

Ansys HFSS for Antenna Simulation

Antennas are virtually everywhere. From commercial applications such as smartphones, RFID tags and wireless printers, to defense applications such as phased array antennas for aircraft radar systems or satellite-based, to provide integrated ground-based communication systems. Electromagnetic simulation is a valuable tool in antenna design and platform integration providing the designer the ability to virtually design and evaluate what if scenarios as well as verify the final manufactured design. Ansys® HFSS™ excels at a wide variety of high frequency, full-wave, electromagnetic applications including antenna design and placement since it uses multiple advanced solver techniques to simulate not just the antenna but also the effects of its interaction with the entire system, including the feeding system as well as the platform.

This paper describes antenna design and simulation with Ansys HFSS, the industry leading 3D electromagnetic (EM) simulation tool for high frequency and high speed electronic components. Figure 1 highlights several antenna-related applications with emphasis on antennas on or around other structures. With multiple simulation technologies and powerful automated adaptive mesh refinement providing gold standard accuracy, HFSS can help antenna designers who are constantly challenged with implementing designs across more and more frequency bands inside a smaller and smaller footprint. With these additional technical challenges along with the ever shrinking time to market, simulation with HFSS is a must-have in the antenna design and integration process.

Miniaturization of the antennas, limited channel bandwidth, reduced design time, and antenna interaction with other components present stiff challenges to the design engineer. HFSS provides automatic, accurate, and efficient solutions to overcome these challenges, making it the ultimate tool of choice for antenna simulation. Basic performance characterization such as return loss, input impedance, gain, directivity and a variety of polarization characteristics can be analyzed in HFSS. Key post-processing features such as the ability to overlay the 3D far-field pattern on the antenna geometry can provide the designer invaluable insight and direct correlation between the antenna and the resulting radiation pattern. HFSS also offers electric and magnetic field visualization both in the near-field and far-field providing design understanding that is not easily available through measurement. This insight allows the engineer to determine the portions of the geometry pertinent to the antenna's performance. Coupled with Optimetrics™, HFSS also allows engineers to parametrically sweep design variations to investigate the antenna's design space leveraging such optimization techniques as Quasi Newton, Pattern Search, Sequential Non-linear Programming (SNLP), Mixed Integer SNLP, and genetic algorithms. This sophisticated level of analysis that can provide design sensitivities and information on overall statistical performance and manufacturing yields allow the engineer to go to production and market with confidence in results and performance.

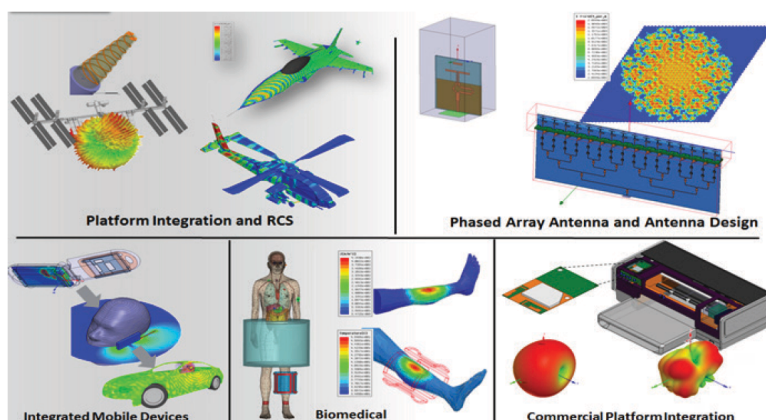


Figure 1. Applications that are simulated using Ansys HFSS.

/ Automatic Adaptive Meshing

A key feature of HFSS is automatic adaptive mesh refinement which generates an accurate solution based on the physics or electromagnetics of the design. This automated meshing technique leaves the focus on the antenna design rather than spending time determining and creating the best mesh. This automation and guaranteed accuracy differentiates HFSS from all other electromagnetic simulators, which typically require manual user controls to ensure that the generated mesh is suitable and accurate for simulation. Without the correct mesh, the results from such simulators can be erroneous. But with automatic adaptive meshing, HFSS lets the physics define the mesh and not the other way around and guarantees accurate results.

The meshing algorithm adaptively refines the mesh throughout the geometry; it iteratively adds mesh elements in areas where a finer mesh is needed due to the localized electromagnetic field behavior. Figure 2 illustrates the adaptive meshing process for a patch antenna operating at 11.5 GHz using the finite element method (FEM) in HFSS.

