WHITE PAPER

Four Advantages System-Level Design Delivers for Phased-Array Development

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Introduction

Phased-array antenna development is entering a new era where speed and agility are critical success factors. Commercial phased-array development projects for the latest 5G and satellite communications systems present new time-to-market and cost challenges compared to legacy, specialty product development projects. The burgeoning space communications economy, with the advent of low-earth orbit (LEO) satellites, will play an important role in the global 5G network build-out over the next several years.

Designers cannot afford to spend long portions of the development cycle testing physical prototypes in the anechoic chamber. Legacy methods that rely on design approximation, hardware prototypes, and multiple testing iterations are inefficient. They lack measures to quickly gain design confidence and risk cost overruns from unpredictable project schedules.

A Better Approach Emerges

The Model Based Engineering (MBE) design methodology, driven by high fidelity modeling and fast simulation speed, is the modern way to develop phased arrays on specification, on time, and within budget. With MBE methods, designers build a virtual prototype that enables them to fully explore the design space to arrive at a topology that satisfies the specifications. They verify the topology against the entire scope of the requirements and gradually increase the fidelity and accuracy of the models. Once they gain high design confidence in simulation, they then build the prototype hardware and test it in the chamber. From there, designers only need to fine tune the design to satisfy the specifications (Figure 1).

Adoption of Model Based Engineering (MBE) methods leads to higher confidence that phased-array projects will meet or exceed specifications in much less time and cost.

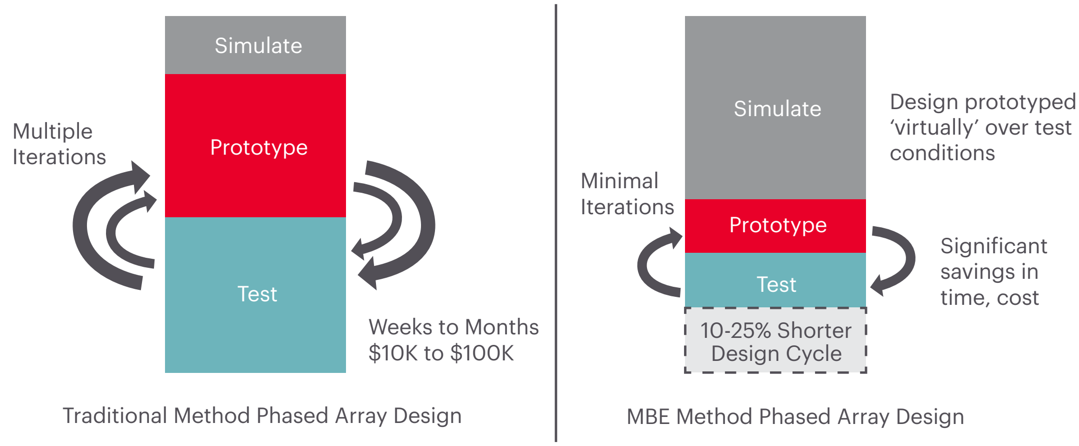
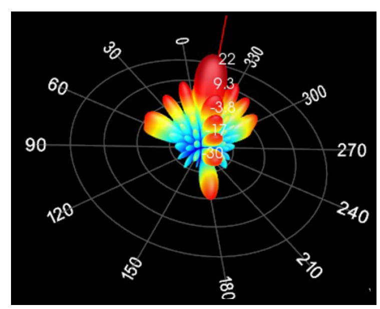


Figure 1. MBE virtual prototypes shorten the design cycle and lower development cost

One of the strongest advantages of using MBE methods is that they enable designers to explore and verify the entire system design space including array topology, beam steering angles, amplitude and phase distribution, side lobe control, and antenna element failures. Typical phased-array specifications are numerous. However, designers can simplify them to the characteristics of the far-field pattern and the corresponding design parameters to obtain the required specifications. If there are no impairments in the front-end electronics, designers can arrive at the far field very quickly by starting with a few simple, fundamental parameters (Figure 2).

Typical Phased Array Specifications

- Gain
- Horizontal and vertical beam width
- Sidelobe level
- Useful steering range (horizontal and vertical)
- Polarization



Design Parameters

1. Number of elements
2. Type of element
3. Geometry of array
4. Spacing between elements
5. Frequency of operation

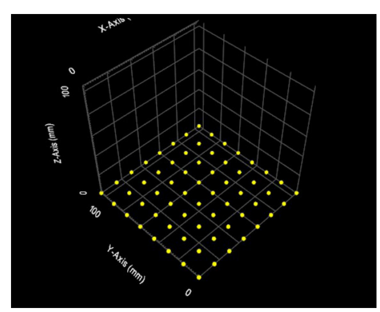


Figure 2. Typical specifications and parameters of a phased-array design

Significant Advantages Realized

Compared to legacy approaches, MBE methods provide for rapid exploration and validation of the system design space and offer a number of significant advantages, particularly when it comes to time-to-market and cost. Four key advantages of MBE include:

Advantage #1: Simulation Is Much Faster

Legacy RF simulators are too slow to handle extensive exploration of complex commercial array designs. During simulation, designers must study the beam steering angles, minimize the side lobe effects through adaptive nulling, and examine what happens to the far-field pattern and array functionality when individual elements fail in each direction.

