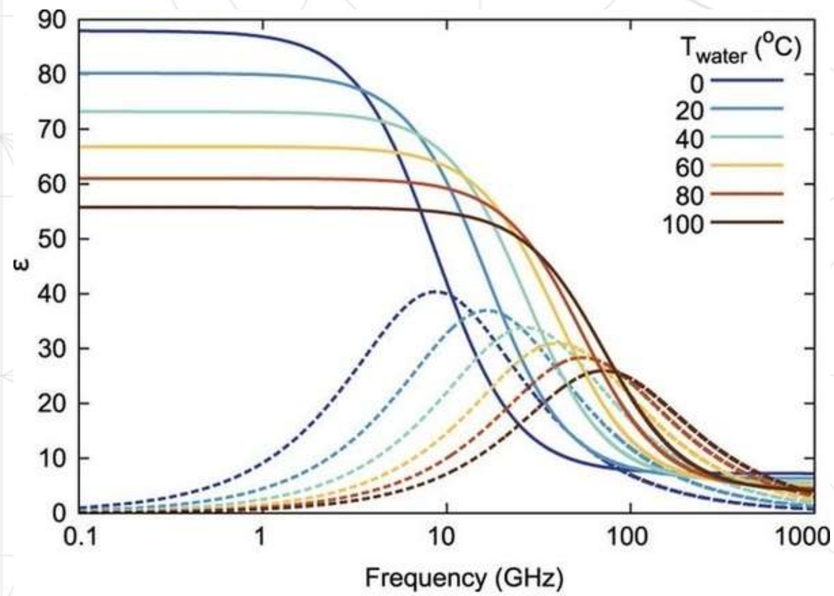
Propagation Physics - Total E-Field

- Sum of:
  - Direct
  - Reflected
  - Wedge-diffracted rays
- Different lines
  - Observation distances
  - Diffraction point
- UTD
  - Continuous fields
  - Shadow boundaries
  - No discontinuities



Materials Database

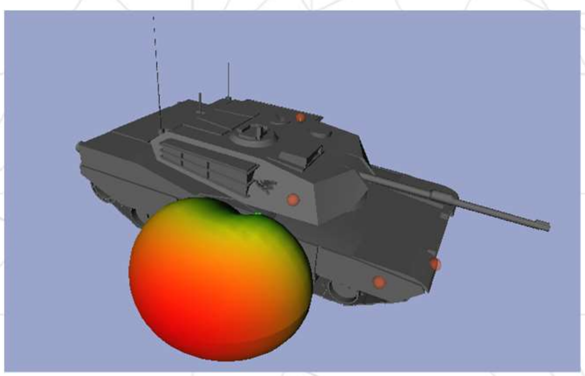
- Electromagnetic properties of materials
  - Complex electric permittivity
  - Complex magnetic permeability
  - Covering a wide frequency range
- Materials applied to terrain, buildings, platforms
- Materials for different use cases
  - Building materials for urban propagation
  - RAM coatings for airframes
- Environmental material such as water and snow

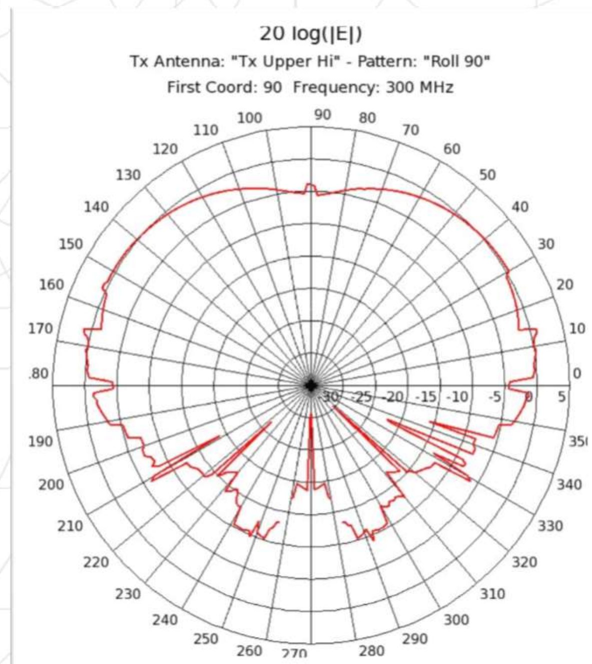


Dielectric permittivity of water as a function of frequency for the temperature 0–100 °C.: Here and in further figures, solid lines correspond to the real part, dashed lines to the imaginary part.

