HFSS Hybrid Finite Element and Integral Equation Solver and Savant for Large Scale Electromagnetic Design and Simulation

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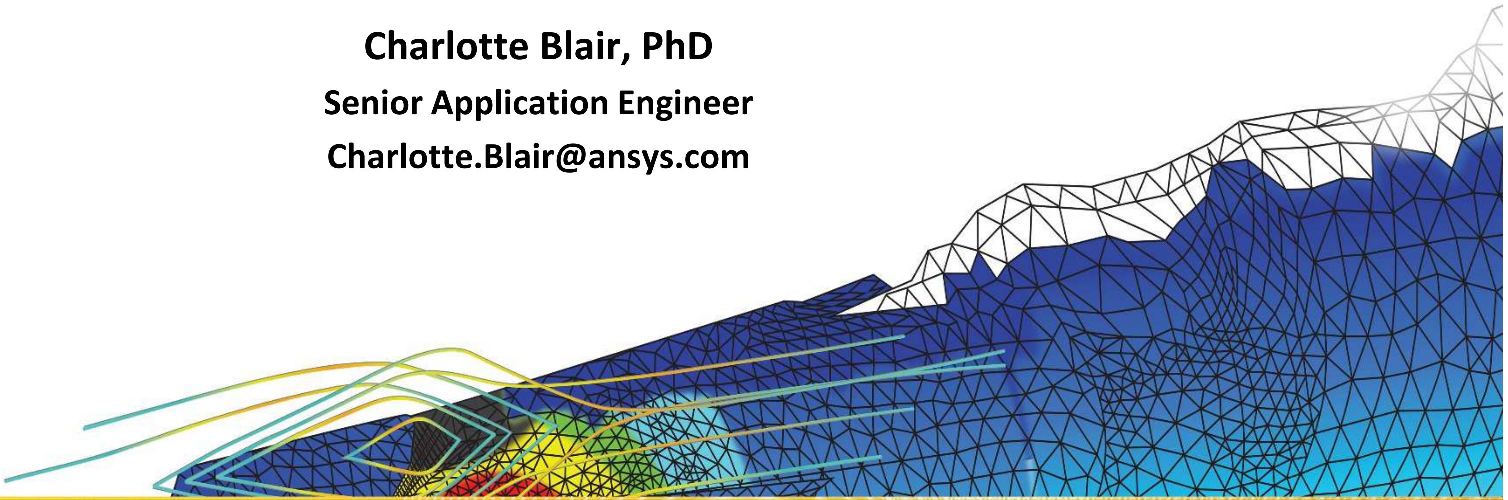


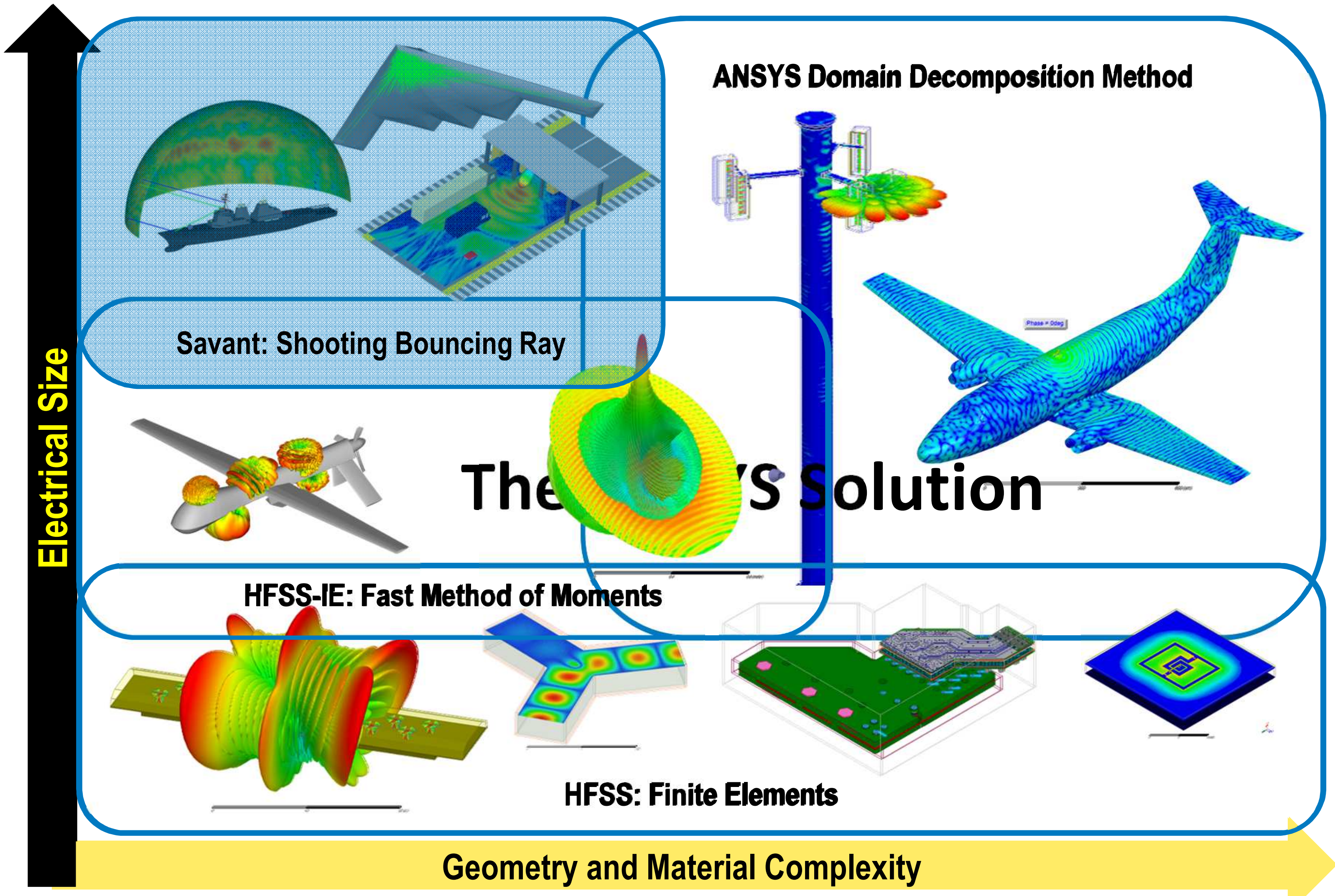
Agenda

- Overview of Simulation Trends and Technologies
- ANSYS Simulation Technologies Overview
- ANSYS Electromagnetic Simulation Techniques
- HFSS-FEM
- HFSS-IE
- Hybrid FE-BI
- Hybrid IE-Regions
- Physical Optics
- Savant
- Examples

The Problem: Installed Antenna Performance

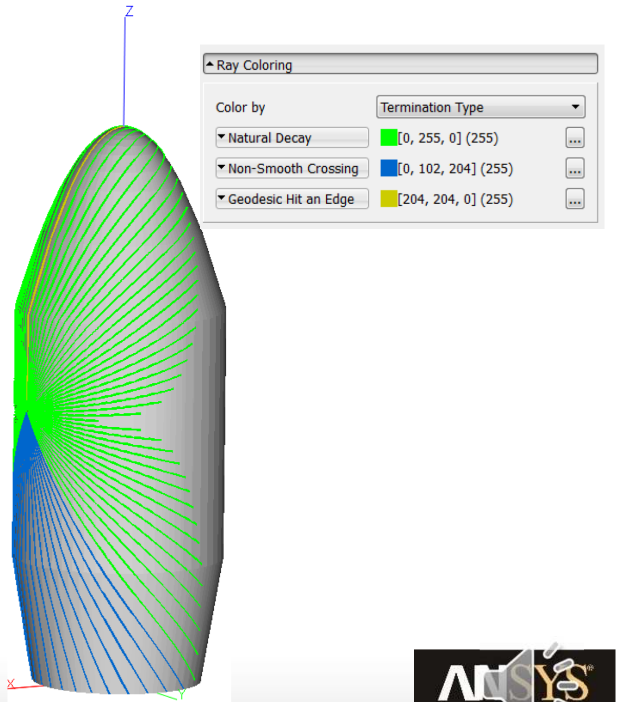
- Antennas often designed in isolation or under ideal conditions
- Mounting antennas on realistic platforms changes performance
- Impacts overall RF system performance
  - Need to know installed performance early in the design cycle!

ANSYS EBU Product Portfolio

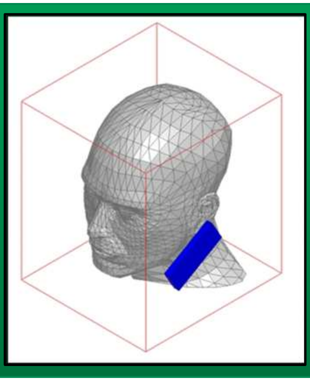


Advantages

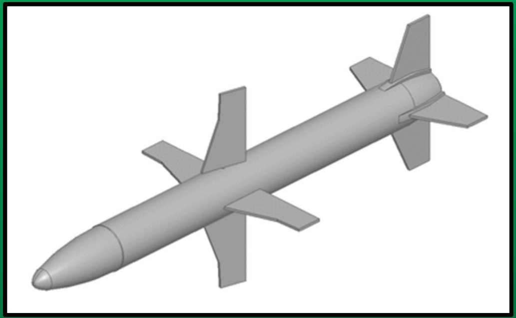
- **Complementary Technology**
  - HFSS: Antenna Design
  - Savant: Installed Performance
- **Extremely Fast**
  - Multicore, GPU and MPI
  - Consumer or Scientific grade GPUs
- **Low Memory Requirements**
  - Most jobs require < 8 GB of RAM
- **Accuracy**
  - Physics models not found in other ray tracing tools
- **Intuitive**
  - Powerful GUI with thorough Help/Tutorials



ANSYS Simulation Technologies



- **Finite Element Method**
  - **HFSS**
  - **Efficiently handles complex material and geometries**
  - **Volume based mesh and field solutions**
  - **Fields are explicitly solved throughout entire volume**



- **Integral Equations**
  - **HFSS-IE**
  - **Efficient solution technique for open radiation and scattering**
  - **Currents solved only on surface mesh**
  - **Efficiency is achieved when structure is primarily metal**

Hybrid Finite Element – Integral Equations

- **Finite Element Method**
- HFSS
  - **Efficiently handles complex**

Insert HFSS Design

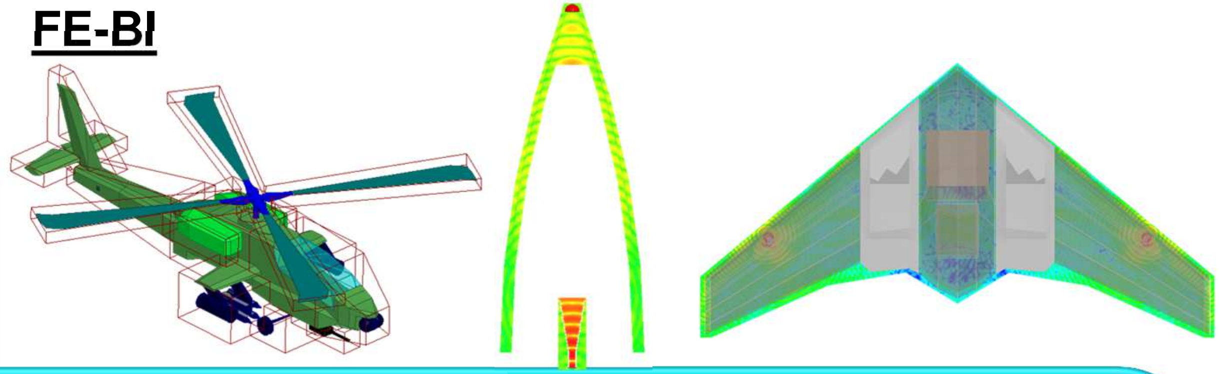
s

Integral Equations

- HFSS-IE
  - **Efficient solution technique for open radiating and scattering of metallic objects**

Insert HFSS-IE Design

FE-BI



- **Hybrid Finite Element - Integral Equations** Insert HFSS Design
  - **FE-BI**
  - **IE-Regions**
- **Hybrid method invoked inside of HFSS Design using IE-Regions or FE-BI boundary conditions**
- **Hybrid method takes advantage of features from both methods to allow for more efficient simulations**

IE-Regions

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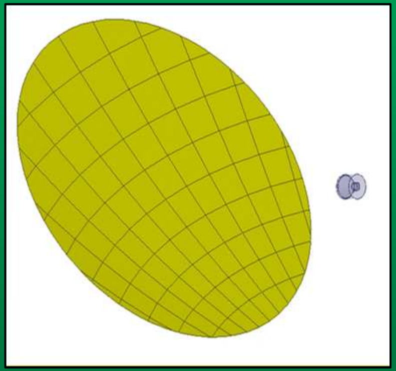
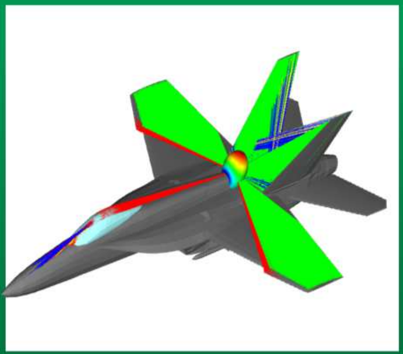
ANSYS Simulation Technologies



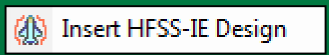
- **Physical Optics**
  - **HFSS-IE**
  - **High frequency approximation**
  - **Ideal for electrically large, smooth objects**
  - **Currents are approximated in illuminated regions and set to zero in shadow regions**
  - **1st order interactions**

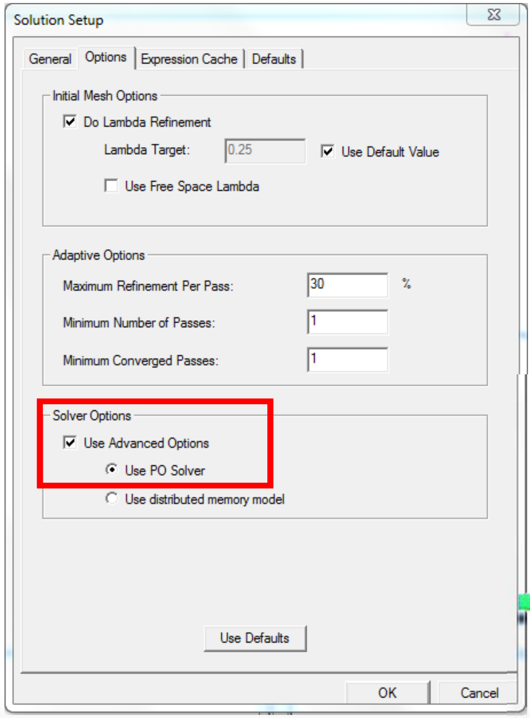


- **Ray Tracing**
  - **Savant**
  - **Extends physical optics (PO) to multiple bounces with GO ray tracing**
  - **Asymptotic technique**
    - **Complimentary capability to full-wave solvers**
    - **Electrically large platforms (i.e., many wavelengths in dimension)**

High Frequency Technique: Physical Optics

- **Physical Optics**
- HFSS-IE
- Ideal for electrically large, conducting and smooth objects