As an example of legacy RF simulator inadequacy, consider the run-time computation of a 256-element phased-array simulation. Assume X seconds to compute the far field for one channel and direction. The designer explores beam width in a range of 60 degrees and elevation in a range of 30 degrees with a resolution of one degree. For each direction, the designer fails 10 percent of the antenna elements and performs 10 Monte Carlo simulations every time. With an RF simulator, designers can run 256 RF channels in about 90 seconds, so the resulting simulation time is 450 hours — an unacceptable and impractical amount of time for commercial development projects.

In contrast to legacy RF simulation, system simulation runs very fast. Using the same computation data, but with each simulation in the system simulator taking just 0.38 seconds, the whole simulation completes in just 1.9 hours. Simulation speed is what makes MBE methods a “must have” for phased-array design (Figure 3).

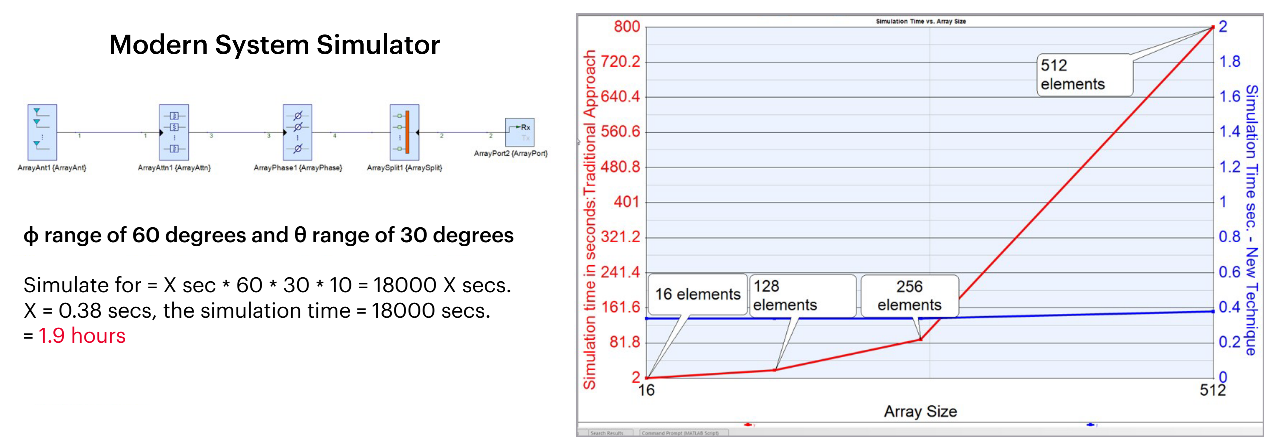
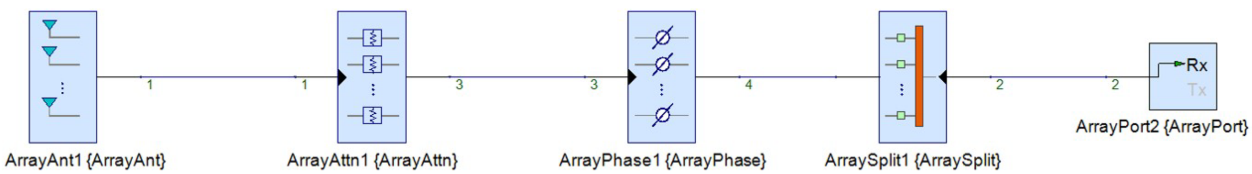


Figure 3. System simulation run times (blue) are short compared with legacy RF simulation times (red)

Advantage #2: MBE Simulation Is Easy to Set Up and Supports Detailed Exploration

The speed of system simulation methods enables designers to perform comprehensive exploration to achieve high confidence earlier in the cycle. System simulation leverages high-level model libraries that accelerate phased-array schematic set up and ease system design capture. Because arrays are multi-channel systems, schematic set up requires a fewer number of parts in a small footprint model library (Figure 4). The library enables the easy creation of 80-90 percent of the different types of phased arrays.