An initial mesh is generated and is used to solve for the electromagnetic fields. From this solution, a localized error estimate is determined for each element or tetrahedron in the mesh. Those mesh elements with relatively high errors are refined to additional, smaller and more accurate mesh elements and thus capturing the localized behavior of the electromagnetic fields with higher precision. Using this refined mesh, HFSS generates another adaptive solution, recomputing the error and resolving as before. This process continues until HFSS converges to an accurate solution as determined by monitoring a convergence parameter called $\text{Max}(|\Delta S|)$ representing the change in s-parameters from one pass to the next. This convergence criterion ensures that the difference in S-parameters between two consecutive adaptive passes is less than a specified magnitude which can conceptually be thought of as the 'noise floor' of the simulation or 'measurement'. For increased accuracy, you can tighten or lower the convergence criteria and HFSS will further refine the mesh. Adaptive refinement ensures that the mesh elements are sufficiently fine in those areas where strong electromagnetic fields exist and/or the field gradients are high. The mesh is coarser in the remaining areas, which are relatively less important thereby not wasting computational resources.

The merits of automatic adaptive meshing are:

- The mesh size is correct and suitable for efficient simulations leading to highly accurate solutions.
- Such a technique reliably 'tunes' the mesh to the electrical behavior of the antenna.
- You do not need to be a meshing expert and you can focus on the design rather than the simulation setup.
- You can explore design options quickly and cheaply and reduce the number of prototypes.
- Fewer or no prototypes ensure huge savings in time and money on hardware development and testing.
- In-depth analysis of the design and its electromagnetic behavior that is not possible from the traditional build and test philosophy.

You only need to create the geometry, specify material properties, boundary conditions, excitations, and solution frequency and HFSS takes care of the rest.

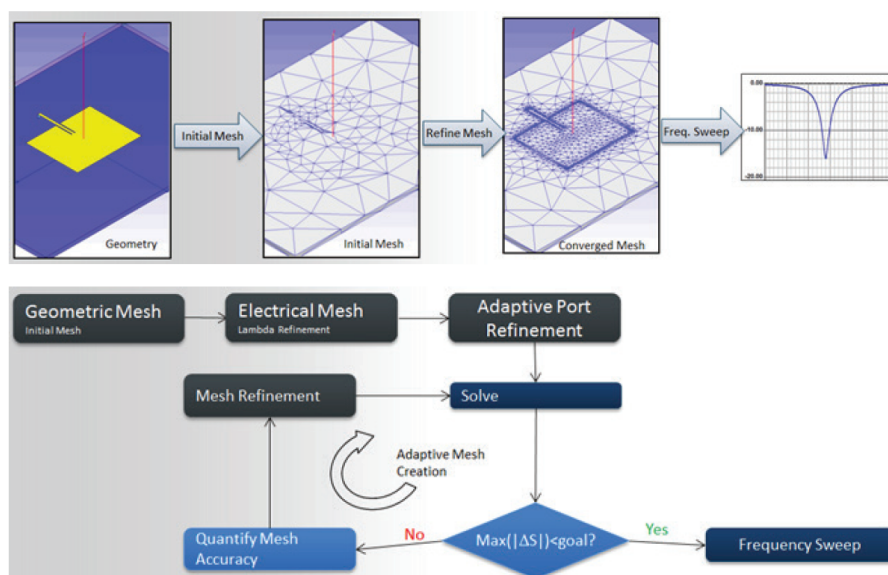


Figure 2. Adaptive refinement on patch antenna and the process flow.

/ Antenna Simulation Technologies in HFSS

HFSS offers the following simulation methods and tools depending upon the kind of problem you want to solve:

- Finite Element Method (Enabled with HFSS).
- Integral Equations (Enabled with HFSS-IE).
- Physical Optics (Enabled with HFSS-IE).
- FEM Transient (Enabled with HFSS-TR).
- Antenna Design Toolkit provided with HFSS including over 50 standard antenna designs.

/ Finite Element Method

The finite element method is highly suited for 3D arbitrarily-shaped geometries. In this method, the geometric model is automatically divided into a number of tetrahedral elements conformal to all surfaces of the geometry. Tetrahedral elements are highly suited for this type of unstructured and non-uniform mesh since they can be stretched and pulled to fit any arbitrary geometry.

