rf & wireless EUROPE

MIMO/Phased-Array Antenna Systems, part 2

This application note discusses trends and presents recent advances in EDA tools for phased-array-based systems.

The mutual coupling between antenna elements affects antenna parameters like terminal impedances and reflection coefficients, and hence the antenna-array performance in terms of radiation characteristics, output signal-to-interference noise ratio (SINR), and RCS. VSS software includes capabilities for more accurate simulation of these parameters, including enhanced modeling of element patterns and mutual coupling. The next section of this article will examine these recent advances in advanced phased-array modeling, including accurate representation of the feed structure.

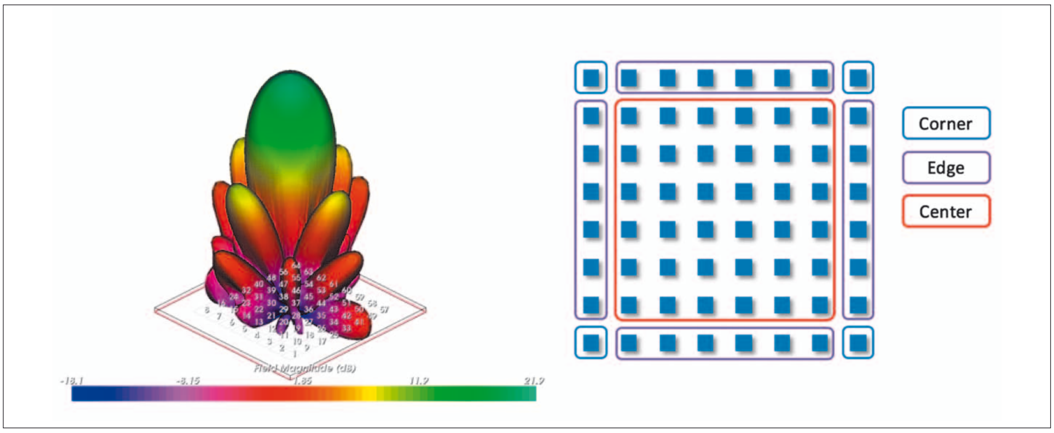

Figure 10: Supports the ability to assign different antenna patterns to individual elements

As mentioned, in VSS designers can define gains or full radiation patterns for each antenna element in the phased array. This enables them to use different radiation patterns for internal, edge, and corner elements of the phased array (Figure 10).

The radiation pattern of each antenna element will likely be affected by its position in the phased array. These patterns may be measured in the lab or calculated in AXIEM or Analyst software. A simple approach to characterizing the appropriate radiation pattern for a given element is to use a 3x3 phased array and excite one element, either the internal element, one of the edge elements, or one of the corner elements, while terminating all others. This will provide the internal, edge, and corner element radiation patterns, which can then be automatically stored in data files using the NI AWR software output data file measurements (the same technique used in the example above). This approach includes the effect of mutual coupling from first-order neighbors. An array with a larger number of elements may be used to extend mutual coupling to first- and second-order neighbors.

It is also important to capture the mutual coupling between neighboring elements. The VSS phased-array model does this through a coupling table defined in the configuration file. Different coupling levels can be defined based on distance from each other. The coupling, which is specified in magnitude (dB) and phase (degrees), is defined for two different distances (adjacent side elements: radius c_1 and adjacent corner elements: radius c_2) (Figure 11).

Modeling Impairments and Yield Analysis

RF hardware impairments of the array will affect the resulting side-lobe levels and beam patterns and will ultimately reduce system-level performance.

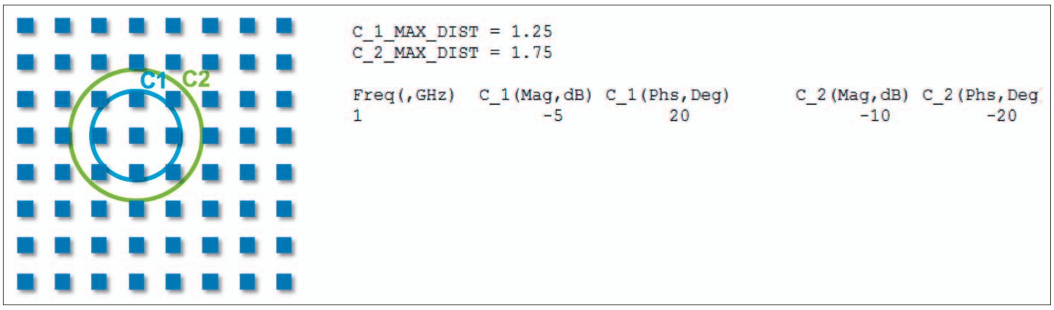

Figure 11: 64-element array showing mutual coupling table.

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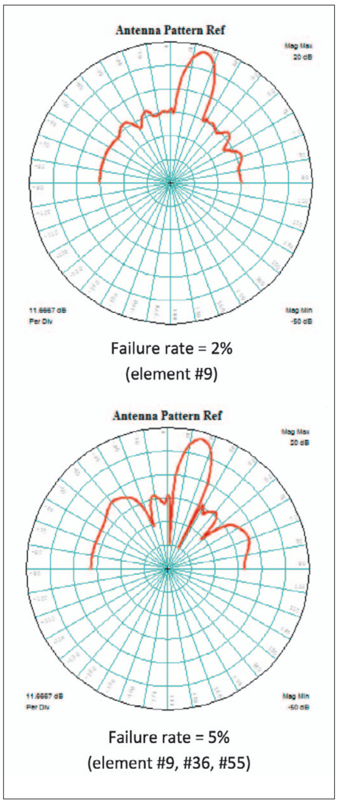

Figure 12: Side-lobe degradation to element failures 2 percent and 5 percent

For transmitter arrays, side-lobe levels from imperfectly formed beams may interfere with external devices or make the transmitter visible to countermeasures. In radar systems, side lobes may also cause a form of self-induced multipath, where multiple copies of the same radar signal arrive from different side lobe directions, which can exaggerate ground clutter and require expensive signal processing to remove. Therefore, it is critical to identify the source of such impairments, observe their impact on the array performance, and take steps to reduce or eliminate them.

