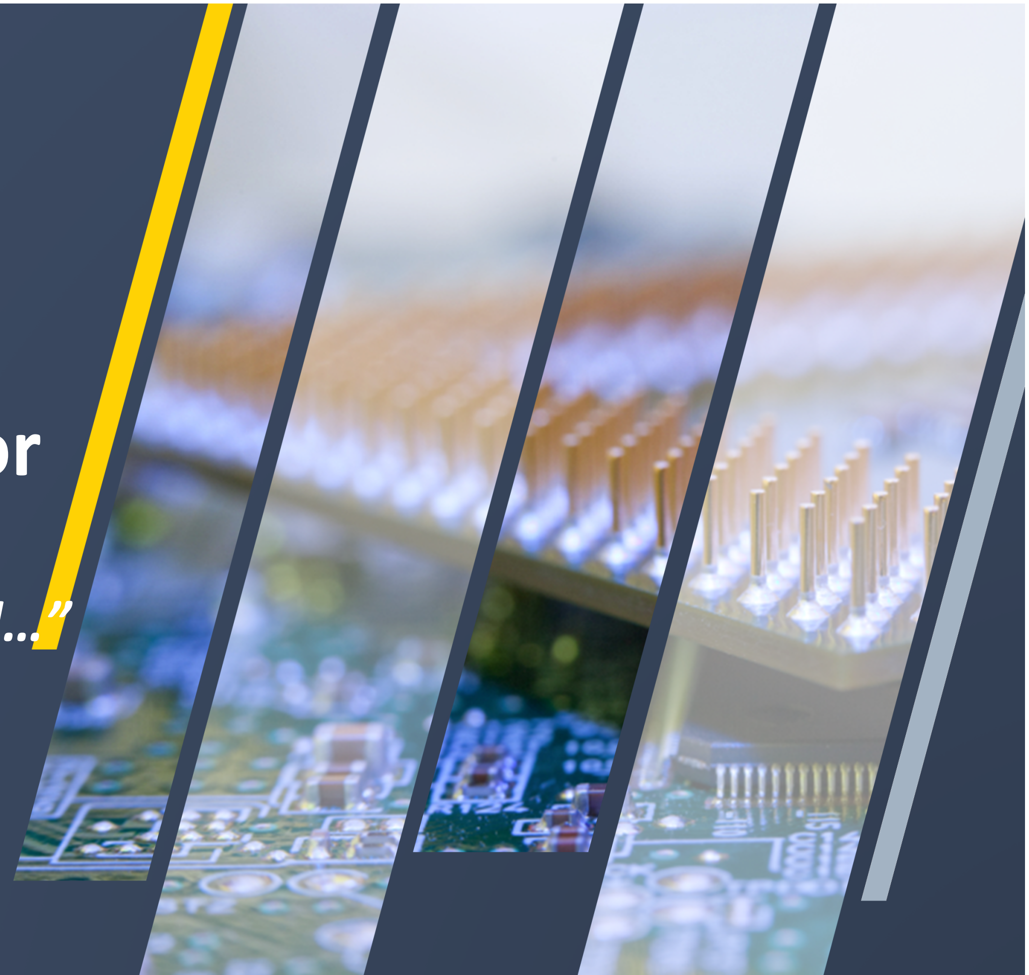
Installed Performance Modeling & Simulation for Antennas

"A good antenna, righteously placed…"



Shawn Carpenter

Sr. Product Manager, High Freq/RF

ANSYS Electronics Business Unit

shawn.carpenter@ansys.com

Advanced Modeling & Simulation (AMS) Seminar Series

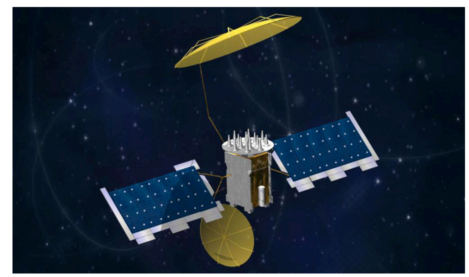
NASA Ames Research Center, February 18, 2020

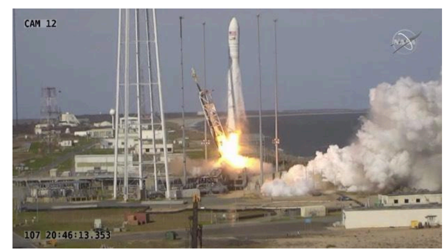
Today’s menu

- The Problem of Installed Antennas
- Installed antenna modeling & simulation: It takes a (small) village
- Examples
- Hybrid electromagnetic simulation in the ANSYS HF electromagnetic product family
- Fast medium-fidelity installed performance modeling

The problem: Installed antenna performance

- Antennas often designed in isolation or under ideal conditions
- Mounting antennas on realistic platforms changes performance
- Impacts overall RF system performance
  - Need to know installed performance early in the design cycle!



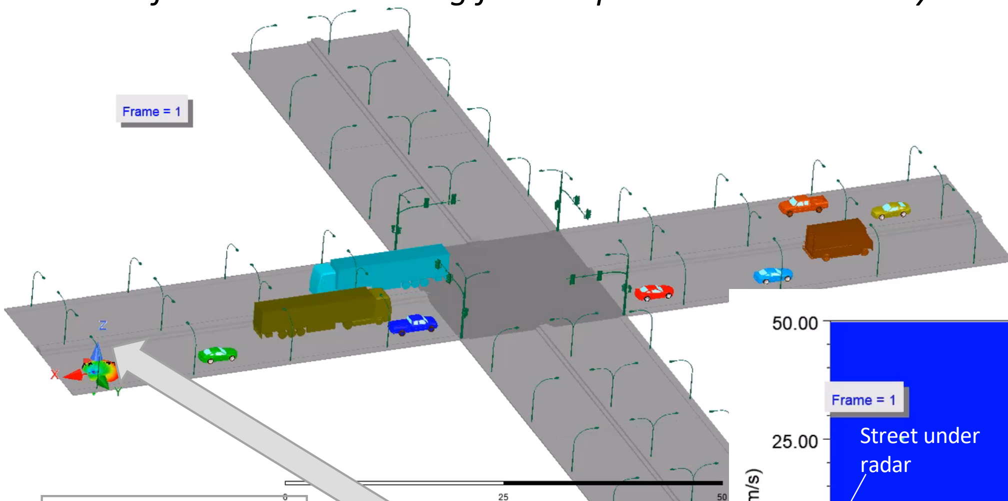


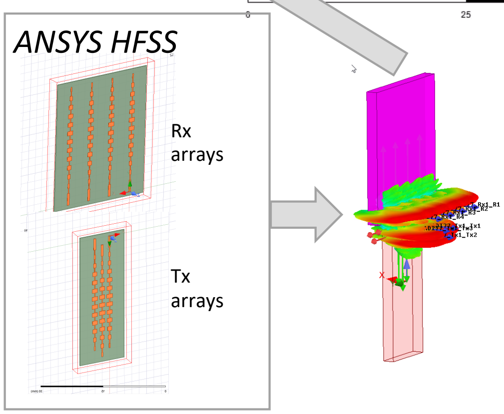
The problem: The environment of installed antennas

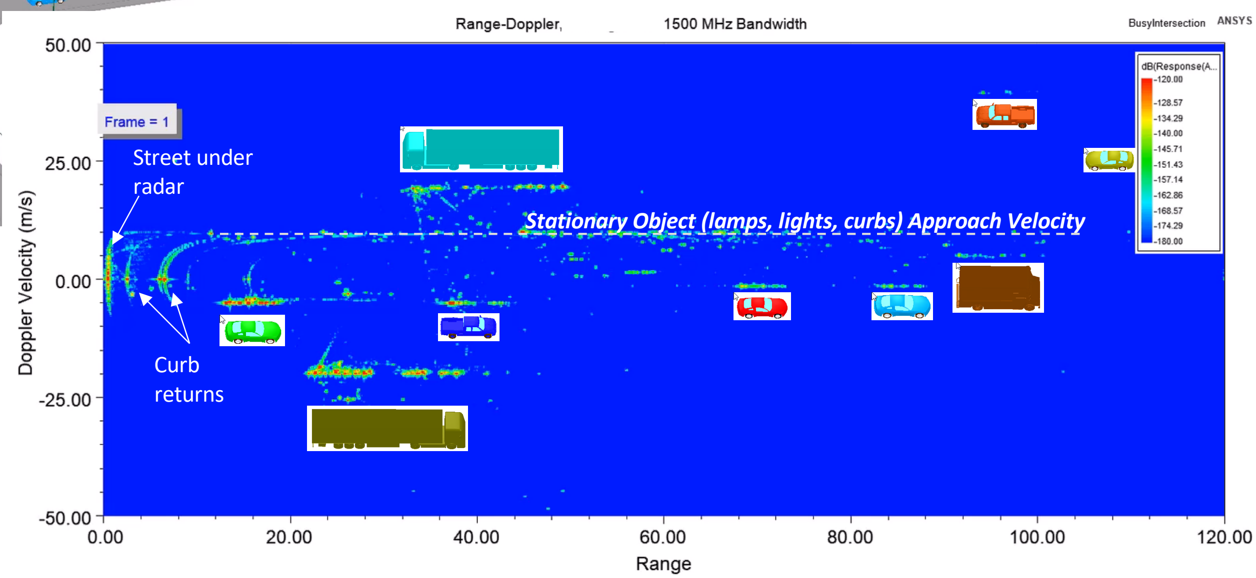
Near-field radar modeling for complete MIMO radars systems

Simulation by ANSYS

CS-FMCW Waveform:
- *BW: 1500 MHz*
- *PRF: 51.035 KHz*







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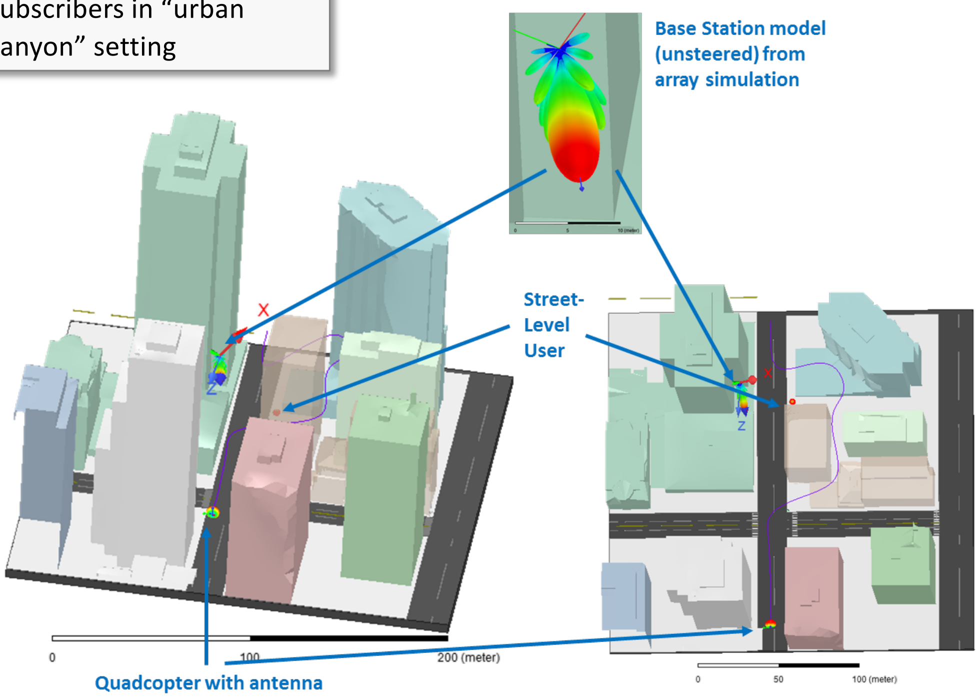
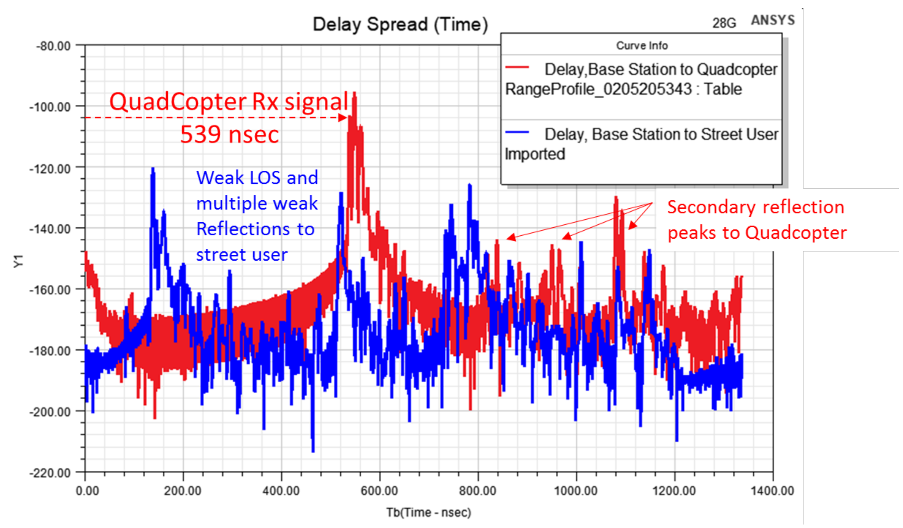
The problem: The environment of installed antennas

Physical Channel modeling for communications and sensors

28 GHz Base station and 2 subscribers in "urban canyon" setting

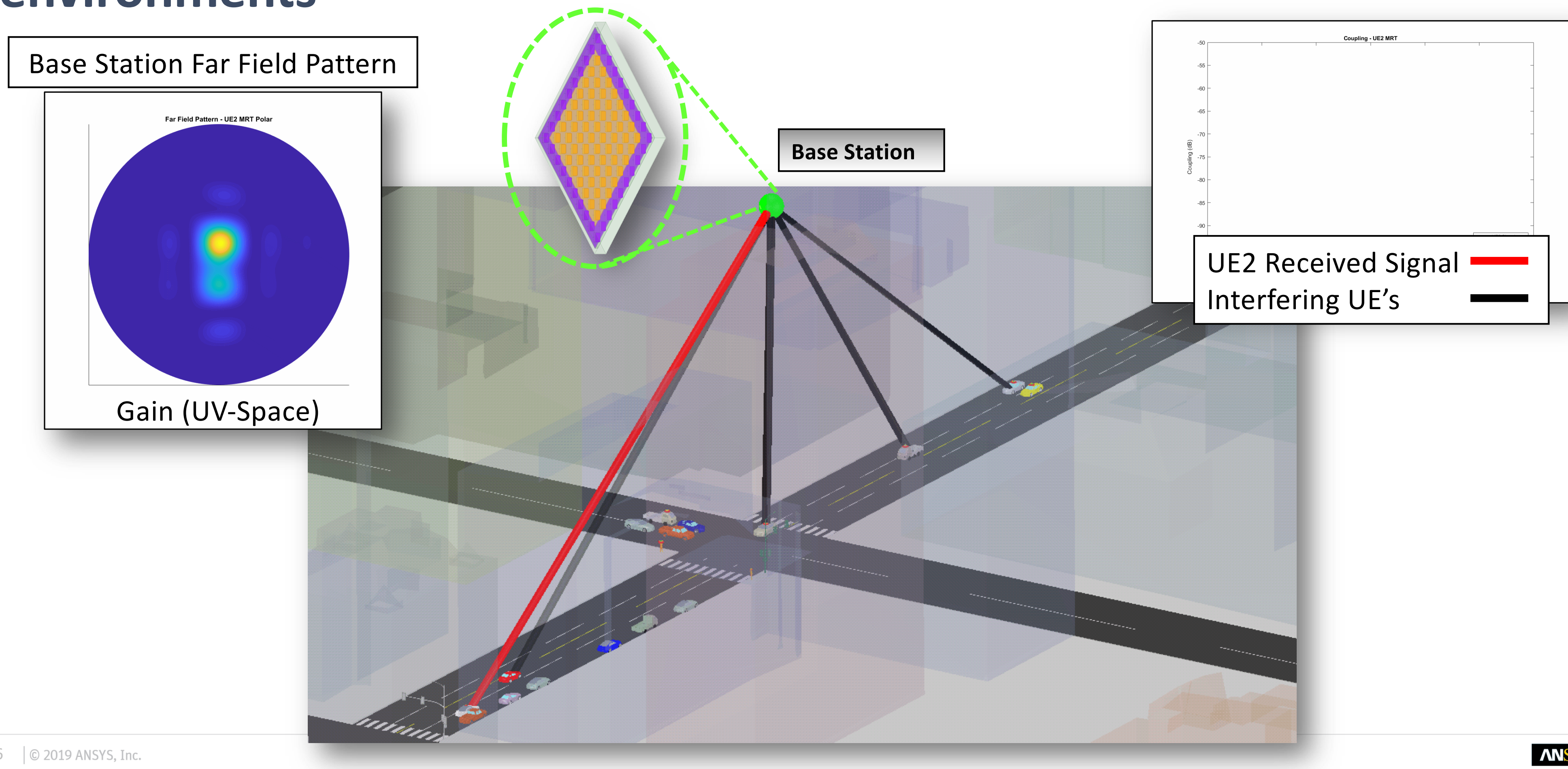


Signal delay spread from BS to each subscriber



Physical channel delay spread modeled at 28 GHz to 2nsec resolution

The problem: The environment of installed antennas in dynamic environments



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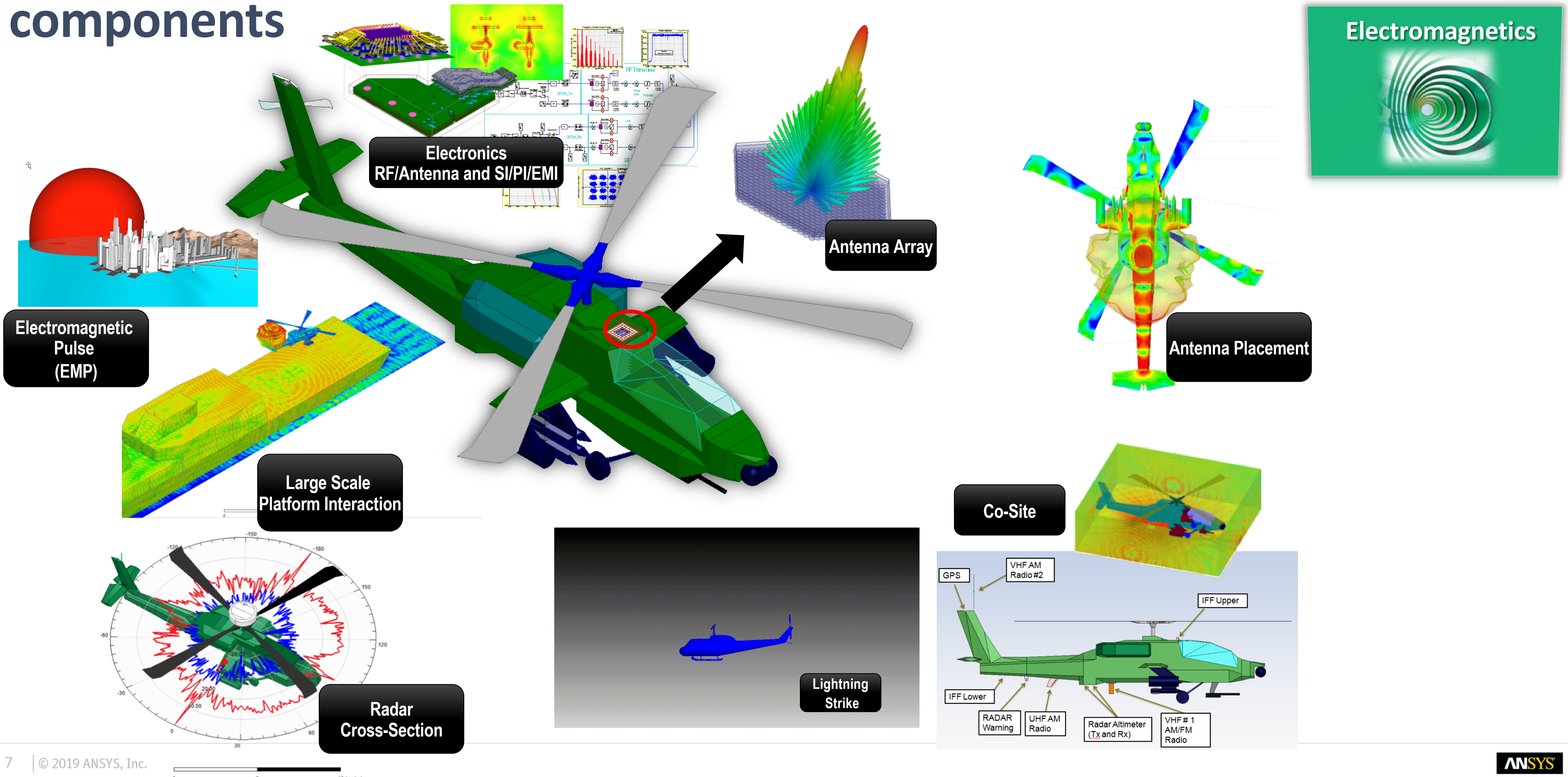
ANSYS Electronics – Physics-based simulation of antennas and components



