

RADAR ROAD TRIP

Modeling better radar antennas and positioning them perfectly could speed the way to driverless vehicles

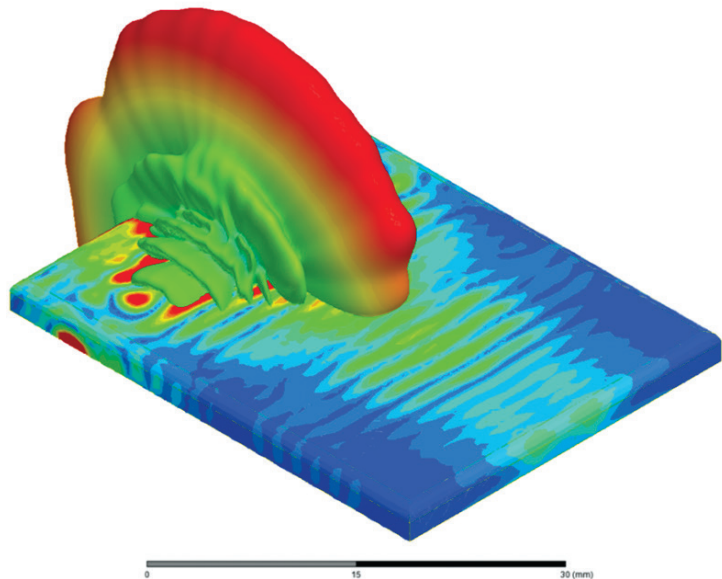
By Markus Kopp, Lead Application Engineer, ANSYS

Whether you know it or not, your car (depending on its age) probably already has some radar capability.

The back-up sensor that beeps when it detects something in your path uses radar. Some luxury vehicles with adaptive cruise control can apply the brakes if the radar system sees that you are approaching the car in front of you too quickly or closely. And the few cars that can parallel park on their own also depend largely on radar to determine where the car is in relation to other parked cars and the curb.

But driverless cars of the relatively near future will rely on radar to a much higher degree. They will have to autonomously maintain a safe driving distance from other driverless vehicles, change lanes safely, exit and enter highways, and make many other driving decisions that are now handled by human drivers. Already fleets of cars have logged hundreds of thousands of miles traveling highways in several countries safely and efficiently — without drivers. These automated vehicles could be available commercially as early as 2020 [1]; the Institute of Electrical and Electronics Engineers (IEEE) predicts that up to 75 percent of vehicles on the road will be driverless by 040. [2] High-quality, reliable radar antennas, among other sensors, are essential for these efforts.

ANSYS HFSS electromagnetic field solver can be used to simulate antennas for radar systems at the very high 77 GHz frequency needed in automotive applications. (While a lower frequency might have made design of these automotive radar systems easier, the 77 GHz band was available on the electromagnetic spectrum; it was not being used by wifi companies, radio stations or other radio-wave-based applications, so automotive radar designers claimed this frequency.) Automotive applications range



▲ Simulated radar pattern from a combined 1 x 10 transmitter and 1 x 10 receiver module. Transmitter is in upper left, receiver in lower right of image.

from developing individual antennas and powered antenna arrays, to simulating operation of a radar system installed on the front bumper of an automobile, where the large amount of metal in the vehicle will affect the shape of the radar beam. Advanced features in HFSS-3D, including finite array domain decomposition method (FA-DDM) and the hybrid finite element-boundary integral (FE-BI) method, give ANSYS users a unique advantage in developing the best radar antennas more quickly.

SPACING ANTENNAS IN AN ARRAY

Antenna design starts with selecting and optimizing a single antenna element, but that's the easy part. No radar system for anything as complex as autonomous driving can operate with a single antenna; an array of antennas is needed. An array can transmit radio waves in a pattern that emulates a spotlight: a bright focus point in the center with decreasing