Antenna Database

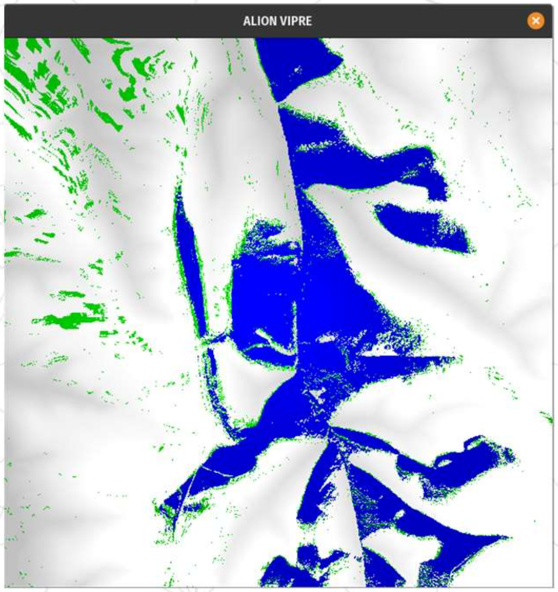
- Gain patterns
  - Full 3D gain patterns for a large variety of antennas
- Antenna models
  - Wire antennas
  - Aperture antennas
  - Horn antennas
  - Integration with industry antenna models

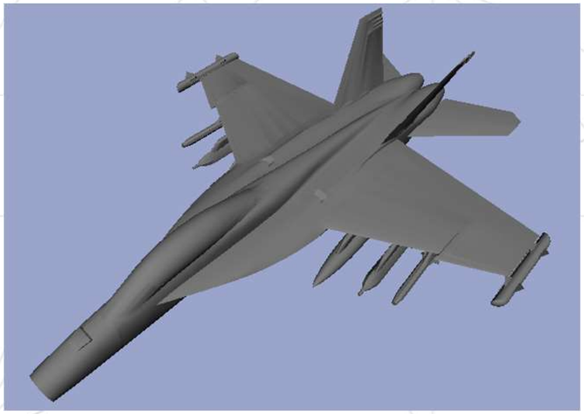




Platform and Geographic Database

- Air, land, and sea platforms
- Urban centers
  - LIDAR
  - KML grey polygon buildings
- Terrain
  - LIDAR
  - Raster in many formats
  - Vector in many formats
- Geometry and geographic services
  - In-house team and resources providing scenario data for customers