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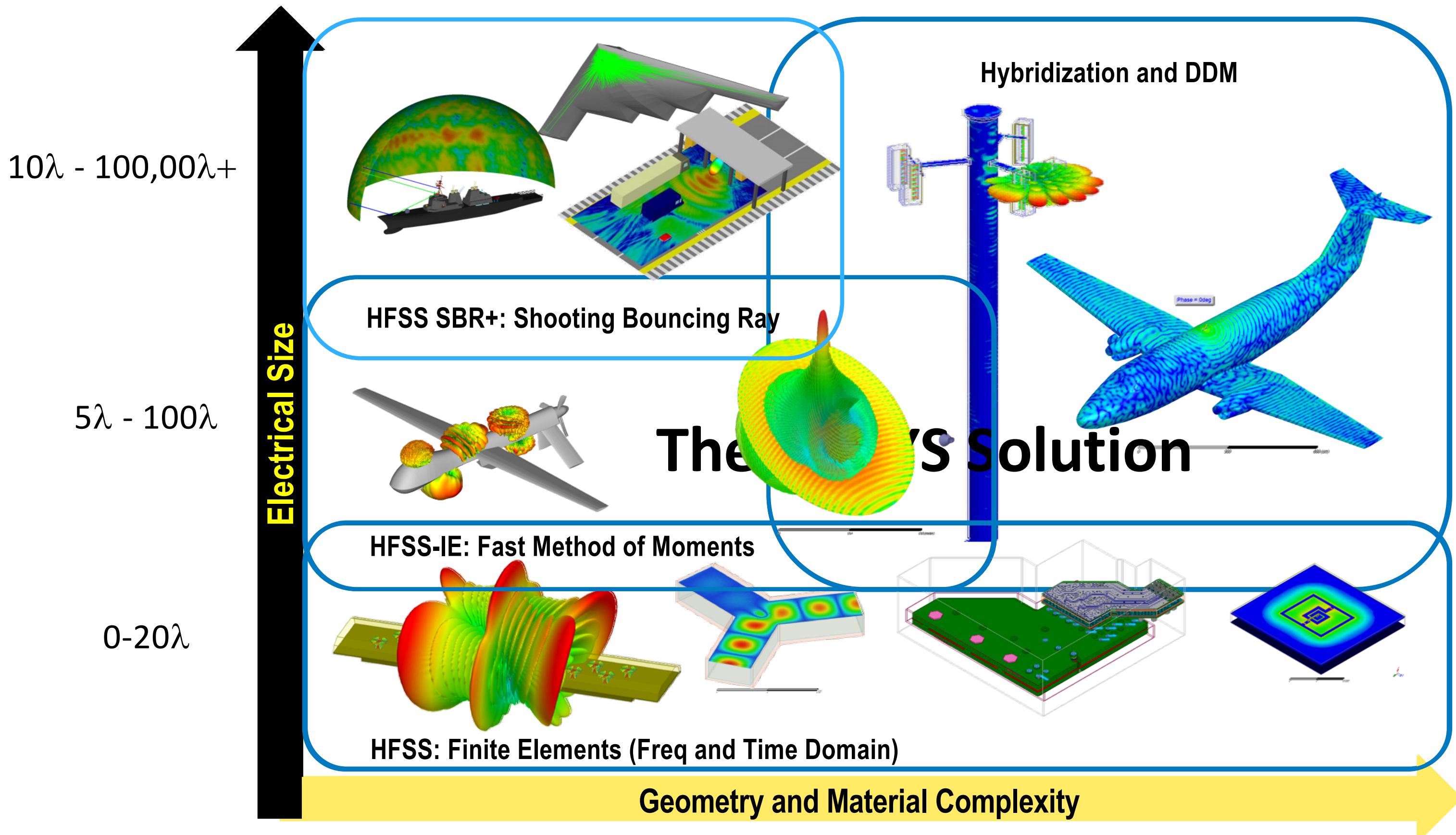
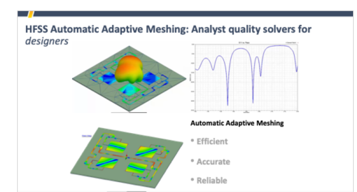
ANSYS high frequency (HF) electromagnetic (EM) solvers



- AUTOMATIC hybridization of techniques
- AUTOMATIC meshing and mesh convergence



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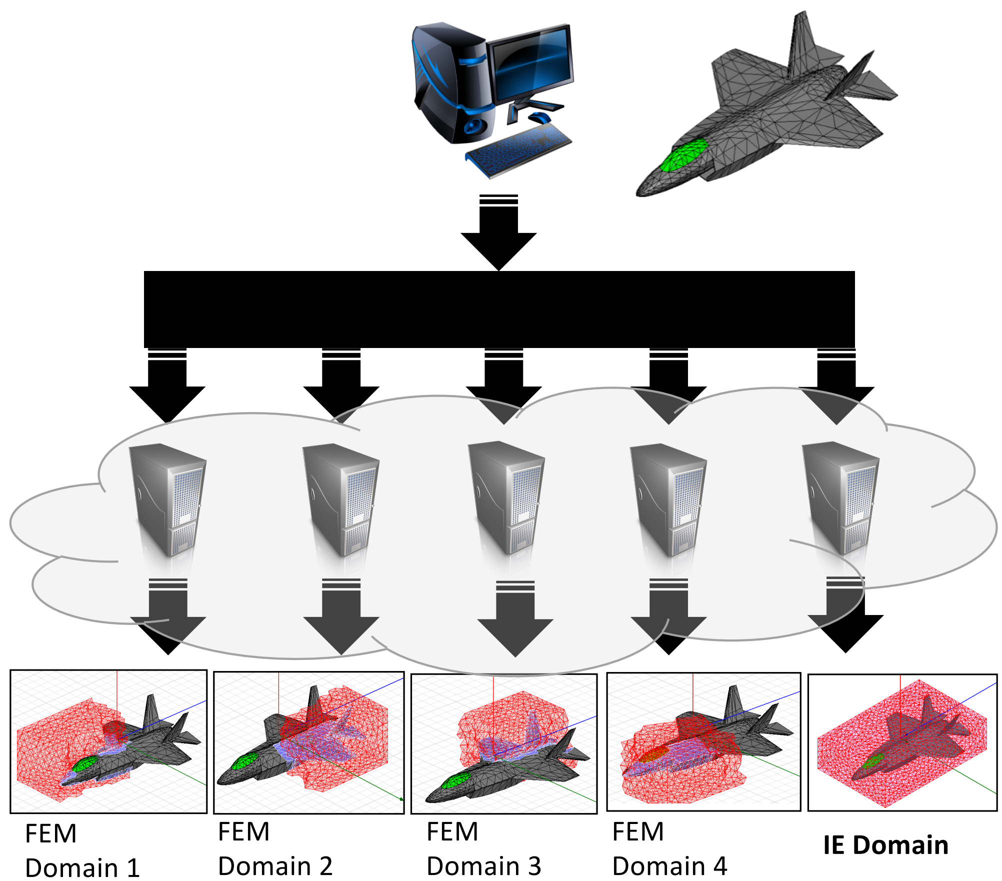
Leveraging High Perf Computing (HPC)

- Multi-solver aware
  - Hybridization in context of a single solve
- Domain Decomposition (divide space and conquer)
- Frequency division (divide solution points and conquer)
- Automated parameter sweeps and optimization processes (divide solution space solutions)
- 2-Level and 3-Level distributed computing
- Increased capacity
- Increased scalability

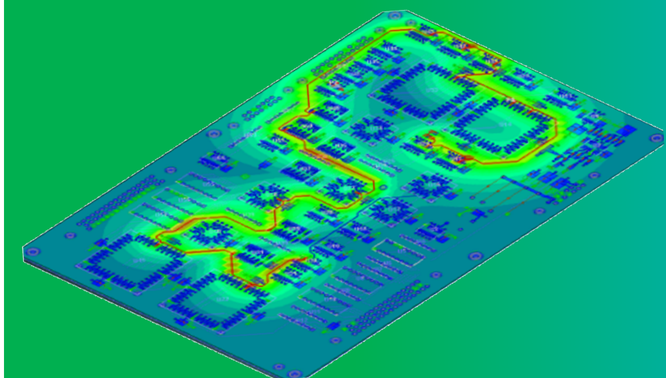
ANSYS Cloud access as a desktop client

- **Scalable, high-capacity HPC**
- **Access on demand for short-term project demands**



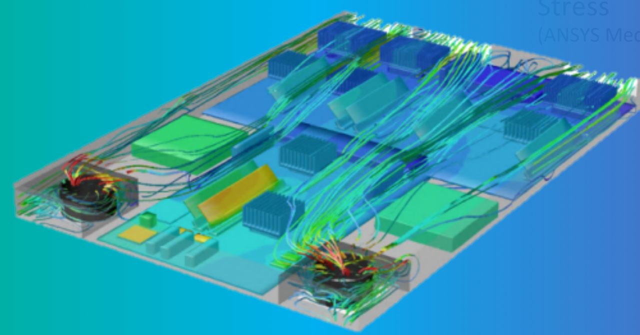
Pervasive simulation to solve coupled physics problems

ANSYS HFSS/SIwave – Electrical reliability



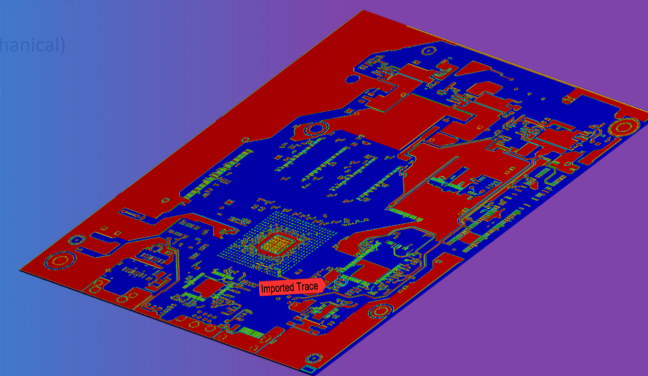
- Signal integrity
- Power integrity
- Electrostatic discharge
- Electromagnetic emission

ANSYS Icepak – Thermal reliability



- Electronics cooling
- Fast hotspots determination

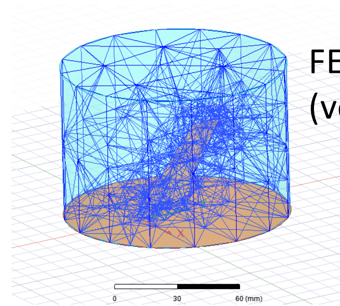
ANSYS Mechanical – Structural reliability



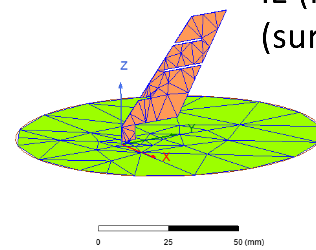
- Board deformations
- Vibrations analysis
- Delamination
- Fatigue

Hybrid Regions define which technique is used, and where

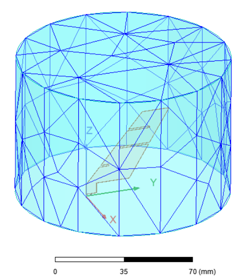
- FEM Regions (volume meshing)
- IE Regions (surface meshing)
- FEBI Regions (surface mesh bounding FEM region that couples to other regions)
- PO Regions
  - Single-bounce interaction to large objects
- SBR+ Regions (multi-bounce PO, one-way coupling with blockage effects and antenna coupling)



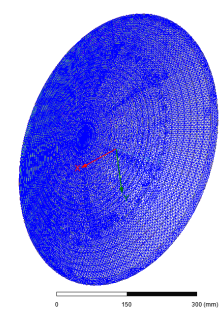
FEM Mesh (volume)



IE (MoM) Mesh (surface)

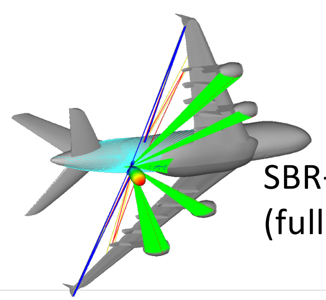


FEBI Mesh (top/side surfaces)



PO Mesh (triangles)

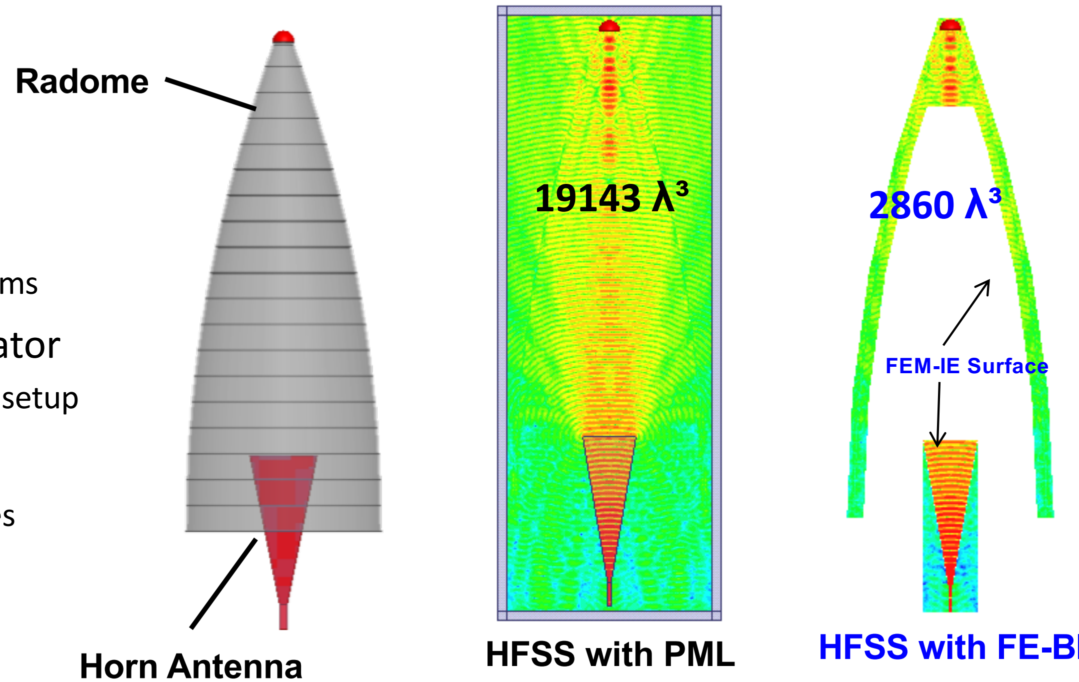
- For geometries with 1-bounce interaction
- Full 2-way interaction



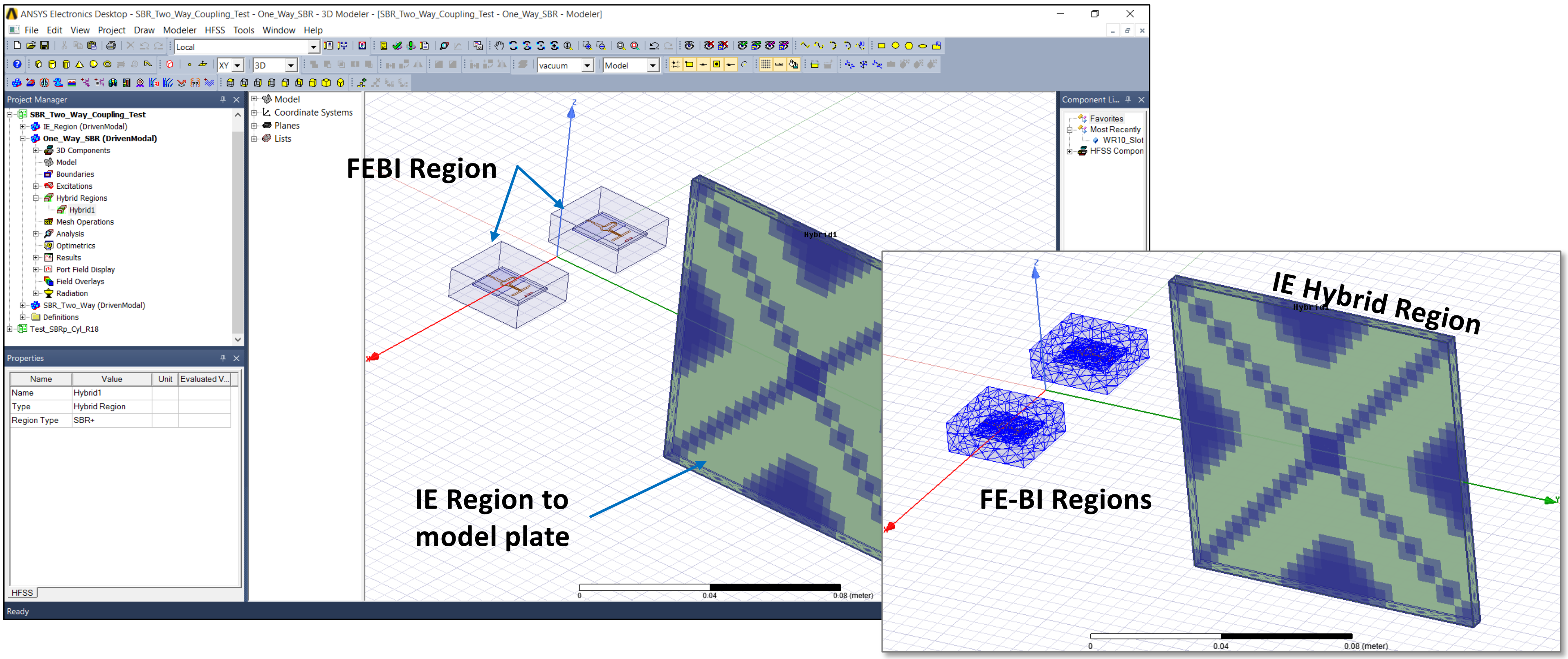
SBR+ Regions (full platform)

Using FEBI to couple FEM regions

- FE-BI: Finite Element-Boundary Integral
- Arbitrary shaped boundary
  - Conformal and discontinuous
  - Minimize FEM solution volume
- Reflection less boundary condition
  - High accuracy for radiating and scattering problems
- No theoretical minimum distance from radiator
  - Reduce simulation volume and simplify problem setup
- Boundary Coupling
  - Disjoint FEM volumes couple via FE-BI boundaries



Using FEBI to couple FEM to IE (MoM) regions



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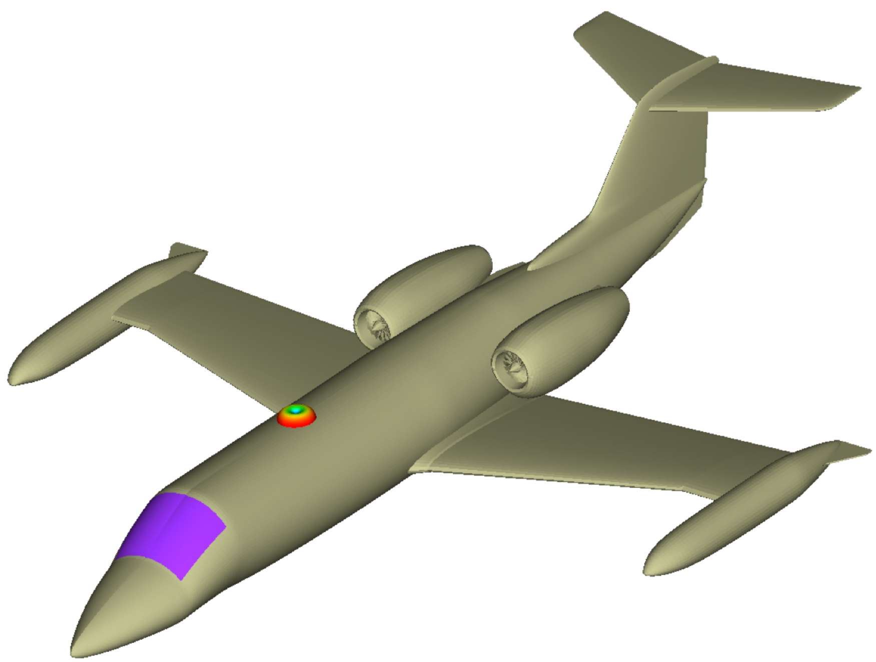
Shooting and bouncing rays (SBR) with advanced diffraction (SBR+)

- HFSS SBR+ is based on Physical Optics (PO) method for solving electrically large problems (antenna+platform, antenna+local_environment)
- Shooting and Bouncing Rays (SBR) method based on the PO framework
  - But with some important extensions for high fidelity modeling!
- HFSS SBR+ extends SBR to multi-bounce ray physics using Geometric Optics (GO) ray tracing
- HFSS SBR+ includes advanced physics from the Uniform Theory of Diffraction (UTD) frameworks (Creeping Waves, PTD Edge Correction, UTD Diffraction Ray sources, Curvature Divergence Correction, etc.)

