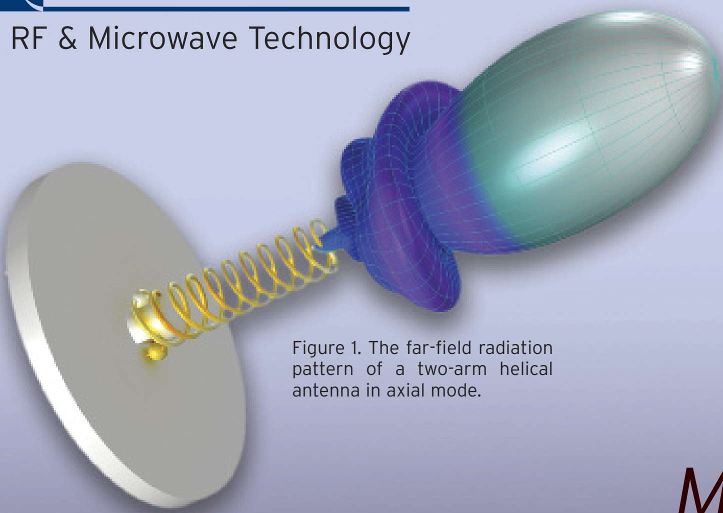

Figure 1. The far-field radiation pattern of a two-arm helical antenna in axial mode.

Communicating from Space: *The Front End of Multiscale Modeling*

As satellites and astronauts travel further out in space, the more communication challenges they face. NASA launched the InSight Mission on May 5, 2018 from Vandenberg Air Force Base, California. InSight was designed to collect data on Mars quakes and the processes that shaped the rocky planet to help us better understand how it formed. Getting the information back to the scientists here on Earth required a variety of antennas on the spacecraft.

The Helical Antenna: An Upward Spiral

Helical antennas have been deployed for communication with orbiters in applications such as global positioning systems (GPS) and NASA's InSight mission. Helical antennas are used to transfer data through the electromagnetic wave in the range of ultra-high frequency (UHF).

A helical antenna is known for its spiral geometry, which features one or more conducting wires wound in a helix. It is essentially a miniaturized monopole antenna with an input impedance mismatched to a typical reference impedance of 50 ohm. A helical antenna is much smaller than a traditional half-wave dipole and a quarter-wave monopole antenna. The smaller size of the antenna is achieved by turning the wire obliquely along the rotational axis, decreasing its input resistance. One way to compensate for the lowered resistance without adding a large matching network next to the antenna is by utilizing the folded dipole antenna design that has four times the resistance compared to that of a half-wave dipole antenna. The input impedance can then be enhanced by turning the single helical wire to a two arm-helical structure.

