Design

Designing Next-Generation AESA Radar

Figure 1: Products within the NI AWR Design Environment provide circuit, system and EM analysis along with interoperability to 3rd party design flows

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The complexity and cost of developing systems based on phased arrays are being addressed through new functionality in electronic design automation (EDA) software, supporting designers with the means to develop new system architectures, component specifications, implement the physical design of individual components, and verify performance prior to prototyping. This article discusses these trends and presents recent advances in EDA tools for phased array based systems.

Phased Array Primer

With electronically steered antennas, an array of individual radiating elements whose phase and amplitude are controlled either digitally, through analog/RF components or by using hybrid techniques to control beam direction without the need to physically move the antenna. Phase and amplitude control of the input signal to the individual elements provides steerable directivity of the antenna beam over both azimuth and elevation.

The design considerations for an actively scanned electronic array (AESA) radar include the individual radiating elements (antenna design), the RF link budget of the feed network, which is directly tied to component performance such as insertion losses and impedance mismatch, as well as the array itself.

Given the complexity of the task, design groups need a system-aware approach that allows team members to explore phased array behavior from different levels

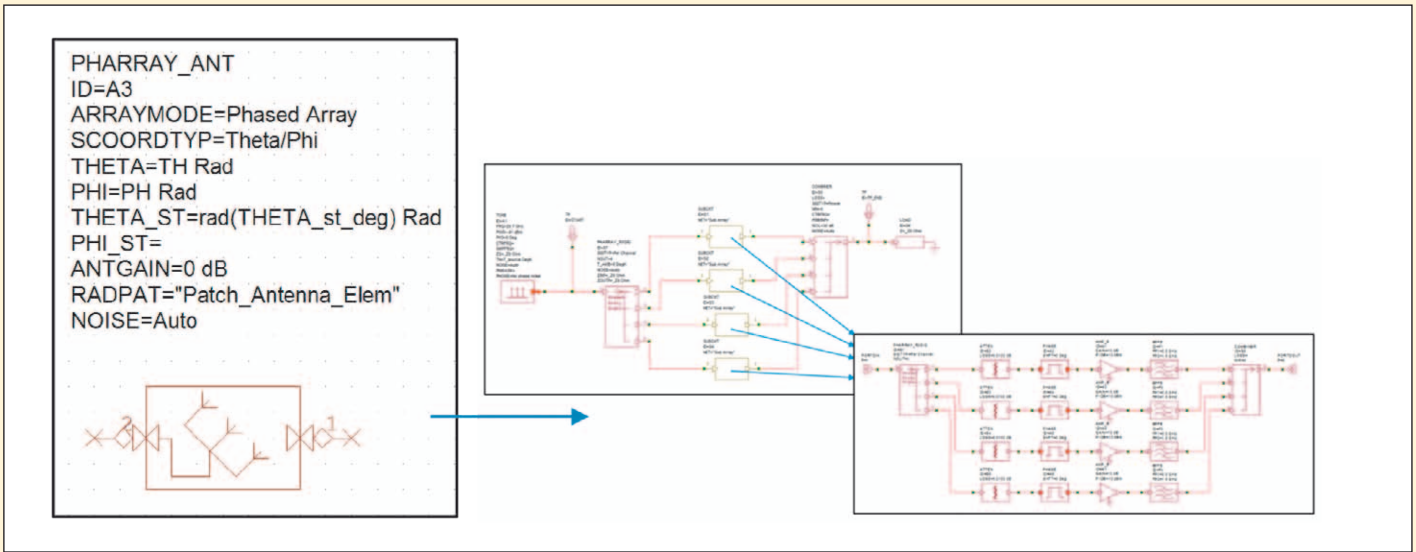

Figure 2: a) Single phased array element can model large scale (1000s of elements) arrays, replacing b) system designs based on individually defined elements

