# Ansys 5G Antenna Solutions

5G promises a spectacular world of wireless communications systems. It presents lucrative opportunities in consumer electronics, internet-of-things (IoT), advanced driver assistance systems (ADAS), telecommunications, entertainment, medical, transportation and other sectors. However, the engineering challenges are daunting!

5G is the next technological revolution — the pervasive, ultra-fast compute network will connect billions of devices with data on-demand. It will drive economic expansion in many sectors, spawn new products and services and transform our lives as we now know it.

To deliver on the promise of 5G we first must build it. To this end, we must rethink the design of electronic components, devices and infrastructure – how they operate and how they connect in less than ideal environments. 5G network infrastructure enabled by high frequency mmwave spectrum, massive MIMO, small cells, beamforming and beam tracking/steering capabilities provides greater speed, bandwidth, coverage and robustness. But 5G increasingly complicates the design of System-on-Chips (SoCs) that need to manage huge amounts of antenna data and support a variety of capabilities such as massive machine type communication (MTC), enhanced mobile broadband (eMBB), ultra-reliable communication (URC) and low latency. The SoCs need to offer significantly higher processing capabilities within power-constrained and thermally constrained environments.

The promise of millimeter wave technologies will be preceded by extension of sub-6 GHz systems leveraging band-aggregation to get to 5G speeds with existing infrastructure. This will require multiple radios to operate simultaneously introducing crosstalk and thermal issues. 5G advanced methods and processing demand highly linear RF front ends, higher integration, more filtering and RF switching.  Then as millimeter wave emerges engineers will leverage simulation to solve sensitivity to temperature, efficiency, and circuit density challenges.

These are enormous challenges! Addressing these challenges requires a pervasive engineering platform to accurately simulate the multiple physics and multiple technologies that comprise these 5G designs — a platform that can make use of advanced high-performance computing and be deployed enterprise wide allowing designers and engineering experts to collaborate and develop 5G-capable systems. The Ansys design platform meets these requirements and is the simulation you need to realize your 5G engineering innovations.

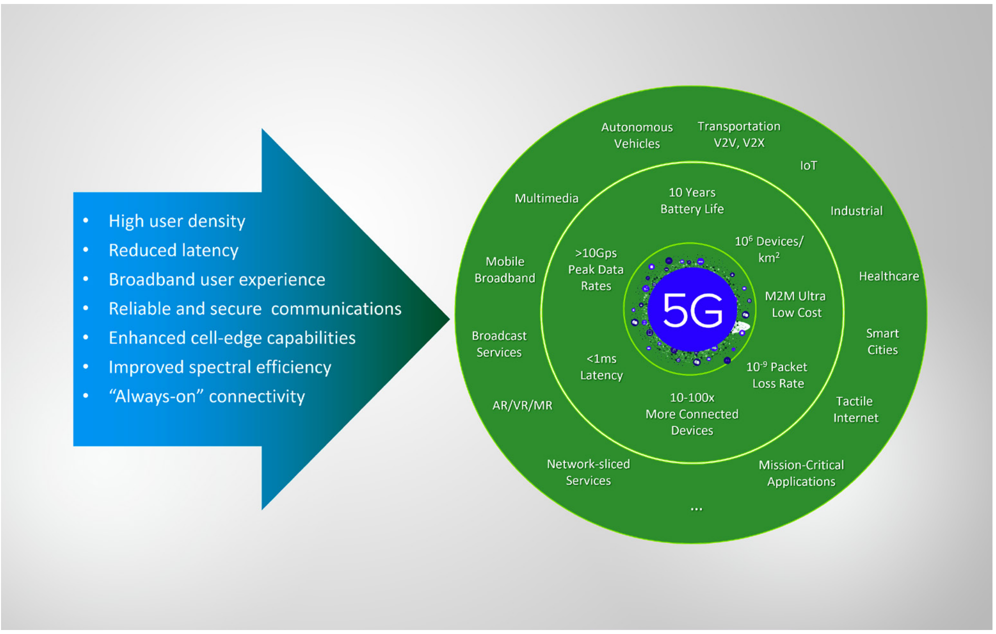



Figure 1. The 5G world.