Installed antenna analysis on a LearJet



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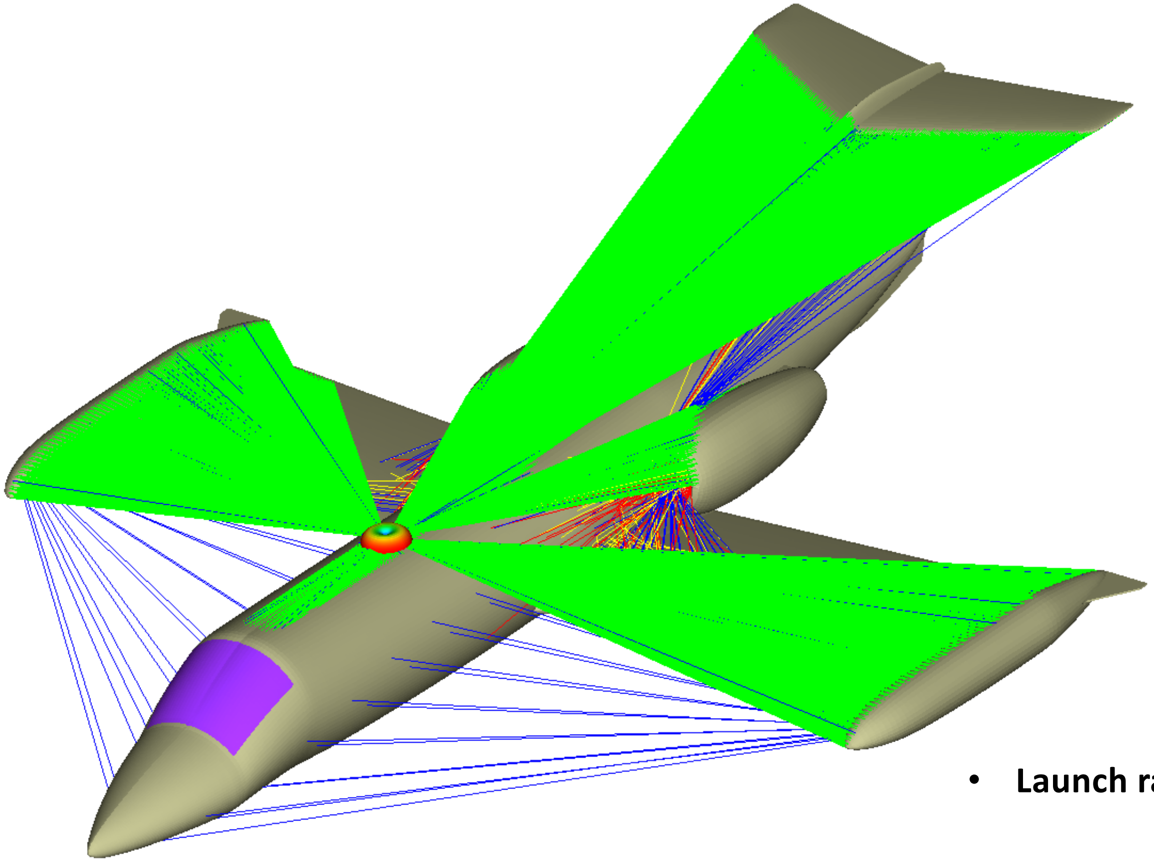
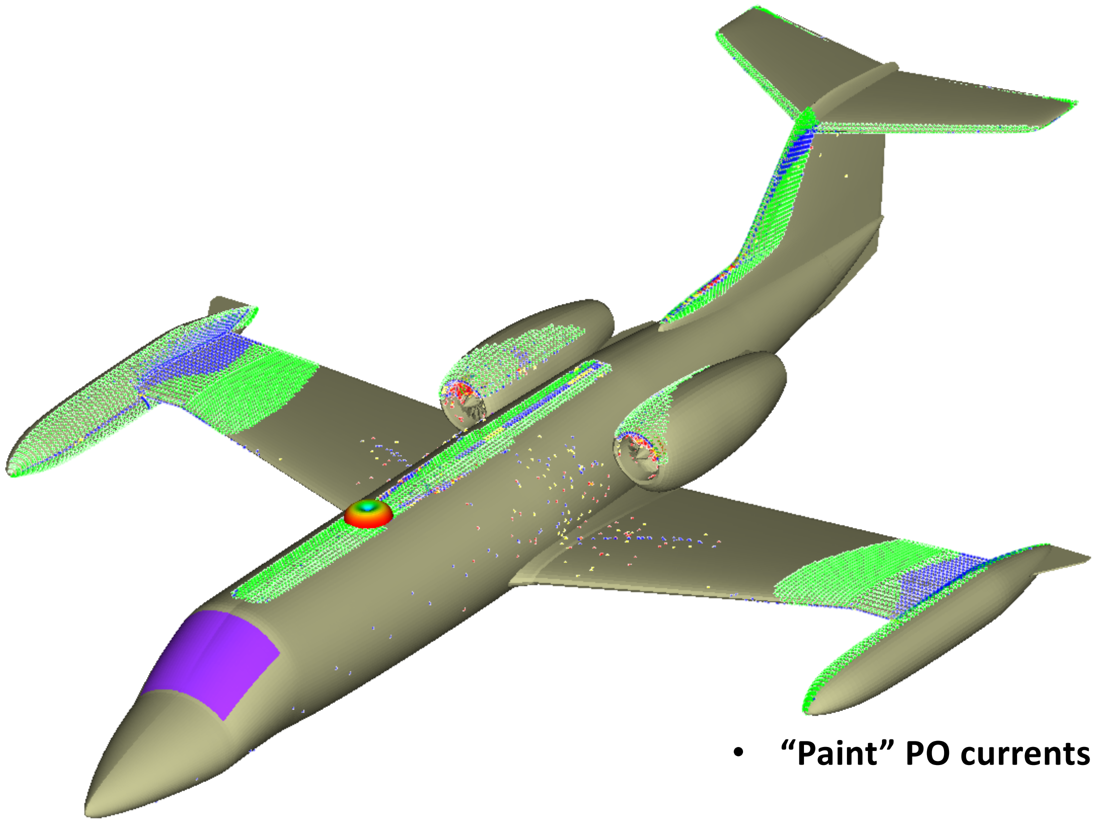
SBR rays from antenna (1-5 bounces)



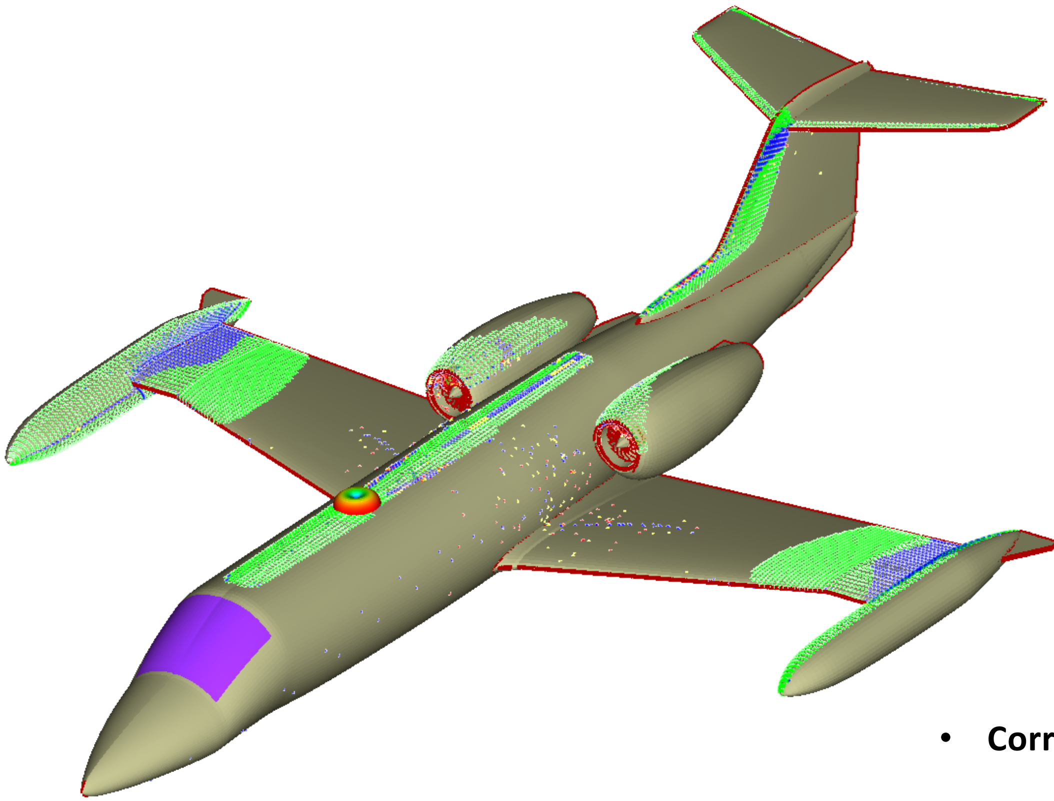
- **Launch rays from antenna**

SBR Ray Footprints



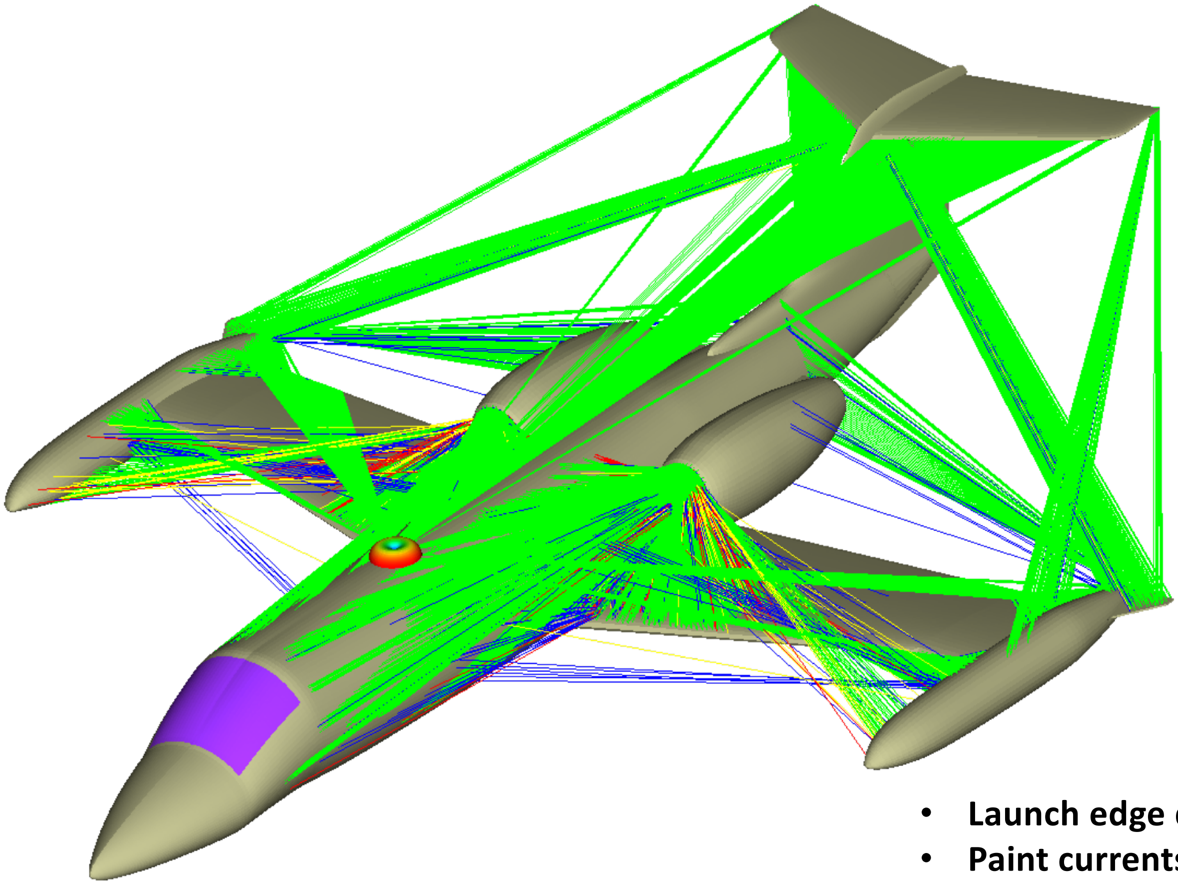
- **“Paint” PO currents on surfaces**

SBR+: PTD Edge Current Correction



- **Correct PO currents along edges**

SBR+: UTD (Edge Diffraction Source) Rays



- Launch edge diffraction rays along edges
- Paint currents in shadow regions

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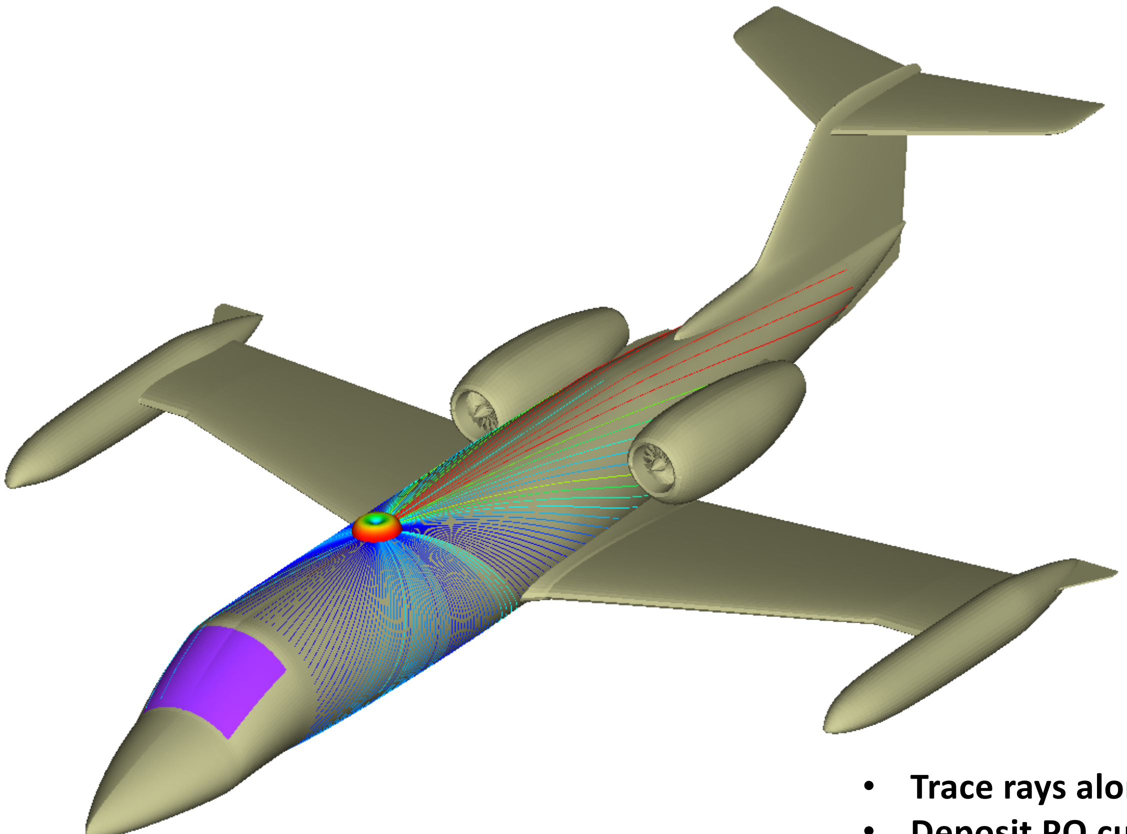
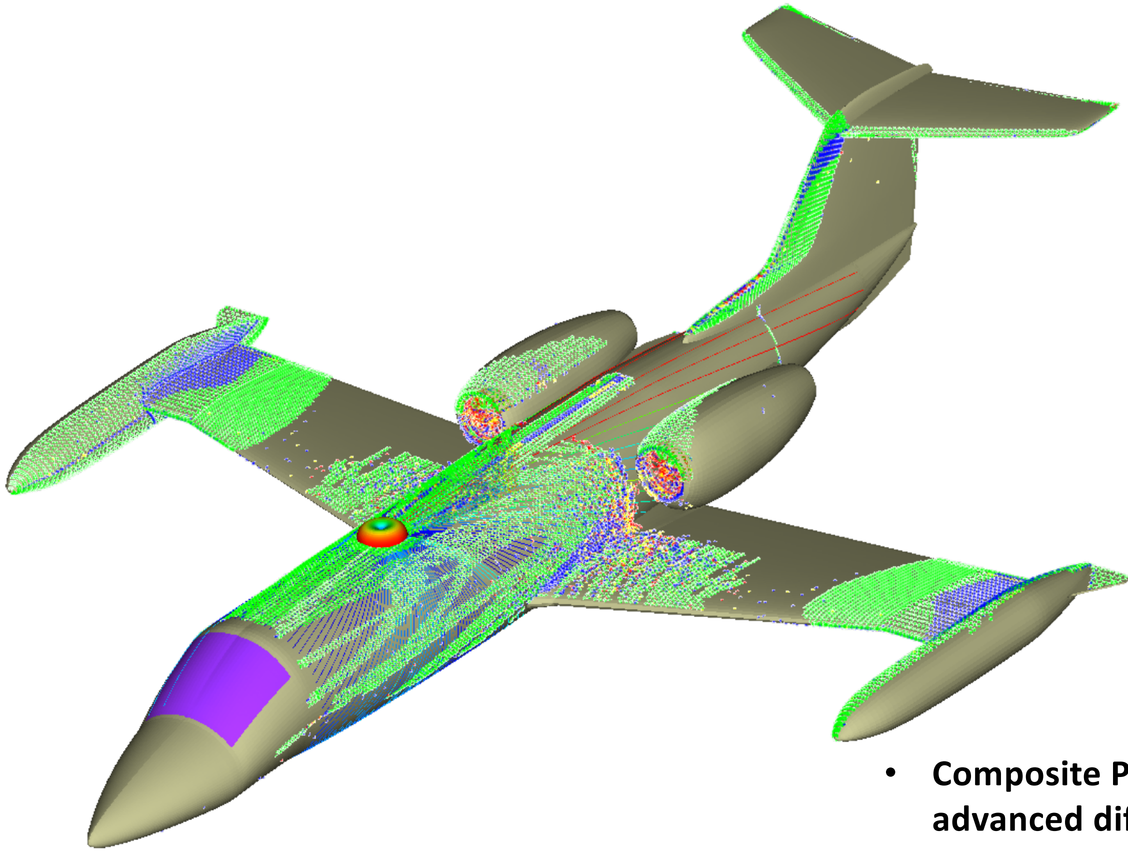
SBR+: Creeping Wave Rays