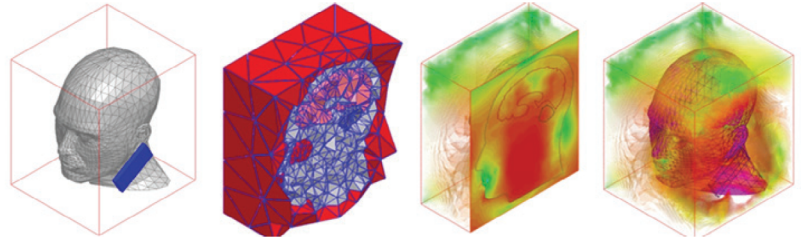


Figure 3. FEM solution example.

The finite element formulation uses advanced mathematical techniques to satisfy Maxwell's Equations in the entire model. This method handles complex materials and geometries efficiently. FEM solves the model by creating a volume based mesh and produces field solutions. As shown in Figure 3, the fields are explicitly solved throughout the entire volume – not just the antenna and the object to which it is coupled (in this case the human head) but also the environment in which it is placed. The example shown in the Figure 3 illustrates a smartphone near a phantom model of the human head that simulates realistic specific absorption rate (SAR) measurements. The solution takes advantage of HFSS' FEM solver and HFSS Optimetrics to specify the placement of the smartphone. This helps organizations meet regulatory compliance before their products hit the market. Accuracy in the SAR measurement saves duplication of efforts and activity.

/ Integral Equations

HFSS-IE shares the same modeler interface and analysis setup as HFSS and is implemented as a design type in the HFSS desktop. Existing HFSS users find HFSS-IE fairly similar to HFSS and thus require minimal training for effective utilization. IE employs the 3D Method of Moments (MoM) technique for efficiently solving open radiation and scattering problems where currents are solved on the surface mesh as shown in Figure 4. This is the most efficient solver for structures that are primarily metal but may also include dielectrics.

Typical applications include radar cross section (RCS), antenna placement (for example, antenna on a vehicle), EMI/EMC, and standalone antenna design.

The antennas solved are in an open environment therefore no radiation boundary or air volume is needed as is the case with HFSS and finite elements. You can use the IE solver for efficient analysis of electrically large metallic structures where applications could include, antenna placement on vehicles, RCS, and reflector antenna analysis. HFSS-IE offers the major advantage of using the adaptive cross approximation (ACA) technique for large problem sizes. The ACA technique provides reduced computational resources for a MoM solution, while being ideally suited to the automatic adaptive meshing algorithm used by HFSS-IE.

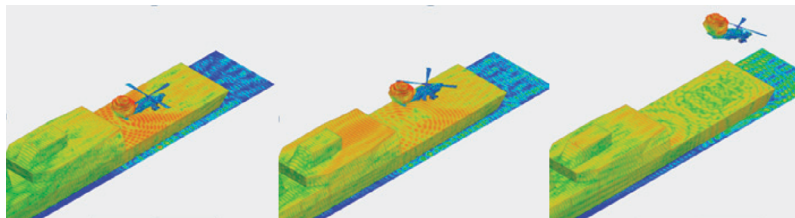


Figure 4. Variation in antenna radiation pattern.

/ Hybrid FEM-IE Solution

HFSS offers the capability to leverage the strength of both finite element method (HFSS) and integral equations method (HFSS-IE) into a single problem. Such a hybrid solution is very advantageous. HFSS-IE can be used to solve for the field propagation through free space and along conductors outside the FEM volume used typically to model the detailed geometry and dielectrics of the antenna elements eliminating the need for a FEM volume mesh throughout. Moreover, the IE solution region can be contiguous with the FEM region such that currents flow from one solution domain to another. Figure 6 illustrates the application of the combined FEM plus IE hybrid solution on two antenna structures. The first is a full wave solution of a reflector antenna 60 wavelengths in diameter with a complex 3D feed horn. The feed horn is solved using HFSS' FEM solution and the main reflector and sub-reflectors are solved using IE. This large problem solved in 37GB RAM in only 3.2 hours.

The second example in Figure 6 is a satellite with an array of helix antennas mounted on its top surface. In this case the IE method is used to truncate the FEM region in an effective absorbing boundary condition. A conformal air box is placed around the satellite on which FE-BI is applied resulting in 10 times RAM reduction over an FEM only solution.

/ Physical Optics Solver

HFSS-IE also offers a Physical Optics (PO) solver for solving electrically large problems where the currents are approximated in the illuminated regions and are zero in shadow regions. PO is an option on the HFSS-IE solution setup. You can even use a linked HFSS simulation as the source.

Using the PO solver, HFSS analyzes the radiation patterns of the antennas including the reflection effects of nearby objects.