256 Element Phased Array Schematic



Small Footprint Library

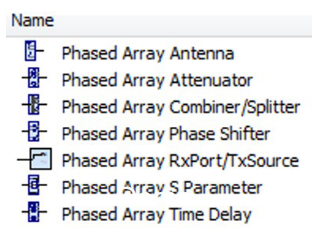


Figure 4. MBE simulation includes schematic libraries that ease system capture

> "For many years satellites have been instrumental in the wide world of telecommunications, albeit, given the high barrier to entry in the market, limited largely to governmental stakeholders and major communications service providers. But the economics of satellites are changing with trends in miniaturization that lower cost, as well as new companies like Space X, Blue Origin, Virgin Galactic and other private enterprises investing in delivering satellites to orbit. Given the importance of space-based network infrastructure, standards body 3GPP is examining the role satellites will play in delivering on 5G connectivity."
>
> —Excerpt from Sean Kinney's RCR Wireless News story, The Role of Satellites in Delivering 5G

With faster speeds in hand, extensive exploration of the design space becomes much easier starting with the geometry of the antenna array. Designers can then perform many simulation experiments such as:

- Exploring different array shapes, sizes, and patterns and adjusting the spacing between each element to view changes in the far-field pattern
- Adjusting the amplitude distribution to control the side lobes and very quickly experimenting with different types of tapers to control the lobes
- Scanning the direction to see the scan loss and acceptable range of scanning angles
- Defining the polarization and enabling dual polarized antennas to study the effect of the non-ideal polarization between orthogonal vertical and horizontal polarizations
- Studying the quantization effects of the programmable phase shifters and attenuators
- Examining the failure of the antenna elements and the impact on the far-field pattern and phased-array system itself

Designers can also easily study multi-level architectures. For example, in the case of broadband systems like 5G and future satellite communications, they may have to follow both time progression and then phase progression in a design simulation. Using system simulation, designers can initially perform a coarse time delay method followed by a fine phase difference method so that the implementation of the phased array becomes more practical.

Advantage #3: System Models Are Highly Accurate

The fidelity and accuracy of system models ensure that simulations behave like the actual hardware. Model accuracy comes from incorporating the measured data into the simulation models. For example, the amplifier model icon behaves exactly like the actual amplifier in the lab. The model captures the amplifier behavior under varying frequency, biasing, load, and temperature conditions and brings that data into the simulator. Using MBE methods, the simulator produces the real-world effects that were only previously possible in hardware with legacy methods.

Designers can also incorporate the element patterns from electromagnetic simulation and the S-parameters of the reflection coefficients of all the design elements. Then the simulator actually considers decoupling between them and produces effects that typically happen in the hardware world.

MBE methods accurately model active impedance or Canning impedance unique to phased arrays. Designers scan the beam looking into the impedance for each one of the elements as the scanning angle changes. The changing beam impedance impacts the performance of the amplifier, assuming the amplifier model behaves based on the load to which it is connected. The X-parameters[1] model contains varying load impedances. The programmable attenuator and phase shifter models include the S-parameters for each one of the states.

Charting both the real and imaginary impedance for three different beam scanning angles shows it changing quite dramatically depending on the angle (Figure 5). In practice, designers simulate and collect the variation of the scanning impedance for all scan angles of their system specification. Then, they derive statistically how much variation is happening and modify the design to effectively match impedance networks between power amplifiers connected to each one of the array elements.

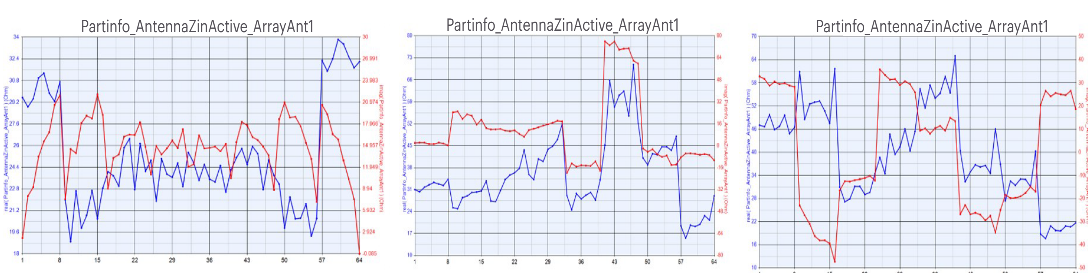


Figure 5. From L to R: accounting for active impedance variation at Theta=0, Phi=0; Theta=15, Phi=0; and Theta=30, Phi=0 respectively (blue is real and red is imagined)

1 **X-parameters** is a trademark and registered trademark of Keysight Technologies in the US, EU, JP, and elsewhere. The X-parameters format and underlying equations are open and documented. For more information, visit http://www.Keysight.com/find/eesof-x-parameters-info

Advantage #4: System Simulation Accounts for Spurious Signals, Standards Compliance

MBE methods enable rapid analysis and prevention of spurious signals created by the nonlinear front-end electronics connected to the phased array. When these additional undesired frequencies reach the phased-array antenna, they radiate along with the desired frequencies.