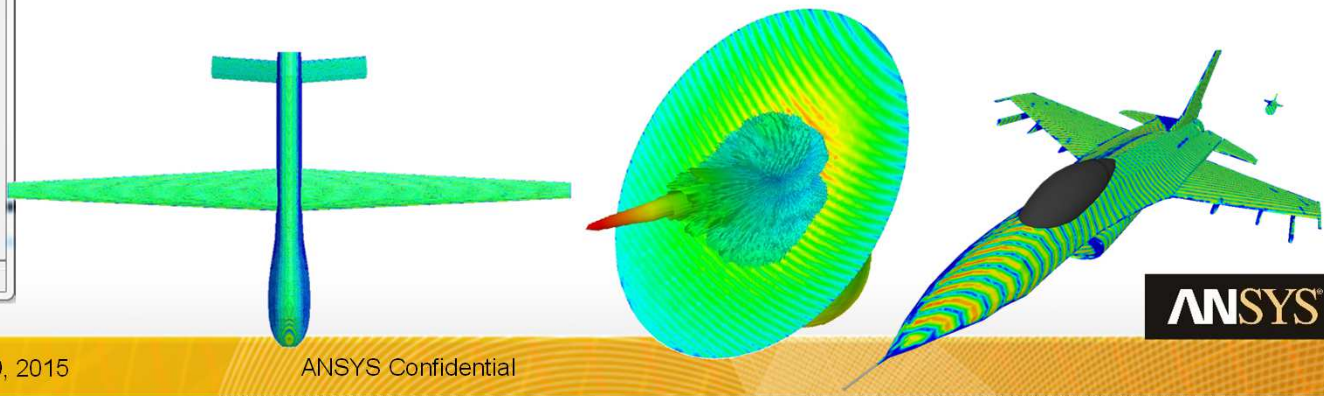


High frequency asymptotic solver available inside of HFSS-IE designs

- Currents are approximated in illuminated regions and set to zero in shadow regions
- First order interaction only, single bounce
- Source excitation from HFSS Far Field Data-Link of incident plane wave

Usage

- Applications include
  - Electrically large - RCS, Antenna Placement, Reflector Analysis
- Quickly estimate performance of electrically large problems
- Full wave solution is beyond computation resources



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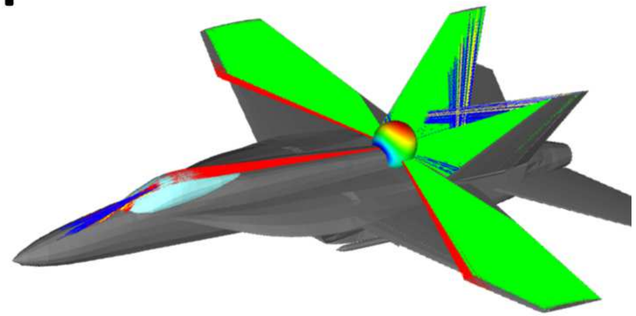
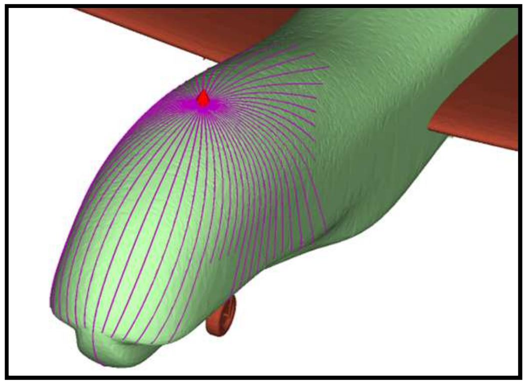
Savant's Methodology: SBR+



- **Shooting and Bouncing Rays**
  - Asymptotic technique
    - **Complimentary capability to full-wave solvers**
    - **Electrically large platforms (i.e., many wavelengths in dimension)**
  - Extends physical optics (PO) to multiple bounces with GO ray tracing
  - Material Modeling: Dielectric/Magnetic stacks, Fresnel table import
- **SBR+ ?**
  - Build on traditional SBR with additional physics
    - **Physical Theory of Diffraction (PTD) Edge Correction**
    - **Uniform Theory of Diffraction (UTD) Edge Rays**
    - **Creeping Wave**
  - Driving philosophy
    - **Use full array of GTD/UTD methods to "paint" currents on platform body**
    - **Radiate painted currents to field observers, Rx antennas**
    - **All models/mechanisms work together to improve accuracy**



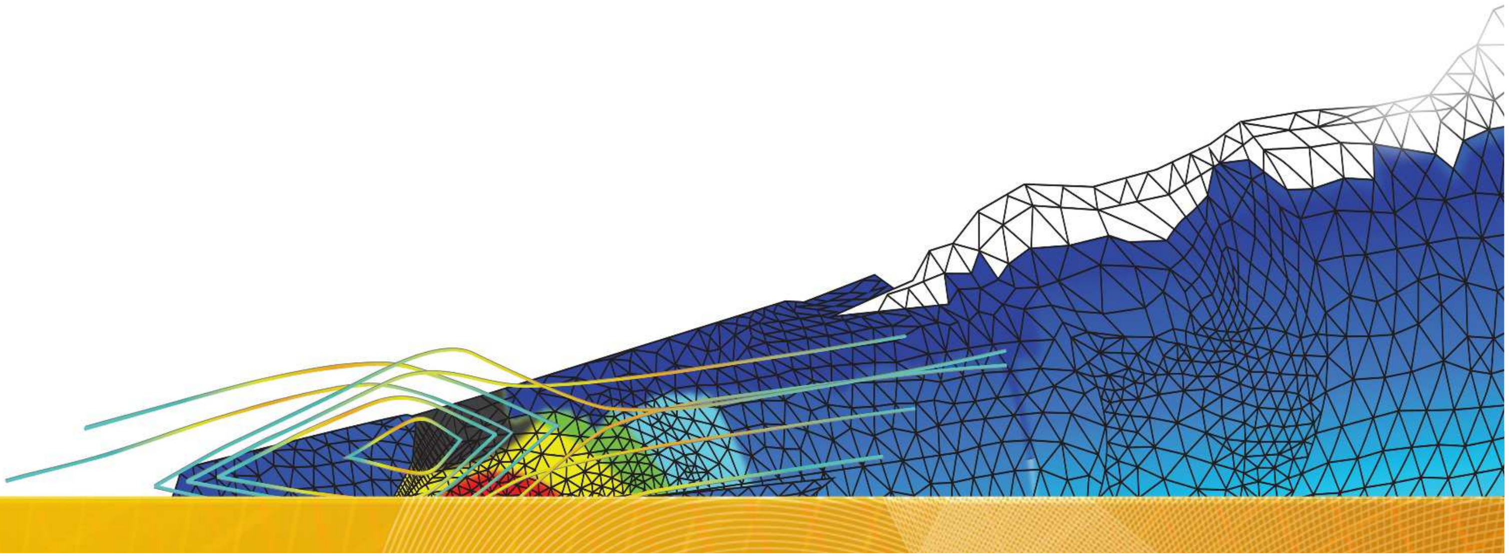
SBR+ Pres

Realize Your Product Promise®

Hybrid Methods

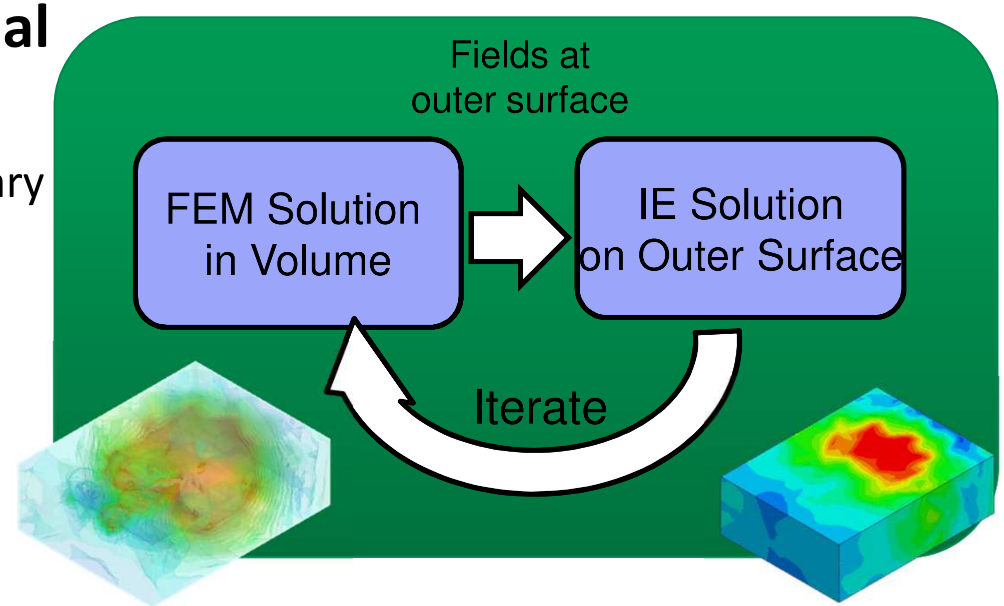
FE-BI

IE-Regions



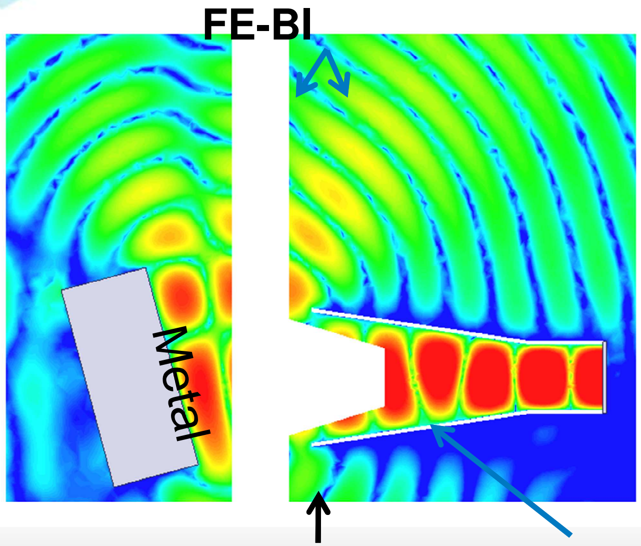
Finite Element – Boundary Integral

- **Mesh truncation of infinite free space into a finite computational domain**
- Alternative to ABC or PML radiation boundary conditions



- **Hybrid solution of FEM and IE**
- IE solution on outer faces
- FEM solution inside of volume

- **FE-BI Advantages**
- Arbitrary shaped boundary
  - Conformal and discontinuous to minimize 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



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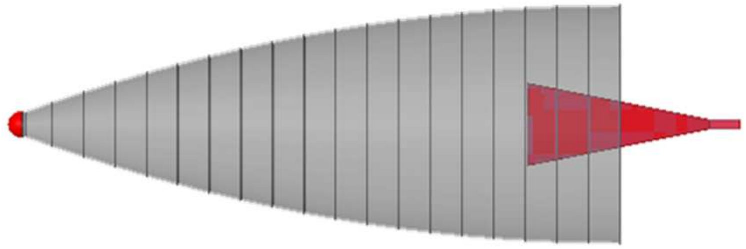
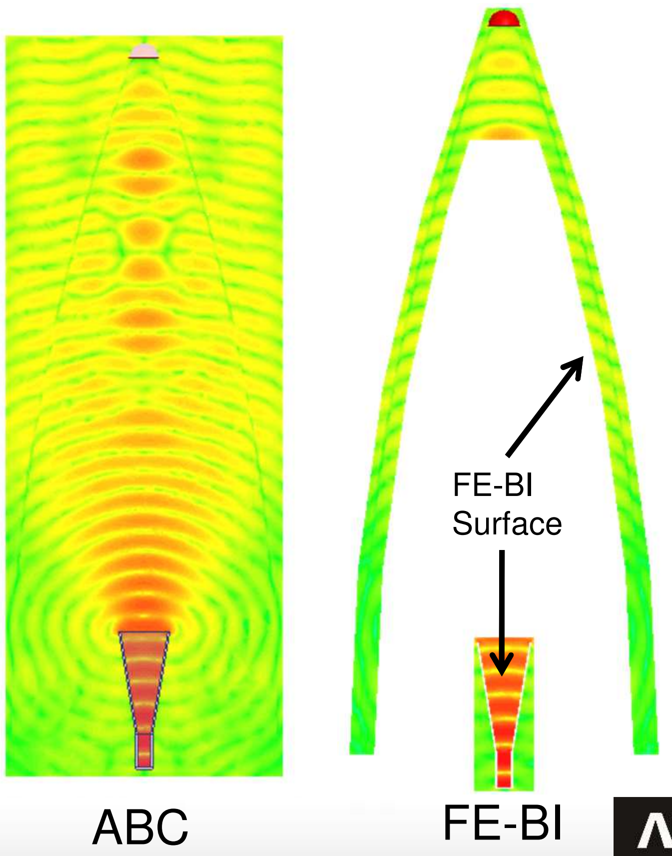
Finite Element – Boundary Integral:
Example Problem



- **FE-BI can be used to significantly reduce required computer resources**
- Large volume of air inside of radome can be removed from the FEM solution domain
  - Air volume would be required if using PML or ABC
- Two FE-BI surfaces will be applied
  - Conformal to radome
  - Conformal to horn antenna (10 GHz)

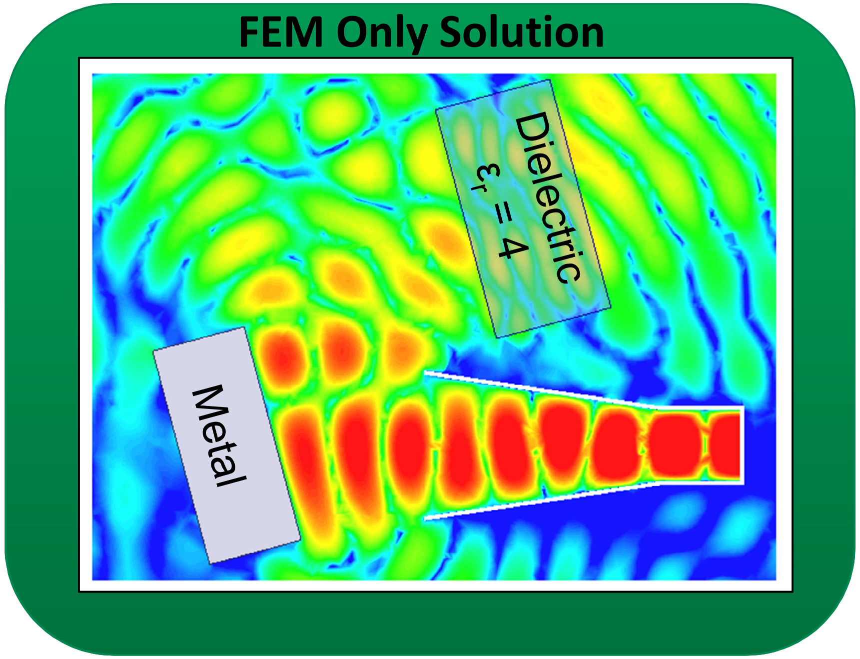
10 GHz	RAM (GB)	Elapsed Time
ABC	15	70min
FE-BI	7	30min

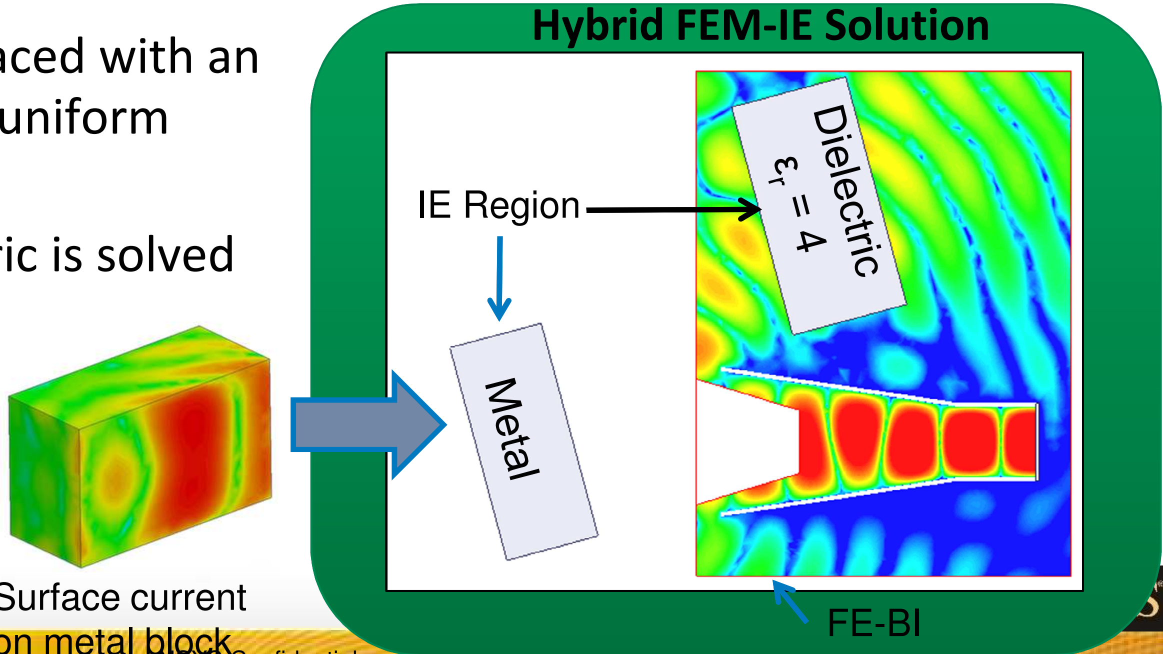


IE-Regions

In a hybrid FEM-IE solution, IE Regions allow uniform regions of free space or dielectric to be removed from the FEM solution