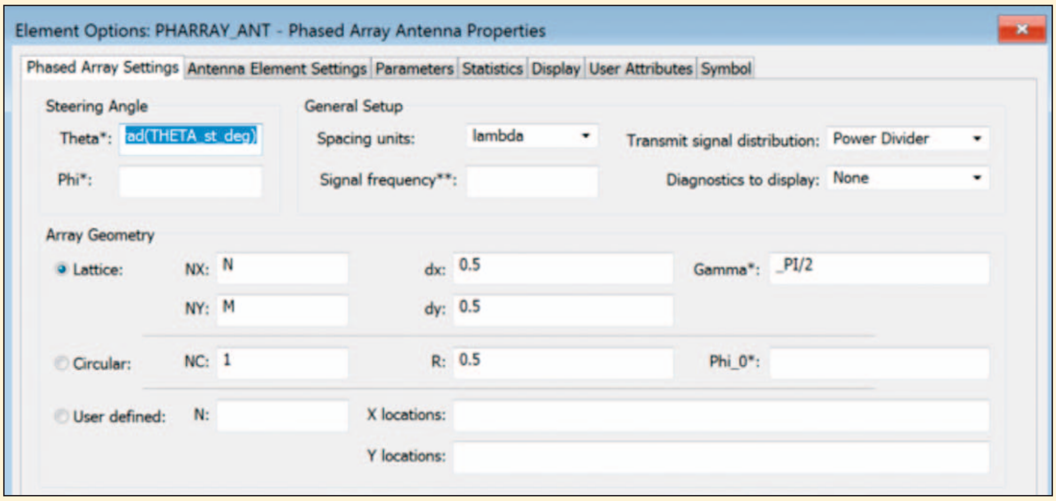

Figure 3: Portion of the phased array parameter dialog box showing geometry configuration options including lattice, circular and user defined configuration

of abstraction, from early conceptual models with little detail through highly-defined array models which account for true component interactions and possible impairments.

Designing the complex packaging schemes for high-frequency signaling must be addressed with circuit simulation and electromagnetic analysis specialized for RF and microwave electronics.

Design Management and EDA Tools

While actively steered phased-array antennas have many advantages, they are extremely complex and their production, especially non-recurring development costs, is significantly higher than conventional antenna design. As the industry shifts toward highly-integrated phased array systems, it is critical to have in-house systems expertise working closely with hardware developers, both fully exploring the capabilities and trade-offs among possible architectures and integration technologies.

In addition, a start-to-finish design flow made possible with electronic design automation (EDA) has become critical in moving beyond the initial system simulation which is focused on early architecture definition, and the development of link budgets and component specifications. A preferred phased array system design flow manages the start-to-finish front-end development, embedding RF/microwave circuit simulation and/or measured data of radio/signal-processing (behavioral) models within a phased array system hierarchy. Such software enables the system designer to select the optimum solution, ranging from hybrid modules through fully-integrated silicon core RFIC devices, addressing the specific requirements of the targeted application.

Perhaps more importantly, a system-aware approach, carried throughout the entire phased array development cycle, allows the team to continually incorporate more detail into their predictive models, observe the interactions between array components and make system adjustments as the overall performance inadvertently drifts from early idealized simulations.

Design failure and the resulting high costs of development is often due in part to the inability of high-level system tools to accurately model the interactions between the large number of interconnected channels, which are typically specified and characterized individually.

Since overall phased-array performance is neither driven purely by the antenna nor by the microwave electronics in the feed network, simulation must capture their combined interaction in order to accurately predict true system behavior. Circuit, system and electromagnetic co-simulation allows verification throughout the design process.

Phased Array Design Flow

A leading phased array design flow is available with Visual System Simulator (VSS), the system-level simulator that operates within the NI AWR Design Environment platform. The simulator provides full system performance as a function of steered beam direction, inclusive of the antenna design, and the active and passive circuit elements used to implement the electronic beam steering. System components can be modeled in greater detail using Microwave Office for RF/microwave circuit simulation with electromagnetic (EM) analysis for antenna design and passive device modeling using AXIEM, planar EM and Analyst, 3D EM.

These tools are fully integrated into NI AWR Design Environment, supporting seamless data sharing within the phased array hierarchy. Furthermore, individual antenna designs can be generated from performance specifications using AntSyn, with resulting geometries imported into AXIEM or Analyst for further EM analysis and optimization. Capabilities within this suite of tools, figure 1, include design assist add-on products and interoperability with third party PCB (layout), RFIC (design/layout) and EM (analysis) tools.