Typical applications include large reflector antennas, antenna placement, RCS of large objects such as aircrafts, ships, or satellites. Figure 7 depicts a reflector antenna analysis. The geometry includes a large metallic reflector surface with a conical feed horn. The feed horn is simulated using HFSS FEM analysis and is the source of the primary electromagnetic radiation. Those fields are then impressed upon the large reflector and an approximation to the electrical currents is computed from the fields. Secondary radiation is computed to find the far-field radiation pattern. The PO solver produces results very quickly and hence is ideal for electrically large structures and rapid design evaluation.

Figure 8 is another example using the HFSS PO solver to compute the radiation from an antenna system mounted on the International Space Station (ISS). The PO method is effective in this example to compute the shadowing of the electromagnetic fields caused by the large solar panels.

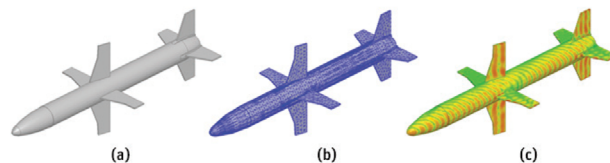


Figure 5. Integral Equations example. a) Missile Geometry. b) Surface Mesh. c) Currents on surface.

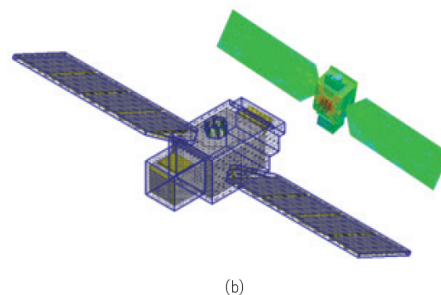
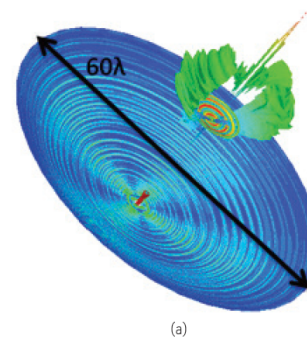
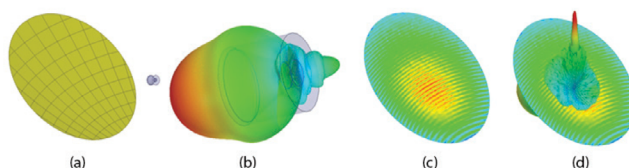


Figure 6. Hybrid simulation for two antenna structures. (a) Reflector antenna. (b) Satellite with conformal radiation boundary.



Physical optics solver used to simulate a reflector antenna.

- (a) Geometry of reflector antenna and feed horn.
- (b) Electric fields surrounding feed horn.
- (c) Surface currents on the reflector.
- (d) Farfield pattern superimposed on the reflector with nearfield currents.

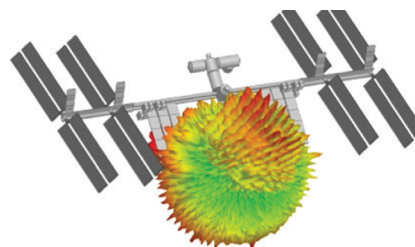


Figure 8. PO example showing antenna pattern of an antenna on International Space Station.

/ HFSS-Transient

HFSS-Transient is a 3D full wave EM field solver based on the discontinuous Galerkin time domain method (DGTD). The finite element transient solver creates an unstructured mesh which incorporates HFSS adaptive meshing. Some typical applications include pulsed ground penetrating radar (GPR), electrostatic discharge, time domain reflectometry, transient field visualization and determining scattering centers for radar cross section (RCS). Figure 9 is an RCS simulation of an F22 aircraft. A plane electromagnetic wave impinges upon the aircraft at an oblique angle and various scattering interactions can be observed as a function of time and position. Figure 9(a) shows the time signature of the RCS and Figure 9(b) shows the electro-magnetic fields.