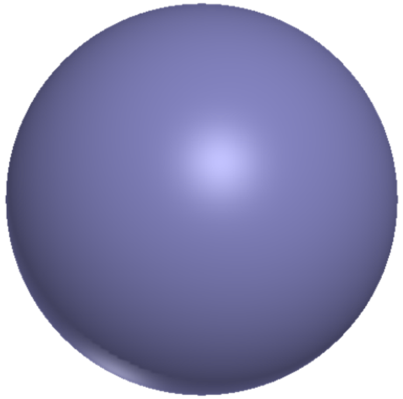
- Metal objects can be solved directly with an IE solution applied to surface
  - Removes need for air box to surround metal objects
- Dielectric regions can be replaced with an IE Region on the boundary of uniform dielectric material
  - Solution inside of dielectric is solved using IE





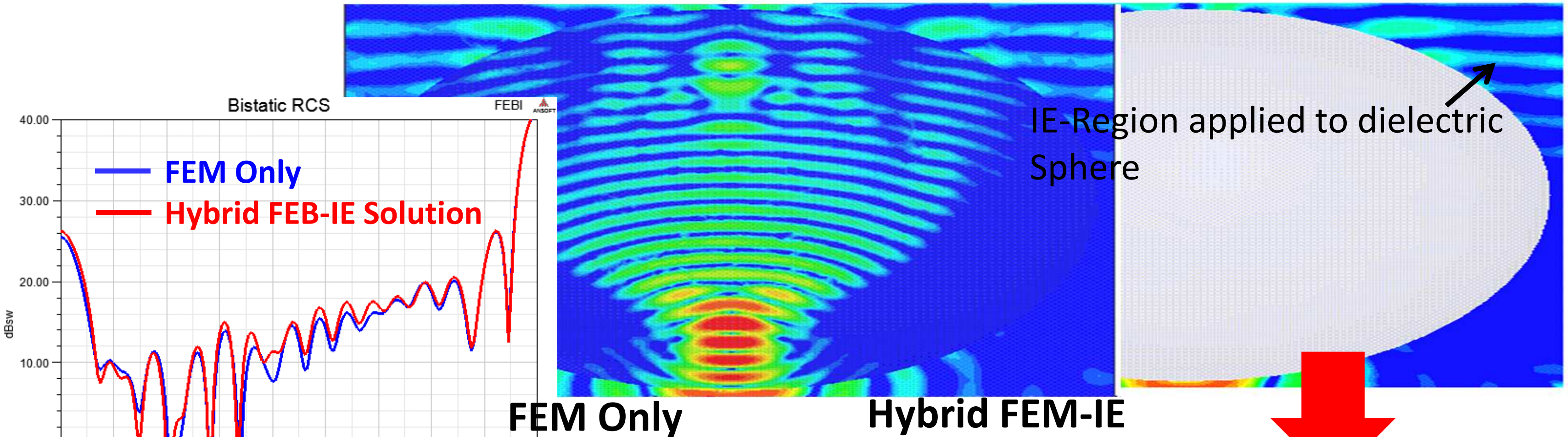
IE-Regions:
Example Problem

Radius = 900mm, $\varepsilon_r = 4$, $F = 1GHz$



IE-Region Applied to RCS of Electricaly Large Dielectric Sphere

- Hybrid FEM-IE solution of scattering from dielectric sphere using IE-Regions
- Uniform volume of dielectric removed by applying IE-Region to surface of dielectric sphere



1 GHz	RAM (GB)	Elapsed Time
FEM Only	33.4	222min
Hybrid FEM-IE using IE Regions	3.2	35min

10X Less **7X Faster**

Hybrid Solution

- With the addition of IE regions, a fully hybridized solution of FEM and IE is capable of solving electrically large problems more efficiently
- FEM and IE
- FE-BI
  - Truncate an FEM solution space with any arbitrary surface using a boundary integral
- IE-Regions
  - When used along with FE-BI, conducting objects outside of FEM solution space can be solved directly with IE, eliminating the need for conducting objects to be enclosed in an air volume
  - Homogenous dielectric volumes can be removed from the FEM solution and replaced with the equivalent IE solution in the region, useful when dielectric regions are electrically large requiring large FEM solution volume

Examples

Finite Element - Boundary Integral

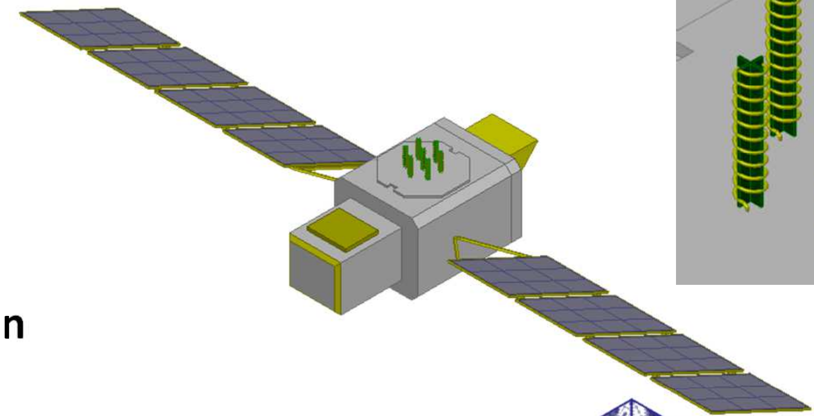
IE-Region

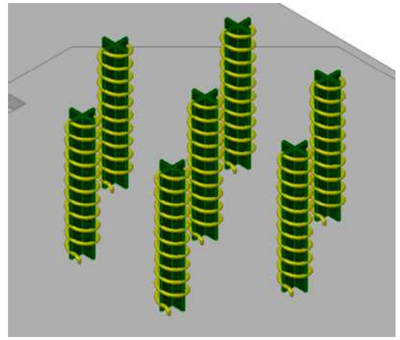
Physical Optics

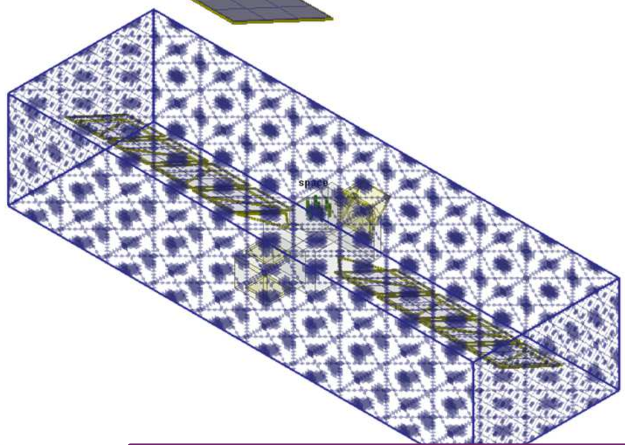
Savant

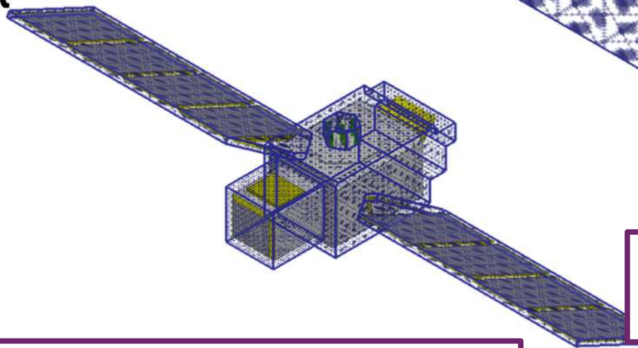
Array on Spacecraft Using FE-BI

- **7 Element Helix Antenna Array integrated on satellite platform**
  - Dielectric solar panels and antenna supports do not make this problem ideal for HFSS-IE
- **Inclusion of solar panels create an electrically large model**
  - 64λ wide at 3.5 GHz
- **Using ABC or PML boundary would require an Airbox equal to 21k λ^3**
- **FE-BI can reduce the required Airbox to 1.2k λ^3**









ABC or PML would be applied to much larger Airbox

FE-BI applied to conformal Airbox

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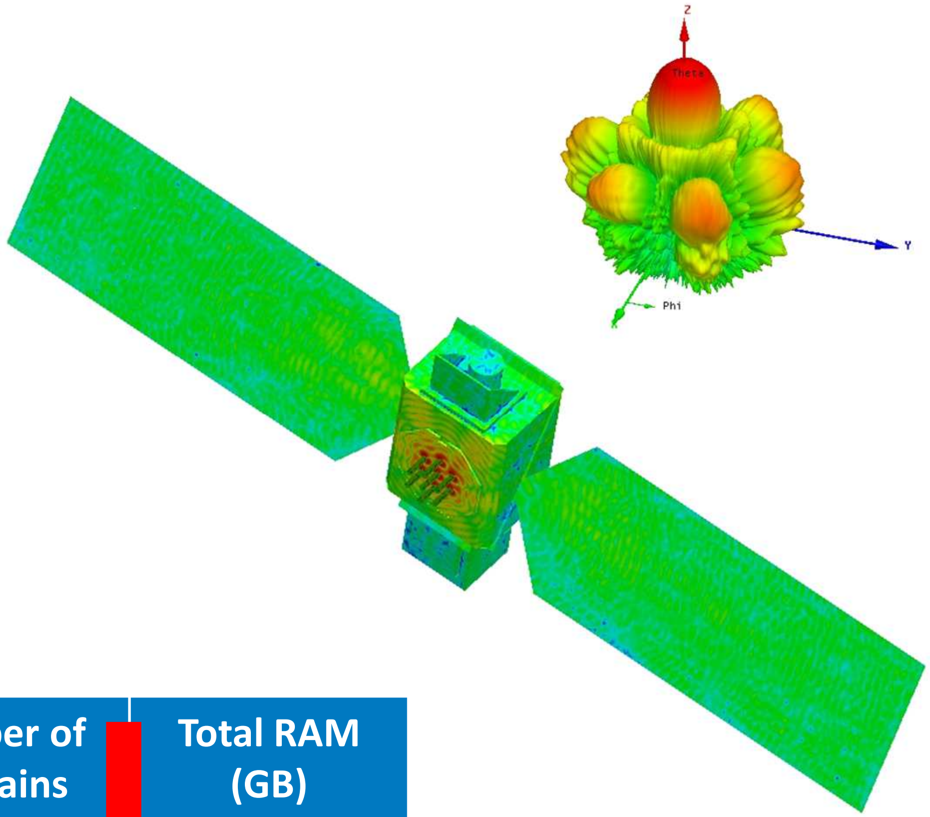
Array on Spacecraft Using FE-BI

- **Array platform integration simulated with conformal FE-BI**
  - RAM requirements reduced by 10x
  - RAM reduction as a result of removing the surrounding free space
- **Only possible using FE-BI**



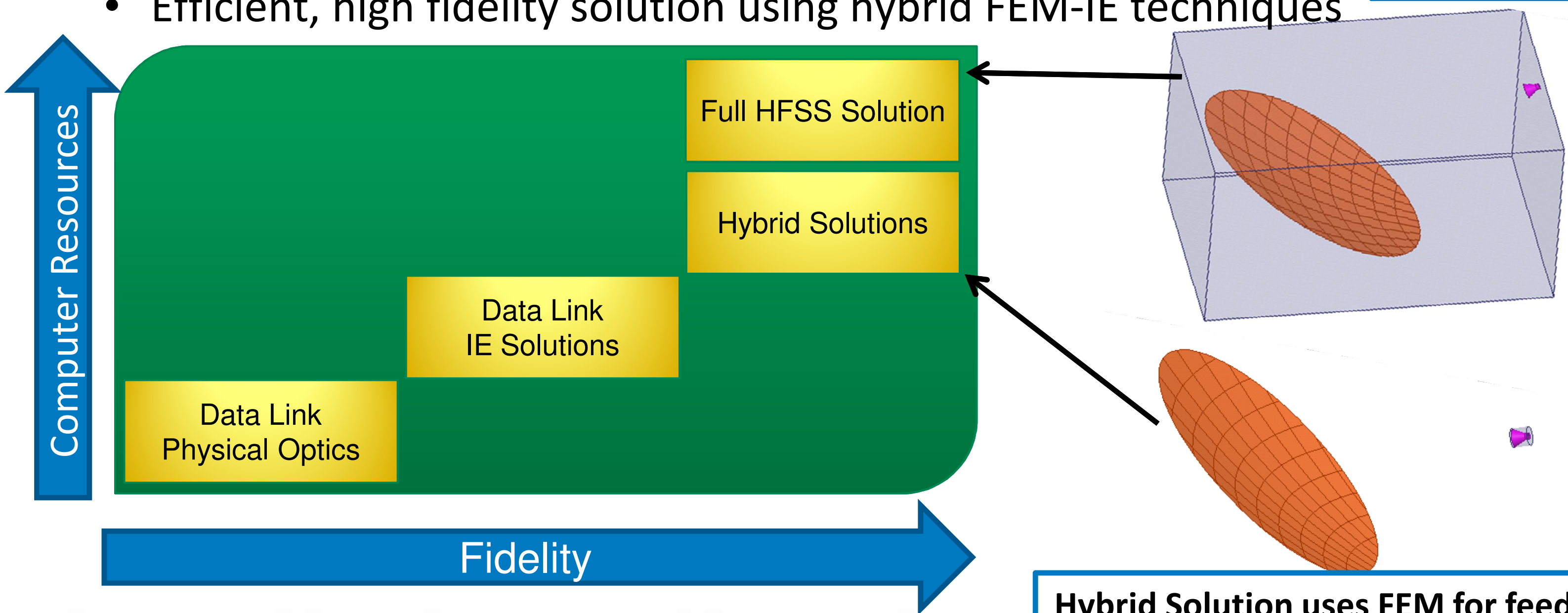
Boundary Type	Airbox Volume	Number of Domains	Total RAM (GB)
ABC	21k λ^3	34	210
FE-BI	**1.2k λ^3**	**12**	**21**

10X Less

Reflector Analysis Using IE-Regions

- **Multiple techniques have been developed to analyze reflector antennas using HFSS**
  - Full HFSS Solution - Model entire solution space using only HFSS
    - High level of fidelity also requires most computer resources
  - Data Link Solutions – Source feed excitation modeled separately from reflector
    - Data link solutions only include 1 way coupling from source excitation to reflector
  - Hybrid Solutions
    - Efficient, high fidelity solution using hybrid FEM-IE techniques

Full HFSS solution requires large air box (~37k λ^3)