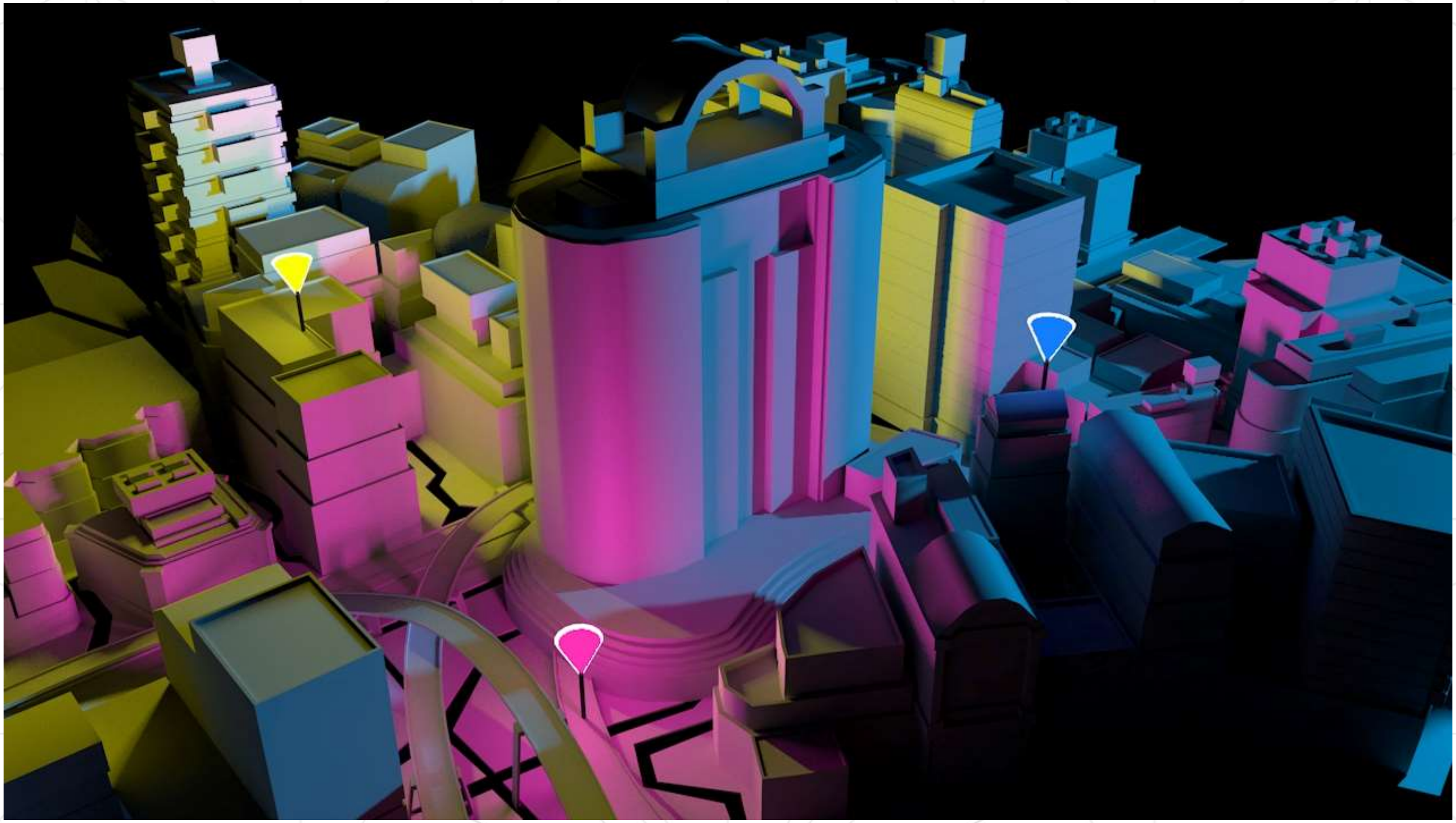




Environmental Data and Modeling

- Weather data
  - Global statistical data for rain, snow, fog
  - Integration with weather services
- Electromagnetic propagation models
  - ITU models for rain, fog, etc.
  - Mie series models

Demo



Q&A

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For more questions, please contact

Emma Morgenstern emorgenstern@alionscience.com or

Jenn Super jsuper@alionscience.com

THANK YOU!

