HFSS for Electrically Large Antenna System Design: Hybrid Simulation Technology

15.0 Release

ANSYS Inc
Agenda

• HFSS 3D Platform Simulations

• ANSYS Simulation Technologies Overview
  – ANSYS Electromagnetic Simulation Techniques
    • HFSS-FEM (Finite Element Method)
    • HFSS-IE (Integral Equation)
    • HFSS-PO (Physical Optics)
    • Hybrid FEM-IE
    • Enhanced Hybrid IE-Regions
  – MPI (Message Passing Interface) Based DDM (Domain Decomposition Method)
    • HFSS
    • HFSS-IE
    • Hybrid FEM-IE

• Examples
HFSS 3D System Simulations

• Full 3D System Simulations
  – Simulate more complicated and electrically large problems
  – Require efficient simulations

Courtesy of Raytheon
Technology Review

• 3D Simulation Technology
  – HFSS: 3D Finite Element Method
  – HFSS-IE: 3D Method of Moments
  – HFSS-IE: 3D Physical Optics (PO)
  – HFSS+HFSS-IE: 3D Hybrid Simulations
HFSS-IE: 3D Method of Moments

- **3D Integral Equation technique**
  - Automated results with accuracy
    - Automated adaptive meshing technique
      - Ensures accuracy
    - Employs Adaptive Cross Approximation (ACA) technique for larger simulation
      - RAM and runtime scale as N*log(N)
  - Easy to use interface
    - Implemented as a new design type in the HFSS desktop
  - Utilization of results from HFSS as a linked source
    - Link can include effects of backwards scattering to the source geometry

- **Target applications:**
  - Large, open, radiating or scattering analyses
    - Antenna placement, co-site
    - Radar cross section (RCS)
Example: HFSS-IE (3D MoM)

13072 λ³

Roof Monopole

HFSS-FEM

HFSS-IE

<table>
<thead>
<tr>
<th></th>
<th>HFSS</th>
<th>HFSS-IE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td>6 hours</td>
<td>1:15 hour</td>
</tr>
<tr>
<td>RAM</td>
<td>98 GB</td>
<td>41 GB</td>
</tr>
</tbody>
</table>

HFSS-IE: 4.8x faster and 58% less RAM
HFSS-IE: Physical Optics (PO)

- Asymptotic solver for large metallic models
  - Solves electrically huge problems
  - Currents are approximated in illuminated regions
    - Set to zero in shadow regions
  - No ray tracing or multiple “bounces”
  - Sourced by incident wave excitations
    - Plane waves or linked HFSS designs as a source

- Target applications:
  - HFSS to HFSS-PO Datalink
    - Large reflector antennas
    - Antenna placement on large platform
  - RCS of large objects such as satellites
The higher the frequency is, the ‘more’ accurate the PO will be
Hybrid FEM-IE Method

- Radiation: Finite Element-Boundary Integral
- IE-Regions: Finite Elements + 3D MoM
• HFSS Hybrid Technology*
  – Hybrid Radiation Boundary
    • Finite Element Boundary Integral (FE-BI)
    • Truncate an FEM Volume with any arbitrary surface using integral equations
  – Hybrid IE-Regions
    • Two-way coupling between Finite Element Volumes with FE-BI radiation boundaries to a 3D
      Method of Moments region.
    • Free Space Coupled
      – Conducting objects outside of FEM solution space can be solved directly with 3D MoM,
        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 3D MoM solution in the region, useful when dielectric regions are electrically
        large requiring large FEM solution volume
    • Free Space + Current Coupled\textsuperscript{New}
      – In addition to Free Space coupling, IE-Regions can touch the FE-BI boundary.
      – Metallic structures can connect across domains allowing electric current to flow from metallic
        objects in the FEM Volume to touching metallic objects in 3D MoM region