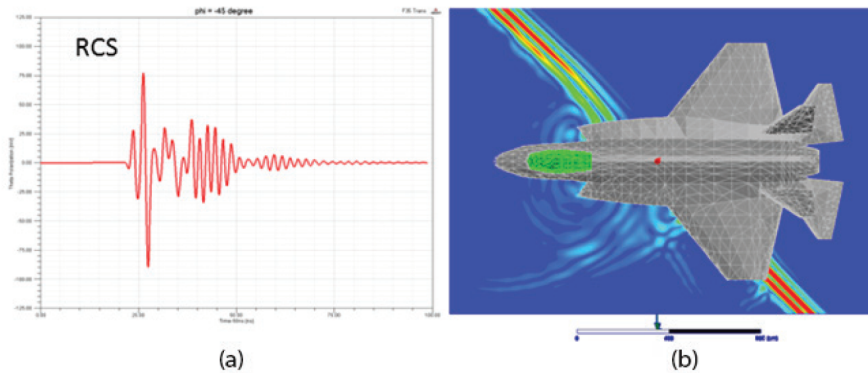


Figure 9. HFSS Transient solution. (a) Time signature of RCS. (b) Snapshot of electromagnetic fields.

/ High-Performance Computing in HFSS

High-performance computing (HPC) enables a range of different technologies in HFSS that allows efficient simulation of extremely large and complex problems. HPC leverages multiple cores through matrix multiprocessing, distributed frequency points (called spectral decomposition method or SDM), domain decomposition (DDM), parallel hybrid FEM/IE solving or the finite antenna array DDM. In addition hierarchical HPC solving is possible where frequency points can be distributed with each frequency point using multiple cores or machines for large scale DDM analysis at each frequency point, all in parallel.

/ Domain Decomposition Method

A unique feature in HFSS is the Domain Decomposition Method that can efficiently and quickly solve large scale electromagnetic problems. DDM is based on a divide-and-conquer philosophy where a large problem domain is partitioned into small sub-domains as depicted in Figure 10(a). A large mesh is broken down into small sub-meshes and each submesh or sub-domain is solved in a separate core or a set of shared cores. These separate cores either reside on a single computer or can be spread across multiple computers in a network. As the following figure shows DDM performs the simulation which is apportioned across many networked computers or different cores in a single computer. DDM is extremely scalable with the ability to show in some cases super linear performance with respect to a single core analysis. For finite periodic structure such as antenna arrays or frequency selective surface the domain decomposition technique is further enhanced by leveraging the repeating nature of the geometry, mesh and matrix. This results in a technique that significantly reduces the memory requirement and simulation time while delivering a comprehensive analysis of the structure including edge effects.

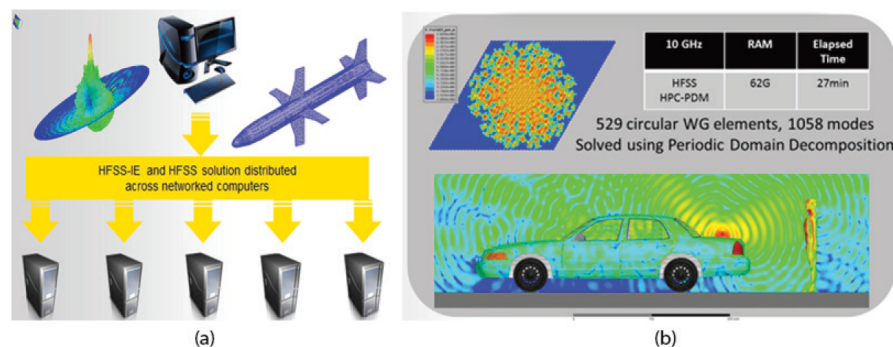


Figure 10. The domain decomposition method. (a) Concept. (b) Examples.

/ Antenna Design Kit

HFSS offers an antenna design toolkit, a standalone utility which automates the geometry creation, solution setup, and post-processing reports for 50 popular antenna elements. This tool allows antenna designers to quickly analyze antenna types and also assists new users in learning to use HFSS for antenna design. The design kit can be integrated into the HFSS user interface or launched from the standard Windows menu. All antenna models created by the design kit are ready to simulate in HFSS.

Figure 12 shows how you can select the desired antenna type from the tree structure and specify the necessary antenna parameters such as dimensional units, solution frequency, physical dimensions for element and feed, choice of the absorbing boundary condition (ABC), or perfectly matched layer (PML) for outer boundary of the HFSS model. Alternatively, HFSS can automatically synthesize an antenna of your choice depending upon the operating frequency that you specify. Figure 13 shows some of the available antenna types.