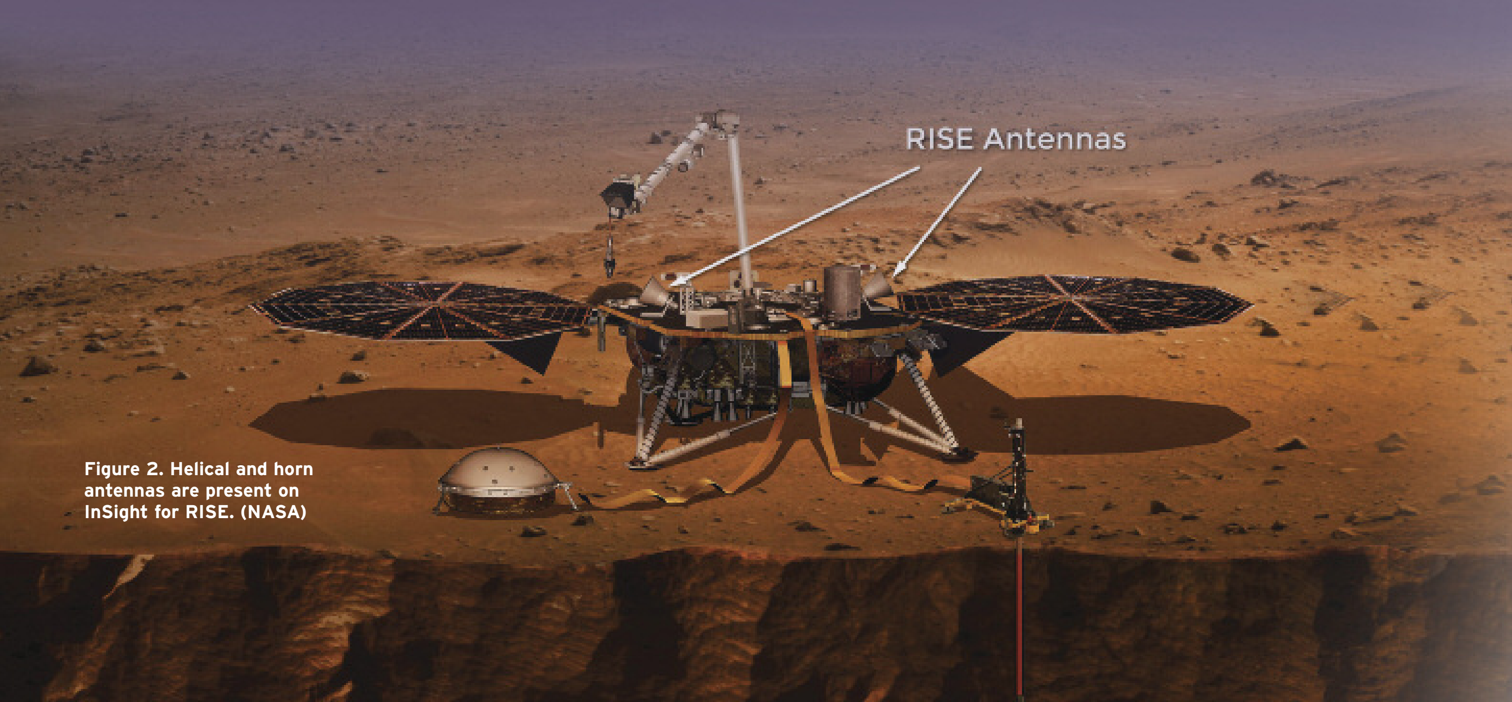

Figure 2. Helical and horn antennas are present on InSight for RISE. (NASA)

The helical antenna provides two resonant modes: normal and axial. In a normal-mode antenna, the radiation pattern resembles the far-field pattern of a monopole antenna that is omnidirectional around the azimuthal angle. The axial mode is the one used to reach the orbiters. When the antenna operates in an axial mode, it behaves like an end-fire ring array and generates a directional beam pattern, so the antenna gain is higher than that at the normal mode. With the higher-gain far-field radiation, the same limited amount of energy used in the normal mode can be transferred over a longer distance. Additionally, the antenna polarization becomes circular due to the nature of the geometry. Compared to the linear polarization, the circular polarization is less sensitive to the multipath fading effect, so it is less vulnerable to environmental fluctuations, making it an ideal candidate for space communication.

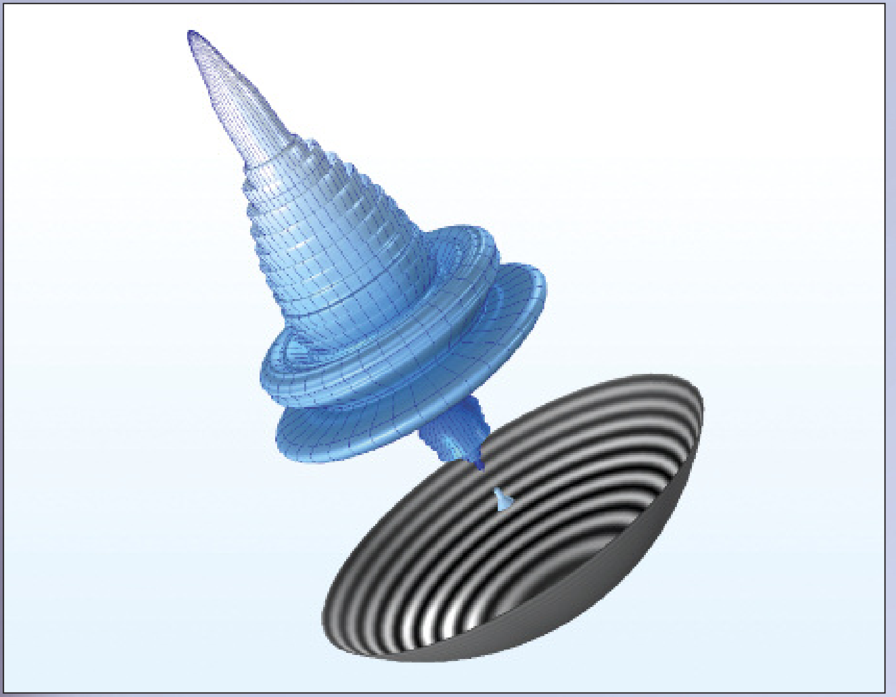

Figure 3. A dish reflector antenna with a feed horn and its far-field radiation pattern in dB scale.