## Beyond 4G

As shown in Figure 2, 5G is not simply an evolution of 4G but a major shift comprising a set of features that augment system-level capabilities including:

- Access to 10x the spectrum
- Integration of licensed and unlicensed spectra
- Mass deployment of small cells
- New network architectures— network function virtualization (NFV), edge computing, network slicing
- Support of IoT (and machine-to-machine communications)

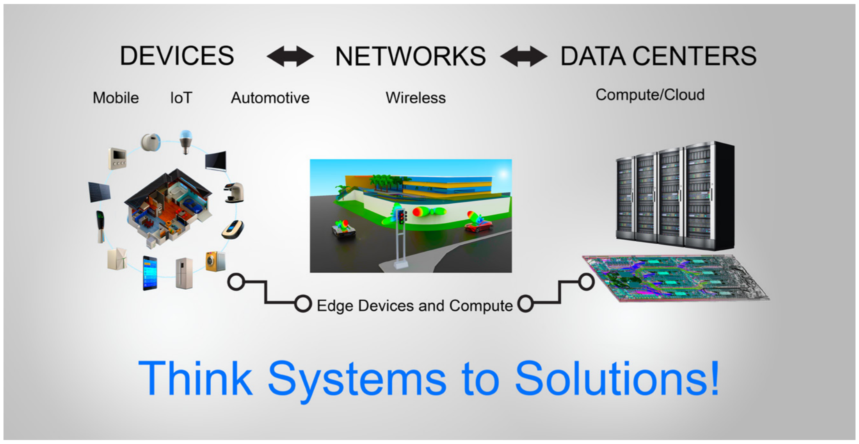



Figure 2. System-level capabilities.

## Why 5G Design Simulation?

As you can see, the design and development of 5G systems is a huge undertaking. To build and iterate till the system becomes operational is time-consuming and costly. A way to manage the front-end of the design process is to use simulation.
Wireless systems engineers rely heavily on simulation doing as much work in the front-end virtual world as possible. It is much quicker and economical to simulate versus building the real hardware/device. It is also easier to change or refine a design as it continually improves. Engineers simulate designs at different levels of abstraction, from component designs to system level simulations. Design and simulation are tightly coupled, integral parts of the product development process from design to spec.

## Leading 5G Technologies

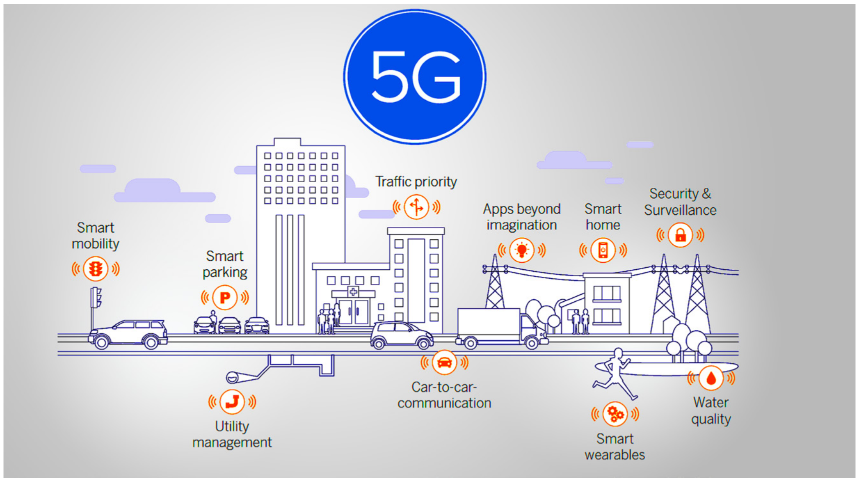
Implementing 5G can be expensive. The good news is that complete virtual prototyping and simulation can substantially reduce the cost and accelerate the design process. Key 5G technologies are described in the following sections.

## Advanced Antennas: Beamforming

Antenna beamforming in 5G can improve the capacity and data rates for wireless applications. MIMO beamforming techniques exploit multipath propagation and spatial multiplexing between the base station and user equipment (UE) to increase data rates and service more subscribers. Proper beamforming and beamsteering optimize connectivity and decrease the risk of dropped connections. Antenna systems must be carefully designed and simulated for tight control over element-to-element phase, housing and installation effects, and for ensuring graceful degradation due to potential in-service element failures.