- Trace rays along surfaces
- Deposit PO currents

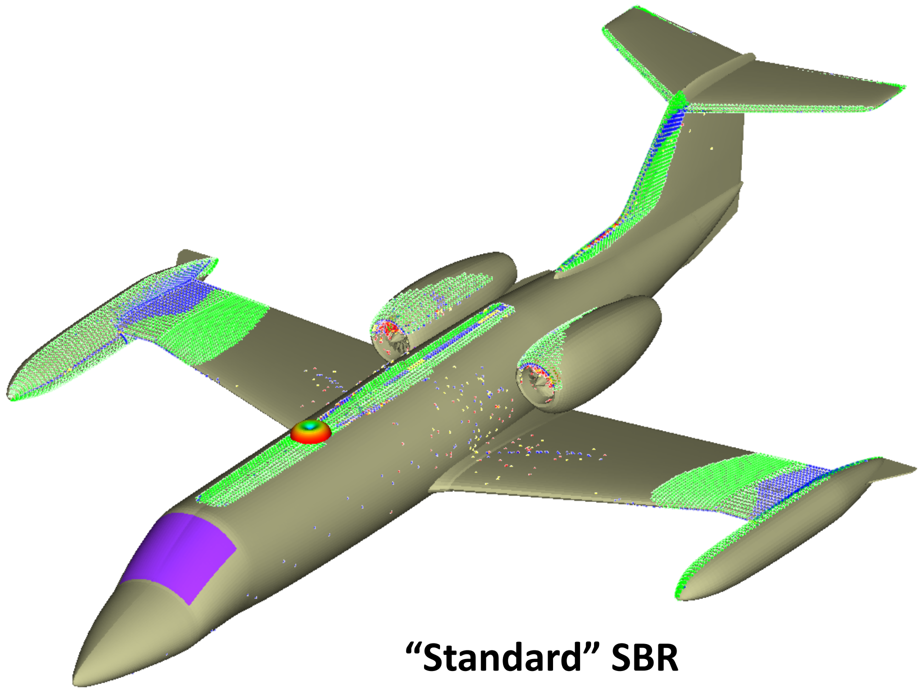
SBR+: PO Currents Painted by all SBR+ Physics



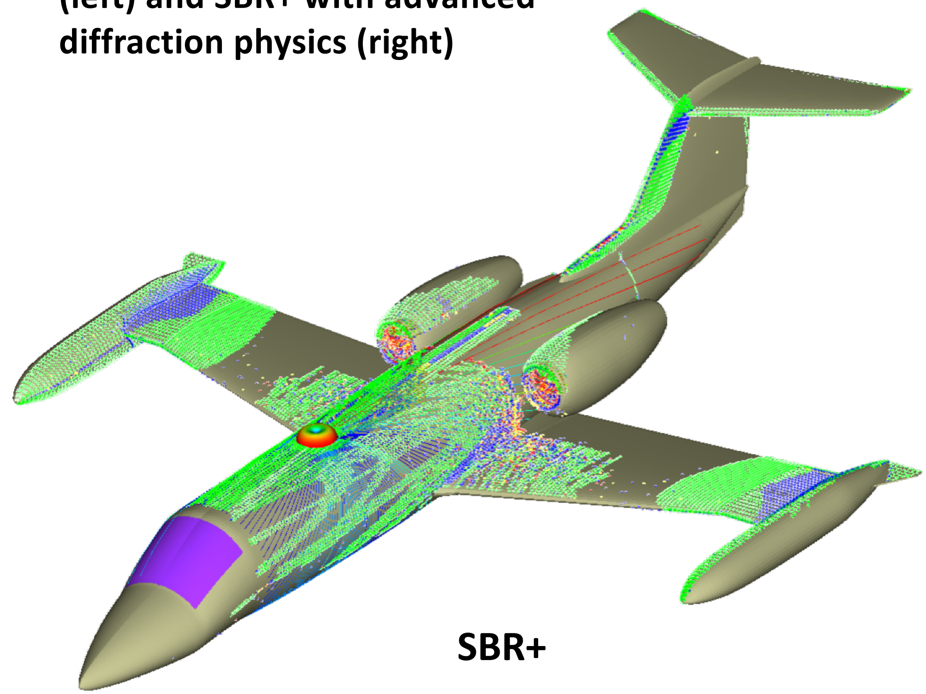
- **Composite PO currents from SBR + advanced diffraction physics**

SBR vs SBR+: Currents Painted

- **PO currents from PO-SBR alone (left) and SBR+ with advanced diffraction physics (right)**



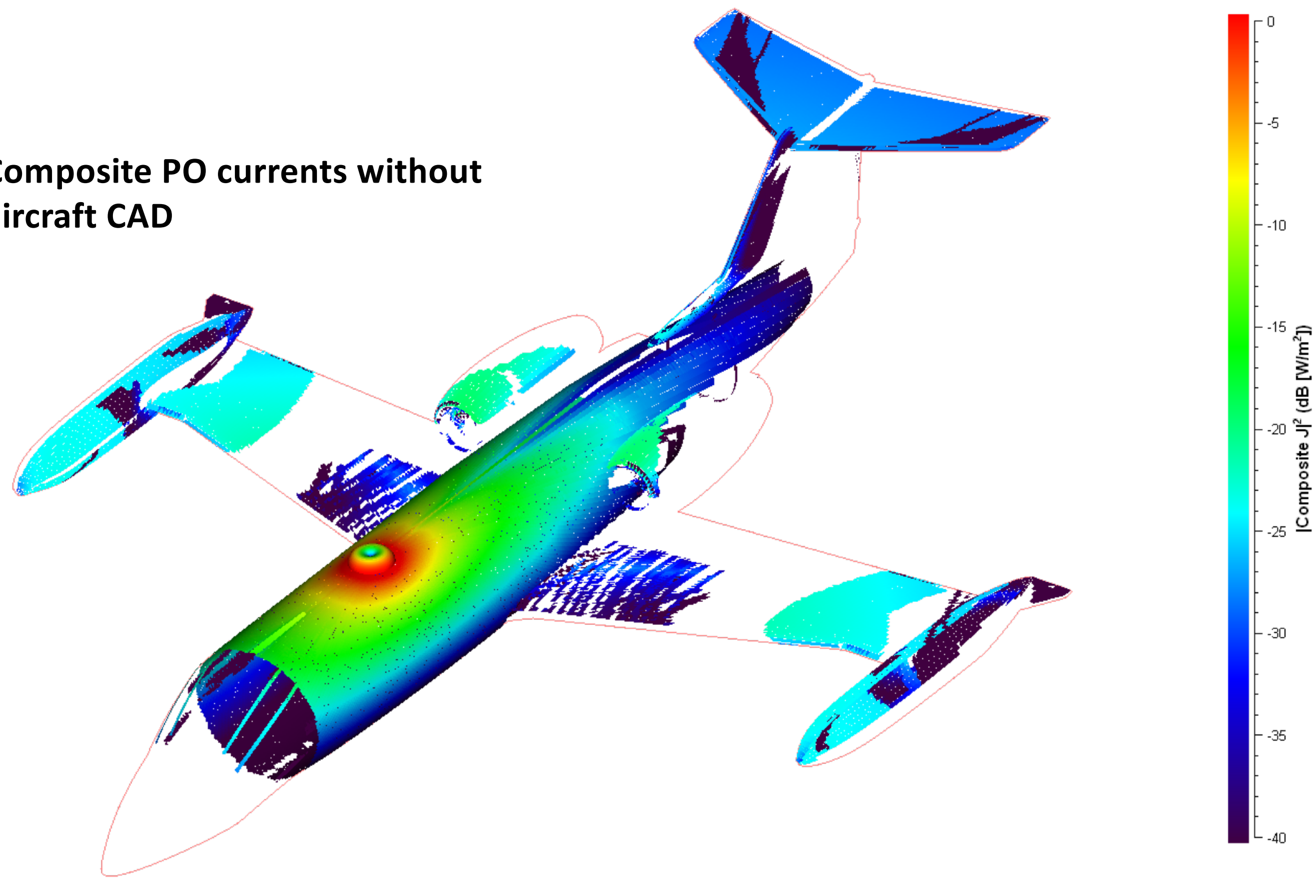
“Standard” SBR



SBR+

PO Currents are Radiated to Observers

- **Composite PO currents without aircraft CAD**



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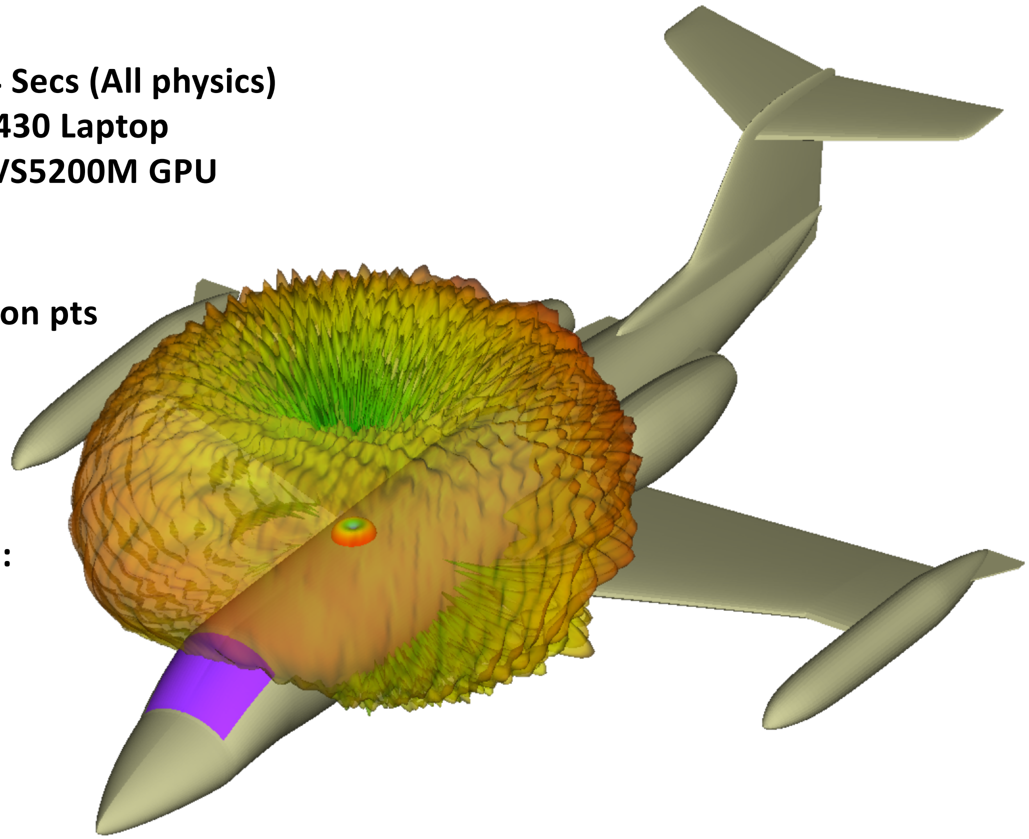
Installed Radiation Pattern by HFSS SBR+

Simulation time: 184 Secs (All physics)
Computer: Lenovo T430 Laptop
Nvidia NVS5200M GPU
RAM Used: 1.1 GB

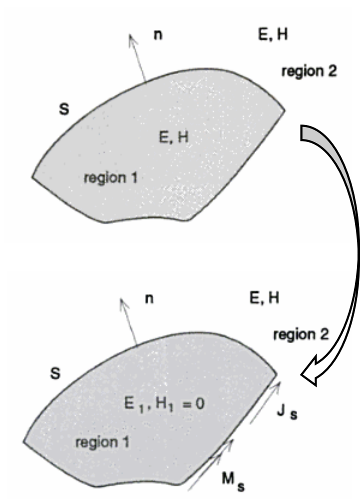
129,600 FF observation pts

Problem size (1 GHZ):
50λ x 40λ x 10λ



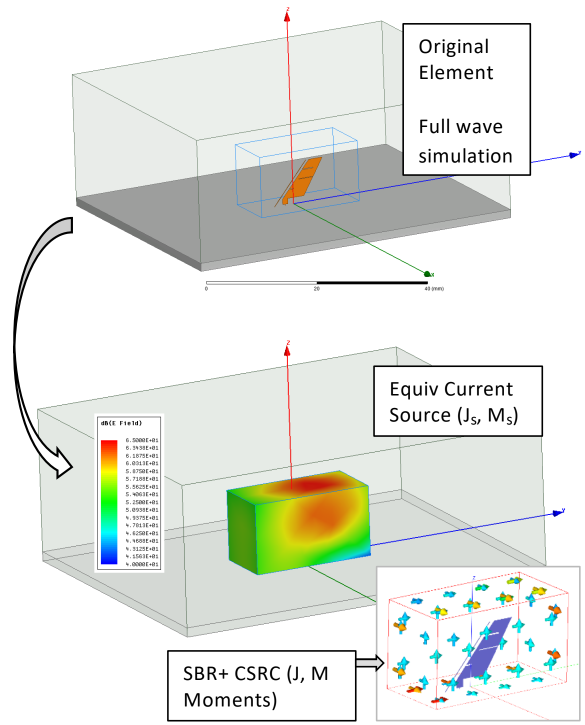
Using FEBI (or IE) Regions to model antennas in SBR+ Regions

Using high-fidelity antenna models from FEM in SBR+ simulations



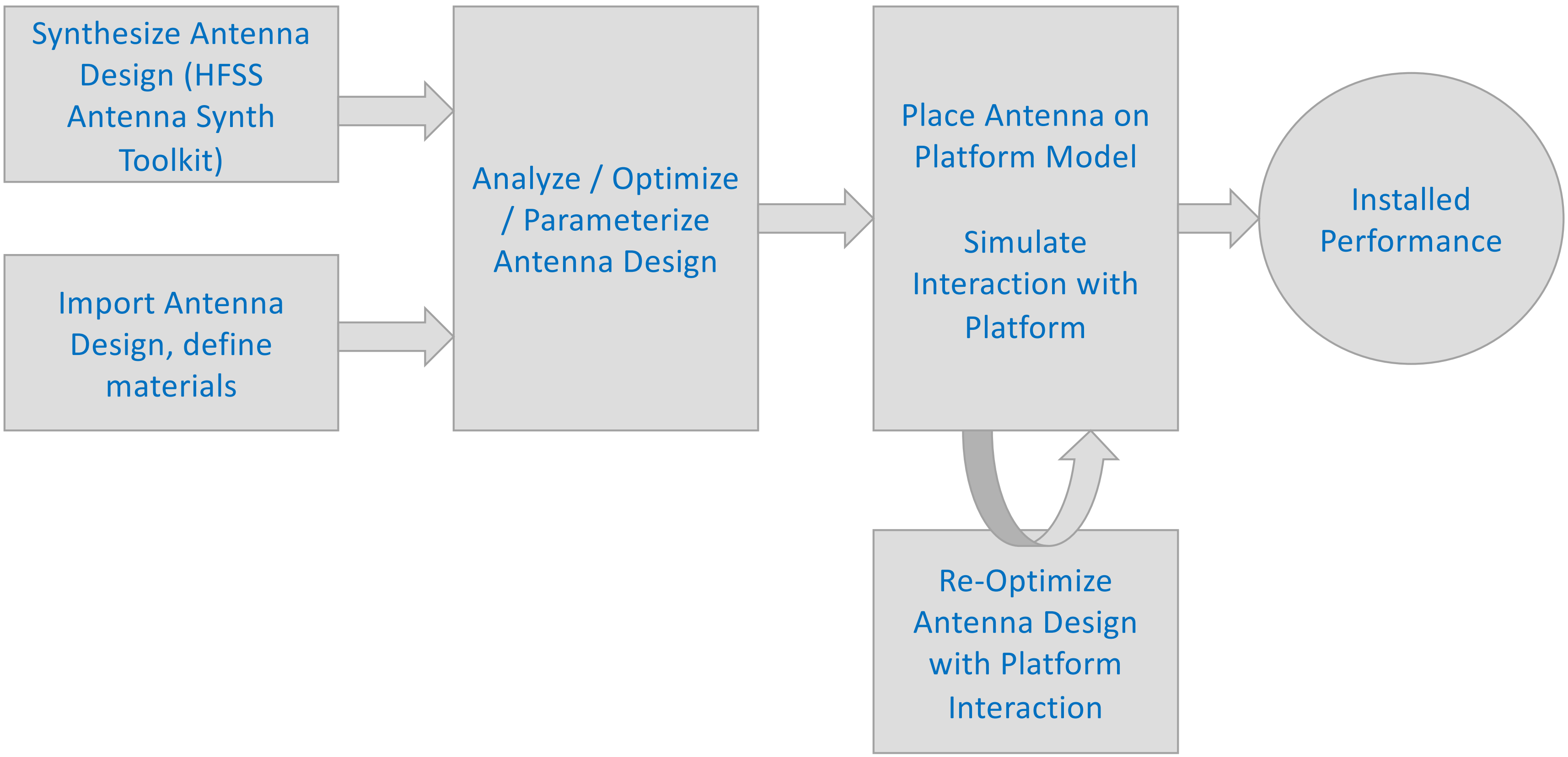
$\mathbf{J}_s = \mathbf{n} \times \mathbf{H}$

$\mathbf{M}_s = -\mathbf{n} \times \mathbf{E}$



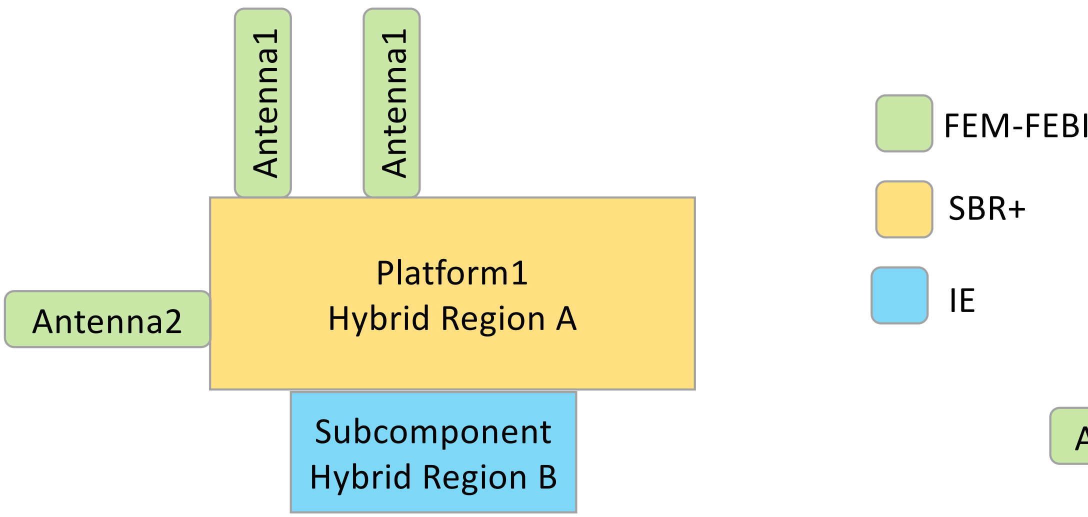
- **Free-standing antennas: - Use complete volume**
- **Antennas integrated into platforms:**
  - **Use bounding surfaces around infinite ground planes**