*Requires HFSS-IE solver license
Hybrid Radiation Boundary

- **Radiation Technologies:**
  - Absorbing Boundary Condition (ABC) – First Order Approximation to Free Space
  - Perfectly Matched Layer (PML) – Anisotropic Absorber
  - Finite Element – Boundary Integral (FE-BI) – Hybrid FEM+IE for Radiation

- **FE-BI Advantages**
  - 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
  - Setup is similar to ABC boundary condition
    - Enabled by checking “Model exterior as HFSS-IE domain”
HFSS Example: FE-BI

- FE-BI significantly reduces required computer resources
  - Large air volume inside of radome is removed from the FEM solution
    - Air volume is required if using PML or ABC
  - Two FEM-IE domains are applied
    - Conformal to radome
    - Conformal to horn antenna (26 GHz)

<table>
<thead>
<tr>
<th>26 GHz</th>
<th>RAM</th>
<th>Elapsed Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>PML</td>
<td>259G (DDM)</td>
<td>840min</td>
</tr>
<tr>
<td>FE-BI</td>
<td>64G</td>
<td>205min</td>
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</table>

FE-BI shows 4.1x speedup factor and 75% less RAM
Hybrid IE-Regions: Free Space Coupled

- HFSS with IE-Regions: Free Space Coupled
  - Metal objects can be solved directly with an IE solution applied to surface
    - Removes the need for air box to surround metal objects
  - Homogeneous dielectric objects can be replaced with IE-Region
    - Dielectric is solved using IE to surface

IE-Regions reduces RAM by ~70%

FEM Solution (20G RAM)

IE-Regions (6.2G RAM)
HFSS Hybrid IE-Regions with Current Coupling

- **HFSS Hybrid IE-Regions**
  - In HFSS 15, metallic objects from IE-Regions are allowed to touch FE-BI boundaries. This new capability allows electric current two-way coupling between the Finite Element domain and the 3D Method of Moments domain.

- **Usage**
  - Finite Element Domains are used to solve complex materials and excitations
  - 3D Method of Moments (IE-Regions) are applied on electrically-large platform(s)
HFSS Hybrid IE-Regions with Current Coupling

<table>
<thead>
<tr>
<th></th>
<th>FEM</th>
<th>FEM-IE touching IE-Region</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Time</strong></td>
<td>9.1 hours</td>
<td>4.5 hours</td>
</tr>
<tr>
<td><strong>RAM</strong></td>
<td>98 GB</td>
<td>23.7G</td>
</tr>
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</table>

Hybrid solver is 2x faster, and uses 76% Less RAM
HFSS Hybrid IE-Regions with Current Coupling

Gain Plot

Black - FEM
Red – Hybrid IE-Regions

81% Less RAM: IE-Region vs. FEM
High Performance Computing

Increase simulation capacity using High Performance Computing (HPC)

New MPI Based Domain DDM

- HFSS-FEM
- HFSS-IE
- HFSS Hybrid FEM-IE and enhanced IE-Regions
Leveraging High Performance Computing Hardware

- Faster
- Multi-Threading
- Distributed Parallel Solvers
  - HFSS-Transient
- Spectral Domain Method
  - Distributed Frequency Sweeps
- HFSS DDM
  - Mesh based Domain Solver
- HFSS Periodic Domains
  - Finite Array Domain Solver
- HFSS-IE DDM
  - Matrix based Domain Solver
- HFSS-Hybrid DDM
  - Hybrid HFSS/HFSS-IE Domain Solver

Increased Productivity and Higher Fidelity simulation
HPC for HFSS 15.0

- HPC Improvements for HFSS 15.0
  - New multi-threaded matrix solver
    - Up to 5x faster solver
      - 20% faster than previous generation multi-processing license
  - Improved Distributed Frequency Solver

- MPI based Domain Solvers
  - Industry Standard MPI
  - Faster communication between domains
HPC: Multi-Threading (MT)