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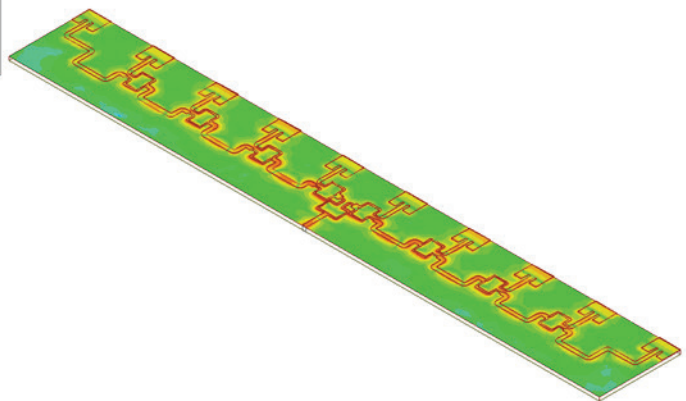
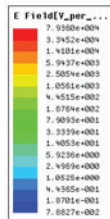
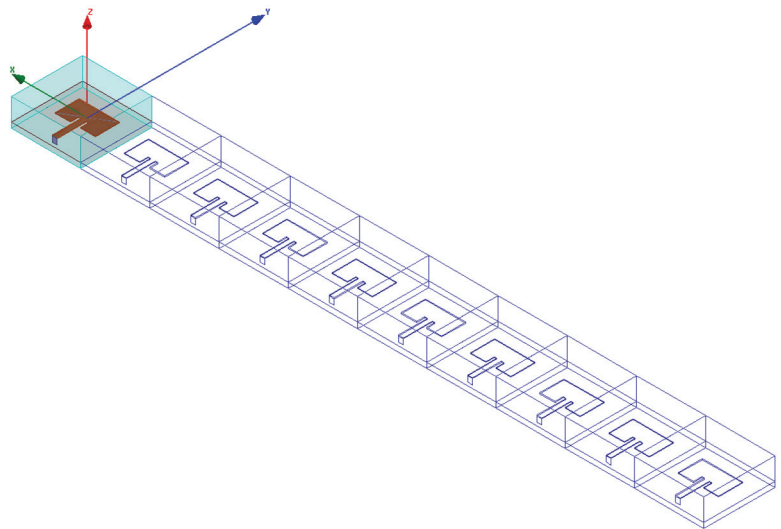
rings of wave intensity spreading concentrically from there. This gives you a narrow beam that points in a very specific direction, so you can pinpoint the location of a possible obstruction ahead, with some peripheral vision on the sides.

Synthesizing an antenna array means optimizing the spacing between each antenna to achieve the desired antenna pattern. Though physics textbooks tell you that you can just space them one-half wavelength apart, that only works for idealized situations and antennas, and engineers have to design for the real 3-D world. Radar beams emanate from antennas in the x, y and z directions, not just in a plane. So there are other spacing factors involved that must be solved by simulation.

Traditional direct-solver numerical methods can be used to optimize spacing of antennas in an array, but this involves explicitly modeling the entire array. In the example here — using a 1 x 10 array — that may not be prohibitive, but real-world arrays can be much more complex. Explicit numerical solution can take a long time. To decrease this time, engineers resort to approximations or assumptions that can speed calculations while introducing errors.

Using the finite array–domain decomposition method in ANSYS HFSS, engineers can perform the entire calculation quickly without sacrificing the accuracy of numerical methods. Domain decomposition takes a large domain and breaks it into smaller subdomains. In this example, the 1 x 10 array is the domain; one-tenth of this domain is a single antenna element, also known as a subdomain or unit cell. Replicated DDM unit cells allow the geometry and mesh for the entire domain to be copied directly from the unit cell mode: the unit cell geometry can be expanded to fill the finite array using a simple graphical user interface,

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▲ 1 x 10 antenna array

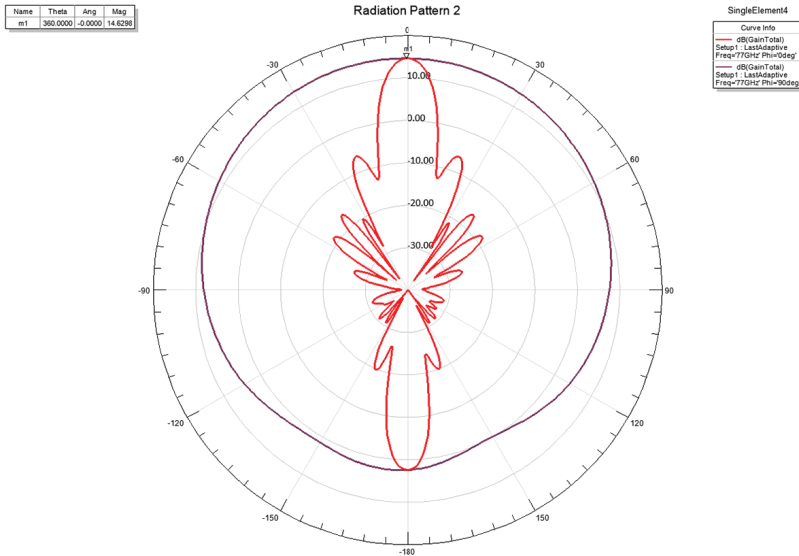
and adaptive meshing process can be imported directly from the unit cell simulation. The mesh periodicity reinforces the array’s periodicity. Quantitatively, a direct solver with 12 computing cores took just more than five hours and 60.8 GB RAM to optimize the spacing for an 8 x 8 antenna array, while a finite array DDM with 12 computing cores required just 45 minutes and 1.8 GB RAM for the same solution.