## Carrier Aggregation (CA)

Emerging 5G standards can increase the number of CA LTE bands used for single subscriber connection to raise transmission bandwidth leading to increased RF front-end complexity and elevated interference potential. A growing number of sensitive filters in both UE and base stations will separate the sub-carriers and signals. Assessing electromagnetic coupling between bulk-acoustic-wave (BAW) resonators, filters and oscillators mounted side-by-side and end-to-end on RF sub-assemblies is critical to the success of these front-end designs.



***Thermal Issues***
Integrating various modules into RF front-ends generates a lot of heat in an installed environment that will not accommodate active cooling methods. Base station antennas must exhaust excess heat for safe operation of the electronics inside without the unreasonable expense and weight of forced air or liquid cooling. Temperature-dependent properties of the electronic systems must be examined to minimize heat and ensure safe operating limits.

***Edge Computing***
Data processing will be combined at the base station or edge compute node to service use-cases and applications requiring real-time to near real-time responses to events and situations.

As density of devices and users in a 5G network increases, the edge node will service mission-critical or user experience scenarios requiring 1 ms (or <1 ms) latency for applications in automotive or video-streaming which cannot afford round-trip time to the cloud and back (~250 ms) to process a request.

The decision-making capability is performed at the edge node. Ansys offers simulation solutions and products for the following:
- Networks.
- System-on-Chip (SoC).
- Mobile/UE Mobile.
- Data center Solutions.

This paper will focus on antenna solutions for the 5G Networks.

## / Ansys 5G Network Solutions

We begin with Ansys solutions from the standpoint of the 5G infrastructure and network providers.

**Advanced Active Phased Array Antennas**
Advanced phased array antennas are critical to achieve the capacity and performance for 5G systems. Massive MIMO requires phased array antennas to be designed accurately to optimize antenna gain and ensure targeted coverage. These large phased array systems will have the ability to develop multiple simultaneous spot beams, each concentrating on an individual UE or targeting a relatively small geography. The spot beams require dynamic positioning of the beams in order to follow subscribers as they move through the coverage region. Designing phased array antennas to meet these requirements is challenging. A larger array with more individual elements enables smaller beams with the capability of targeting more UEs. At the same time, a larger array design increases the size and complexity of the RF signal distribution and installation platforms as well as a need for higher electronics density for channel receivers, digitizers and signal processing. Performance considerations for 5G antenna array design include beam steering, null steering (to reduce the effect of unwanted signal sources in the environment), mutual coupling and electromagnetic interference issues.

Figure 4 shows a phased array design flow in Ansys HFSS, a 3D high frequency electromagnetic (EM) tool for designing and simulating high frequency (HF) electronic products like antennas, antenna arrays, RF and microwave components, resonators, filters and other HF electronic components. The phased array design flow in HFSS begins with a single element prototype in a unit cell, followed by a design of experiments (DoE) approach to optimize the antenna design parameters. A full array is then synthesized from the unit cell to model full array performance in Ansys HFSS, followed by the process of modeling the installed antenna and the interaction with its environment using the hybridized Ansys HFSS SBR+ shooting-and-bouncing rays solver.

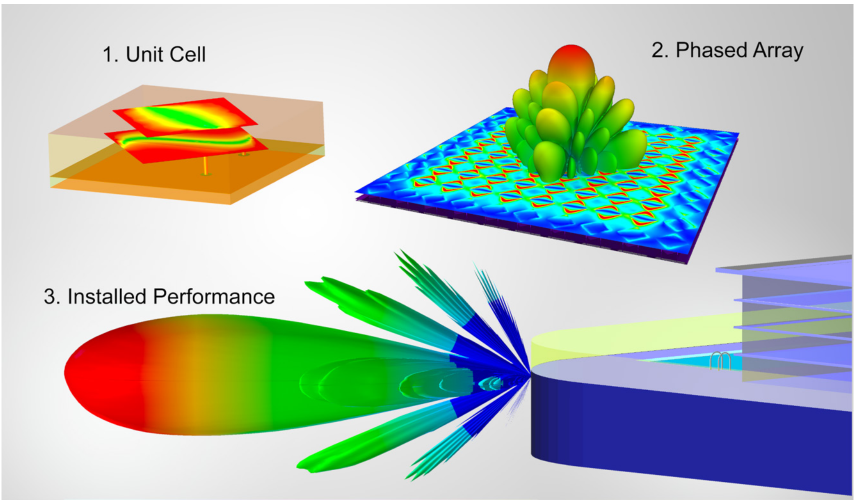


Figure 4. Phased array design flow in Ansys HFSS and Ansys HFSS SBR+.