- Multi-Threading (HPC-MT)
  - Single workstation solution to increase the speed of the solver
  - TAU Initial Mesh Generation
    - Parallelized mesh generation
  - Direct Matrix Solver
    - Parallelized matrix solver
  - Iterative Solver
    - Parallelized matrix pre-conditioner
    - Parallelized excitations
  - Field Recovery
    - Parallelized field recovery for multiple excitations
  - Available with HFSS, HFSS-IE, and HFSS-Transient

**HFSS – HPC-MT Processor Performance**
Up to 5x faster solver.

- 8 Cores: 5.6x
- 4 Cores: 3.6x
- 2 Cores: 1.9x
- 1 Core: 1x (Baseline) No HPC

*HFSS Direct Matrix Solver*
HPC: Spectral Domain Method

- **Spectral Decomposition Method (HPC-SDM)**
  - Accelerates frequency sweeps by distributing the spectral content across a network of processors
  - Increases simulation speed
    - Combines with HPC-MT
  - Scalable to large numbers of cores
  - Available with HFSS, HFSS-IE, and PSI

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**HFSS Frequency Sweep – HPC-SDM**

- **32 SDM Points**: 16.6x
- **8 SDM Points**: 5.3x
- **Serial Sweep (Baseline) No HPC**: 1x

*Interpolating Sweep: 0-20GHz, 201 frequencies*
HPC: HFSS-DDM (Mesh Based)

- **Domain Decomposition Method: Meshed Based**
  - Distributed memory parallel technique
    - Distributes mesh sub-domains to network of processors/RAM
  - Significantly increases simulation **capacity**
  - Highly scalable to large numbers of processors
    - Uses industry standard MPI
    - Combines with HPC-MT
  - Automatic generation of domains by mesh partitioning
    - User friendly
    - Load balance
  - Hybrid iterative & direct solver
    - Multi-frontal direct solver for each sub-domain
    - Sub-domains exchange information iteratively via Robin’s transmission conditions (RTC)
  - Available with HFSS
HPC: HFSS-DDM (Mesh Based)

2meter aperture diameter @7.6GHz
(50 λ aperture)

<table>
<thead>
<tr>
<th></th>
<th>HFSS v14</th>
<th>HFSS v15</th>
<th>Improvement</th>
</tr>
</thead>
<tbody>
<tr>
<td>Elapsed Time</td>
<td>5.5 hours</td>
<td>4.5 hours</td>
<td>1.2x</td>
</tr>
</tbody>
</table>

HFSS v15 is 1.2x faster with new MPI DDM Solver and new Multi-threading solver
HPC: HFSS-IE DDM (Matrix Based)

- Domain Decomposition Method: Matrix Based
  - Distributed memory parallel technique
    - Distributes matrix solution to network of processors/RAM
  - Significantly increases simulation capacity
  - Highly scalable to large numbers of machines
    - Uses industry standard MPI
    - Combines with HPC-MT
  - Automatic generation and load balancing of matrix partitions
  - Available with HFSS-IE

<table>
<thead>
<tr>
<th>Frequency</th>
<th>RAM</th>
<th>Elapsed Time</th>
</tr>
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<tbody>
<tr>
<td>18 GHz</td>
<td>146G</td>
<td>7.3h</td>
</tr>
</tbody>
</table>

HFSS-IE HPC-DDM
MPI Based DDM for HFSS-IE Example

17.4x13.7x3.1 meters
2.45GHz

Time (minutes)

RAM (GB)

1.7x Speedup with 2 HPC Pack (14% more RAM)
2.4x Speedup with 3 HPC Pack (57% more RAM)
• Domain Decomposition Method
  – Distributes mesh sub-domains to network of processors
    • FEM volume can be sub-divided into multiple domains
    • IE Domains that are discontinuous will be distributed to separate nodes when they become large
  – Significantly increases simulation capacity
  – Uses Industry Standard MPI
  – Extension of HFSS DDM to support the Hybrid FEM/IE solver
    • IE Regions & FE-BI
  – Available with HFSS+HFSS-IE Hybrid
Hybrid HFSS - FEM DDM with IE Regions