In legacy methods, designers use the anechoic chamber to find the spurious frequencies, taking measurements at each one to understand their far-field pattern – a tedious process that requires several days to complete. Using system simulation, designers can understand the impact of spurious signals on the far-field pattern in a matter of hours without leaving their desk. They then plot simulation results in both 3D and more intuitive 2D charts to identify the maximum values of the radiated spurious signal frequencies.

MBE methods also help ensure compliance with spectral emission mandates from standards or regulating bodies. Designers generate pie cut graphs for a specific angle and plot each one of the frequencies from the 3D chart onto a 2D graph. They impose a spectral emission mask (SEM) to find any violations in the simulation. Then, they quickly correct the violations, such as by modifying the filter after the amplifier before the signal for the spectrum enters the phased-array front-end electronics.

In the example, the designers tighten the filter from a range of 9.2 to 10.8 to a range of 9.5 to 10.5, which eliminates the offending 8 GHz signal violation (Figure 6). Again, this is a very time-consuming, iterative testing and hardware re-design process using legacy physical prototyping methods in an anechoic chamber.

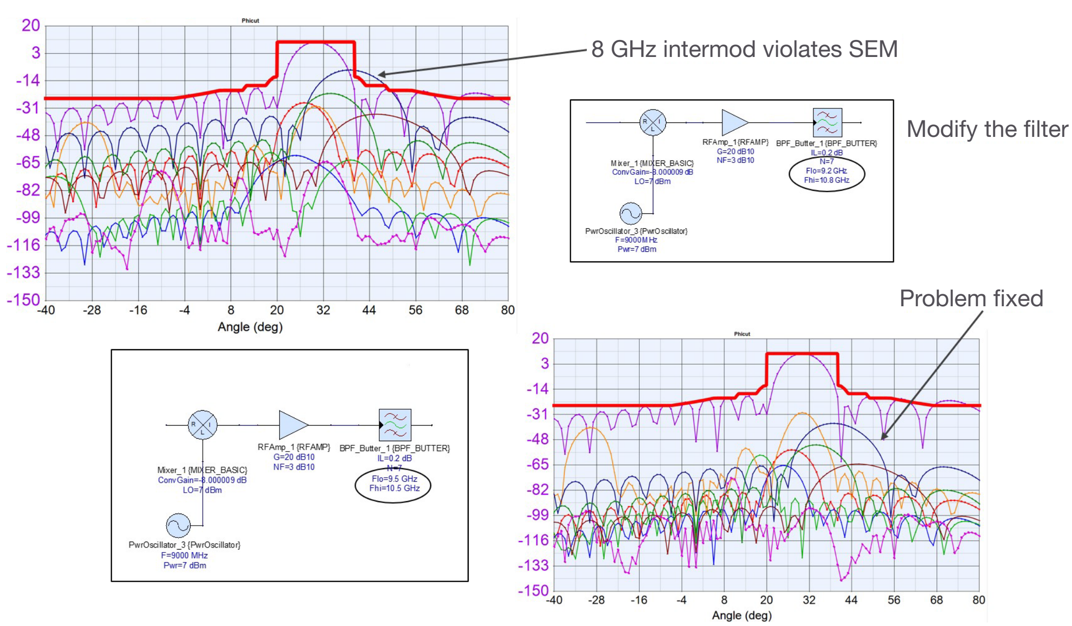


Figure 6. Checking for standards compliance with a spectral emission mask (red)

Finally, MBE methods give phased-array designers confidence to reach the optimal far-field error vector magnitude (EVM) measurements for their system. A prime example is taking an over-the-air (OTA) measurement of a 5G new radio downlink source. In a simulation, designers can obtain the EVM plot very quickly, whereas with legacy measurement methods it takes days.

Conclusion

Phased-array designers adopting MBE methodology benefit from four key advantages: faster simulation, detailed exploration of the system design space, highly accurate modeling, and accounting for spurious signals and standards compliance. Adoption of MBE methods leads to higher confidence that phased-array projects will meet or exceed specifications in much less time and cost. Ready to adopt system modeling and simulation in your next phased array design project? Visit PathWave System Design (SystemVue) to learn more about Keysight's MBE software solution and apply for a free 30-day trial.

Additional Resources:

PathWave System Design (SystemVue)
Video: Designing Phased Arrays with Confidence
Webinar: Model-Based Engineering (MBE) - A Design and Test Perspective

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