Hybrid Solution uses FEM for feed and IE applied to reflector

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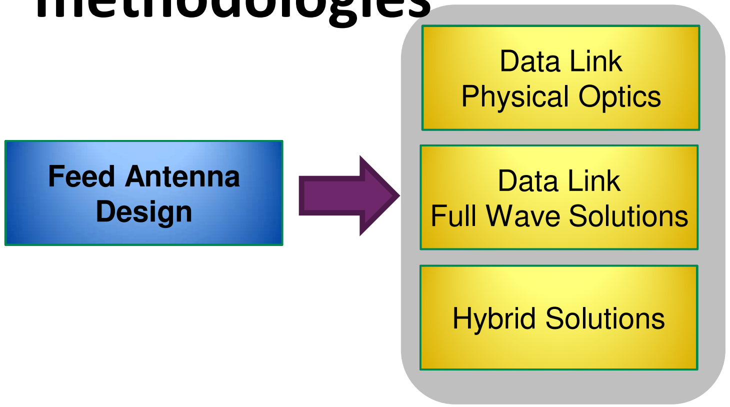
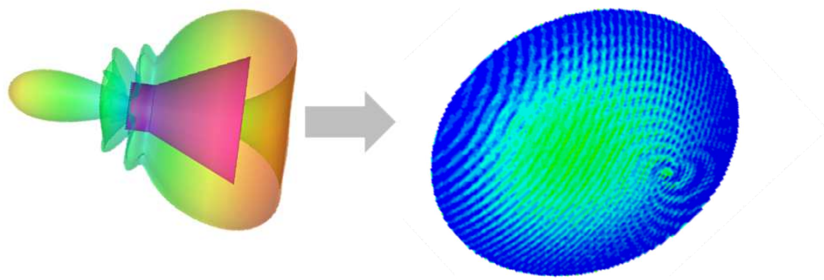
Reflector Analysis Using IE-Regions: Setup

- **Analysis of electrically large reflector antennas may benefit from multi-step design approach utilizing several simulation methodologies**



Data Link with HFSS and Physical Optics



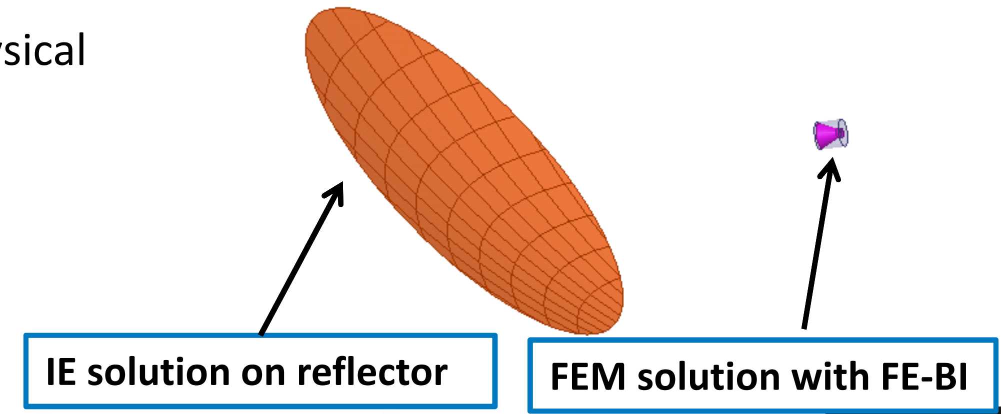
HFSS to HFSS-IE or PO Data-link:

- Source excitation solved in HFSS
- Used as data linked excitation into a Physical Optics or HFSS-IE simulation

Hybrid Solution - FE-BI and IE-Region

- Full wave simulation performed using a hybrid solution in HFSS
  - IE-Region applied to reflector
  - FE-BI applied around feed

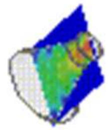
Hybrid FEM-IE Solution

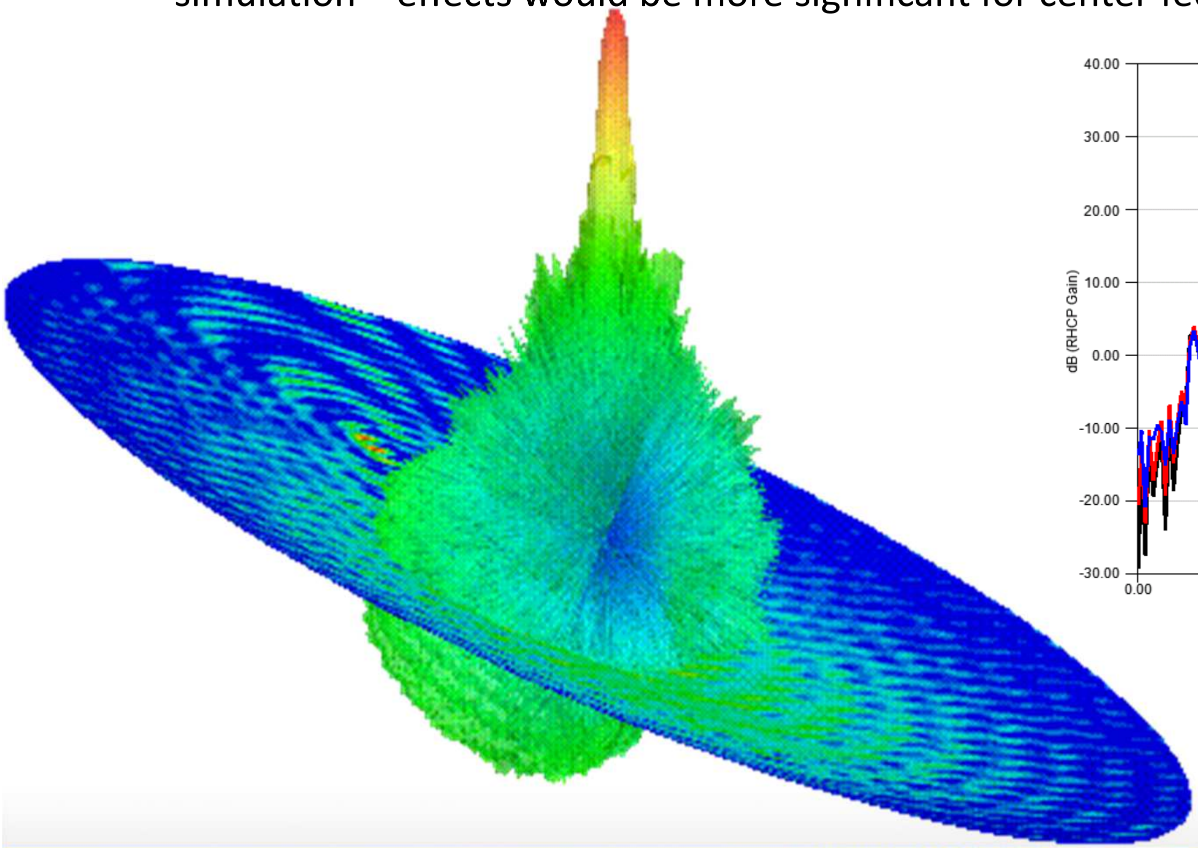


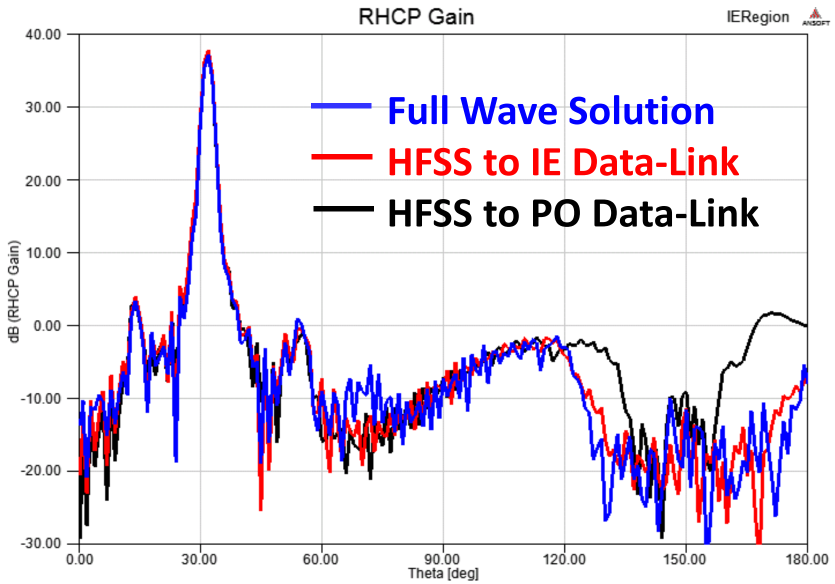
Reflector Analysis Using IE-Regions: Results

- **Full wave solution possible using hybrid FEM-IE solution, enabled with FE-BI and IE-Regions**
    - Agreement between methods only show small difference in peak and side lobe levels
- **Offset fed reflector**
    - Backscatter and blockage not fully included in either data-linked simulation – effects would be more significant for center fed reflector

FEM Solution with FE-BI







IE solution on reflector

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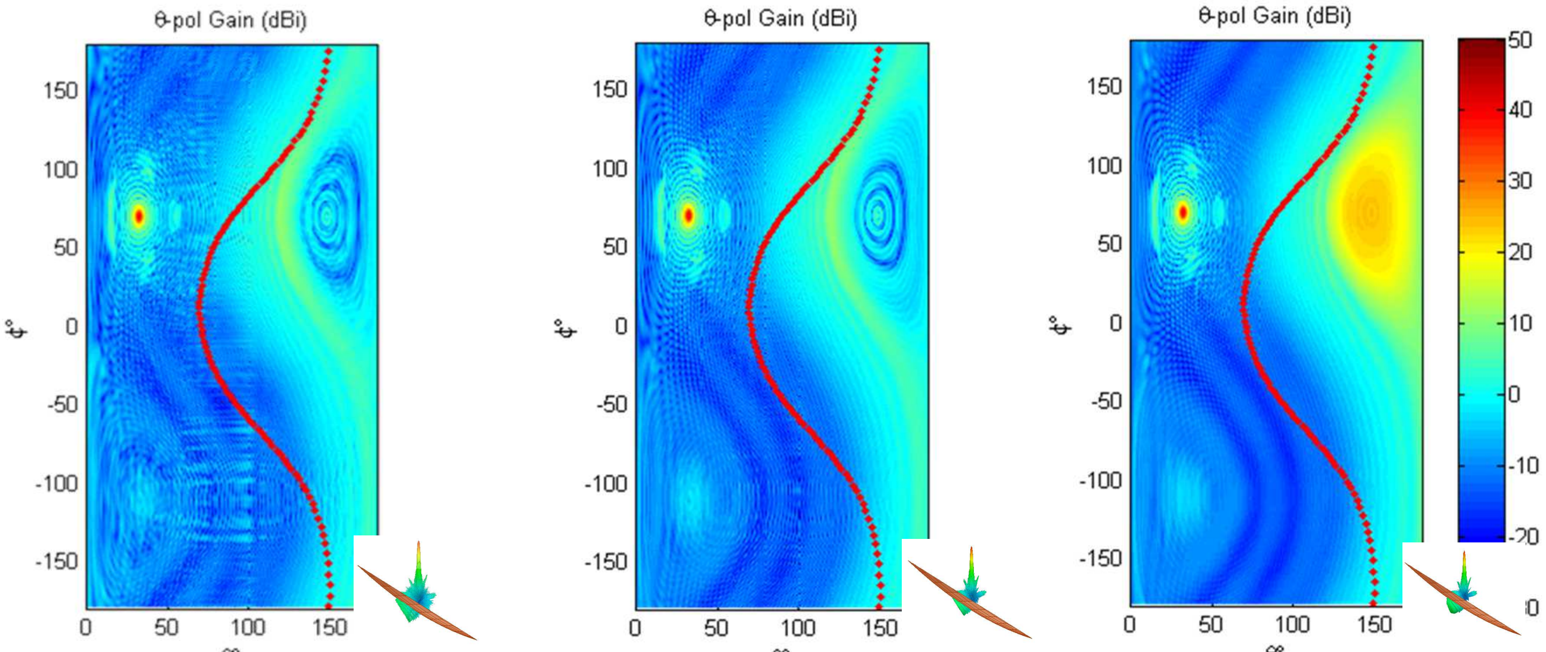
Reflector Analysis Using IE-Regions: Results

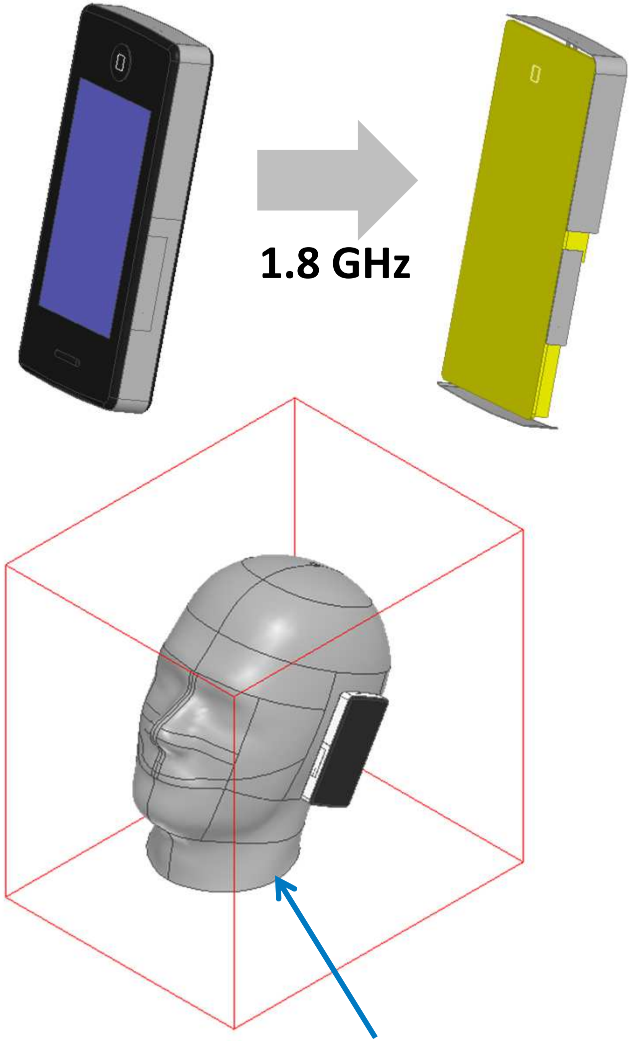


Hybrid FEM-IE | **HFSS to IE Data-Link** | **HFSS to PO Data-Link**

Boundary Type	Airbox Volume	Total RAM (GB)	Elapsed Time (hours)
Full HFSS solution (FEM Only, DDM)	37k λ^3	163.5 (1st pass)	2.7 (1st pass)
Full Wave Hybrid FEM-IE	**8.6 λ^3 (Feed Only)**	5 **>32X Less**	0.5 **>10X Faster**
HFSS to IE Data-Link	NA	3.4	0.2
HFSS to PO Data-Link	NA	0.4	1 minute

Hybrid Solution for Antenna Placement Analysis Using IE-Regions

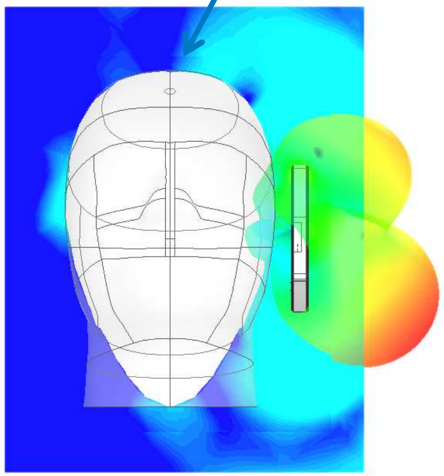
- **Antenna performance modeled with placement in proximity to human head**
  - Cell phone platform and antenna with complex material properties and geometry are ideally modeled using FEM solution
  - The uniform, high dielectric properties of the head are ideally modeled using IE solution
- **Hybrid Solution**
  - An internal dielectric IE Region can be applied to head geometry to reduce computational size and improve efficiency
  - FEM solution is applied remaining volume



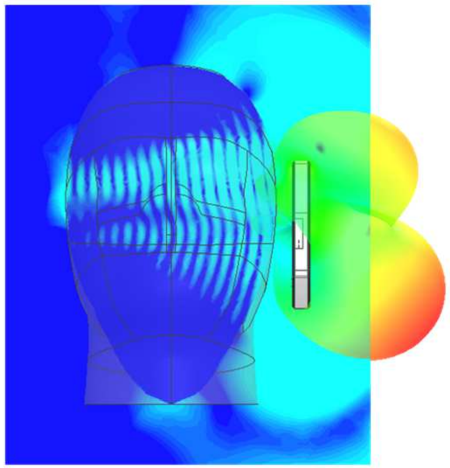
Human Head Material Properties:
ε_r= 79, σ= 0.47siemens/m