>900,000 \( \lambda^3 \)

Beam Waveguide

Courtesy of Raytheon
Beam Waveguide Model

Local vs. MPI

HPC speed up of 2.1x

<table>
<thead>
<tr>
<th></th>
<th>RAM</th>
<th>Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Local</td>
<td>80G</td>
<td>5h35m</td>
</tr>
<tr>
<td>HPC-DDM</td>
<td>56G</td>
<td>2h39m</td>
</tr>
</tbody>
</table>

Local Machine

- 16 cores

MPI with 5 domains

- 6 cores x 5
Examples
F16 Antenna Placement @ 1060 MHZ

- 4 Antennas
- 2 Antennas
- 2 Antennas
- 1 Antenna
Only 32% longer and 26% more RAM: 4 excitations vs. 1 excitation
Reflector Antenna
(FEBI/IE-Region/PO Datalink)
Cassegrain Reflector Antenna Example

- 0.32-meter Sub-parabolic (9.6 λ)
- 2-meter main parabolic (60λ)
- Frequency = 9GHz

37G RAM, 3.2 hours
Large Reflector Antenna Simulation
Full-wave Solution

Horn

1. FEM-IE

2. IE-Region

Radiation Boundary

- Name: [Input]
- Radiating Only
- Incident Field
- Enhanced Field
- Model exterior as HFSS IE domain
- Reference for FSS
- Include for near field calculation
  (Not appropriate when source is on an internal surface)

OK Cancel

2.7 million unknowns
373G RAM
71.4 hours

150 λ

45 λ
Large Reflector Antenna Simulations

HFSS to PO Datalink

1. HFSS for Fed Horn

2. HFSS-IE Design for Parabolic

FEM to HFSS-PO Datalink

1.7G RAM
3 minutes
Full-wave vs. HFSS to PO Link

Less than 0.5 dB peak-gain difference (48dB) using HFSS to PO Link
RCS from Electrically-Large Models
(HFSS-IE/PO)
Harm RCS @ 18GHz

<table>
<thead>
<tr>
<th></th>
<th>HFSS-IE</th>
<th>HFSS-PO</th>
</tr>
</thead>
<tbody>
<tr>
<td>RAM</td>
<td>146G</td>
<td>2.24G</td>
</tr>
<tr>
<td>Time</td>
<td>7.3 hours</td>
<td>4.7 minutes</td>
</tr>
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93x speedup, 98% less RAM
Fighter Aircraft RCS using PO

Incident Wave

15.15 meter
910 λ @ 18GHz

10GHz

10.325 meter
620 λ @ 18GHz

18GHz

4.19 meter
252 λ @ 18GHz

Bistatic RCS
Blue – 18GHz
Red – 10 GHz

Mesh # | RAM | Elapsed Time
---|---|---
10GHz | 5.03 million | 15.4 G | 27.5 minutes
18GHz | 16.19 million | 50.6G | 174.5 minutes
X-band 75-element Array on Fighter Aircraft
(HFSS to PO Link)
X-band 75-element Array on Fighter Aircraft
(HFSS to PO Link)

Red – Array on Fighter
Black – Array Itself
Conclusion

• HFSS v15 Hybrid solutions offers best in class solver technology
  – Integrates the Finite Element Method with 3D Method of Moments
  – Apply the “best” solver for the individual pieces in the entire 3D System
  – Improves solver accuracy and speed
    • Efficient solution of electrically large structures
    • Reduces the FEM Volume for speed

• HFSS v15 with HPC runs faster and larger designs
  – Domain Decomposition increases capacity by distributing the solution across a network of computers
  – HPC provides solver enhancements to FEM, HFSS-IE, and HFSS Hybrid solutions

• HFSS-IE v15 improves upon the previous generation solver
  – Improved accuracy and speed for electrically large models
  – Improved communication with MPI
  – HFSS-IE solver scales to enable simulating multiple antennas distributed across a platform