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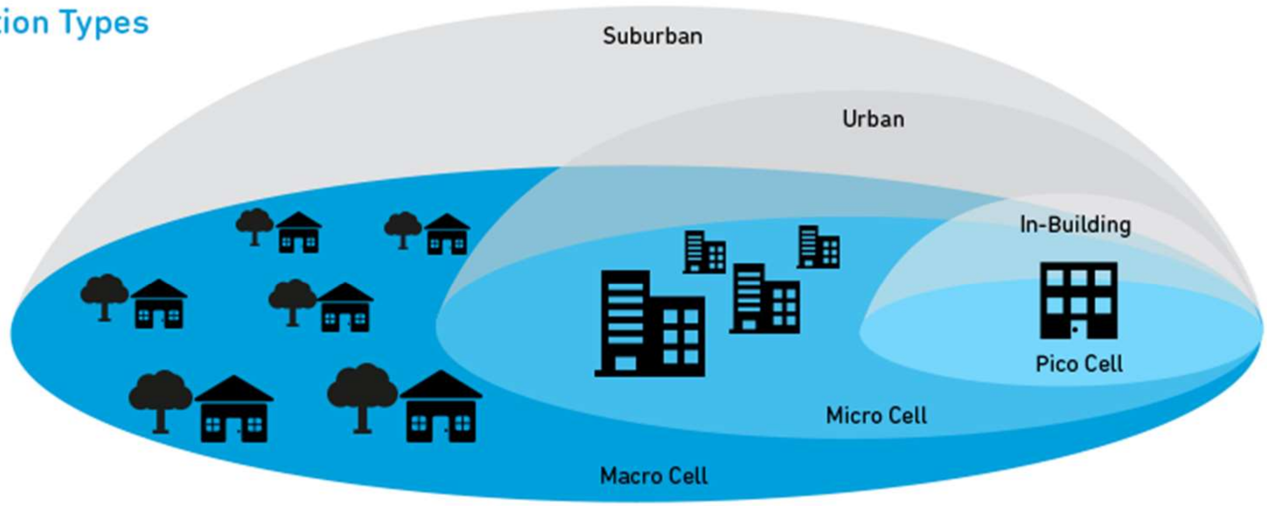
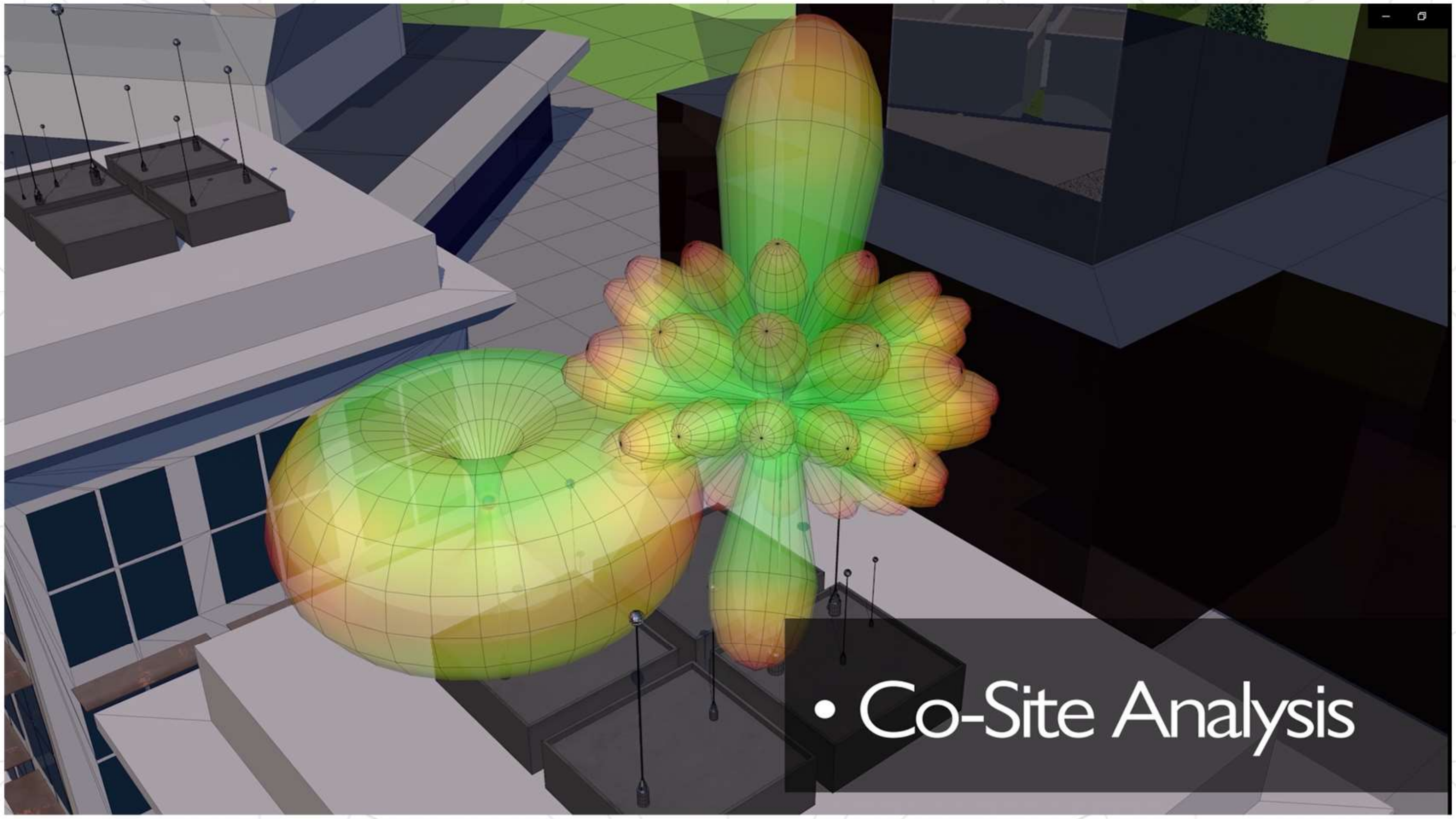
Back Up Slides