Hybrid Solution for Antenna Placement Analysis Using IE-Regions: Results

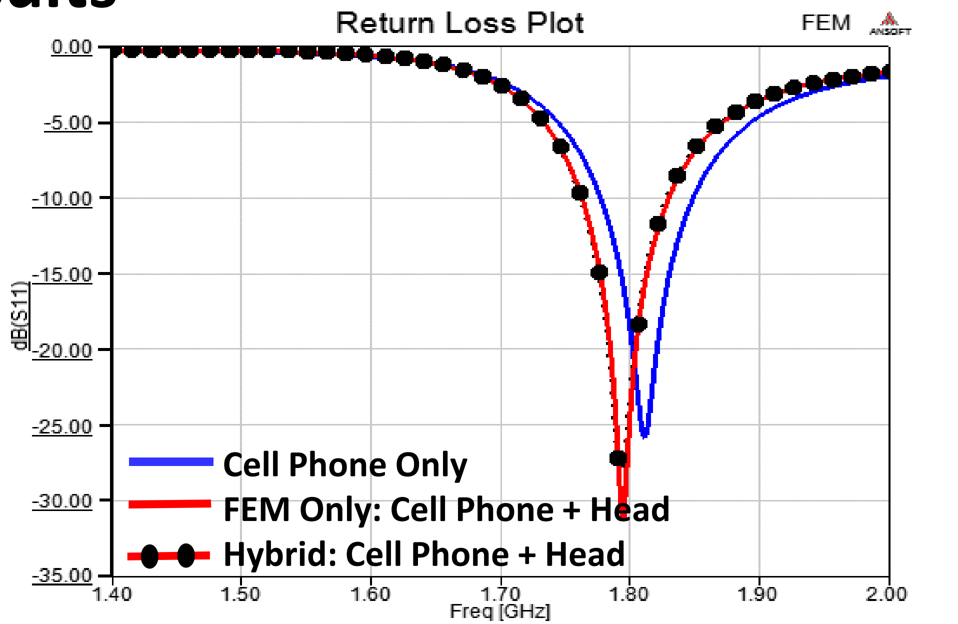
IE-Region Boundary Condition Applied

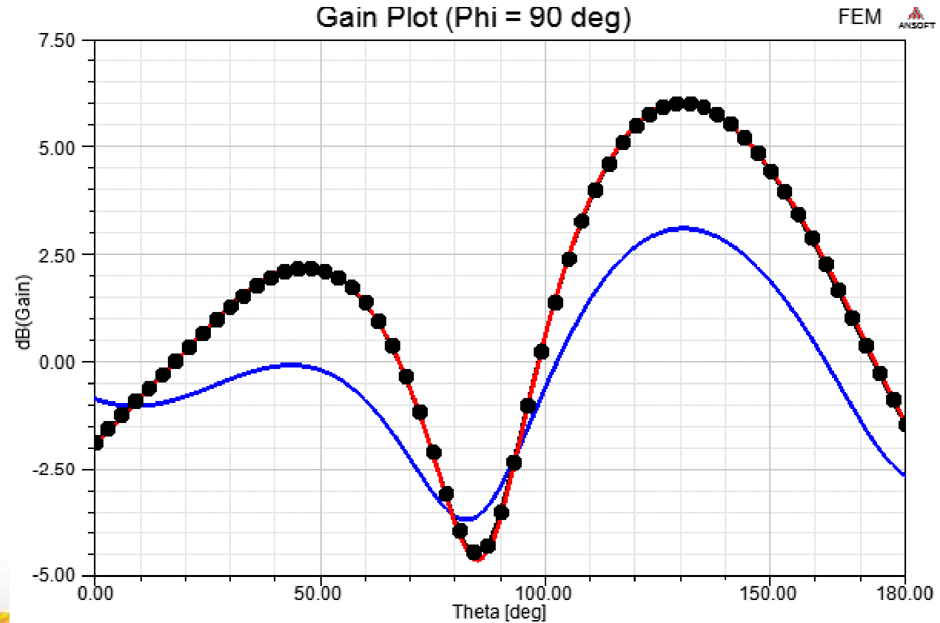


Hybrid FEM-IE Solution
1.8 GHz



FEM Only Solution
1.8 GHz



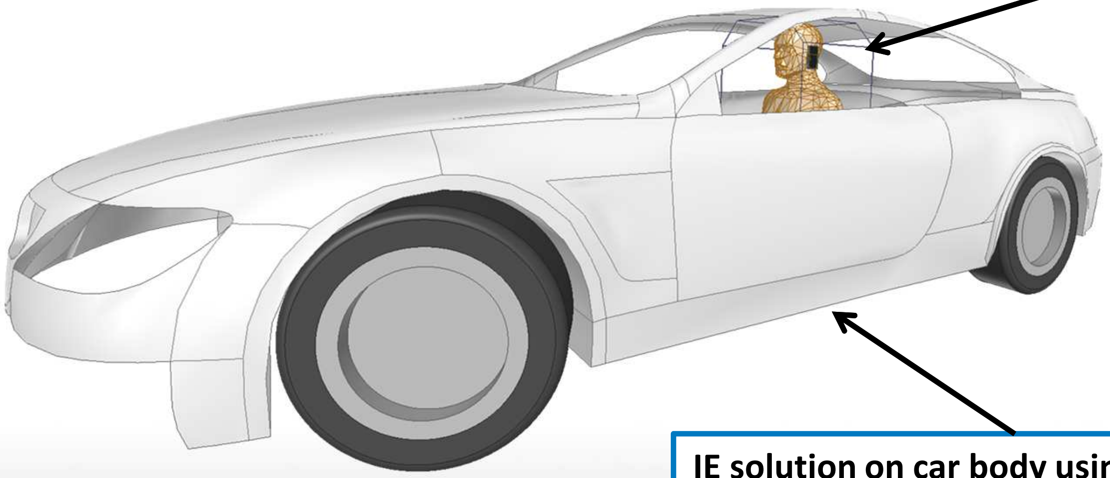


Solution Type	Total RAM (GB)	Elapsed Time (hours)
FEM Only	6.2	1
Hybrid Solution	3	0.5

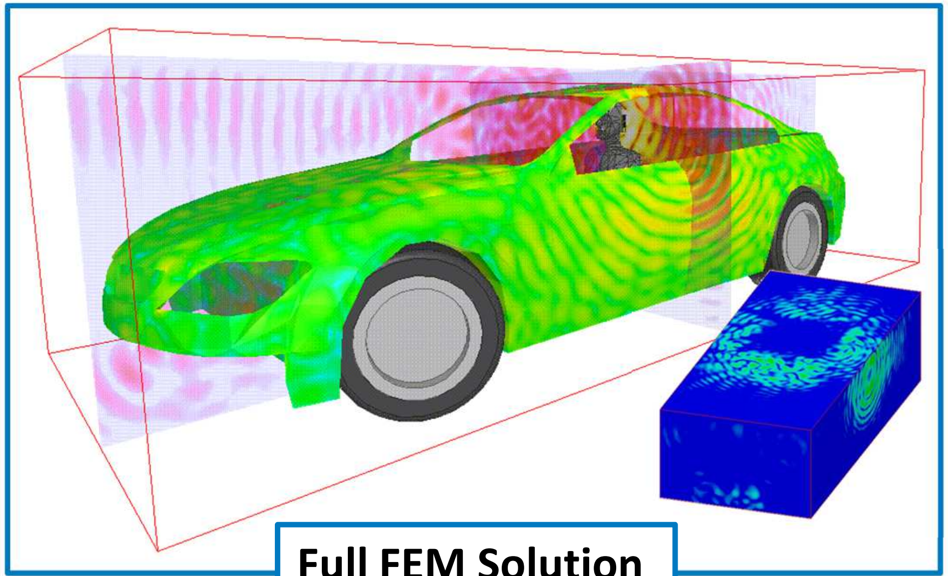
2X Less **2X Faster**

Hybrid Solution for Antenna Placement Analysis Using IE-Regions

- **Antenna performance modeled with placement in proximity to human head inside vehicle**
  - Cell phone platform and antenna with complex material properties and geometry are ideally modeled using FEM solution
  - The uniform, high dielectric properties of the head are ideally modeled using IE solution
  - The car is ideally modeled using IE-Region
- **Hybrid Solution Setup**
  - An internal dielectric IE-Region can be applied to head geometry to reduce computational size and improve efficiency
  - An exterior metallic IE-Region is applied to car model
  - FEM solution is applied remaining volume



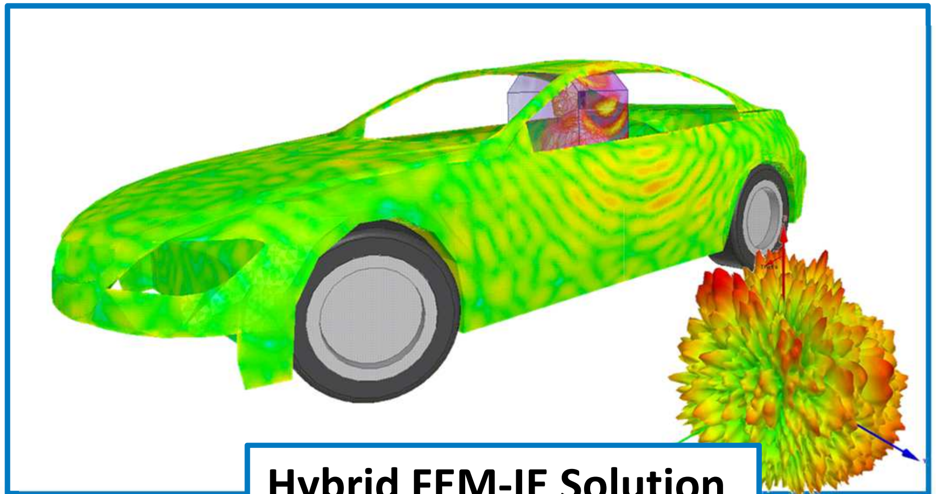
Hybrid Solution for Antenna Placement Analysis Using IE-Regions: Results



Full FEM Solution

Solution Type	Total RAM (GB)	Elapsed Time (hours)
Full FEM Solution	160 GB (DDM)	8

15X Less ↓ **3X Faster**



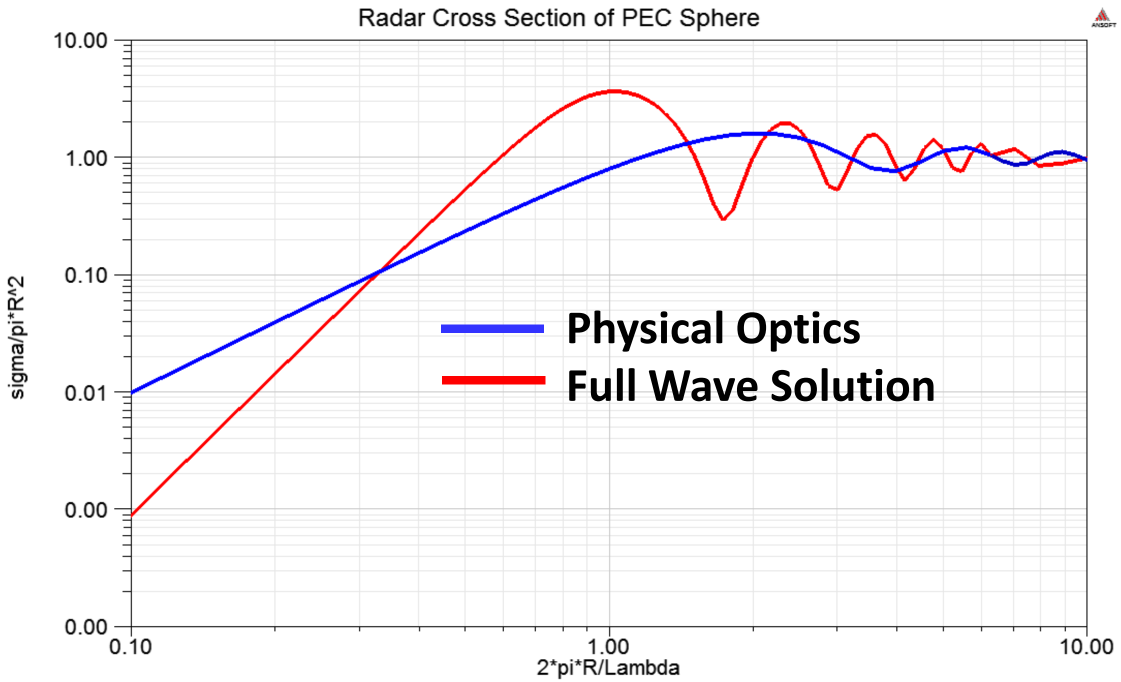
Hybrid FEM-IE Solution

Solution Type	Total RAM (GB)	Elapsed Time (hours)
Hybrid FEM-IE Solution	11	2.7

Physical Optics (PO) for Electrically Large Simulations

High frequency asymptotic solver

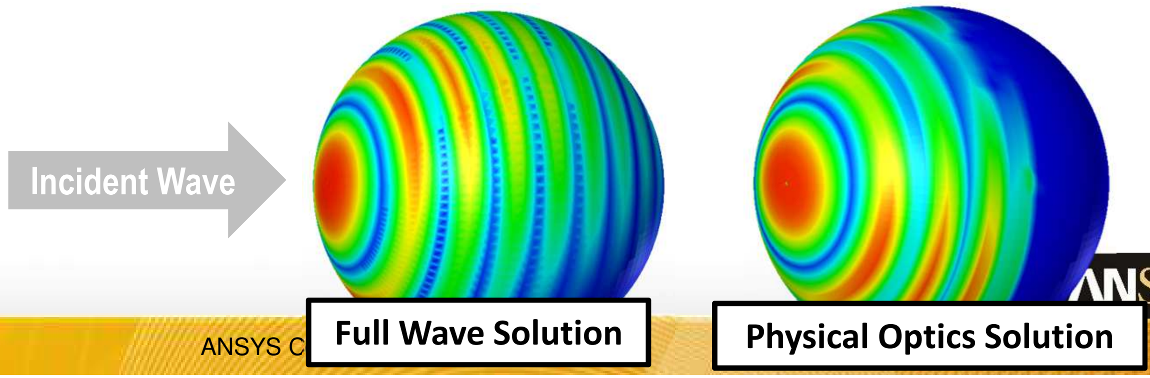
- Scattering and antenna placement of electrically large objects



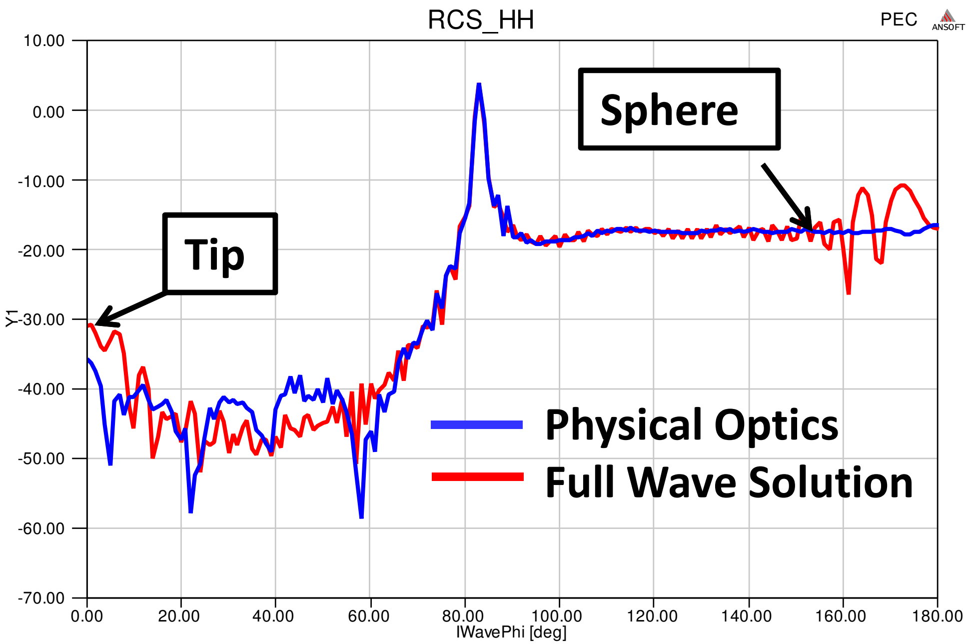
RCS of PEC Sphere

- Highlights capabilities and limitation of physical optics
- Creeping wave effects not accounted for by PO
- When electrical size of sphere becomes large, full wave solution converges with physical optics solution