HFSS provides finite antenna array analysis by combining finite element methods (FEM) with the finite array domain decomposition method (faDDM), a powerful technique for quickly solving large phased array antenna systems. The faDDM approach exploits the array's repetitive structure, providing a fast and full-fidelity solution to a finite array. Designers need only specify the number of elements with the lattice directions and HFSS automatically generates the array. The entire structure is analyzed explicitly with arbitrary excitations to capture edge effects, mutual coupling terms, directivity, gain, electric fields and other antenna parameters under all possible beam scanning conditions.

HFSS enables visualization of radiation patterns, element-to-element coupling matrices and electromagnetic fields around the array. These capabilities are depicted in Figure 4.

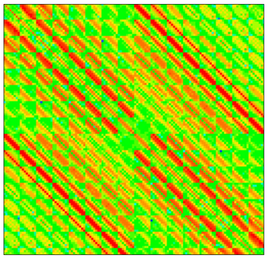


Figure 5. Coupling matrix visualization.

Enhanced visualization of the complex scattering parameters (see Figure 5) is accomplished through a feature known as network data explorer in Ansys HFSS. Color-coded plots are convenient for simultaneous examination of mutual coupling levels across a large array.

Simulating beamsteering capabilities of the complete, finite phased array antenna is critical for ensuring optimal communication links with the targeted user equipment.

Most 5G antenna systems include an integrated radome to protect the antenna from environment factors such as rain, ice or dust. At millimeter wave frequencies, radomes must be carefully designed to minimize their impact on the energy that is intended for area coverage. Radome material thickness becomes comparable to a wavelength at these frequencies, increasing loss in the radome material and causing unwanted electromagnetic interaction with the antenna system.

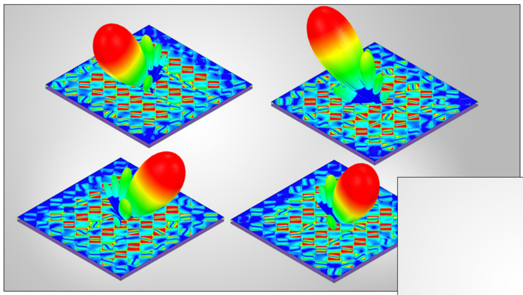


Figure 6. Beamsteering.

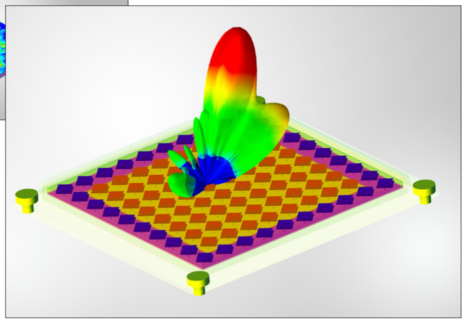


Figure 7. Effects of the radome on the far field radiation pattern.

The impact of a radome can be captured using faDDM in HFSS by approximating the radome as a thick slab above the array, and its effect on the far field radiation pattern can be accurately assessed in HFSS. Other antenna parameters such as return loss of the array in presence of the radome can also be evaluated (see Figure 8). The simulation predicts higher return loss for the antenna with the radome. 2D far-field radiation patterns of the array (see Figure 9) in both cases (with and without the radome) are comparable, predicting good transparency of the radome. These results provide insight into the radome's material, thickness and shape and their overall impact on the radar gain. For a high-fidelity solution, an explicit array finite element analysis comprising a fully meshed model of the antenna array may be combined with a fully coupled radome simulation using an automated hybrid solution of FEM and method of moments (MoM) or FEM and shooting and bouncing rays (SBR) methods. Thus, multiple solvers in Ansys HFSS enable efficient and accurate design of the complete antenna and radome assembly to yield accurate antenna RF feed point and radiation characteristics, under all beamsteering conditions.