Installed Antenna workflow

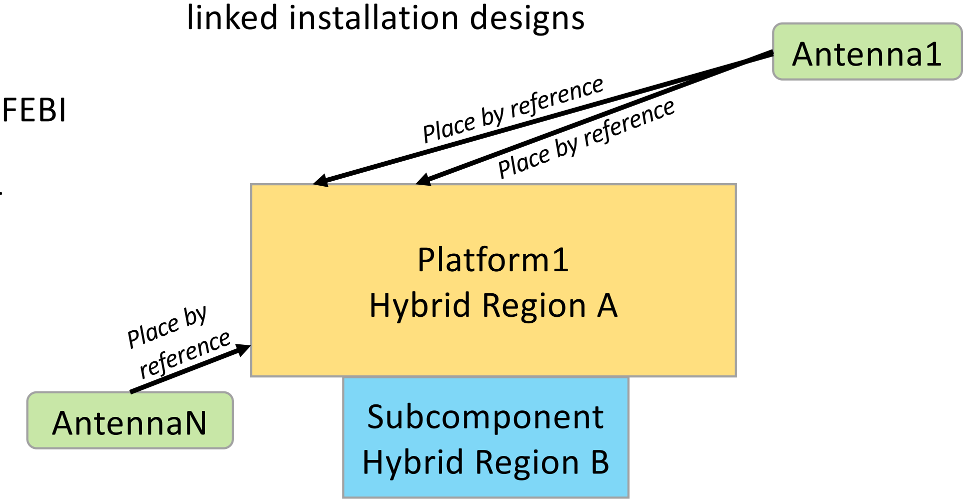


Hybrid electromagnetic simulation – 2 workflows

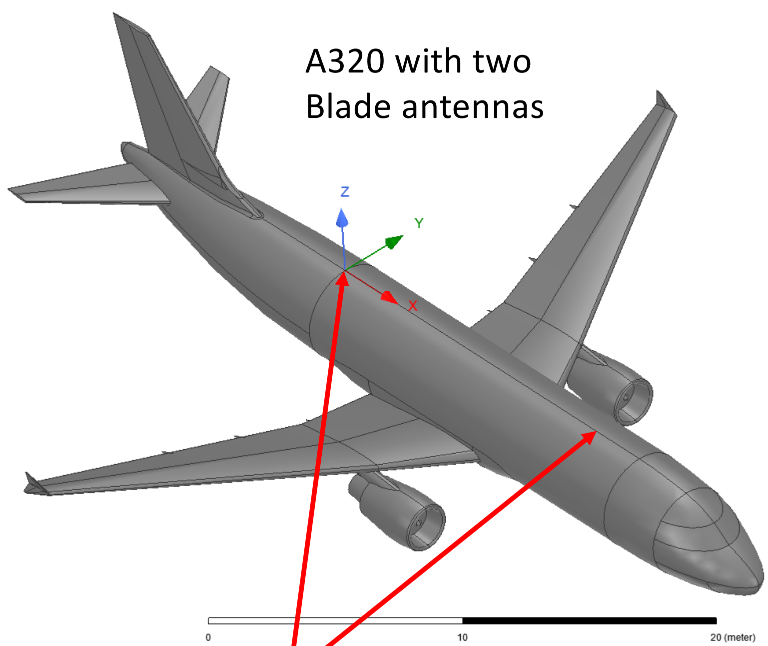
- Explicit Hybrid modeling
  - Everything is in one project
  - All antennas solved together with the installation platform
  - More flexible when the antenna is tightly integrated to platform discontinuities



- Linked-Source Hybrid (Hierarchical) modeling
  - Platform in one simulation (IE, PO, SBR+), antennas in another (FEM, FEBI, IE)
  - Allows antennas to be pre-solved
  - Solved antenna designs can be referenced to multiple instances
  - Source antenna design changes propagate to linked installation designs

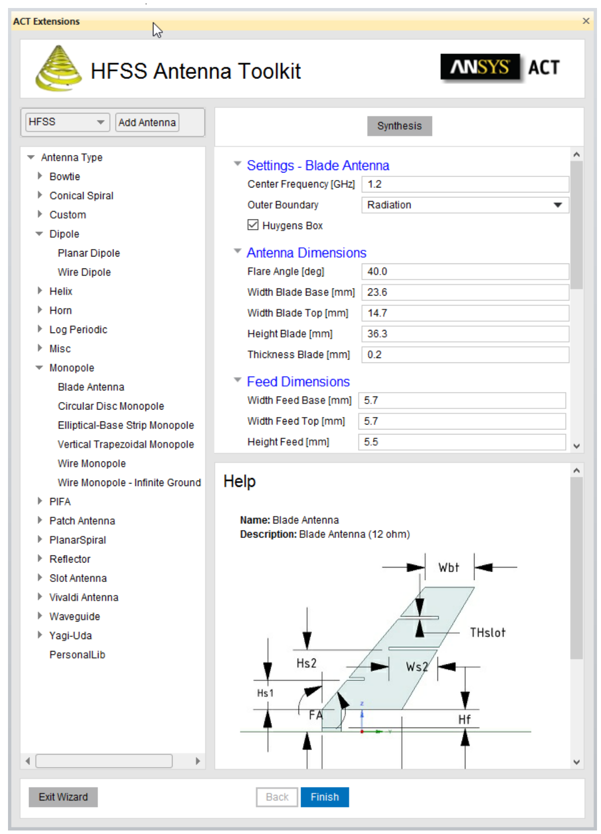


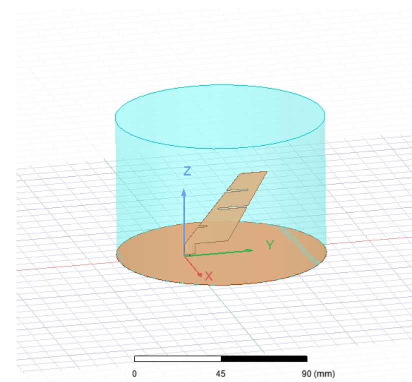
Installed Antennas – ANSYS Workflow for Explicit Hybrid modeling



A320 with two
Blade antennas

Place 1.2 GHz blade antenna in
2 locations to model coupling

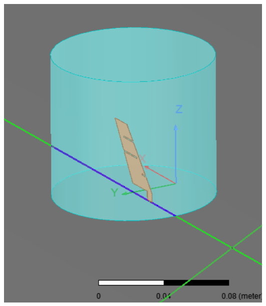




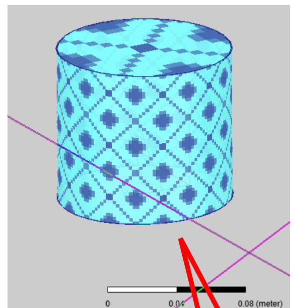
HFSS Antenna Toolkit creates
1.2 GHz Blade Antenna model

Take the antenna geometry
and place on the aircraft body

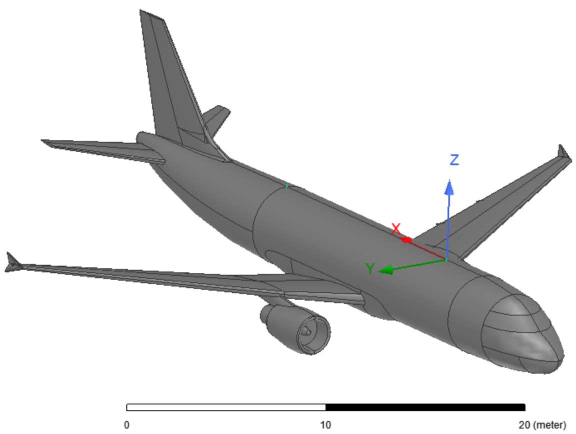
Installed Antennas – ANSYS Workflow for explicit hybrid modeling

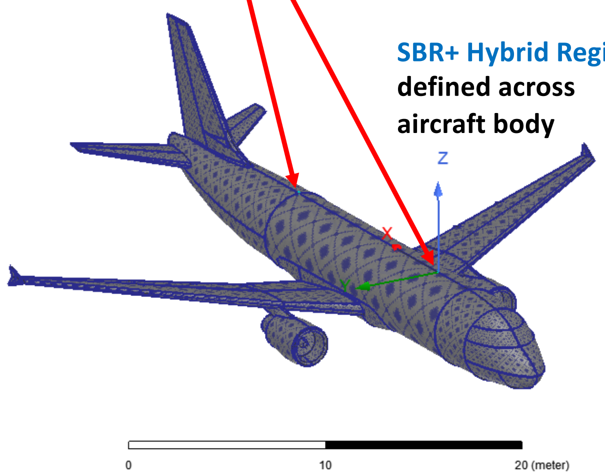


Create a vacuum “box” around the antenna



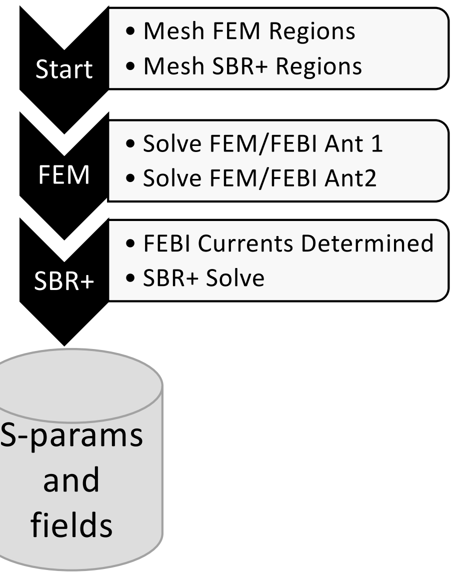
FEBI Hybrid Region defined on outer surface of the vacuum box (sides and top). Conductor found on bottom.
1 model for each antenna (2 ports)



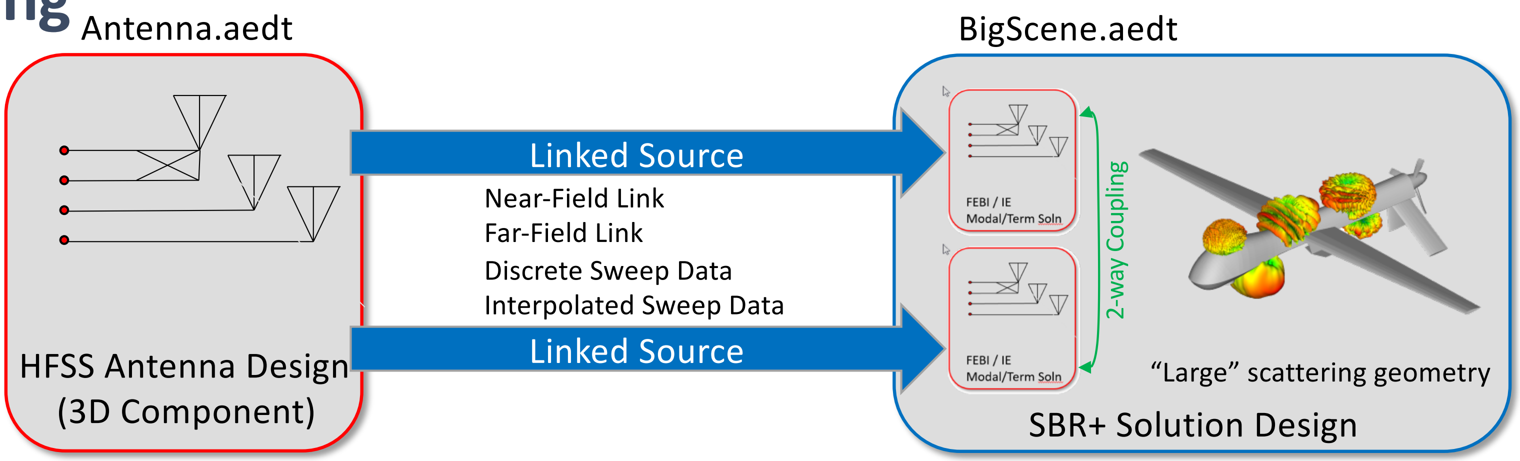


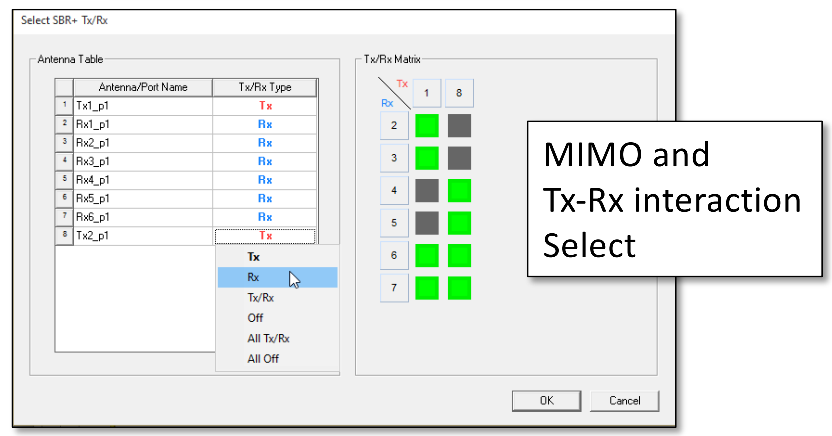
SBR+ Hybrid Region defined across aircraft body

Solution Process



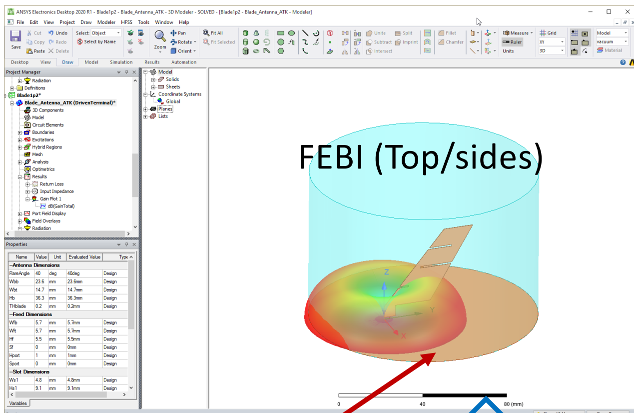
Installed Antennas – ANSYS Workflow for Linked-Source Hybrid modeling





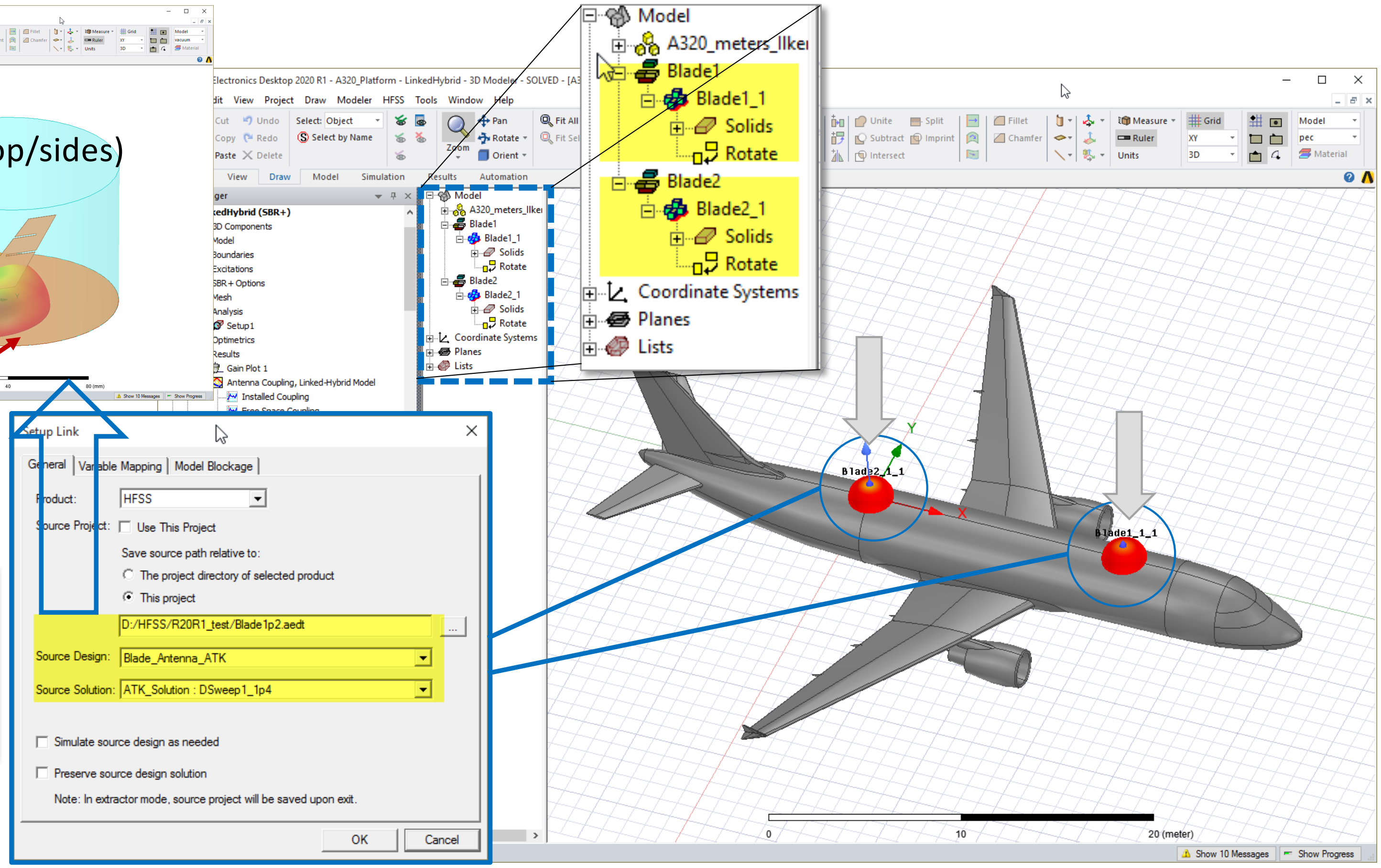
- Installed couplings between any antennas
- Efficient MIMO coupling in large environments