Solution @ High Freq.	Total RAM (GB)	Elapsed Time (sec)
Full Wave (HFSS-IE)	1.4	87
Physical Optics	0.1	14

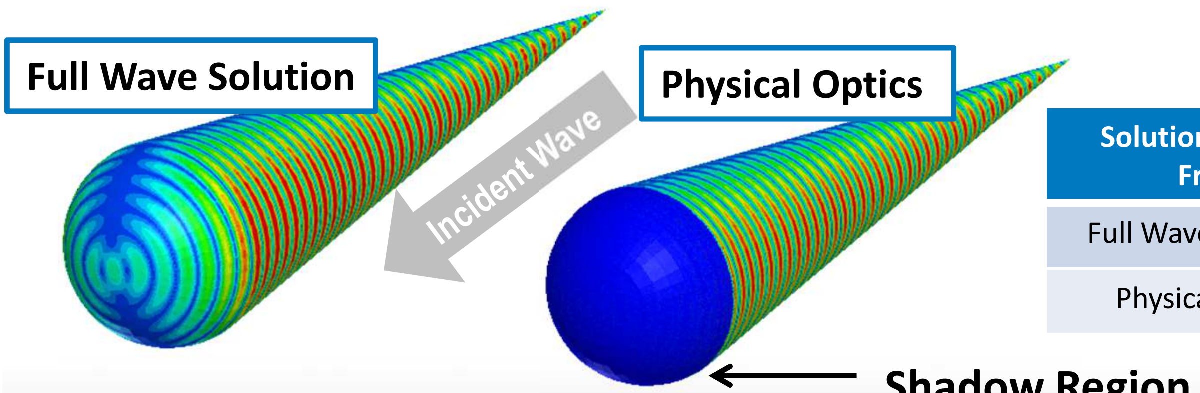


Physical Optics for RCS of Electrically Large Structures



Good correlation between full wave solution and physical optics solution for RCS of electrically large cone-sphere

- Creeping wave effects not accounted for in physical optics solution
  - Apparent as incident angles approach tip and sphere side of cone-sphere



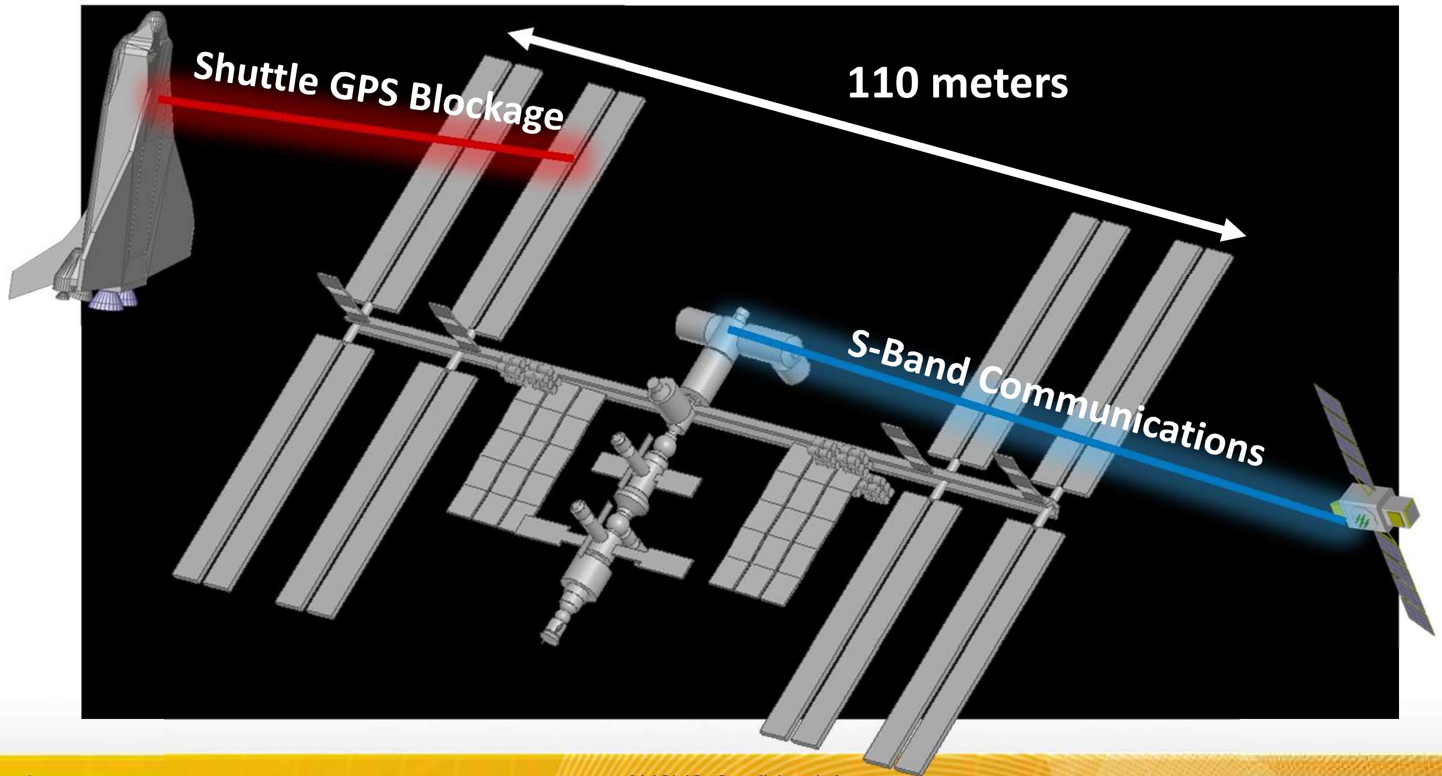
Solution @ High Freq.	Total RAM (GB)	Elapsed Time
Full Wave (HFSS-IE)	6.6	2 hours
Physical Optics	4.8	16 minutes

ANSYS

International Space Station (ISS): Antenna Placement and Blockage Simulations

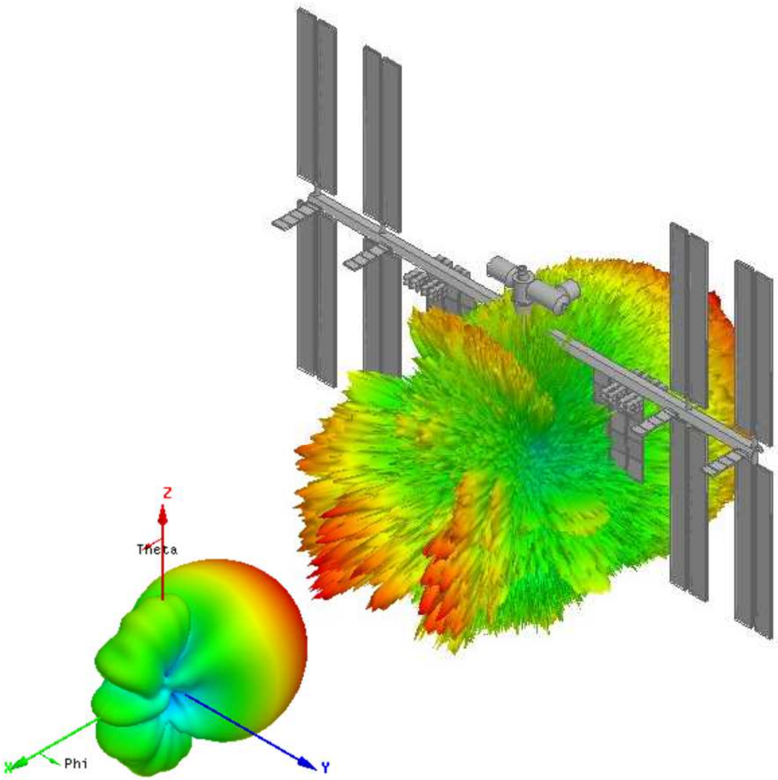
Multiple antenna and communication channels operating on and around the ISS are subject to blockage due to the large structure

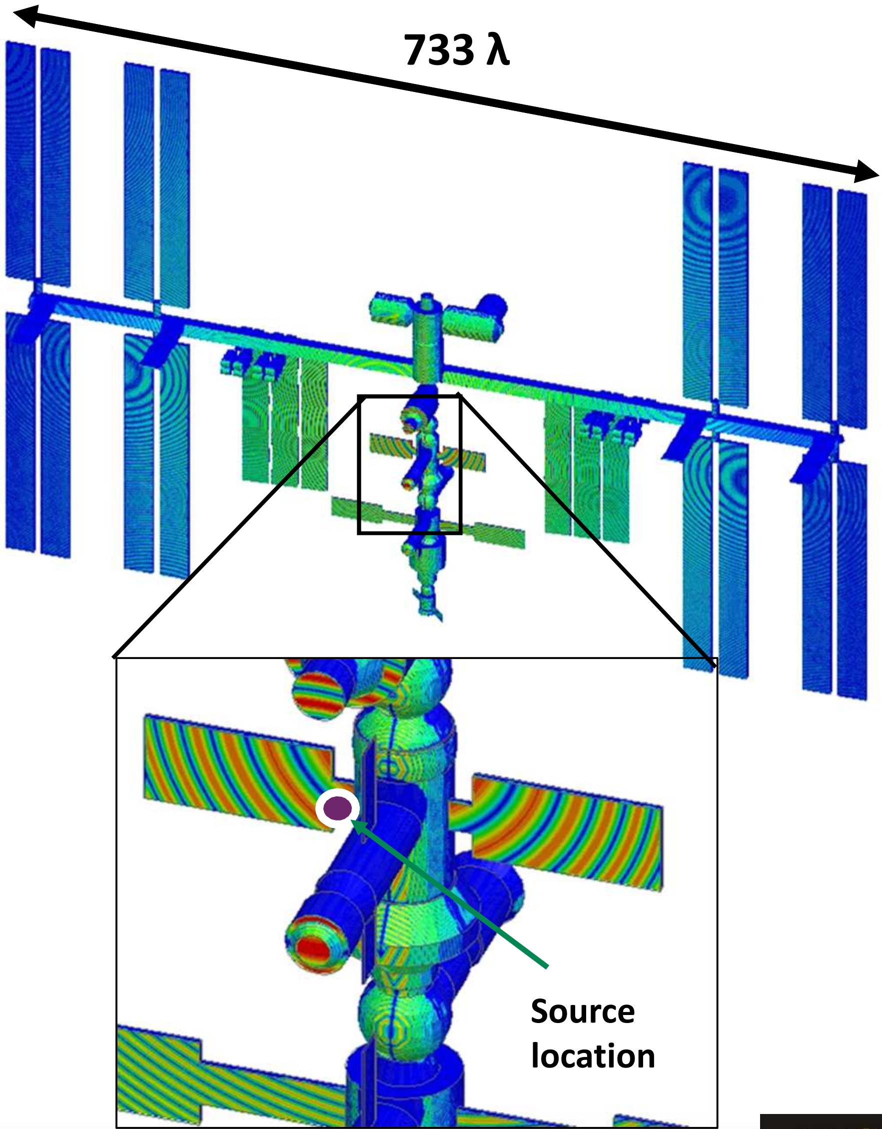
- **Physical Optics allows us to model important navigational and communications challenges**
  - **Degradation of communications due to adjusting solar panels on ISS**
  - **Blockage of GPS signals used by docking vehicles**



Physical Optics for S-Band Communications on ISS Antenna Blockage

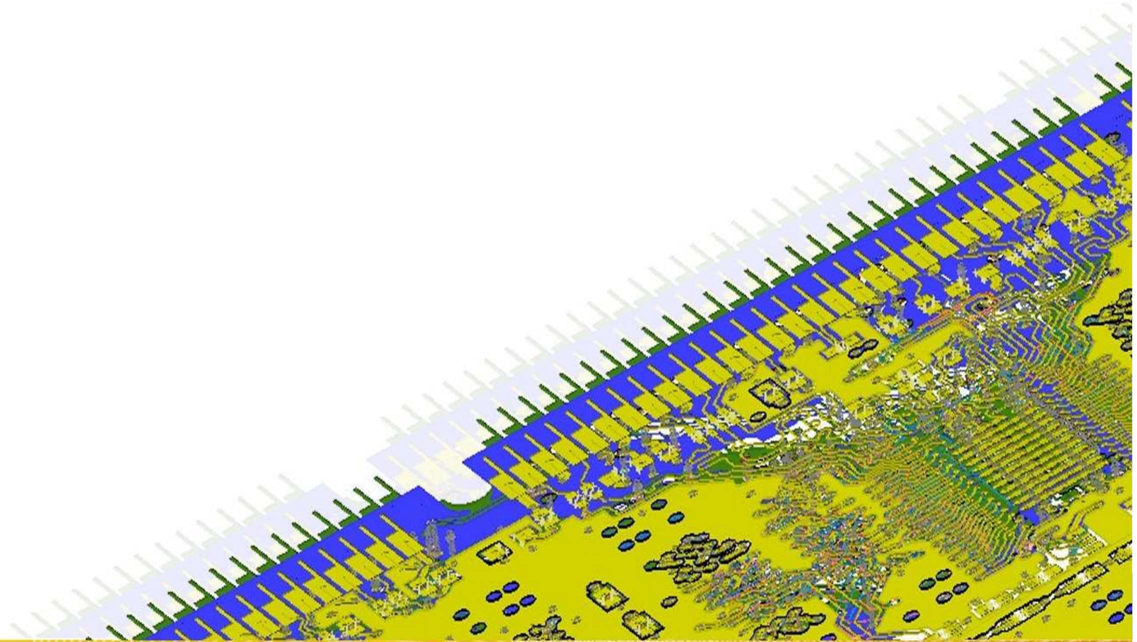
Solution @ 2GHz	Total RAM (GB)	Elapsed Time (min)
Physical Optics	47	57





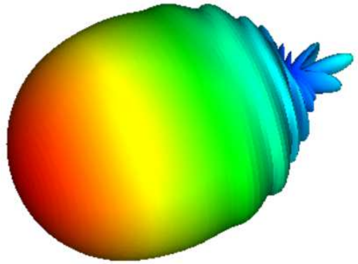
ANSYS®

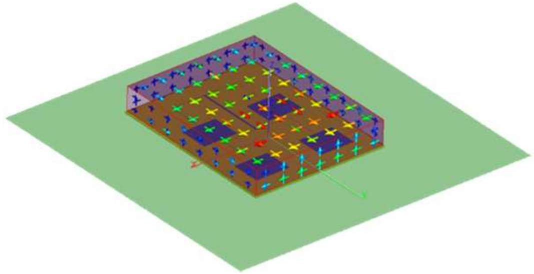
Savant

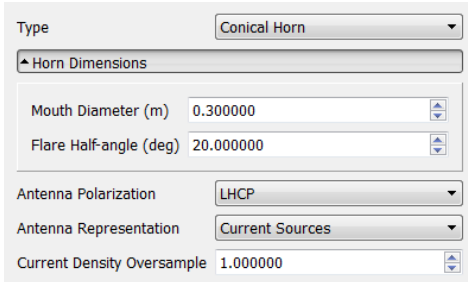


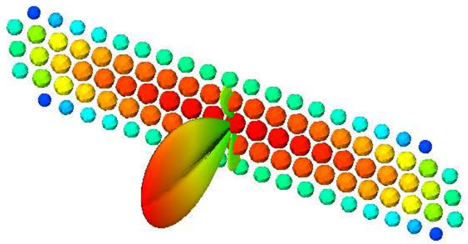
Antenna Models

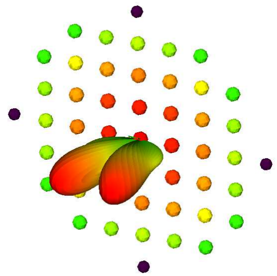
- **From HFSS**
  - **Far-field radiation patterns**
  - **Current sources**
- **Built in parametric models**
  - **Dipoles, monopoles, loops, slots**
  - **Pyramidal and Conical horns**
  - **Parametric Beam**
- **Array Design Tool**
  - **Linear, Rectangular, Elliptical & By File**
  - **Weighting and phasing of elements**
- **Near-Field to Current Sources**
  - **Third Party CEM tools**
  - **Measured Data (Microwave Vision Group)**