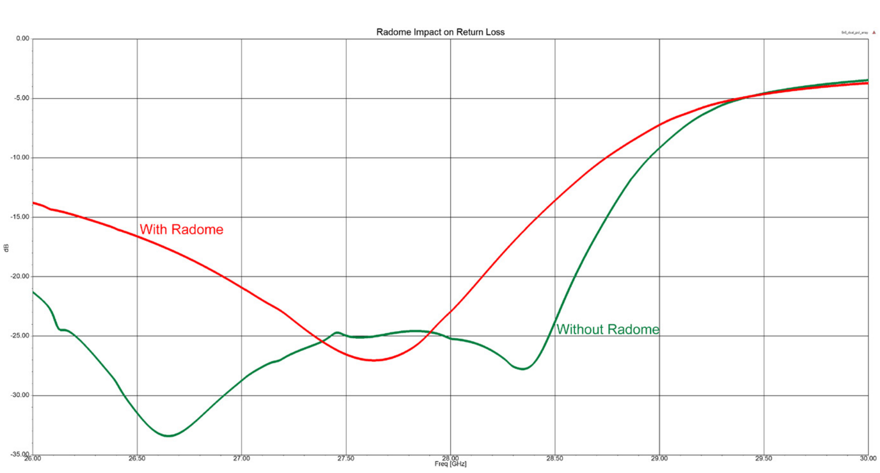



Figure 8. Radome impact on return loss.

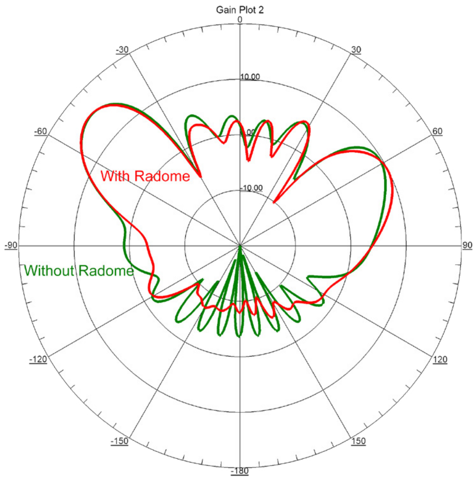



Figure 9. Gain plot with and without radome.

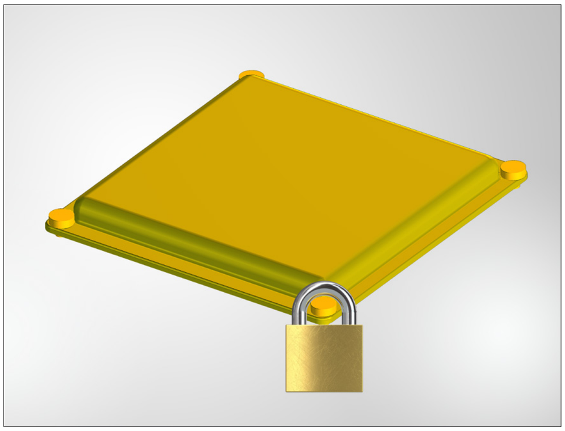


Figure 10. Encrypted 3D Component with radome.

***HFSS 3D Component***

Once an antenna design is created, engineers can store it for reuse as an HFSS 3D Component. Simulation-ready 3D Component is a patented technology from Ansys that allows users to exchange HFSS 3D models through the supply chain without disclosing critical intellectual property (IP). Notably different from S-parameter or SPICE model representations of the parts that are exchanged, HFSS 3D Components provide fully-coupled high-fidelity models for EM analyses.

They hold a distinct advantage over an S-parameter model which only delivers a "black box" terminal response of a component. A system integrator needs to add only the 3D Component to a larger system design to simulate the installed performance. For example, an antenna designer can convert the array design into an encrypted 3D Component so that the integrator can later add it to a target design to evaluate its installed performance. If the design of the original antenna model contains sensitive IP, encrypting the 3D component protects the internal details. Full EM fidelity of the original model is encapsulated and encrypted in a simulation-ready 3D Component. The installed performance of the encrypted antenna model can be simulated, keeping its accuracy and details intact without fear of exposing sensitive IP. Users can parameterize 3D components to move them around on the platform and calculate their response in a dynamic simulated environment.