Linked-Hybrid: 1.2 GHz blade example on A320 aircraft

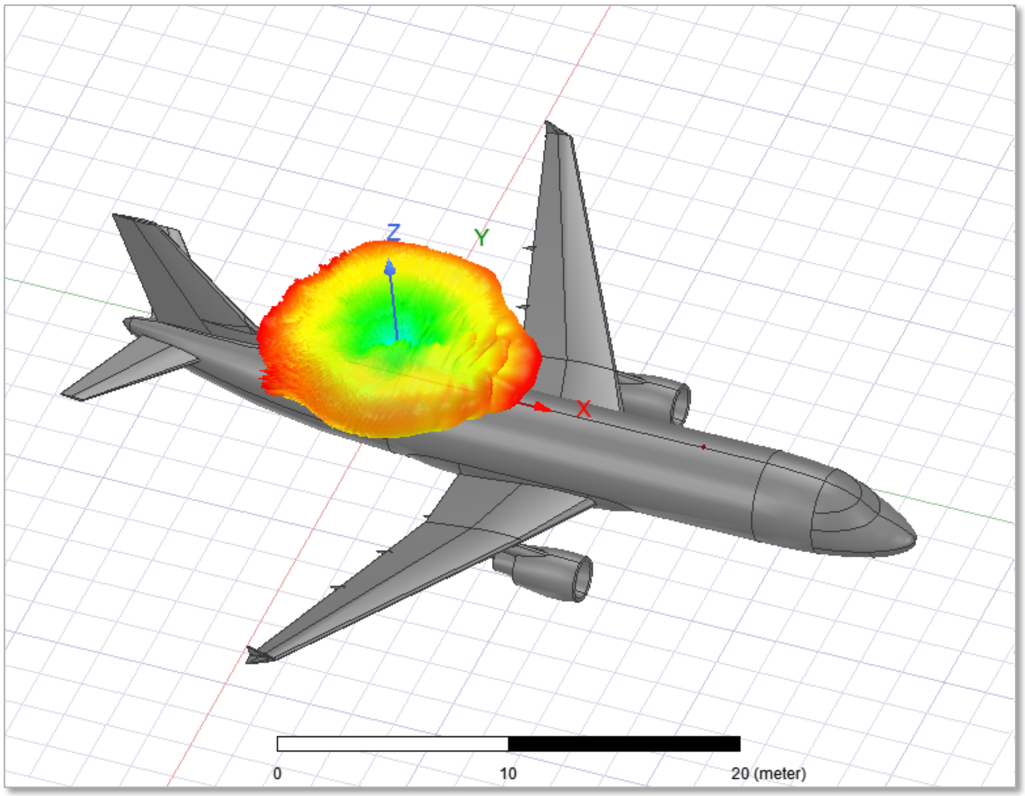


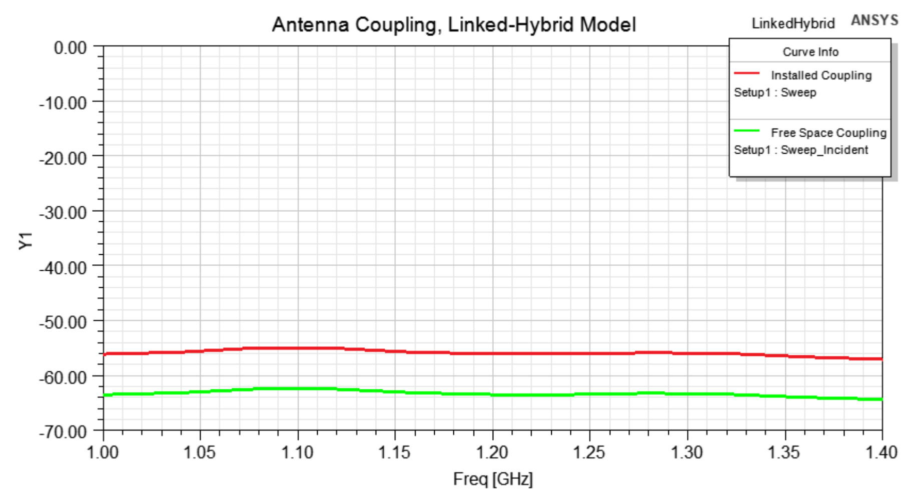
Conductive Gnd Plane
(Modeled as "Infinite
Ground Plane")

Infinite ground plane definition used for "pristine" fields without finite ground plane truncation effects



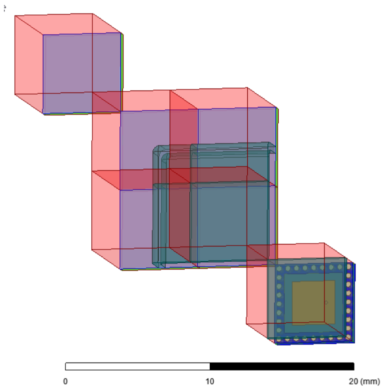
Linked-Hybrid: 1.2 GHz blade example on A320 aircraft





Installed pattern for rear blade antenna and antenna-to-antenna coupling (free space and installed)

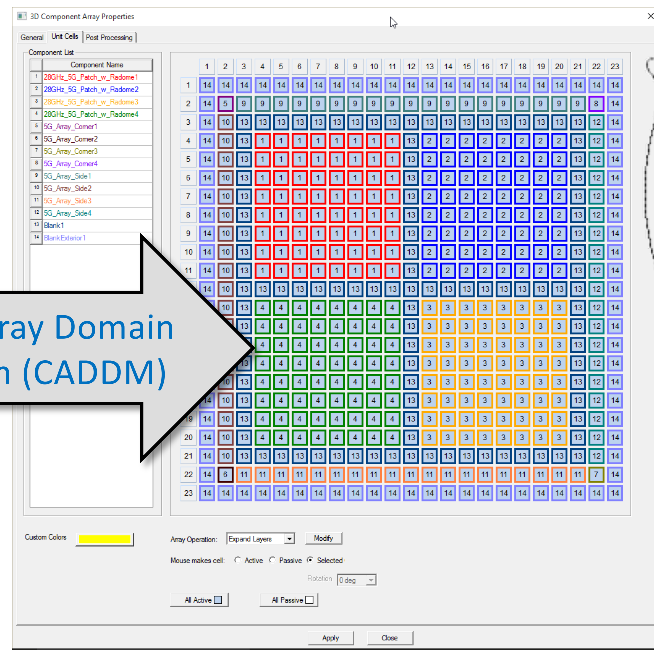
Phased Array Antenna (PAA) Analysis in HFSS – ultimate hybrid for complex array design

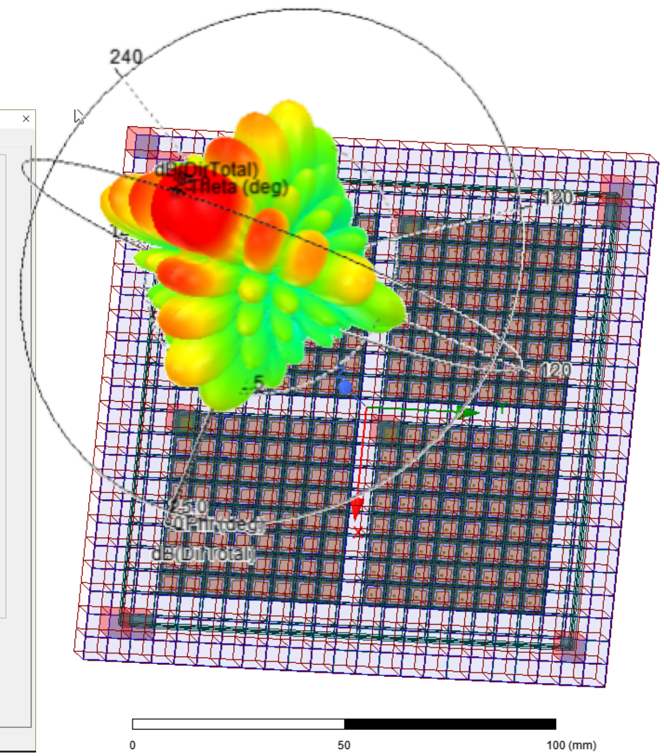


Unit Cells

- Models a single, repeated building block for a large array
- Low computational resources
- Can model finite edge effects, multiple element types on lattice, dummy elements and element failure effects

Component Array Domain Decomposition (CADDM)

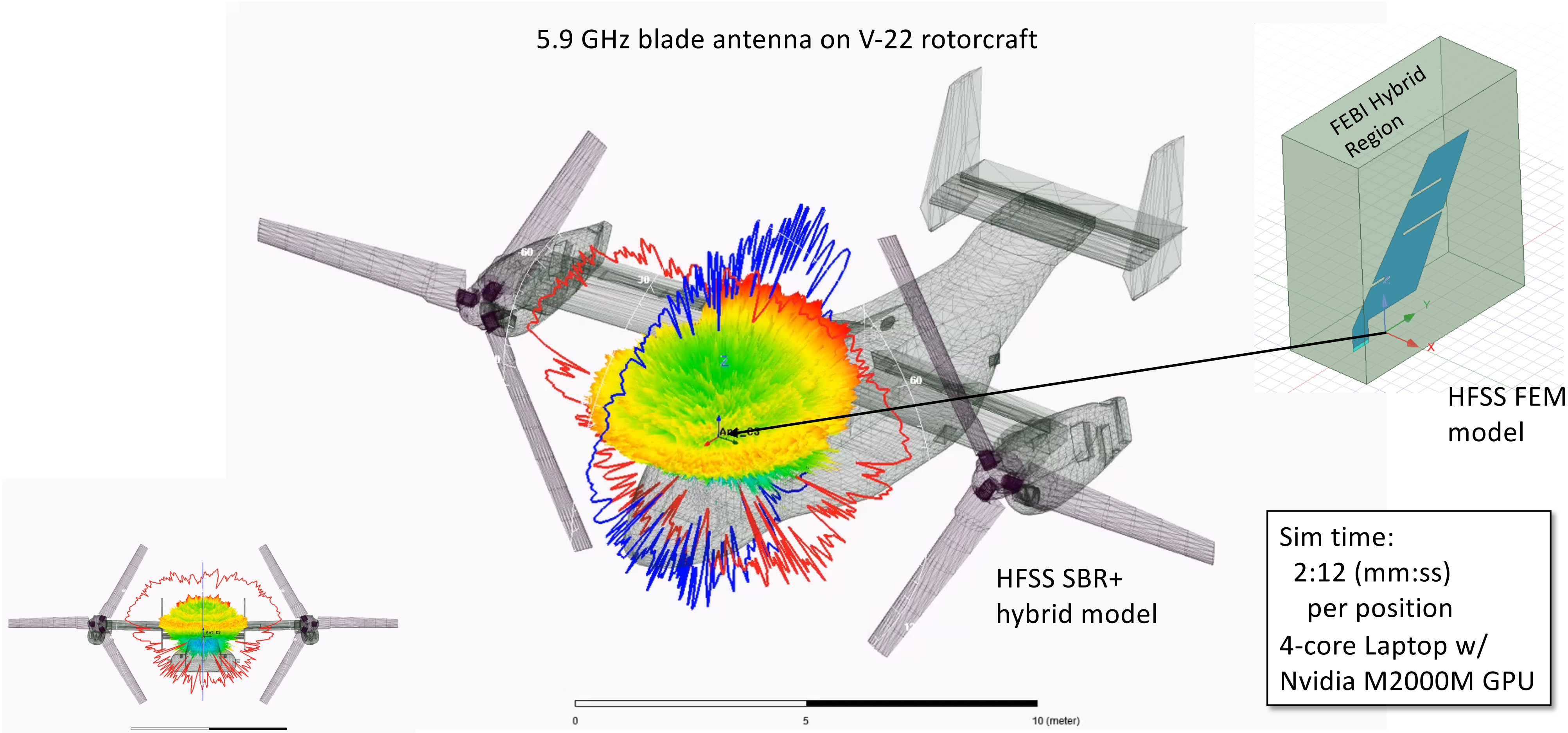




Compute scanned beam/directivity

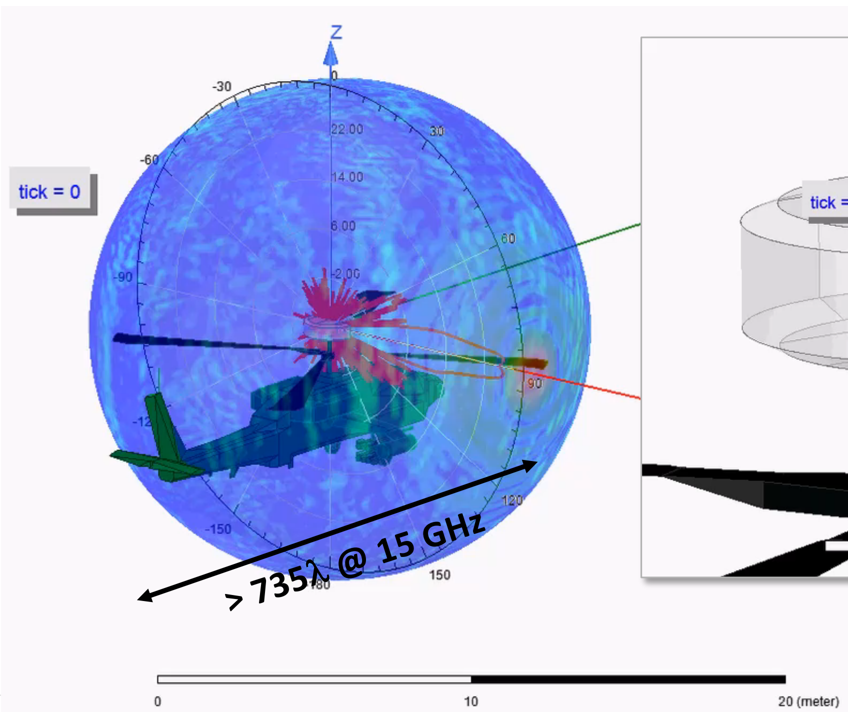
Some additional installed antenna analysis examples…

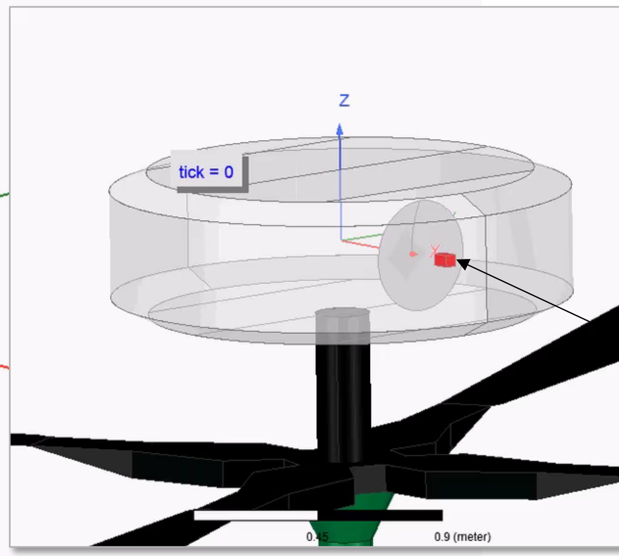
Installed antenna performance modeling

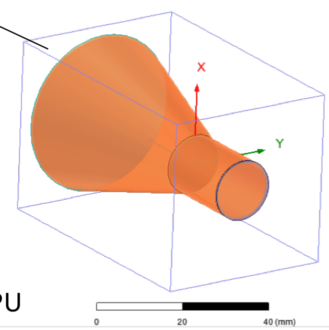


Hybrid installed antenna simulation example

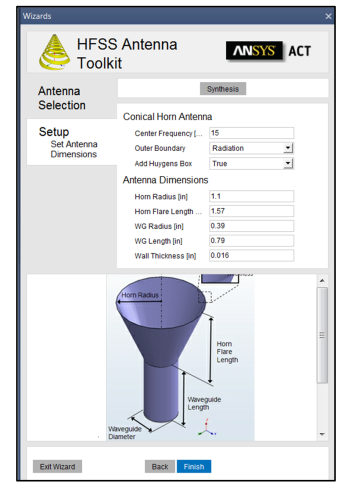
- 15 GHz reflector antenna mounted under a radome atop the Apache helicopter
- Hybrid approach: FEM for feed, SBR+ for reflector, radome and helicopter; includes feedhorn blockage







Sim Time: 5.5 min/position
4-core laptop w/M2000M GPU
GPU: 26x acceleration

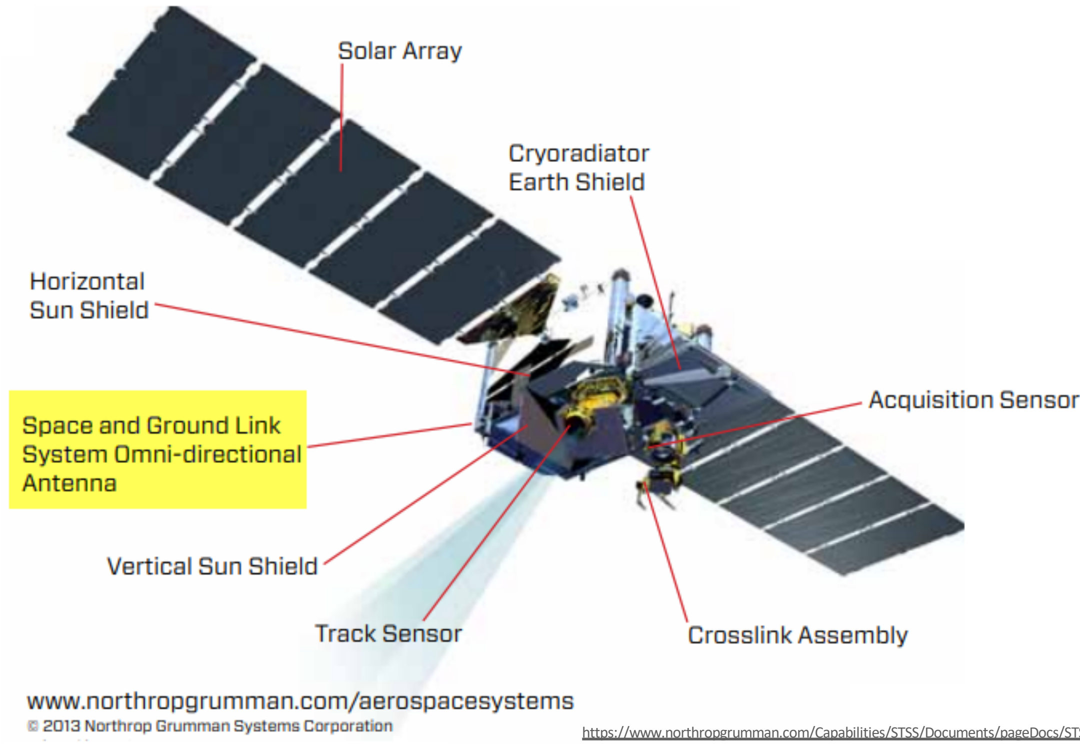


Quick synthesis of antennas in HFSS

LHCP (dual mode) feedhorn In 2-port HFSS FEM solution

Objective: High-fidelity installed antenna pattern for S-Band SatCom link

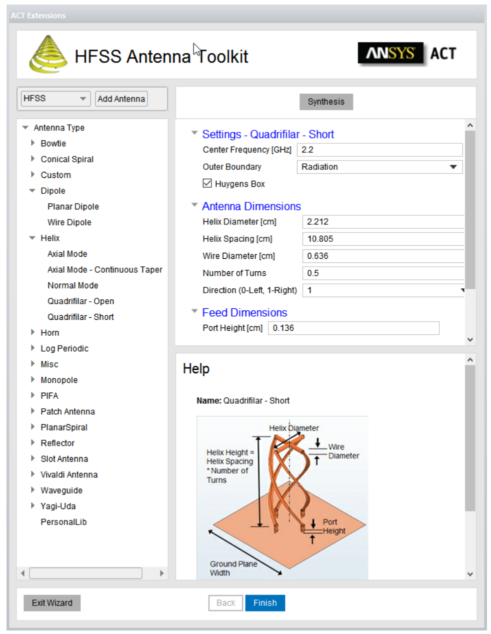
- Focus on Space and Ground Link System Omni-directional Antenna
- RF link: S-band (2.2 GHz)
- Antenna: Omnidirectional Antenna, RHCP (from Tx) assumed
- A “Perfect Omni” antenna assumption may not be sufficient for RF link budget modeling
- Assess installed antenna performance with ANSYS HFSS and ANSYS HFSS SBR+

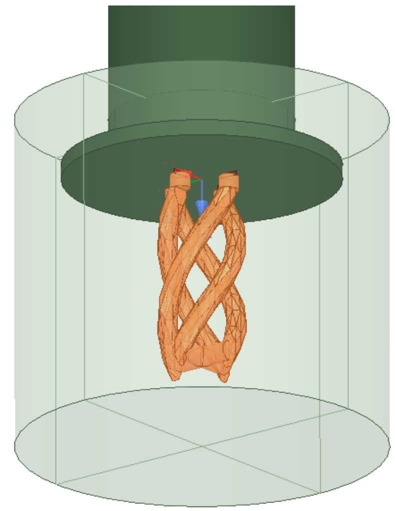


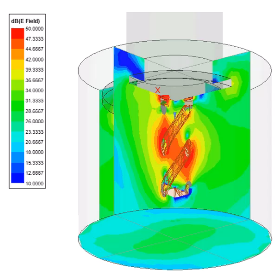
https://www.northropgrumman.com/Capabilities/STSS/Documents/pageDocs/STSS_Datasheet.pdf