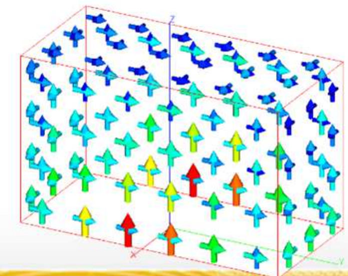




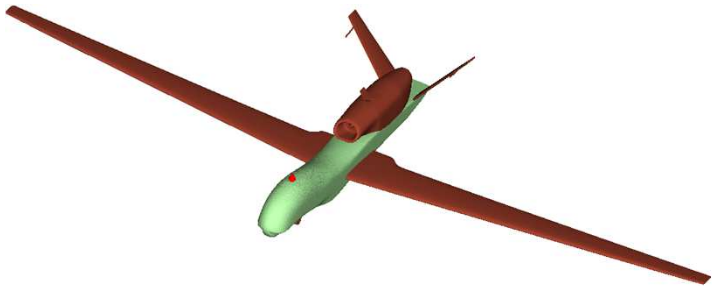




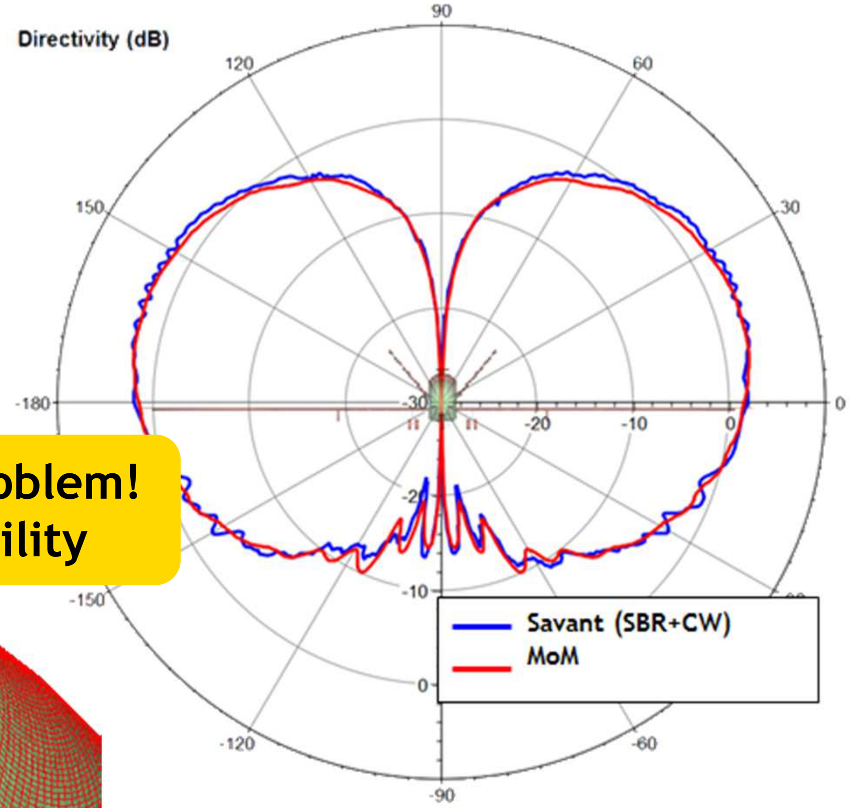




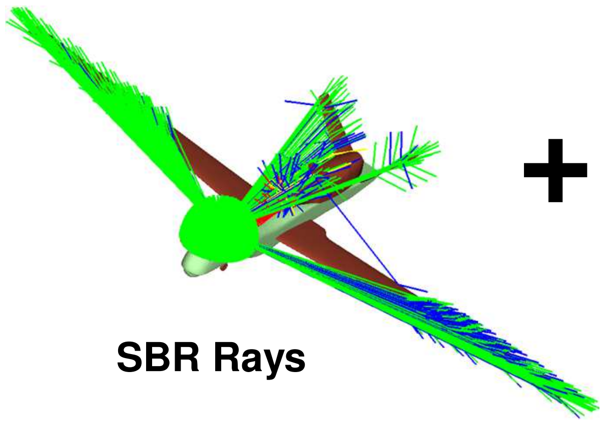
Accuracy: Creeping Wave



1 GHz monopole mounted on Global Hawk

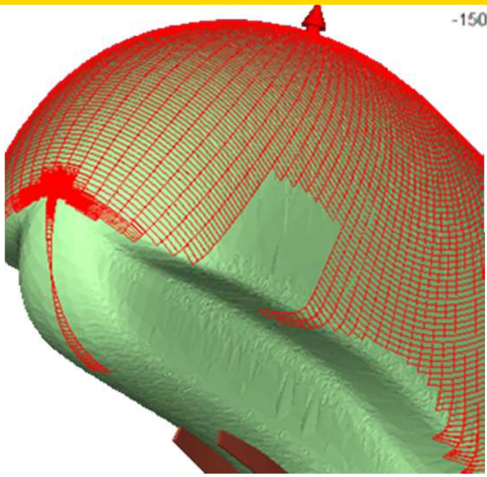


Creeping Wave Is Very Important For This Problem!
Savant is the only SBR tool with this capability



SBR Rays

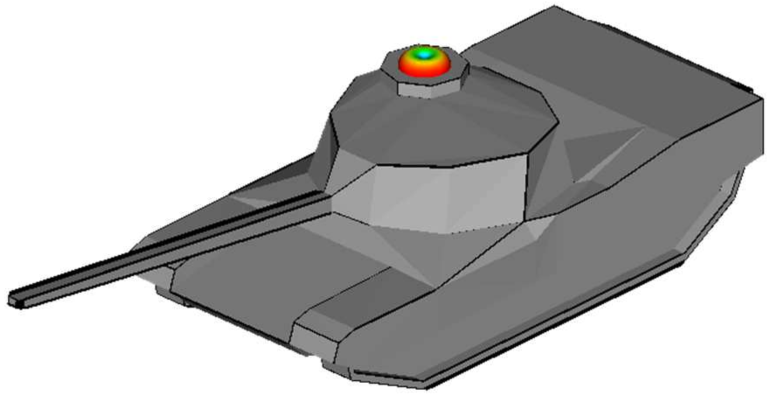
+

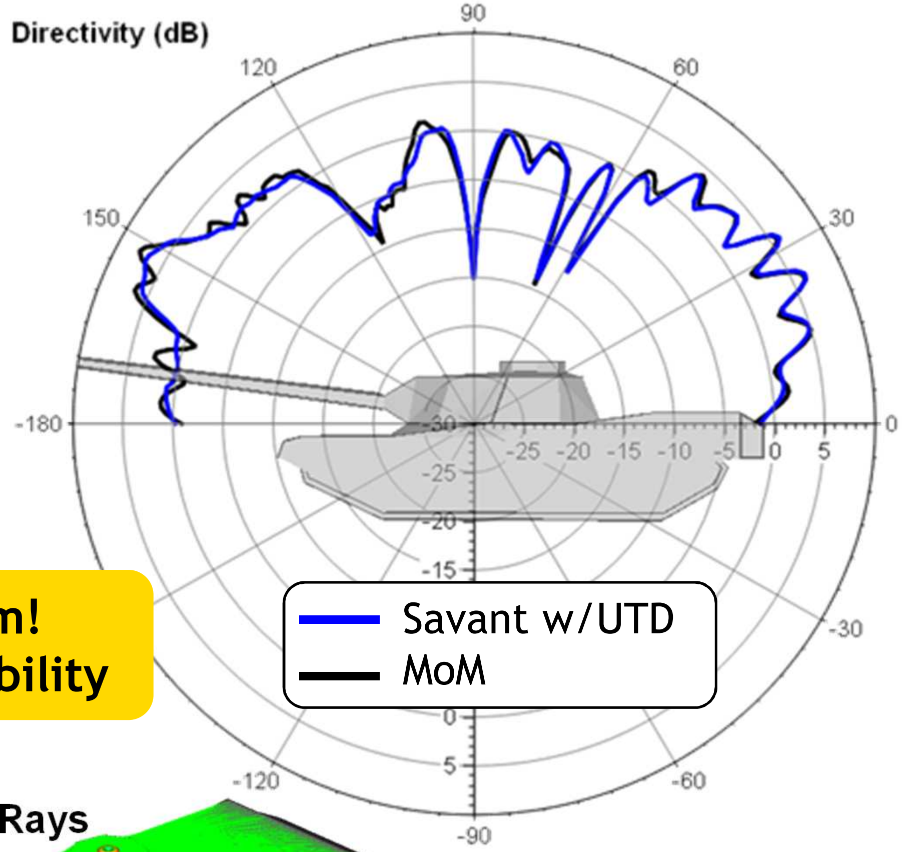


Creeping-wave Rays

Accuracy: UTD Diffraction Rays

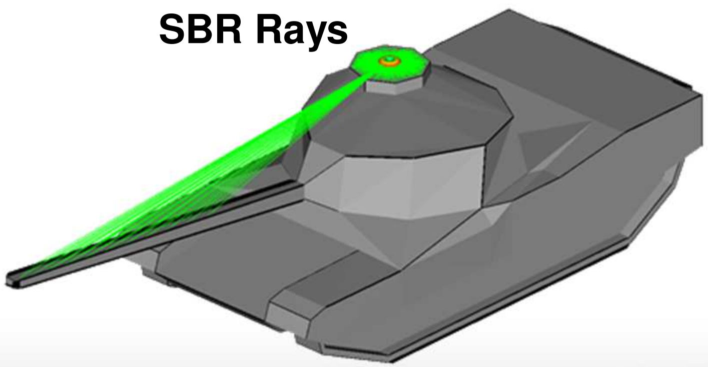
1 GHz monopole





UTD Is Very Important For This Problem!
Savant is the only SBR tool with this capability

SBR Rays



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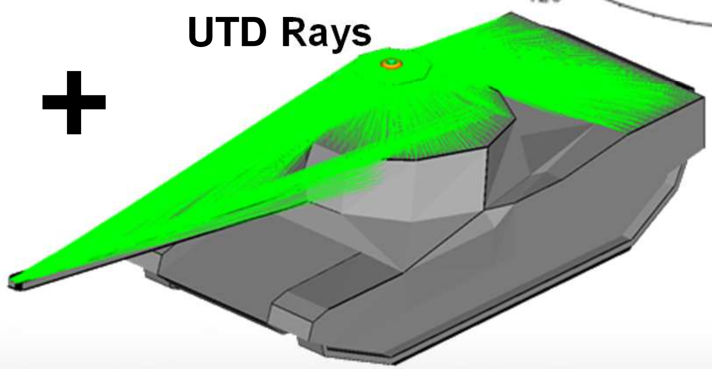
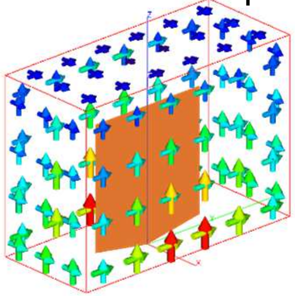
UTD Rays