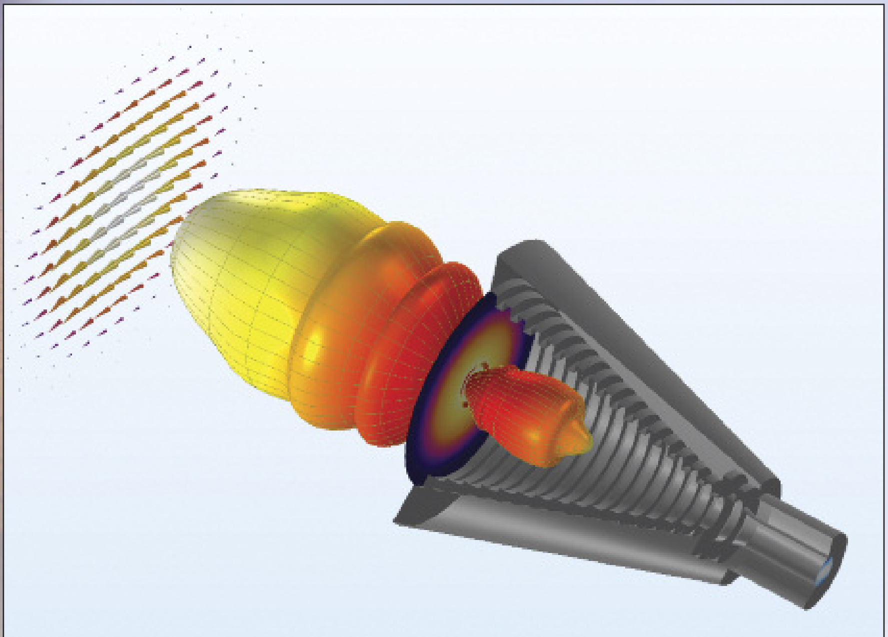

Figure 4. The far-field radiation pattern and aperture electric field results of a corrugated horn antenna.

From Helical to Horn Antennas

In conventional satellite communication applications, a large aperture or reflector antenna is preferred since it provides the high-gain output without building a complicated antenna structure. Medium-gain x-band horn antennas are also present on the InSight for Rotation and Interior Structure Experiment (RISE) to find the geometrical stability of the North Pole of Mars through the revolution that Mars makes around the Sun by tracking its location.

The geometry of a horn antenna is relatively simple; however, when it comes to simulating the electromagnetics, its computational cost can be expensive due to the large electrical size scaled by the operating wavelength. To address the increased computational costs when computing an electromagnetic (EM) wave propagation and resonance analysis, the horn antenna can be designed using 2D axisymmetric modeling that reduces the computation time by orders of magnitude.

A simulation of the x-band circular horn antenna deployed on the InSight spacecraft would benefit from the 2D axisymmetric modeling approach. When improving the performance of a circular horn antenna, a dielectric lens and corrugated antenna interior are used to enhance the radiation characteristic and refine the circular waveguide polarization to appear more linear by combining two waveguide modes. In Figure 4, a conical horn antenna is fed by a circular waveguide. And thanks to the corrugated surface throughout the cone, there is a lower cross-polarization at the aperture. Cross-polarization oc-