Base Station Types



Cell Type	Output Power (W)	Cell Radius (km)	Users	Locations
Femtocell	0.001 to 0.25	0.010 to 0.1	1 to 30	Indoor
Pico Cell	0.25 to 1	0.1 to 0.2	30 to 100	Indoor/Outdoor
Micro Cell	1 to 10	0.2 to 2.0	100 to 2000	Indoor/Outdoor
Macro Cell	10 to >50	8 to 30	>2000	Outdoor

qorvo


• Co-Site Analysis

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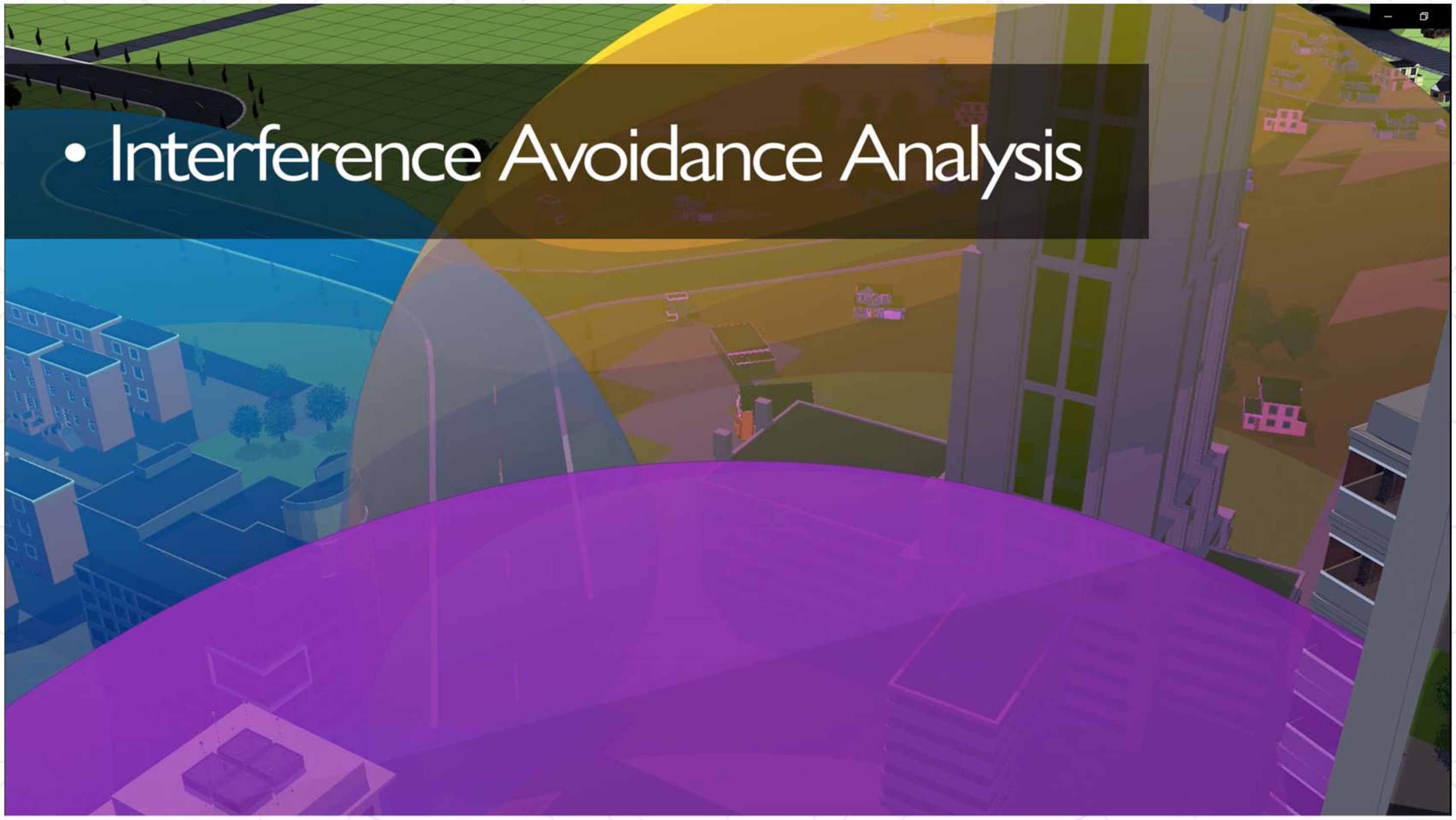