HFSS & Savant Integrated Workflow

Isolated Antenna Element Solved in HFSS

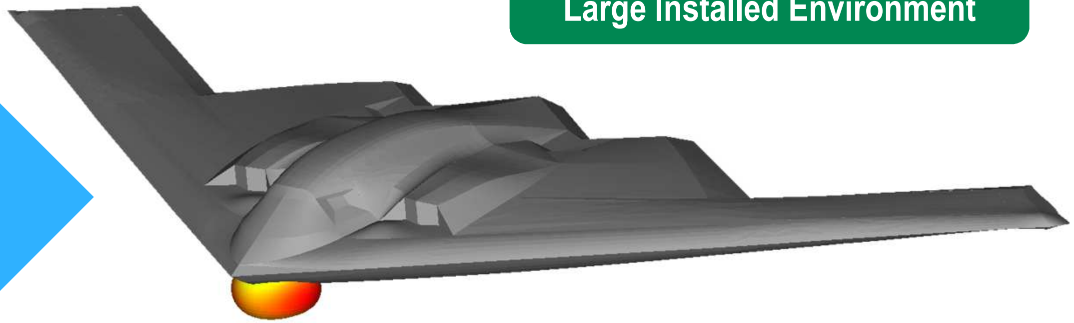
250 MHz Monopole

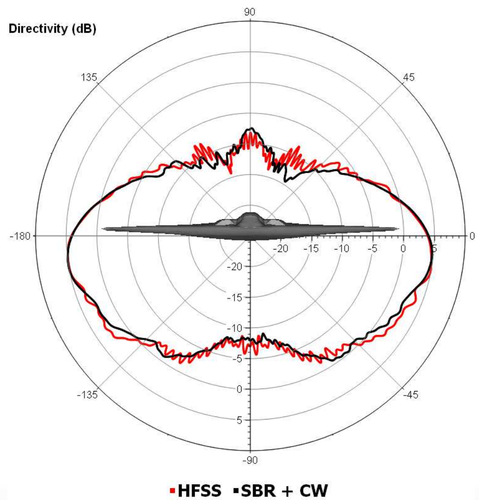


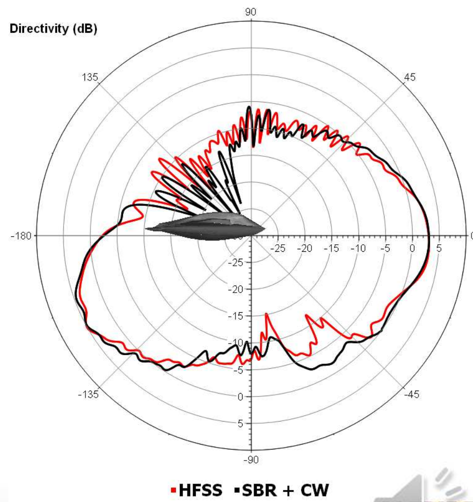
HFSS Currents Used by Savant

42λ x 17λ x 3.75λ

Savant Quickly Simulates the Large Installed Environment



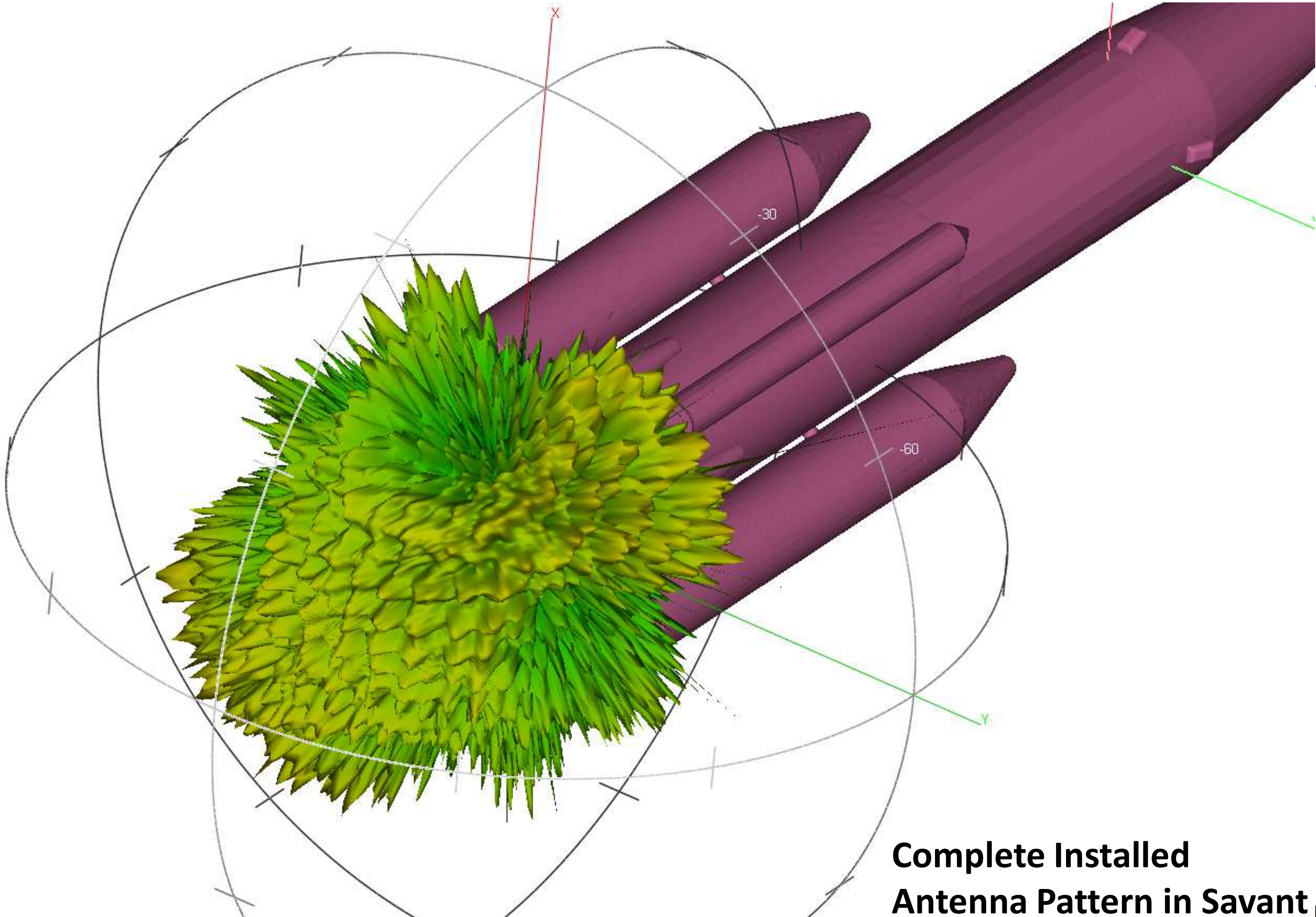




Simulation Time for Installed Antenna

Savant: 12 minutes
HFSS: 195 minutes

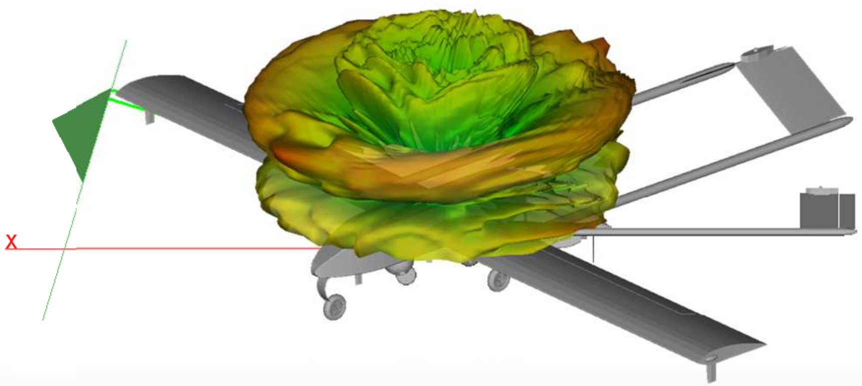
HFSS & Savant Integrated Workflow

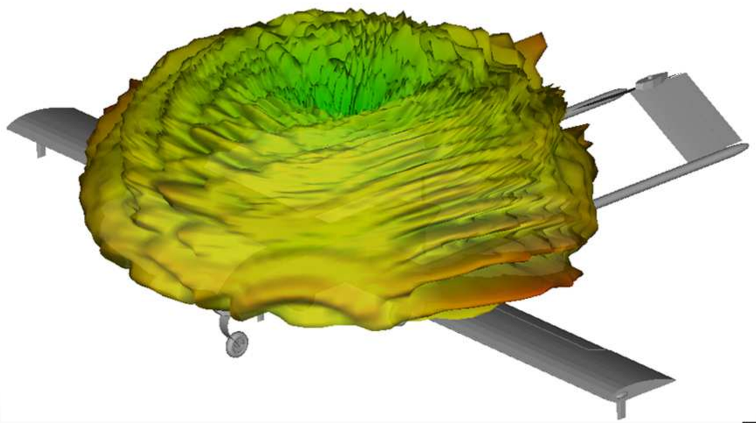


Complete Installed Antenna Pattern in Savant

Value Proposition

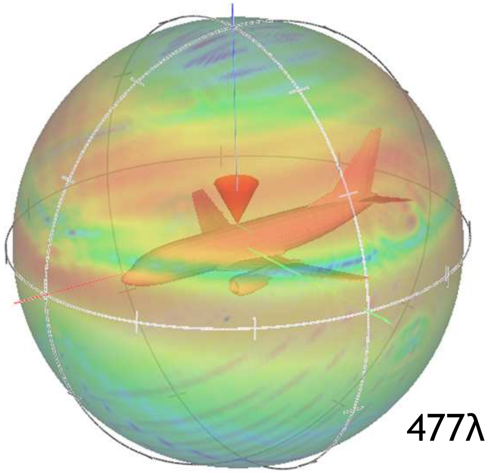
- Extend the capabilities of HFSS users to address much larger problems
- Enhance the investment in HFSS and other ANSYS tools
- Rapid simulations allow for many iterations during design cycle
- Optimize amount of testing required
- Advanced diagnostic features help users to understand results
- Recognized as best-in-class ray tracing technology
  - Shooting and Bouncing Rays (SBR)





GPU and MPI Examples

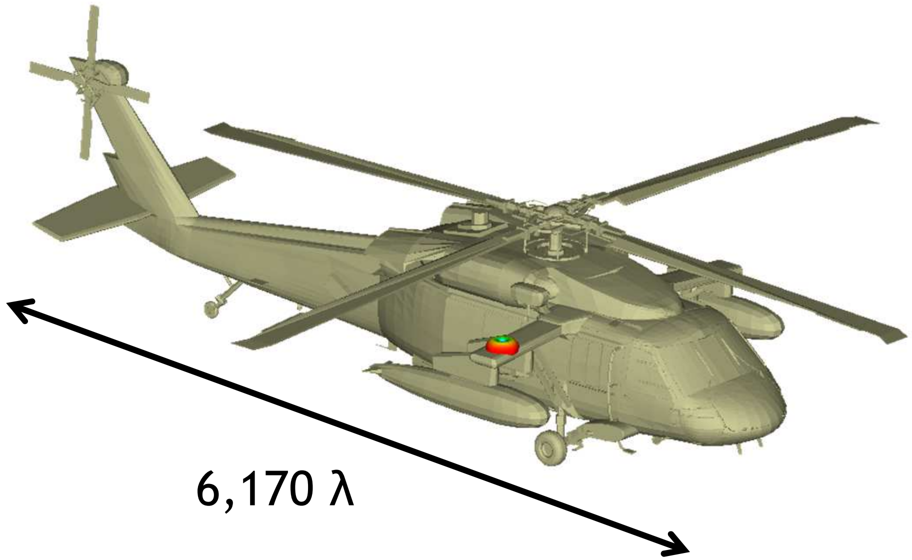
- CPU and GPU
  - Monopole on 737-800
    - 40,000 angular samples
    - 3 to 4 GHz, 40 MHz steps
    - 747,820 rays hit CAD



477λ x 527λ x 167λ

Configuration	Time	Speedup
1 CPU Core	12 hrs, 18 min	-
4 CPU Cores	3 hrs, 12 min	4x
1 CPU Core, 1 GPU	10.7 min	>70x
4 CPU Cores, 2 GPU	6.2 min	>118x

- CPU, GPU and MPI
  - 94 GHz Antenna on UH-60

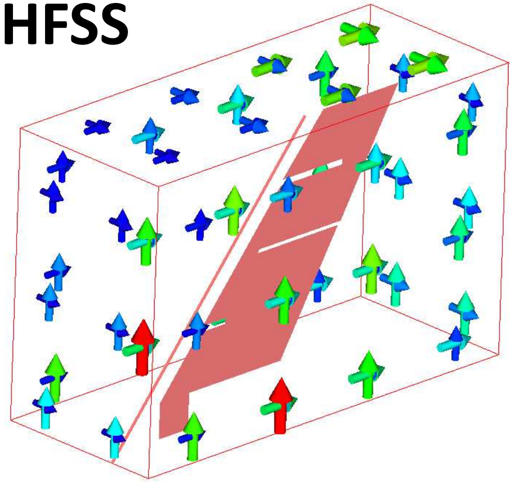


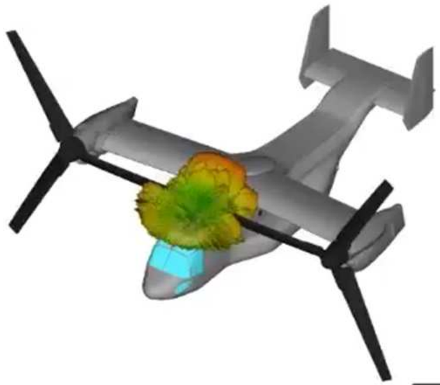
Configuration	Time	Speedup
1 Node, 6 cores, 2 GPU	720 sec	-
5 Nodes, 30 CPU cores, 10 GPUs	143 sec	5x

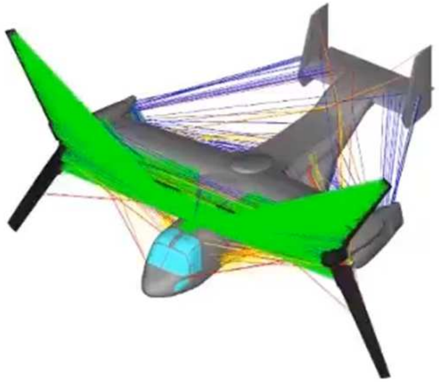
  - Computer hardware costs $20K

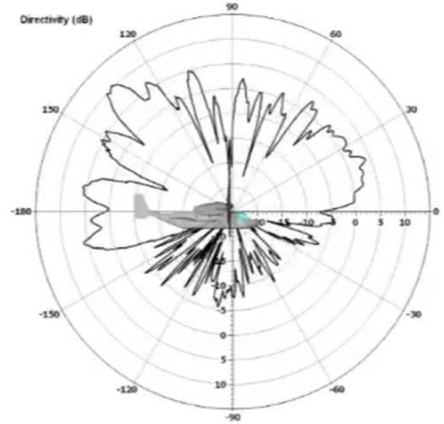
Workflow + Hardware Acceleration

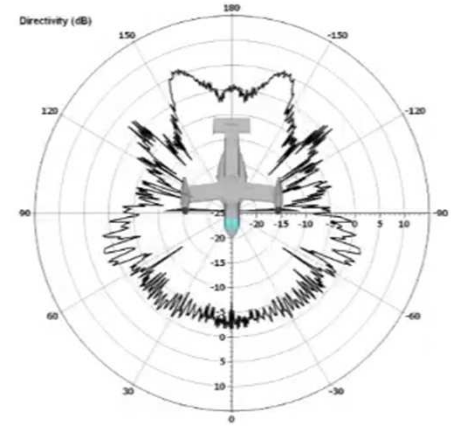
HFSS









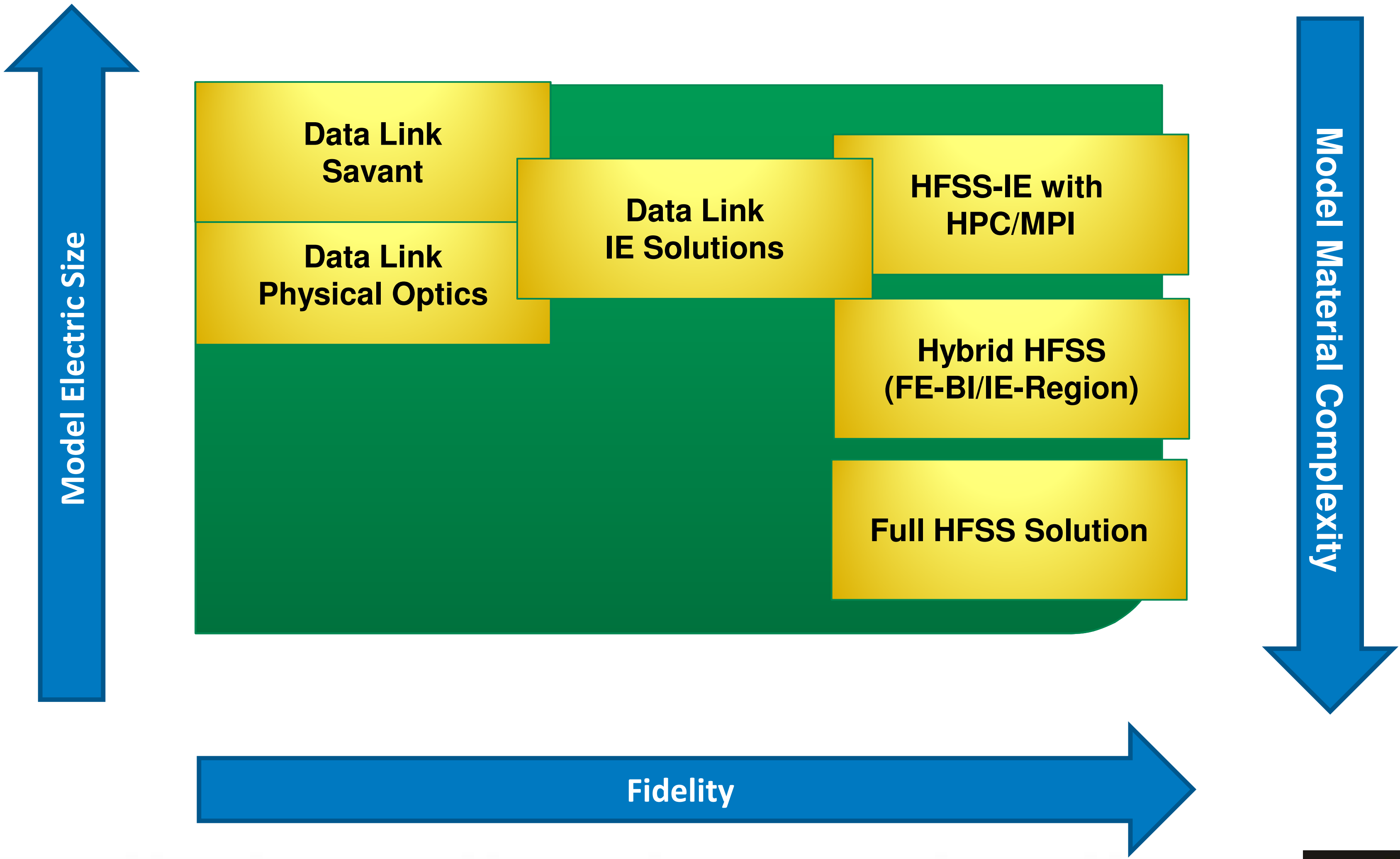


UHF Blade Antenna
2.3 GHz

<u>1,620</u> simulations to capture moving blades and engine assemblies

<u>6 hours to compute all jobs on laptop!</u>

Summary



Model Electric Size
Data Link
Savant
Data Link
Physical Optics
Data Link
IE Solutions
HFSS-IE with
HPC/MPI
Hybrid HFSS
(FE-BI/IE-Region)
Full HFSS Solution
Model Material Complexity
Fidelity

Realize Your Product Promise®

Thank You!