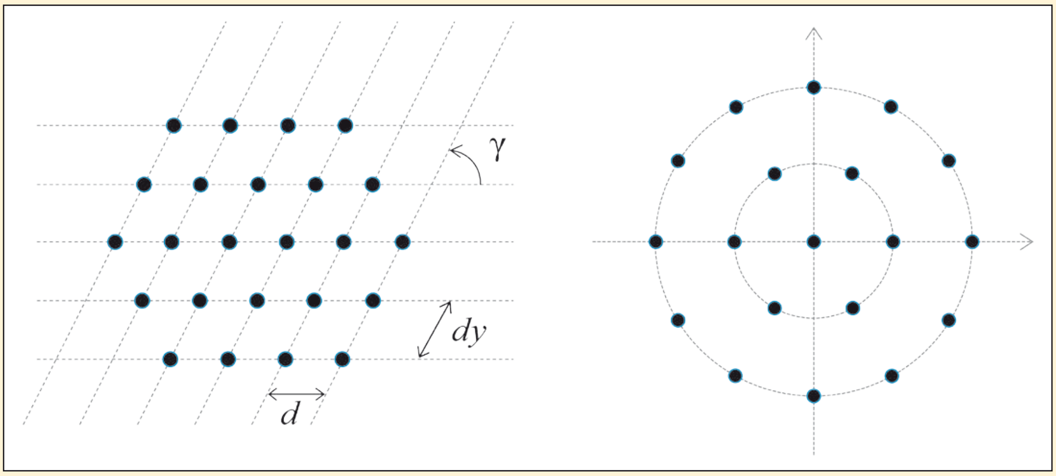

Figure 4: Standard array geometries for phased arrays in VSS – a) lattice, b) circular

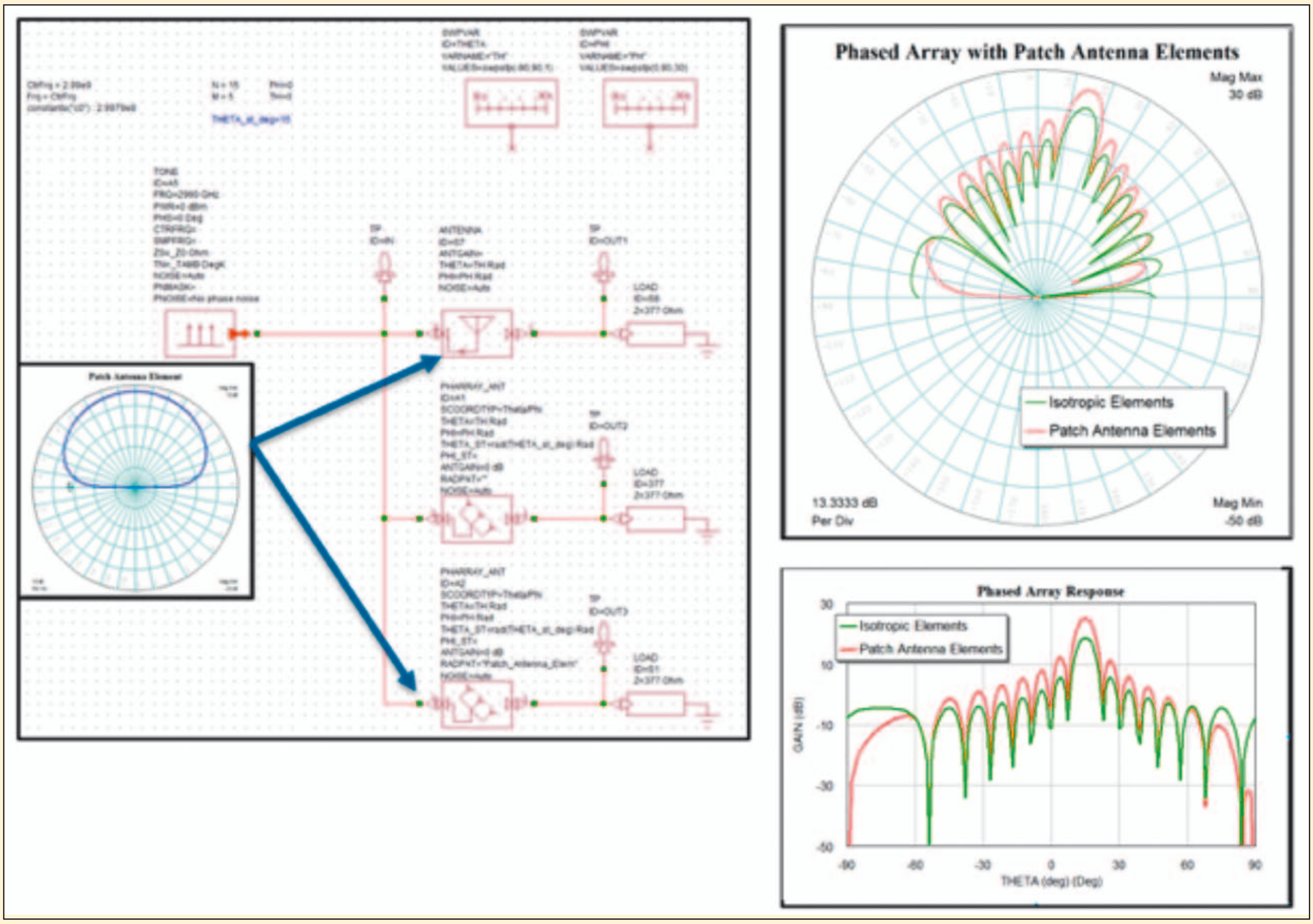

Figure 5: 2, 15 x 5 element phased arrays based on isotropic and patch antenna radiation patterns with theta angle set to 15°