Vendors and developers of discrete components, such as TDK, Johansson, etc., create 3D Components in HFSS and provide them to end-users who utilize them in larger system simulations. They can position, tune and match the part in the target assembly. With this ability to collaborate through 3D Components, vendors can provide their customers with HFSS simulation-ready models, giving them a valuable edge over the competition by accelerating the development cycle and enabling first-pass design success with build-accurate modeling. 3D Component models are not limited to antennas but also include components like RF connectors or surface mount RF devices.

## / Fully-Coupled Hybrid EM and Co-existence Solutions for Electrically Large Structures

The performance of an antenna and radome assembly is impacted by coupling to the platform where it is mounted and the structures in its vicinity. Studying this impact requires advanced EM solutions. Depending on the type of the problem, designers can choose and combine a variety of Ansys EM solvers:

- Ansys HFSS can be used to solve the antenna array with FEM simulation, and its coupling with the radome using a coupled MoM solution.
- In a larger EM simulation, the effects to the host platform and to the electrically large environment can be assessed in Ansys HFSS SBR+.

Thus, designers and site planners can combine multiple numerical techniques to obtain an efficient solution to these electrically large problems. These solutions help to understand the performance of the array upon installation as shown in Figure 11. 5G antenna systems will be integrated into the existing infrastructure, in many cases requiring installation alongside current equipment. In addition, 5G phased array antennas are likely to be mounted on the sides or corners of buildings. Site effects for deploying the antennas can be explored for appropriate placement using Ansys HFSS and Ansys HFSS SBR+.

The design of the phased array antennas should also incorporate real-world installation challenges. Figures 12 and 13 show wireless performance when arrays are mounted on structures near busy traffic intersections. Real time vehicle-to-everything (V2X) and vehicle-to-vehicle (V2V) communication can be simulated to evaluate the performance of the 5G wireless environment at busy intersections. These solutions are critical to ensure successful deployment of V2X and V2V systems, thereby improving the safety of self-driving cars.

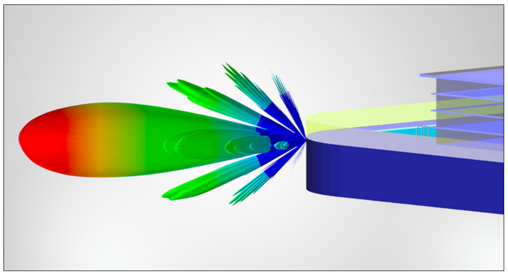


Figure 11. Installed performance of the phased array antenna.

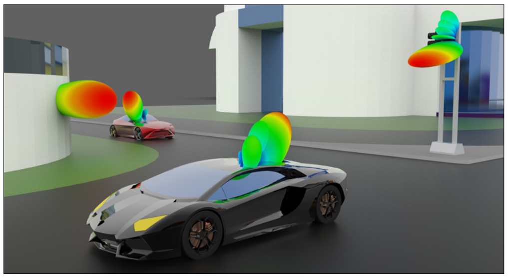


Figure 12. Platform effects + V2X and V2V.

Figure 13. Successful V2X and V2V communications boost safety of self-driving cars.

## Large-Scale Simulations in a City/Urban Environment

After assessing the installed antenna system performance, engineers can evaluate the physical environment impacts through simulation using Ansys solvers. Due to high carrier frequencies, 5G antenna array systems require physically small antenna elements. Multiple antenna arrays constituting many active elements can be developed and installed on the supporting infrastructure.

Ansys EM tools provide the ability to model real interaction of the physi cal (PHY) channel between the base station and mobile UE antennas. This physical channel can be of a city or urban geographical topology, including both static and dynamic elements.