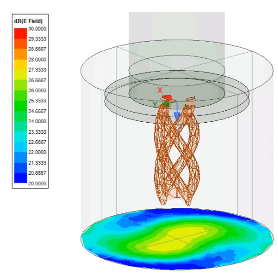
Antenna model: S-band shorted quadrifilar helix antenna (QFHA)

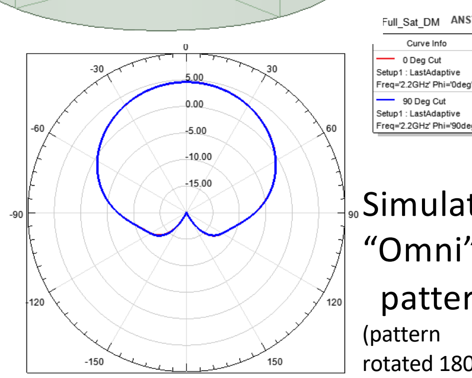
- ANSYS HFSS: High frequency electromagnetic (EM) modeling software
  - Uses FEM, MoM techniques for high-accuracy modeling
- HFSS Antenna Synthesis Toolkit
  - Used to synthesize a shorted quadrifilar helix antenna (QFHA)
  - Tuned to 2.2 GHz
  - Operated in Normal Mode (Omni)
  - Right-hand circular Pol (RHCP)
- HFSS accurately predicts antenna pattern and matching in isolation











Simulated "Omni" pattern (pattern rotated 180°)

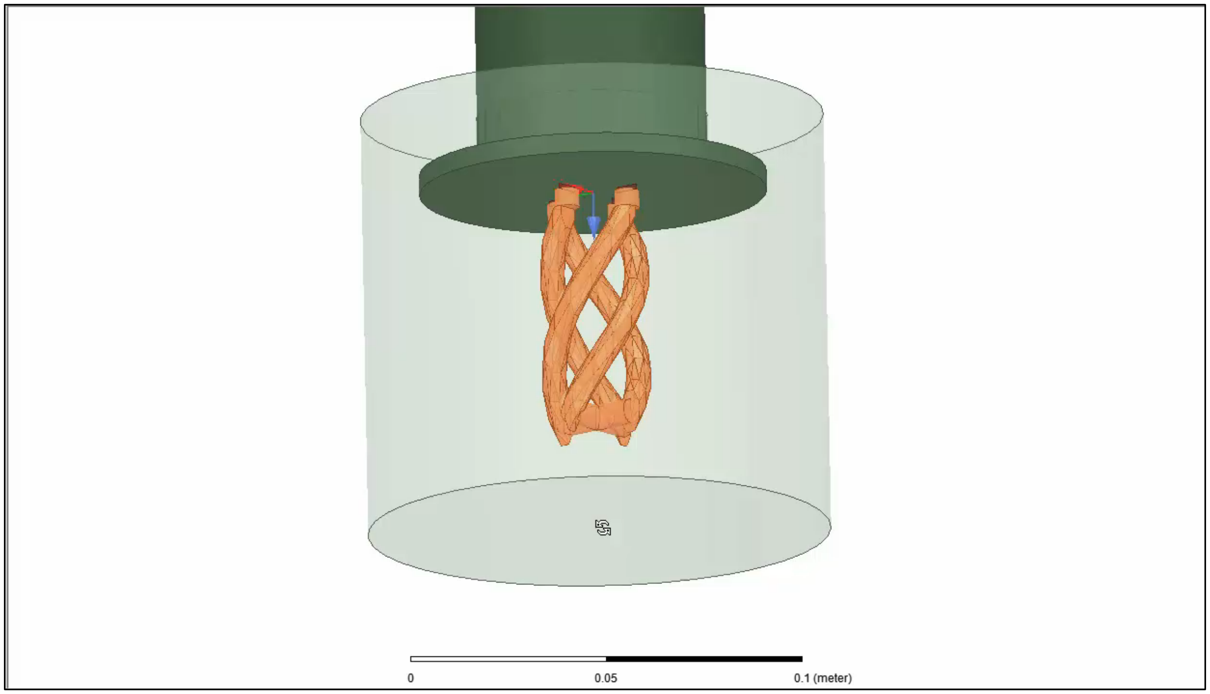
ANSYS

Modeling antenna interaction with the host satellite vehicle

- Antennas always interact with their hosts
  - Antenna performance can be altered dramatically, impacting the associated system
  - Interaction effects should be included in Mission model

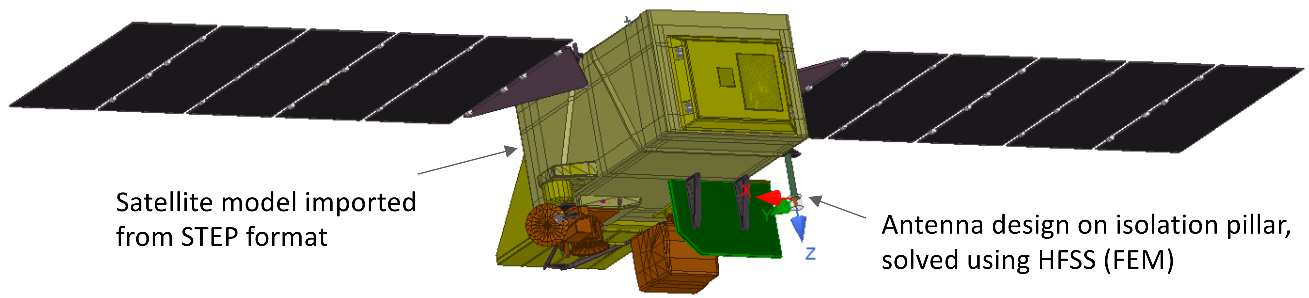
- ANSYS HFSS SBR+ uses Shooting and Bouncing Rays to solve antenna interaction with large hosts

- Requirements:
  - Satellite Vehicle CAD model
  - Material properties for vehicle
  - HFSS Antenna model



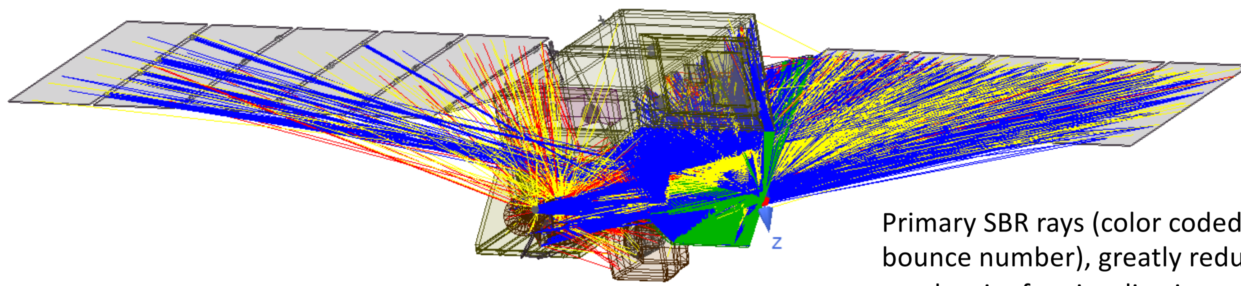
Hybrid simulation: FEM/FEBI and Shooting and Bouncing Rays

- The HFSS FEM/FEBI solution for the antenna is used to drive a Shooting and Bouncing Rays (SBR) simulation
- Includes PTD edge diffraction and UTD edge rays for advanced diffraction
- Computes installed patterns, antenna-to-antenna coupling, radar signatures and more
- Single simulation action—hybridization is automatic



Satellite model imported from STEP format

Antenna design on isolation pillar, solved using HFSS (FEM)



Primary SBR rays (color coded by bounce number), greatly reduced ray density for visualization

Installed pattern results

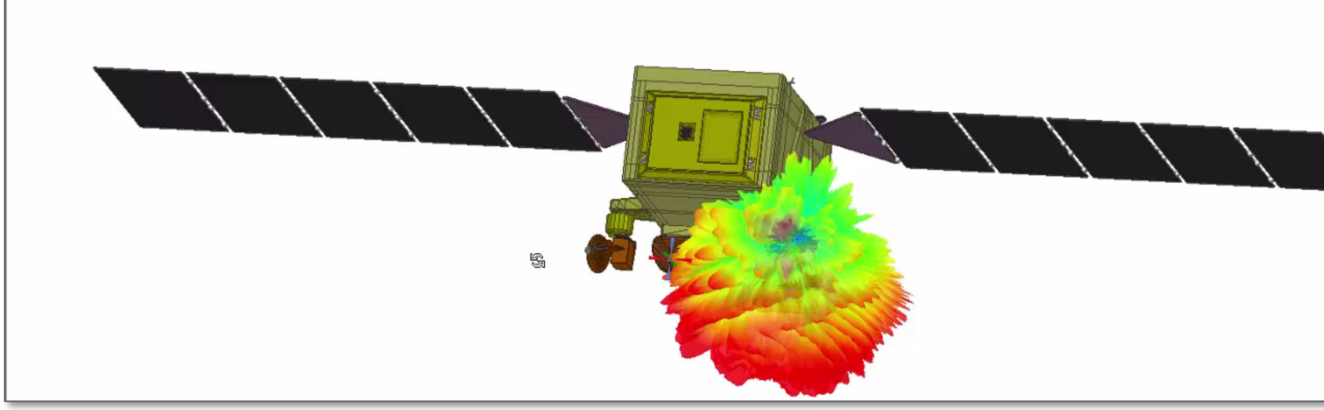
- Antenna <u>and</u> host interaction solved in 18 minutes on 16-core workstation
  - Under 2GB RAM required for TOTAL solution

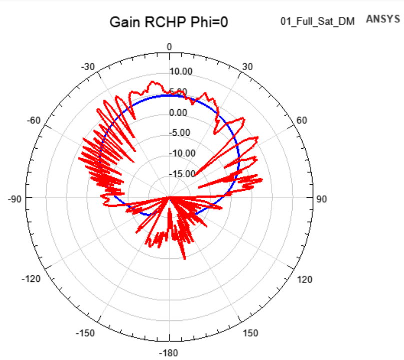
- Installed pattern exhibits peaks/nulls due to local multi-path

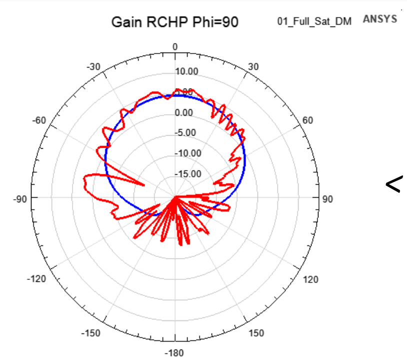
- Radiation pattern variations directly influences the RF Link Budget!

- This installed radiation pattern is used in AGI STK for RF Link modeling to other stations

Installed Pattern, Right-Hand Circular Polarization, 2.2 GHz



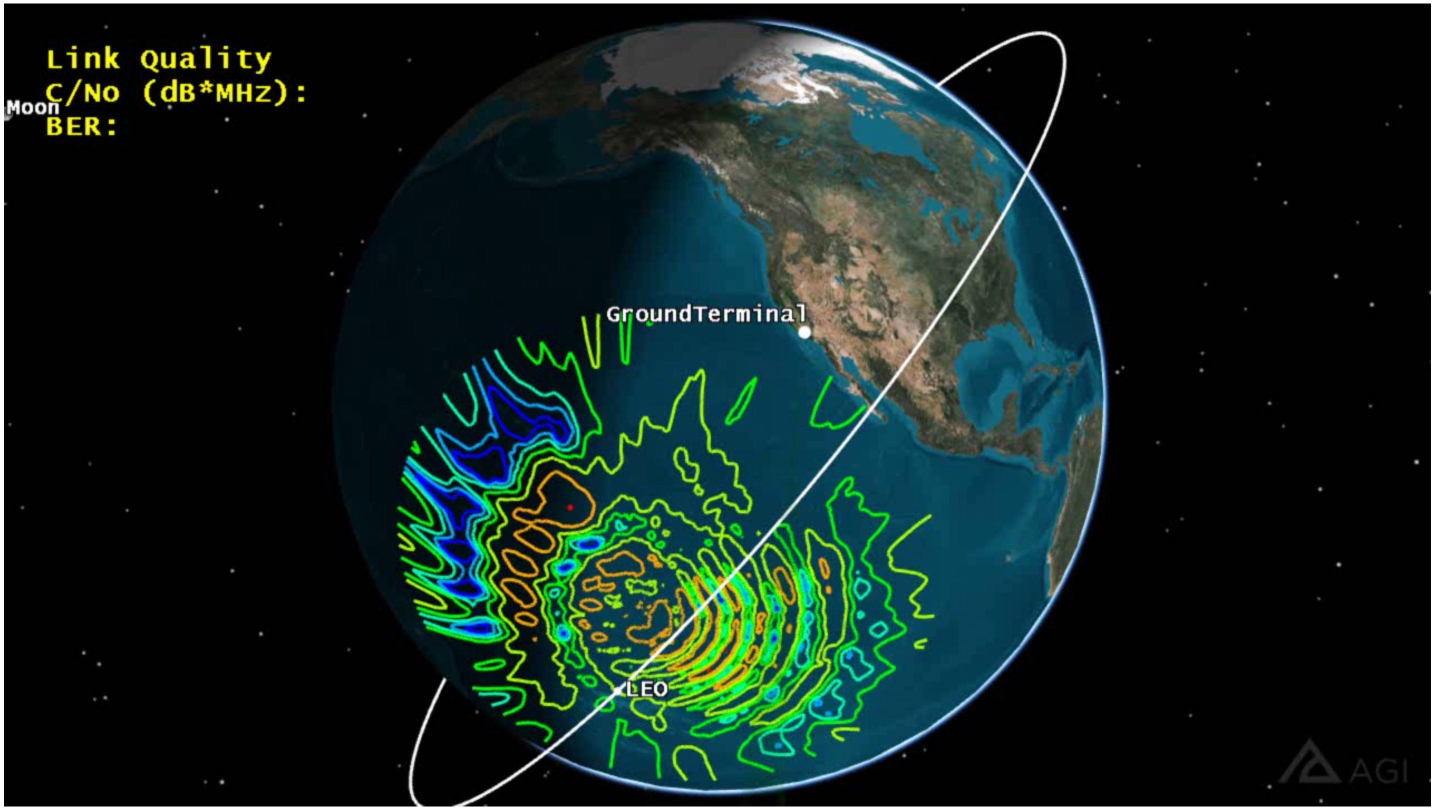




< *Isolated antenna (blue) and Installed antenna (red) show installation interaction effects*

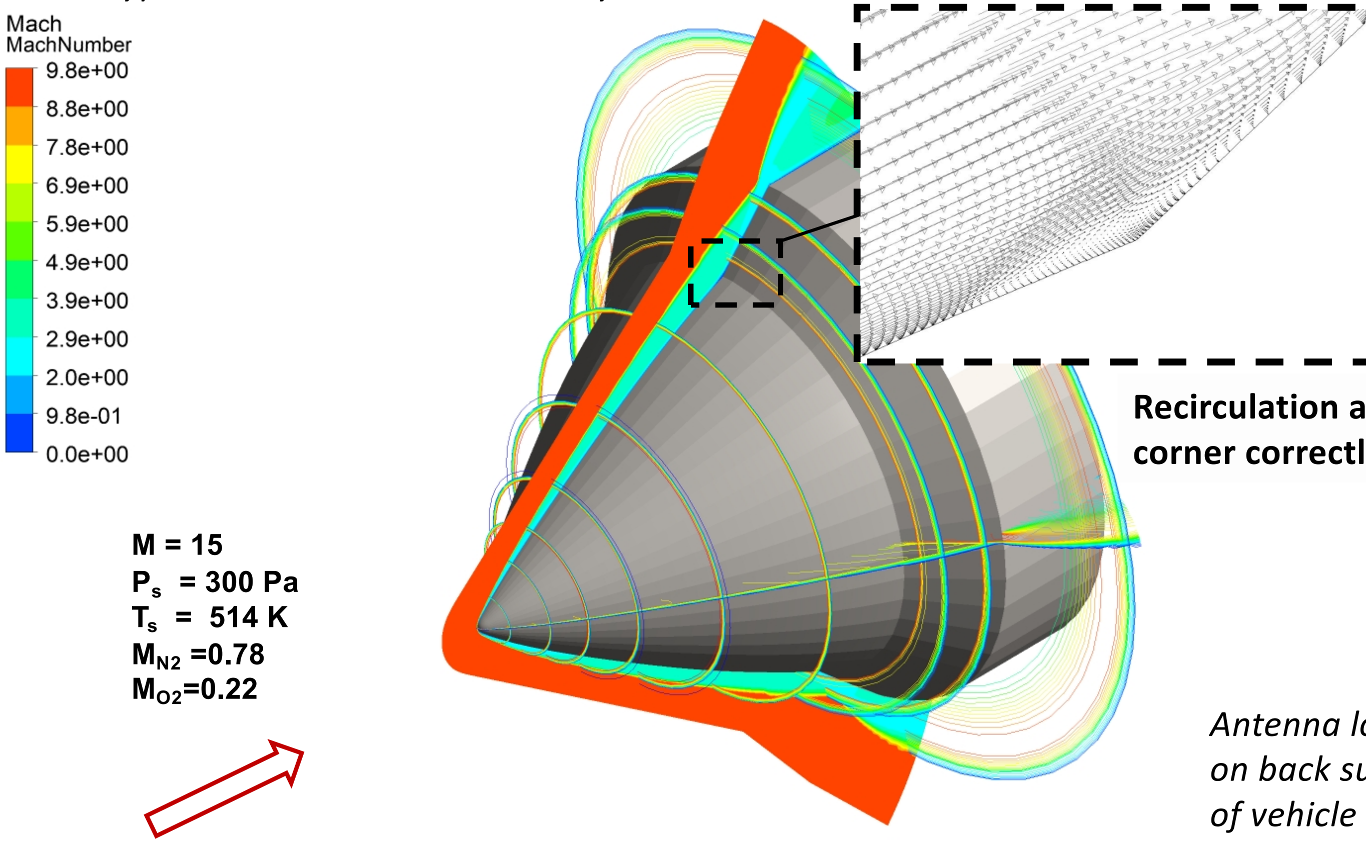
Installed radiation pattern applied to the mission simulation

- **AGI STK** models satellite mission kinematics, navigation and maneuvers
- **ANSYS HFSS** model of installed antenna is attached to the satellite, pattern moves with satellite through engagement
- **AGI STK Communications** shows earth coverage power contours, updates signal link quality to earth base station



Comms antennas on hypersonic vehicles

Mach 15 Flow Over Hyperboloid Flare - Simulation by ANSYS Fluent



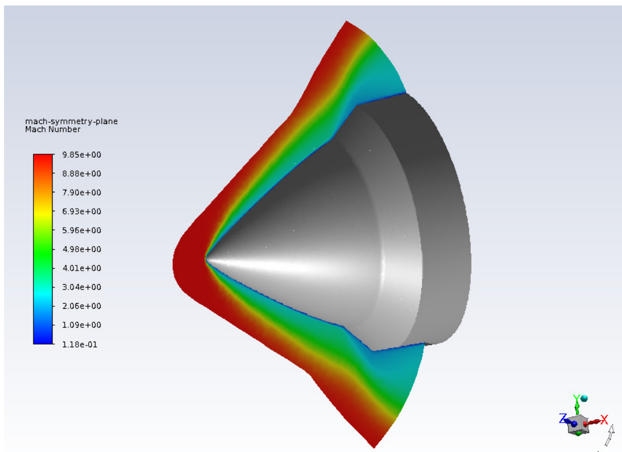
Recirculation area at flap corner correctly captured