Highlights of phased array analysis in VSS includes:

- Automate/manage the implementation of beamforming algorithms and determine phased array antenna configuration from a single input/output block
- Perform array performance for over a range of user-specified parameters such as power level and/or frequency
- Perform various link budget analysis of the RF feed network including measurements such as cascaded gain, NF, output power (P1dB), gain-to-noise temperature (G/T), etc.
- Evaluate sensitivity to imperfections and hardware impairments via yield analysis
- Perform end-to-end system simulations using a complete model of the phased array
- Simulate changing array impedance as a function of beam angle to study impact of impedance mismatch and gain compression on front-end amplifier performance

Defining Phased Array Configurations

Specifications for any phased array radar are driven by the platform requirements and the intended application. For example, weather observation,

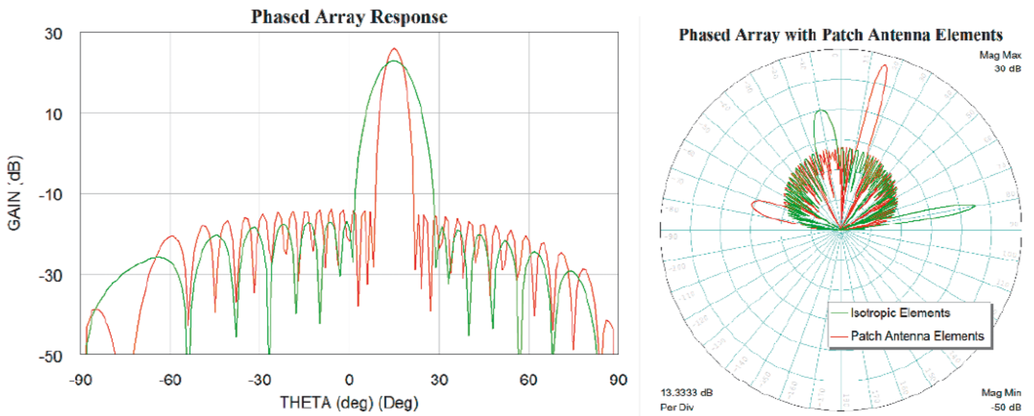

Figure 6: a) radiation patterns for 15 x 5 and 30 x 5 arrays, b) side lobe behavior for array (15 x 5) with element spacing = .95° at steering angle of 15° and 80°

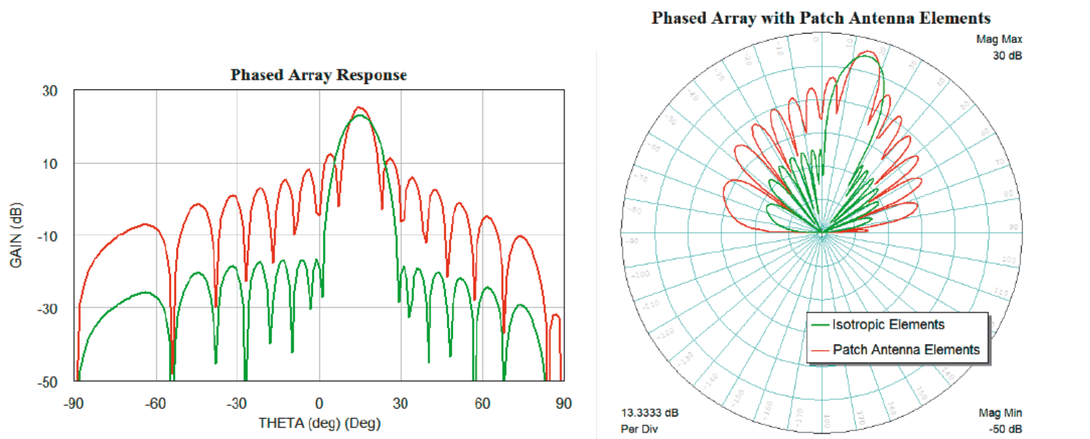

Figure 7: 15 x 5 Patch array with uniform vs. Dolph-Chebyshev gain tapering

which has relied on radar since the earliest days of this technology, most commonly uses airborne surveillance radar, to detect and provide timely warnings of severe storms with hazardous winds and damaging hail so that can be issued. The weather surveillance radars are allocated to the S (~ 10 cm wavelength), C (~ 5 cm wavelength) and X (~ 3 cm wavelength) frequency bands. While the shorter wavelength radars have the benefit of a smaller antenna size, their radiated signals are significantly affected by atmospheric attenuation.