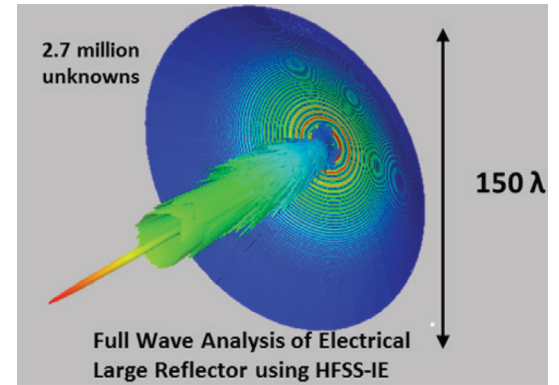


Figure 11. Hybrid solution of a large reflector antenna using DDM.

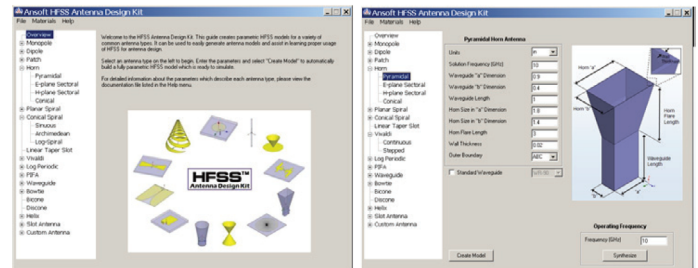


Figure 12. Antenna Design Toolkit.

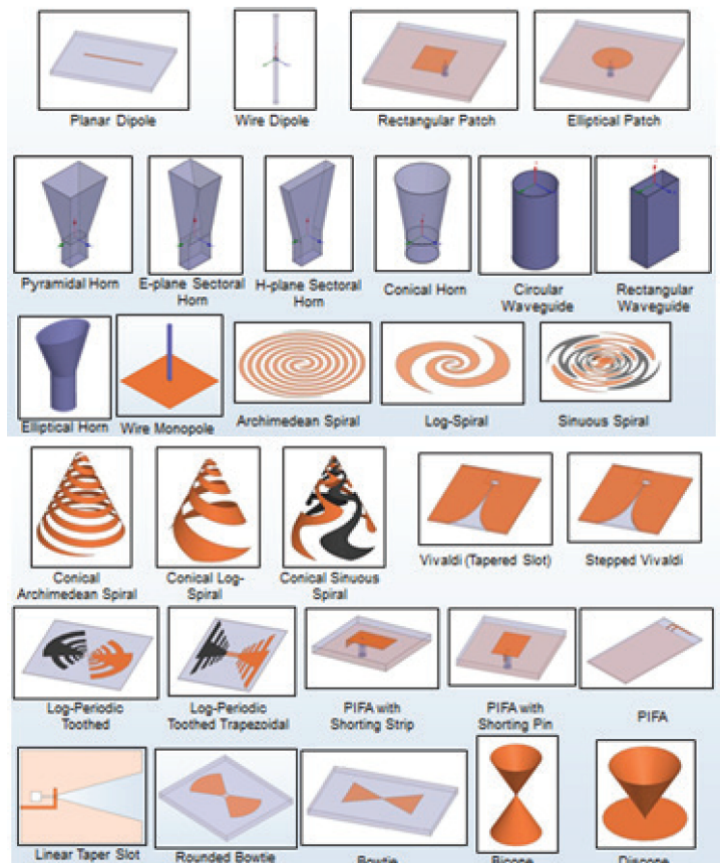


Figure 13. Available antenna types in the toolkit.

/ Summary

Companies, universities and government institutions involved in wireless applications including antenna design and placement are increasingly looking at electromagnetic simulators to gain a competitive advantage. To this end, it is imperative to invest in a simulator that guarantees accurate results and establishes the confidence for the designer or integrator that the antenna will perform as expected in the real world. Ansys HFSS provides a cost-effective means of accurately predicting the behavior and performance of antennas and other EM devices so that companies no longer need to invest heavily in pilot programs and prototypes. This helps companies save aggressively in its design process and further increases the workforce productivity not to mention significant savings in time and capital. For every design iteration or variation in placement several thousands dollars or more can be saved, which otherwise would be spent on carrying out a traditional build and test philosophy. The importance of HFSS cannot be understated since it offers automatic accuracy within several different simulation technologies for solving a wide variety of antenna designs and integration challenges. When coupled with high performance computing technologies like domain decomposition or hybrid solving, large scale problems can be solved efficiently and within a reasonable period of time. Moreover, HFSS is easy to use and does not require the designer or integrator to be an expert in electromagnetics or meshing methods. Coupled with existing antenna design toolkits offered with HFSS, modeling, designing, and analyzing antennas make HFSS an obvious tool of choice among engineers. Benefitting from HFSS, companies can rest assured of faster time-to-market with great and reliable products.

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