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

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

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of abstraction, from early con-
ceptual models with little detail
through highly-defined array
models which account for true
component interactions and pos-
sible impairments.

Designing the complex packag-
ing schemes for high-frequency
signaling must be addressed with
circuit simulation and electro-
magnetic 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 devel-
opment 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 sys-
tem design flow manages the
start-to-finish front-end devel-
opment, embedding RF/micro-
wave circuit simulation and/or
measured data of radio/signal-
processing (behavioral) mod-
els within a phased array sys-
tem 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 incorpo-
rate more detail into their predic-
tive models, observe the interac-
tions between array components
and make system adjustments as
the overall performance inadvert-
ently drifts from early ide-
alized simulations.

Design failure and the result-
ing high costs of development
is often due in part to the inabil-
ity of high-level system tools to
accurately model the interactions
between the large number of
interconnected channels, which
are typically specified and char-
acterized individually.

Since overall phased-array per-
formance is neither driven purely
by the antenna nor by the micro-
wave electronics in the feed net-
work, simulation must capture
their combined interaction in
order to accurately predict true
system behavior. Circuit, system
and electromagnetic co-simula-
tion allows verification through-
out 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 oper-
ates within the NI AWR Design
Environment platform. The
simulator provides full system
performance as a function of
steered beam direction, inclu-
sive 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 Environ-
ment, supporting seamless data
sharing within the phased array
hierarchy. Furthermore, individ-
ual antenna designs can be gener-
ated from performance specifica-
tions using AntSyn, with result-
 ing 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 inter-
operability with third party PCB
(layout), RFIC (design/layout)
and EM (analysis) tools.

![Figure 3: Portion of the phased array parameter dialog box showing geometry configuration options including lattice, circular and user defined configuration](image)

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

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