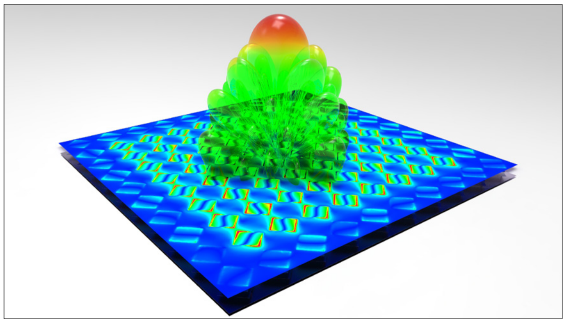


Figure 14. Phased array antenna's far field radiation pattern and electric field plot.

Figure 15 shows an example of a signal propagation simulation in a large city environment at 28 GHz. In this large-scale electromagnetic simulation, Ansys HFSS SBR+ employs the shooting and bouncing ray technique to model antenna interactions in regions spanning tens of thousands of wavelengths. Accurate analyses of the antenna array obtained from an HFSS FEM solution are combined with asymptotic techniques in SBR+ to solve this large problem.

These installation site simulations give the following insights:

- Antenna array performance, beamforming, beam steering and the received signal strength at the UE.
- Base station to base station interference, unintentional jamming, and outside EM interferences caused by other mobile users, wireless products, or other sources of RF emissions.

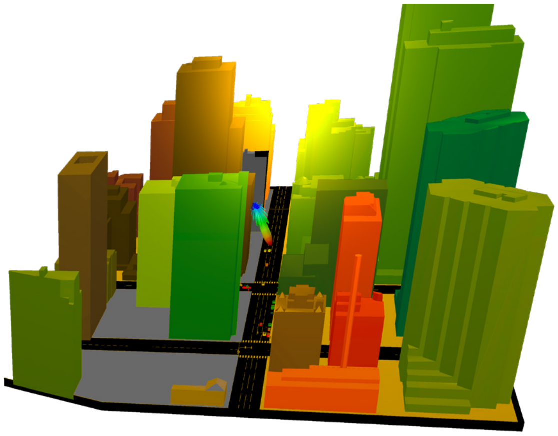


Figure 15. Simulation of a large-scale city environment.

Beamforming performance of a 28 GHz adaptive phased array antenna systems communicating with cars and multiple moving user equipment can be simulated. The locations of the user equipment and self-driving cars vary from 500 meters to 200 meters from the base station; each is out of direct line of sight of the array for most of its trip. Maximum ratio transmission (MRT) beamforming is applied to the feeds of each element of the antenna to keep the beam focused on the moving UE, leveraging the available simulated multipath created by the simulated environment. In some cases, the beam could be pointing in directions that are not directly at the UE; in these cases, the optimal beamforming is leveraging other reflection paths of opportunity to maximize the signal strength received by the UE.

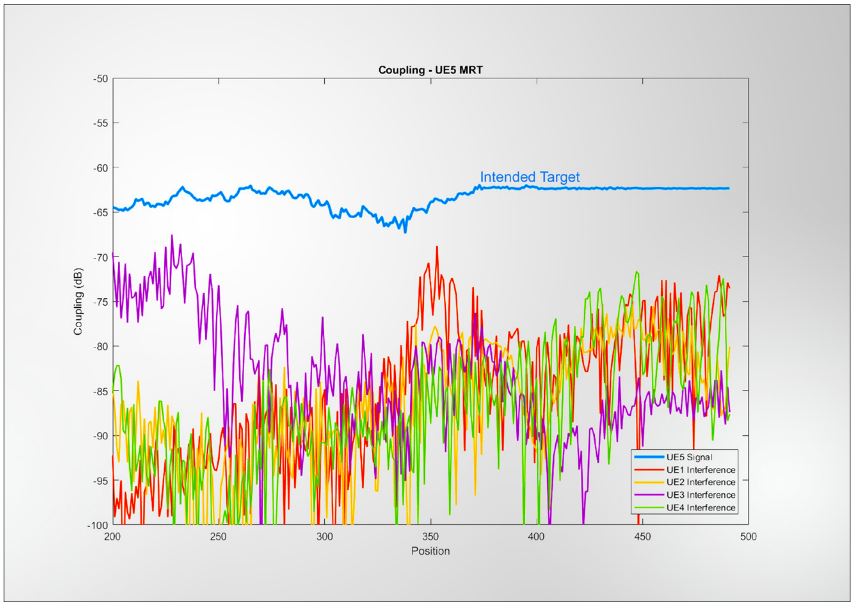



Figure 16. MRT for a base station interacting with multiple UE in a city environment.