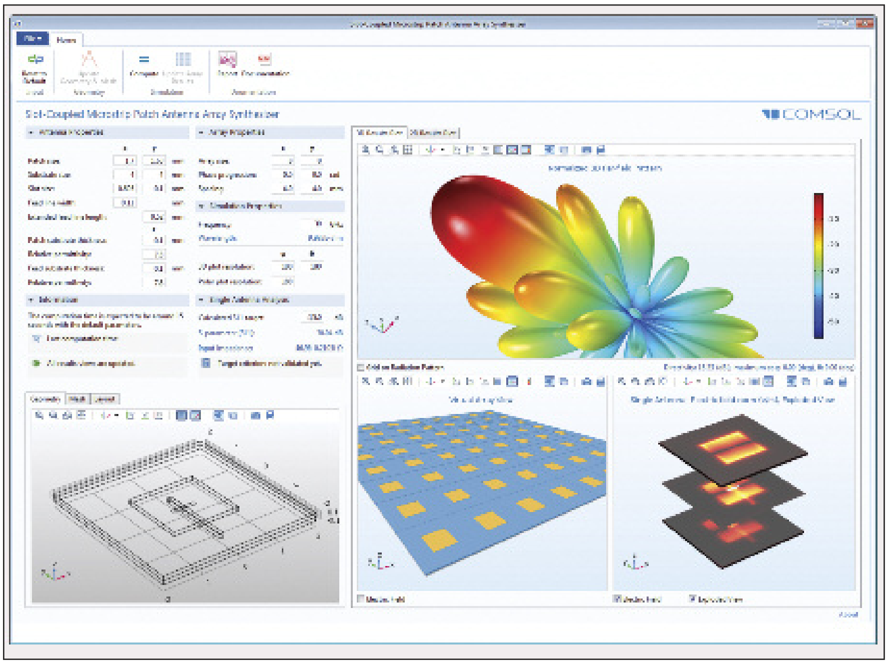

Figure 5. The user interface of the antenna array simulation app, built using the Application Builder within COMSOL Multiphysics, with an 8 x 8 virtual array, electric field distribution, and 3D far-field radiation pattern view.

curs when the electromagnetic fields are polarized opposite than what was intended; for example, if the fields from an antenna are meant to be horizontally polarized, the cross-polarization occurs vertically. If an antenna has a great degree of cross-polarization, the signal is likely to interfere with nearby channels, which is not a desired outcome.

Deploying High-Gain Antennas

The deployment of these high-gain antennas is sometimes quite limited due to their large size and weight or angularly restricted visibility from a sharp radiation pattern with a high directivity. Actively electronically scanned array (AESA) antennas offer not only a high-gain radiation pattern with a conformal shape of a smaller antenna, but also beam-steering capabilities so the shortcomings from a large dish reflector and aperture antennas won't be significant. These benefits come at a computational cost due to the large electrical wavelengths it produces.

The necessity of high-speed communication and beam-steering capability has grown with emerging trends such as the Internet of things (IoT), SatCom, and the Internet of Space (IoS). As such, the AESA has become more popular not only in traditional military applications, but also in consumer electronics. The antenna array size is often smaller than that found on reflector and aperture antennas; however, the design process of an antenna array could be memory-intensive because it remains electrically large in terms of wavelength.

The computational cost for simulation can be reduced by using efficient modeling techniques. An antenna array application available in the COMSOL Multiphysics RF module application library — the Slot-Coupled Microstrip Patch Antenna Array Synthesizer application — shows how the simulation can be compressed at the prototyping stage. It simulates an FEM model of a device that is fabricated on a multilayered, low-temperature, co-fired ceramic (LTCC) substrate, and extends the results to the user-specified array configuration.

Here we use the analysis of a single antenna to describe the behavior of the entire array. First, an accurate 3D full-wave simulation of a single microstrip patch antenna is performed. Then, user inputs such as array size, arithmetic phase progression, and angular resolution are taken into account to describe, for example, the 3D far-field of the entire array. The two-dimensional antenna array factor has been implemented to include the translational phase shifts and array element weighting coefficients needed to determine the radiation pattern of the entire array.

Fast and Accurate Results

Efficient modeling techniques with low computational cost and fast computational speed are critical for modern-day design and simulation engineers in the millimeter-wave industry. The purpose of simulation is to describe real-world devices and components as close as possible through mathematical representation. When simulating and analyzing axisymmetric objects such as spheres, conical dish antennas, and circular waveguides, the 2D axisymmetric modeling approach offers orders of magnitude faster computation time compared to a full 3D model.

Simulating a simple shape structure may appear to be easy and fast without considering the impact of the electrical size of the model in terms of wavelength. It is feasible to simplify the simulation process without losing accuracy with the support of the 2D axisymmetric modeling approach while sustaining the integrity required to analyze electrically large real-world components.

Summary

Using a variety of antennas, such as the InSight, is the most effective way to ensure that communication from space arrives back to Earth in a timely fashion. Making sure those antennas are ready for space travel requires multiphysics simulation that allows you to scale your model to ensure efficient use of computational resources while maintaining high accuracy.

This article was written by Jiyoun Munn, Technical Product Manager, RF, at COMSOL Inc., Burlington, MA. For more information, visit ***http://info.hotims.com/69509-541.***