Requirements for 10 cm wavelength (S-band) weather surveillance radars, based on years of experience with the national network of non-Doppler radars (i.e., the WSR-57), are shown in table 1 [1]. These requirements showcase some of the application specific metrics that drive range, frequency, antenna size, and gain. These factors represent the starting point for the system designer, who will also weigh cost and delivery concerns, available semiconductor and integration technologies, when considering possible architectures and defining individual component performance targets.

VSS provides system designers with the capabilities to convert these requirements into hardware specifications and work out the initial design details. Starting with the phased array configuration, VSS is able to represent thousands of antenna elements with a single model, allowing the antenna team to quickly produce radiation patterns with basic array properties such as number of elements, element spacing, individual element gain or radiation pattern (imported measured or simulated antenna data), array configuration and gain taper. The model allows designers to specify the array's physical configuration based on various standard lattice and circular geometries, as well as custom geometries (s. figure 2).

The array behavior is easily defined through a parameter dialog box or a data file containing configuration parameters such as gain and phase offset, theta/phi angles of incidence, number of elements in both X/Y locations (length units or lambda-based), spacing and signal frequency. This model greatly simplifies early exploration of large-scale phased array configurations and individual antenna performance requirements over implementing such a model using basic individual blocks where array sizes were generally limited to several hundred elements, each modeled as a single input/single output block.

Figure 3 shows a portion of the parameter dialog box used to quickly define an antenna-array architecture using standard or custom geometries. The lattice option allows configuration of the phased array in a lattice pattern, which is configured using the number of elements along the X and Y axes, NX and NY, element spacing along these axes, dx and dy, and gamma, the angle between these axes, figure 4b. Setting gamma to 90° results in a rectangular lattice, while setting it to 60° creates a triangular lattice. Any positive value for gamma may be used to configure the lattice while the circular option enables configuration of circular phased arrays with one or more concentric circles. The number of elements in each concentric circle and the radius of each circle can be defined as vectors by variables NC and R. Examples of lattice and circular array configurations are shown in Figures 4a and b.

To demonstrate some of the capabilities of the phased array model, an example project was constructed showing two 15 x 5 element arrays operating at 2.99 GHz, s. figure 5. One model represents an array of lossless isotropic antennas defined simply by setting the antenna gain to 0 dBi, while the elements of the other array utilize a data set containing the radiation pattern of a single simulated patch antenna. Both arrays use a lattice configuration with a 1/2" spacing between elements and uniform gain tapering - explained in more detail below. For the simulation shown, the steering angle (theta) was set to 15" , figure 5. Note that the antenna and phased array blocks support specifying the signal direction using U/V coordinates as well as THETA/PHI angles.

The VSS array model provides antenna designers with a rapid and straightforward tool to observe key antenna metrics, providing a means to examine the main beam and side lobe behavior as a function of any number of variables including array size (figure 6a) and configuration, gain vs. steering angle, and the occurrence of grading lobes as a function of element spacing and/or frequency (figure 6b). From these results the array team can develop an optimum configuration for the given requirements such as range and overall array physical size. In addition, the array team can provide design targets for the individual antennas and incorporate subsequent antenna simulation results back into the array analysis.

Control of the amplitude excitation through gain tapering is often used to control beam shape and reduce the side lobe levels. A number of commonly used gain tapers are implemented in the phased-array block. Gain taper coefficient handling defines whether the gain taper is normalized or not. If it is, the taper is normalized to unit gain. Standard gain tapers implemented in the phased-array model include Dolph-Chebyshev, Taylor Hansen, and uniform. The earlier example (15 x 5 element patch array) was re-simulated with uniform vs. Dolph-Chebyshev gain tapering, showing the impact on the main beam and side lobes, s. fgure 7. In addition, the user can define custom gain tapers by specifying the gains (dB) and phases for each array element.

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