Figure 16 shows MRT for a base station interacting with mobile UE in a simulated city environment. Ansys HFSS SBR+ simulates the coupling formed in the physical channel between the base station and UEs and provides this critical characteristic necessary for computing optimal beam steering weights for channel-level precoding. With HFSS SBR+ analysis of the physical channel, site planners can evaluate alternative beam steering algorithms for scenarios concerning multichannel arrays together with multiple UEs and undesirable RF emission sources in a simulated environment.

## Application: 5G Simulation and Self-Driving Cars in a City

Bringing two complex application areas of 5G communications together with self-driving cars provides flexibility for modeling communication systems on several levels.

In this example, we highlight Ansys 5G solution capabilities in a system-context of a city.

Maintaining continuous connectivity with base stations in a multipath environment is critical for self-driving cars to sense, perceive and make appropriate decisions in order to navigate safely.

Figure 17 shows an electrically large city environment with complex multipath propagation solved in Ansys HFSS SBR+. Antenna-to-antenna coupling for a self-driving car is calculated in SBR+ as the car moves along a defined route through the city. SBR+ employs advanced ray tracing to model signal propagation through the environment.

The rays in the top image of Figure 17 are colored according to the bounce number of each ray track segment. Figure 18 shows the coupling between base station and the mobile antenna mounted on top of the vehicle passenger cabin. Signal strength varies as the car travels through the urban canyon and the signal propagation experiences line-of-sight (LOS) blockage, EM diffraction and multipath effects

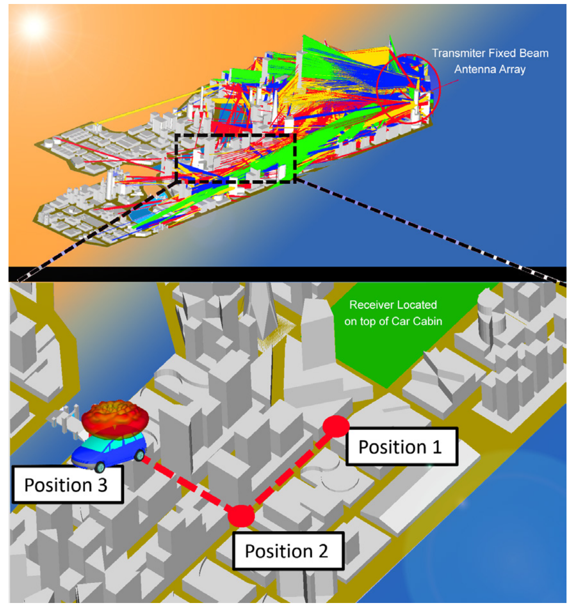



Figure 17. Varying positions of a self-driving car.

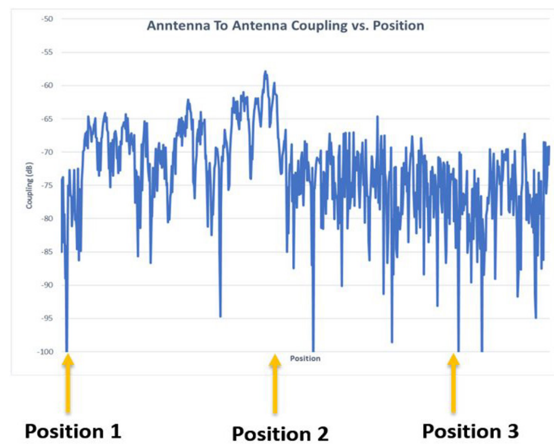



Figure 18. Antenna-to-antenna coupling.

## Conclusion

As we have explored in this white-paper, the transition to 5G is exciting, but no small task given the degree of complexity at various points in the system. The solutions described in this volume of the paper are built on a set of trusted Ansys products and capabilities, namely Ansys HFSS and HFSS SBR+, to design and simulate antenna systems, antenna-to-antenna coupling, environmental effects on signal propagation as well as V2V and V2X communication for traditional and autonomous vehicles.

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