M = 15
P_s = 300 Pa
T_s = 514 K
M_{N2} =0.78
M_{O2}=0.22

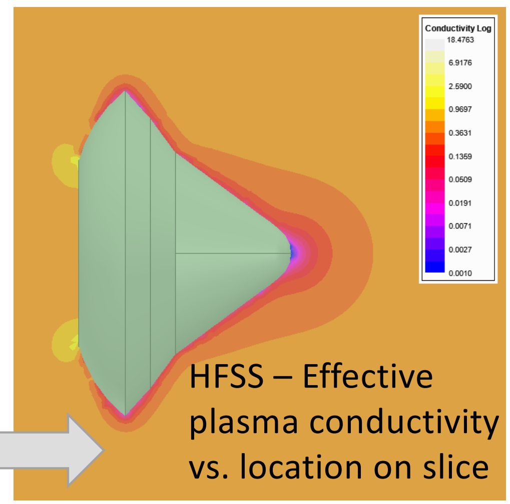
Antenna located on back surface of vehicle

Plasma Inclusion in HFSS with new 3D spatial-variant material properties

- Multiphysics simulation coupling Aero/Fluids with High Frequency Electromagnetics



Fluent – Charged Species & Temperature



HFSS – Effective plasma conductivity vs. location on slice

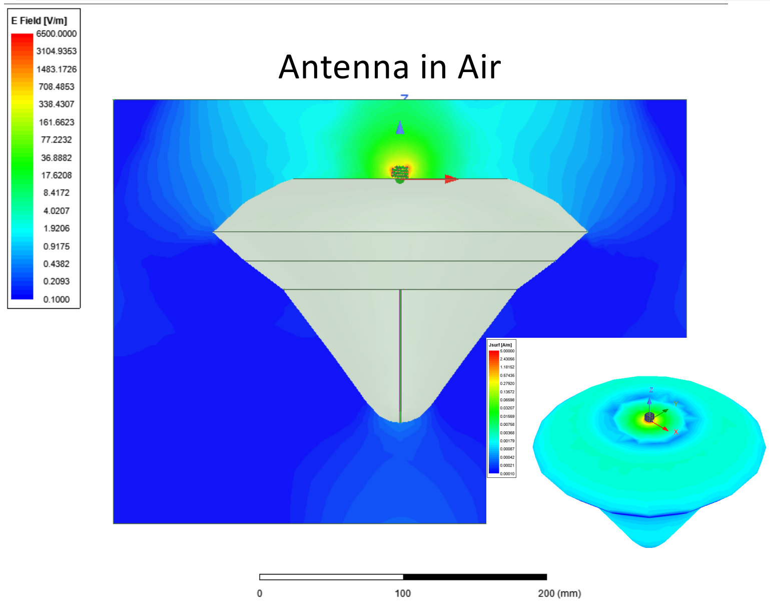
Map to Spatially Varying Conductivity

Antenna Simulation Comparison

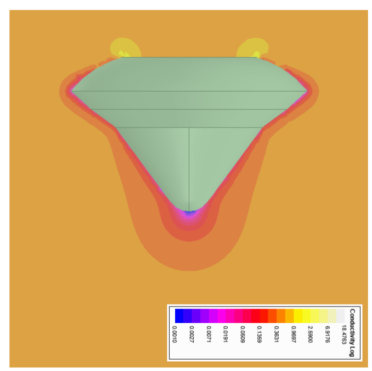
- Helical antenna at 1GHz

  Z_ant = 3.7 + j*218.65

Freq [GHz]	dB(St(Helix1_T1,Helix1_T1)) Setup1 : LastAdaptive	re(Zt(Helix1_T1,Helix1_T1)) Setup1 : LastAdaptive	im(Zt(Helix1_T1,Helix1_T1)) Setup1 : LastAdaptive
1.000000	-66.247662	3.702541	218.647442

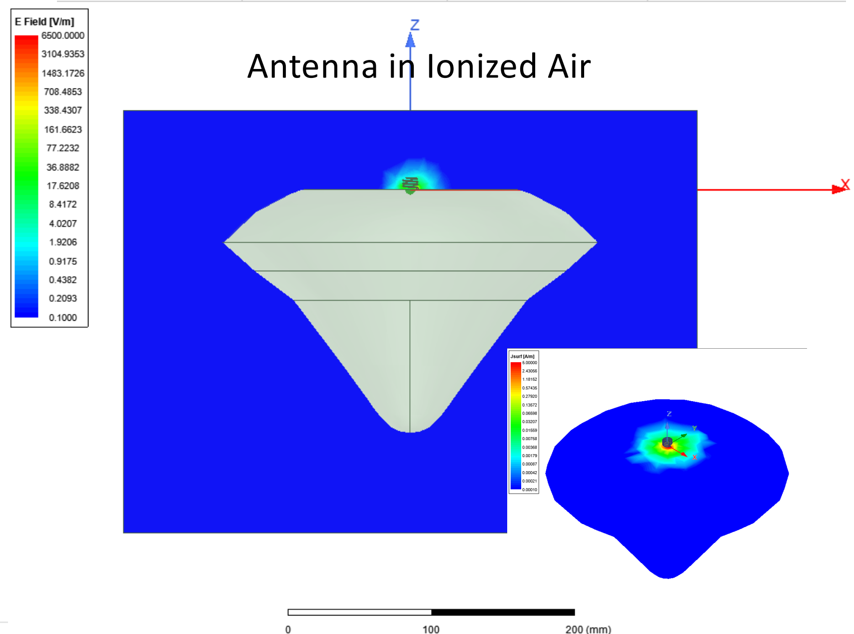


Mapped Complex Conductivity



Z_ant = 2.0 + j*18.17

Freq [GHz]	dB(St(Helix1_T1,Helix1_T1)) Setup1 : LastAdaptive	re(Zt(Helix1_T1,Helix1_T1)) Setup1 : LastAdaptive	im(Zt(Helix1_T1,Helix1_T1)) Setup1 : LastAdaptive
1.000000	-0.003267	2.043576	18.170713



Fast medium-fidelity model of installed antenna performance

- Applicable to SBR+ Solutions
- Use Current Source models for antennas integrated into platforms
- Use Far-Field models for “distant” free-standing antennas
- Perfectly matched to impedance you choose
- Quick and easy to place; FAST simulations
- Suitable for quick placement and coupling studies

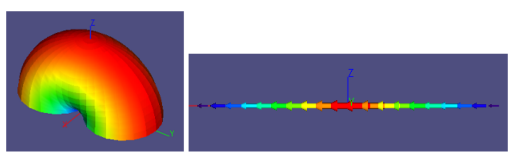
SBR+ Antenna Model Sources
Integrated Parametric Antennas

Far-Field Models:

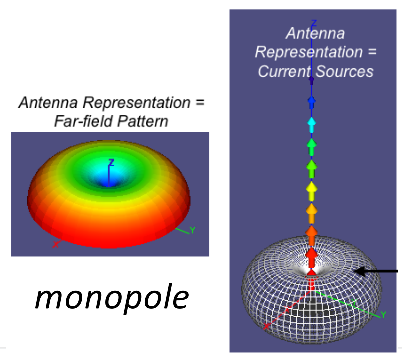
- **Short Dipole**
- **¼λ Monopole**
- **½λ Dipole**
- **Wire Dipole**
- **Wire Monopole**
- **Small Loop**
- **Parametric Slot**
- **Pyramidal Horn**
- **Circular Horn**
- **Parametric Beam**

Near-Field (Current Source) Models:

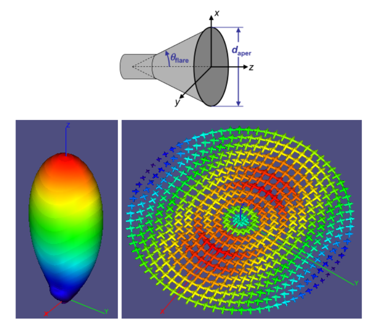
- **Wire Dipole**
- **Horizontal Dipole over Gnd Plane**
- **Crossed Dipole (opt. Gnd Plane)**
- **Wire Monopole**
- **Parametric Slot**
- **Pyramidal Horn**
- **Circular Horn**



dipole



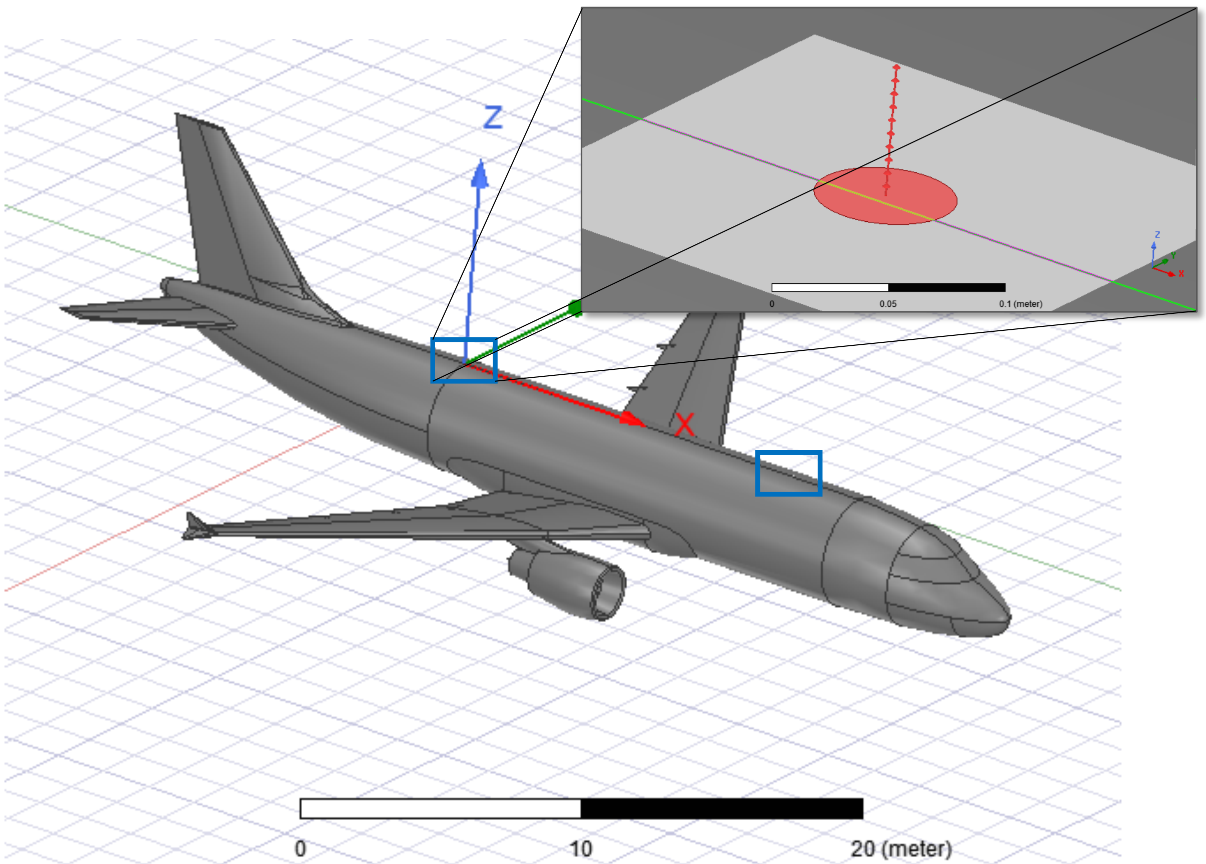
monopole

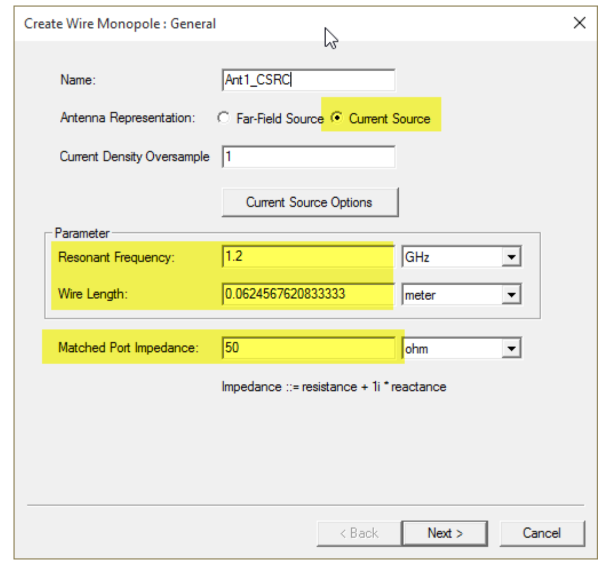


Circular feedhorn

Fast medium-fidelity antenna coupling example

1.2 GHz blade monopole on A320 aircraft

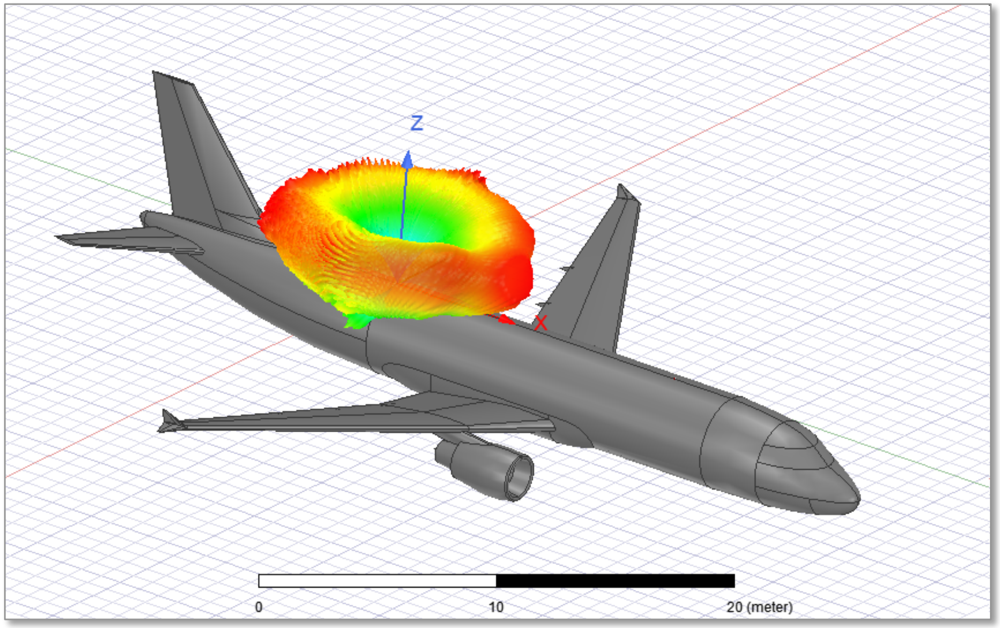


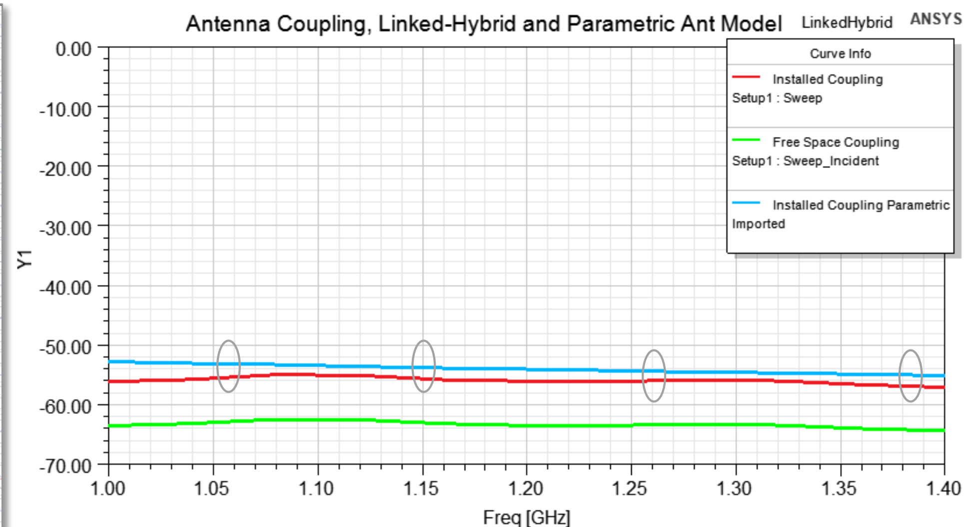


- Quick-create: 1.2 GHz wire monopole with current source realization
- Perfect match to 50 ohms at all freqs (max coupling)

ANSYS

Installed Coupling with Parametric Monopoles



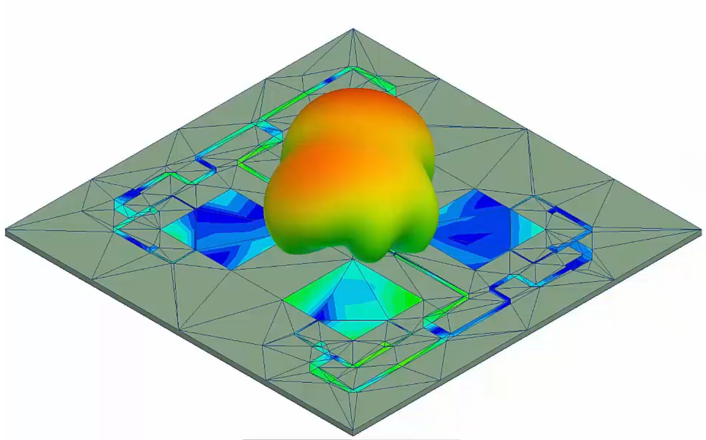


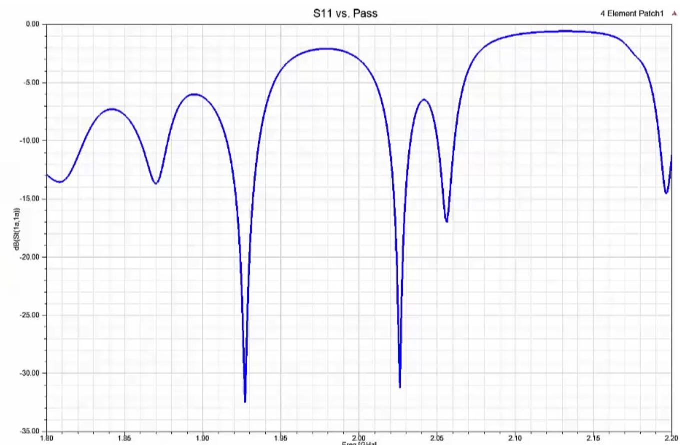
- Much faster simulation than linked Hybrid with high-fidelity antenna model (4X faster for this case)
- Coupling results within 1-2 dB of high-fidelity antenna model
- Fast, medium-fidelity approach

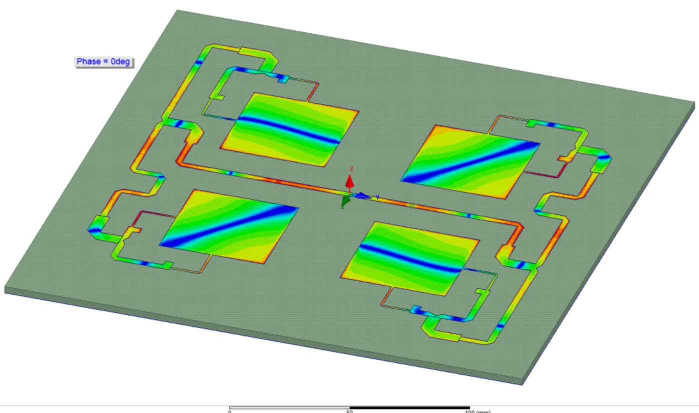
In Summary

- Antennas interact with their hosts and/or environment
- Multiple EM solver technologies are needed for efficiency AND good fidelity
- Two approaches to solving installed antenna problems:
  - Explicit Hybrid solution
  - Linked Hybrid solutions
- Parametric antenna elements enable a fast, medium-fidelity approach to testing installation siting and antenna coupling

HFSS Automatic Adaptive Meshing: Analyst quality solvers for *designers*







Automatic Adaptive Meshing

- Efficient
- Accurate
- Reliable