BACK

BACK

$$\vec{E}^r(Q) = \vec{E}^i(Q)\cdot \mathbf{R}\sqrt{\frac{\rho_1^r\rho_2^r}{(\rho_1^r+s)(\rho_2^r+s)}}\,e^{-jks}$$

$$\frac{1}{\rho_1^r} = \frac{1}{2}\left(\frac{1}{\rho_1^i}+\frac{1}{f_1}\right)$$

$$\frac{1}{\rho_2^r} = \frac{1}{2}\left(\frac{1}{\rho_2^i}+\frac{1}{f_2}\right)$$

$$\frac{1}{f_{1,2}} = \left(\frac{\theta_{12}^2+\theta_{22}^2}{R_1}+\frac{\theta_{11}^2+\theta_{21}^2}{R_2}\right) \pm\frac{1}{2}\left\{\left(\frac{1}{\rho_1^i}-\frac{1}{\rho_2^i}\right)^2 + \frac{4\cos\theta_i}{|\theta|^2}\left(\frac{1}{\rho_1^i}-\frac{1}{\rho_2^i}\right)\left(\frac{\theta_{22}^2-\theta_{12}^2}{R_1}+\frac{\theta_{21}^2+\theta_{11}^2}{R_2}\right)+\frac{4\cos^2\theta_i}{|\theta|^4}\left[\left(\frac{\theta_{12}^2+\theta_{22}^2}{R_1}+\frac{\theta_{11}^2+\theta_{21}^2}{R_2}\right)-\frac{4|\theta|^2}{R_1R_2}\right]\right\}^{1/2}$$

$$\vec{E}_d = \vec{E}_i(Q_e)\cdot \mathbf{D}\sqrt{\frac{\rho}{s(\rho+s)}}\,e^{-jks}$$

$$\frac{1}{\rho} = \frac{1}{\rho_e^i} - \frac{\hat{n_e}\cdot(\hat{s'}-\hat{s})}{a\sin^2\beta_0}$$

$$L_{Total} = L_{FS} - G_T - G_R$$

$$L_{FS} = 20\log_{10}\left(\frac{\lambda}{4\pi r}\right) = -20\log_{10}(2kr)$$

$$\vec{E}(\vec{r}) = jk\frac{e^{jkr}}{4\pi r}(Z_0\vec{N} - \hat{k}\times\vec{L})$$

$$P_R = \frac{1}{16P_{R/T}}|\vec{E}_T(\theta,\phi)\cdot\vec{N}_R^*(\theta,\phi)|^2$$

$$\vec{N} = \int_S \vec{J}(\vec{r'})e^{j\vec{k}\cdot\vec{r'}}\,dS'$$

$$\vec{L} = \int_S \vec{K}(\vec{r'})e^{j\vec{k}\cdot\vec{r'}}\,dS'$$

BACK