Lecture 7: Introduction to HFSS-IE

ANSYS HFSS for Antenna Design
HFSS-IE: Integral Equation Solver Introduction

• **HFSS-IE: Technology**
  - An Integral Equation solver technology in the HFSS desktop
    - A 3D Method of Moments (MoM) Integral Equation technique
      - Efficient Solution Technique for Open Radiation and Scattering Analysis
    - Only surfaces are meshed and solved
    - Hybrid IE and FEM solution can be used to leverage most efficient techniques from either method simultaneously
  - Physical optics, high frequency solver also included within HFSS-IE design type

• **HFSS-IE: Applications**
  - Antenna design, antenna placement, Radar Cross Section, S-parameter extraction, EMI/EMC Analysis, Efficient analysis of electrically large structures

\[ E(r) = j \frac{\eta}{k_0} (\nabla \nabla \cdot + k_0^2) \int_S J(r') G(r - r') dS' \]
Adaptive mesh

- **HFSS-IE: Advantage**
  - Automated results with accuracy
    - Effective utilization of automated adaptive meshing technique from HFSS to ensure accuracy
    - Employs Adaptive Cross Approximation (ACA) technique
      - Compression is independent of mesh creation leads to efficient results with minimal user interaction. Robust and invariant to problem description.
    - Employs Multilevel Fast Multipole Method (MLFMM)
      - Decomposes geometry into boxes and then solves the fields based on a physics decomposition. Efficient for models with low complexity and geometric dynamic range.
  - Utilization of results from HFSS or HFSS-IE as a linked source excitation

- **HFSS-IE: User Interface**
  - Implemented as a design type in the HFSS desktop
    - Shares same modeler interface and similar analysis setup
    - Minimal user training required for existing users of HFSS
Choice of Solution Methods

• Solution to geometry using either FEM or IE

• Both solution yield the same results
  • FEM solution requires an air volume surrounding antenna, IE solution does not
  • Integral equation solution would be most efficient when geometry is primarily metal

HFSS-IE Model

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

Integral Equation

HFSS Model

- Efficiently handles complex material and geometries
- Volume based mesh and field solutions
- Fields are explicitly solved throughout entire volume

Finite Element Method
HFSS-IE Solver Examples

<table>
<thead>
<tr>
<th>Solver</th>
<th>Memory (GB)</th>
<th>CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFSS-IE</td>
<td>84.4</td>
<td>0.5 hours</td>
</tr>
</tbody>
</table>

Antenna Placement on Commercial Aircraft @ 2.45GHz

<table>
<thead>
<tr>
<th>Solver</th>
<th>Memory (GB)</th>
<th>CPU</th>
</tr>
</thead>
<tbody>
<tr>
<td>HFSS-IE</td>
<td>94.3</td>
<td>2 hours</td>
</tr>
</tbody>
</table>

RCS of Fighter Aircraft @ 2GHz

130λ

183λ
Adaptive mesh

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HFSS-IE Solvers

- HFSS IE Solver:
  - ACA Solver:
    - Is an algebraic method without physics consideration
  - MLFMM Solver:
    - MLFMM solver decomposes geometry into boxes
    - Fields in these boxes are solved based on a physics decomposition
- Factors that influence efficiency of MLFMM relative to ACA:
  - Feature size variation
    - High complexity and geometric dynamic range cause longer simulation
  - Aspect ratio of bounding box of model
    - High aspect ratio results in longer simulation
- In general ACA is more robust and invariant to problem description
  - When in doubt use ACA
HFSS-IE Solvers

Boeing X-48 Blended Wing Body (BWB)

361 incident angle in Phi

@ 150 MHz, 0.9M matrix unknowns

- ACA Performance
  Time: 2:28:15
  Memory: 97.3 GB

- MLFMM Performance
  Time: 1:20:39
  Memory: 51.7 GB
Guidelines for Choosing IE Solver

Geometric/Mesh Complexity*

High

ACA

Low - Medium

Aspect Ratio of Bounding Box

> 100

ACA

MLFMM

< 100

* Automatic adaptive meshing for accuracy can result in large elements variation. An example could be a small antenna on an aircraft.
HFSS-IE, Physical Optics Solver Introduction

• Asymptotic solver for extremely large problems
  – Included in HFSS-IE
  – Solves electrically huge problems
  – Currents are approximated in illuminated regions
    • Set to zero in shadow regions
  – No ray tracing or multiple “bounces”

• Target applications:
  – Large reflector antennas and antenna placement
  – RCS of large objects such as satellites

• Option in solution setup for HFSS-IE.

• Sourced by incident wave excitations
  – Plane waves or linked HFSS designs as a source

\[ J \approx 2nH^{inc} \]
Physical Optics

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

<table>
<thead>
<tr>
<th>Solution @ High Freq.</th>
<th>Total RAM (GB)</th>
<th>Elapsed Time (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Wave (HFSS-IE)</td>
<td>1.4</td>
<td>87</td>
</tr>
<tr>
<td>Physical Optics</td>
<td>0.1</td>
<td>14</td>
</tr>
</tbody>
</table>
Fighter Aircraft RCS using PO

Incident Wave

Front View

Top View

10GHz

18GHz

Bistatic RCS
Blue – 18GHz
Red – 10 GHz

<table>
<thead>
<tr>
<th>Frequency</th>
<th>Mesh #</th>
<th>RAM</th>
<th>Elapsed Time</th>
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</thead>
<tbody>
<tr>
<td>10GHz</td>
<td>5.03 million</td>
<td>15.4 G</td>
<td>27.5 minutes</td>
</tr>
<tr>
<td>18GHz</td>
<td>16.19 million</td>
<td>50.6 G</td>
<td>174.5 minutes</td>
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</tbody>
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HFSS-IE: Offers Advanced Features for Antenna Design

- **Advanced solver technology**
  - ACA Solver robust Method for Efficient Solution
  - MLFMM solver efficient for structures with low complexity New in R16
  - Hybrid FEM-IE solver takes advantage of strengths from both FEM and IE technologies

- **Advanced Functionally**
  - Layered Impedance Boundary Condition
  - Spatially Dependent Boundary Conditions New in HFSS 2014
  - Data-Link Source Excitations
    - HFSS to HFSS-IE
    - HFSS-IE to HFSS-IE New in HFSS 2014
  - High Loss Impedance Boundaries New in HFSS 2014
  - Anisotropic Impedance Boundary New in HFSS 2014
  - Curvilinear Mesh Elements New in HFSS 2014

- **High Performance Computing**
  - Scalable Multi-Threading
  - Distributed Parametric and Frequency Sweeps
  - Distributed meshing for hybrid solutions
  - Distributed memory solution for large scale simulations
    - Hybrid solution supports distributed FE-BI and IE-Regions New in HFSS 2014
    - Hierarchical distributed solutions New in HFSS 2014

- **Output quantities**
  - Network Parameters
  - Antenna trace characteristics (Beamwidth, SLLs)
  - Near fields and far fields

- **Design automation**
  - Parametric modeling
  - Parametric sweeps
  - Optimizations
  - Sensitivity and statistical analysis
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