INTEGRATING THE RADAR ARRAY INTO AN AUTOMOBILE

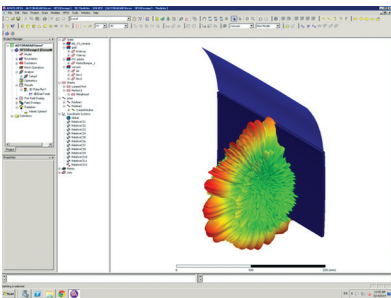
With the antenna array spacing determined, the amount of power you want to send through each antenna — in this case a single row of 10 antennas — must

be specified. By sending the most power through the two central antennas, and decreasingly less through each pair as you move away from the center, you can achieve the desired spotlight pattern. However, again this is not as simple as it looks. Small changes of flow through the power divider affect the shape of the radar array pattern. In fact, everything you do from here on affects the radar array pattern — the plastic cover known as the radome, placement of the antenna system on the bumper of the car, the amount of plastic or metal near the antennas, and most importantly, that

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▲ Graph of 2-D radar radiation pattern from a 1 x 10 antenna transmitter array (located in center of circle), showing “spotlight” pattern with high intensity in middle, tapering off peripherally.



▲ 3-D radar transmission pattern from antenna module placed on the bumper of a car (shown in purple).

huge hunk of electrically conducting metal known as an automobile sitting in near proximity to the radar system.

At the 77-GHz scale, cars are enormous structures for which conventional simulation solutions are not efficient. If you were the size of a wavelength at 77 GHz, then a car would seem as big as a shopping mall. To solve really large models efficiently you have to use the finite element-boundary integral (FE-BI) method.

ANSYS HFSS contains a simple, easy-to-use, efficient version of FE-BI. The finite element method uses volume-

based mesh and field solutions to handle complex materials and geometries efficiently; thus, it is most useful in the radar antenna module of the complex automobile system. The boundary integral method is a surface-only mesh-and-current solution that solves open radiation and scattering problems efficiently. For the automobile, in which there is a lot of air along with a metal skin, the boundary integral method works best here. So the FE-BI hybrid leverages advantages of both methods to achieve the most accurate and robust solution for radiating and scattering problems.

FE-BI offers a true solution to the open boundary condition. Surface currents are directly computed by an integral equation solver to produce very accurate far fields. No minimum distance from the radiator is required. A reflection-free boundary condition ensures that absorption of incident fields is not dependent on a single angle. With arbitrary-shaped boundaries, outward facing normal fields can intersect and can contain separated volumes.

FE-BI is essential in determining the “sweet spot” for positioning the radar unit on a vehicle. The best position is

ANSYS HFSS contains a simple, easy-to-use, efficient version of the finite element-boundary integral (FE-BI) method.

different for each car, depending on local conditions – is there plastic below and metal above, or both metal and plastic below? The sweet spot is where the radar unit is going to be positioned just right – not too high and not too low on the bumper. With ANSYS HFSS, engineers can simulate a vehicle, pick the optimal place to put the radar module, and know how it's going to work without having to build a prototype and test it.

So a few years from now, when you are driving down the highway and look over to see someone working on their laptop in the passenger seat but no one behind the wheel, you won't have to worry. A myriad of models in the simulation world will have ensured that things are safe for you and your family on the road home.▲

REFERENCES

- (1) “Let the Robot Drive: The Autonomous Car of the Future Is Here” http://www.wired.com/2012/01/ff_autonomouscar/all/
- (2) IEEE News Release http://www.ieee.org/about/news/2012/5september_2_2012.html

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