The VSS phased-array configuration file allows engineers to simulate array imperfections due to manufacturing flaws or element failure. All gain/phase calculations are performed internally, and yield analysis can be applied to the block in order to evaluate sensitivity to variances of any of the defining phased-array parameters. As an example, VSS was used to perform an element failure analysis on a 64-element (16x4) array, producing the plots in Figure 12, which illustrates the side-lobe response degradation.

RF impairments can also be caused by any number of items relating to the feed network design and related components. Systematic errors that may be compensated include inter-chain variations caused by asymmetrical routing (layout), frequency dependencies, noise, temperature, and varied mismatching due to changing antenna impedance with steer angle, which also impacts amplifier compression. Therefore, it is imperative to be able to simulate the interactions between the antenna array and the individual RF links in the feed network.

RF Link Modeling

NI AWR software products include the simulation and modeling technology to capture these impairments accurately and incorporate these results into the VSS phased-array assembly model. This is an important functionality, since RF links are not ideal and can cause the array behavior to deviate significantly. The phased-array assembly can operate in either the RX or TX mode, supporting the configuration of the array-element geometry, each element's antenna characteristics, the RF link characteristics, and the common linear characteristics of the combiner/splitter used to join the elements together. The configuration is performed primarily through a text data file, with commonly-swept settings either specified directly via block parameters (such as steering angles) or specified in the data file but capable of being overridden via block parameters (such as individual element gain and phase adjustments).

The configuration of the phased-array assembly can be divided into several sections:

Array geometry - defines the number of elements, their placement, and any geometry-related gain and phase tapers.

Antenna characteristics – defines antenna gain, internal loss, polarization loss, mismatch loss, and radiation patterns for both receive and transmit configurations.

RF link characteristics – defines links for individual elements including gain, noise, and P1dB. Supports 2-port RF nonlinear amplifiers using large-signal nonlinear characterization data typically consisting of rows of input power or voltage levels and corresponding output fundamental, harmonic, and/or intermodulation product levels. Frequency-dependent data is also supported.

Assignment of antenna and RF link characteristics to individual elements.

Power splitter characteristics - splits the incoming signal into n-connected output ports.

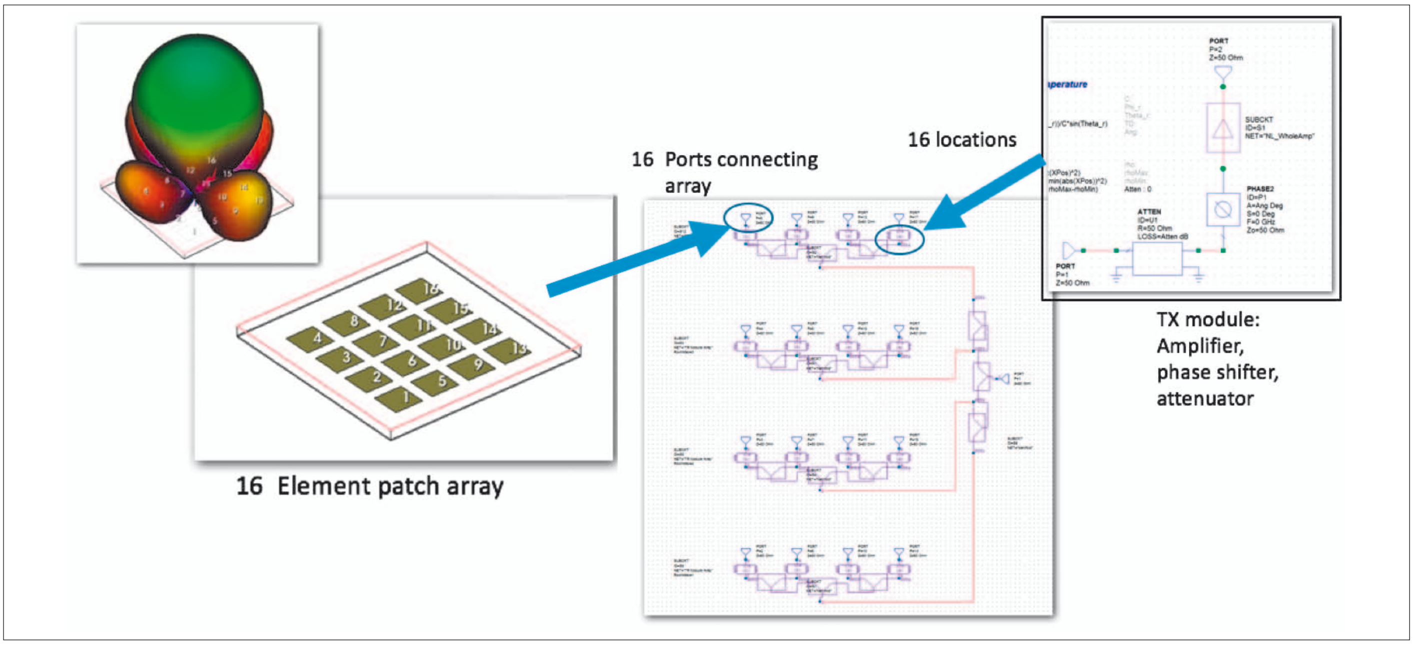

Figure 13: Changing antenna feed impedance as a function of beam steering using the variable phase and attenuator settings defined in the feed network design

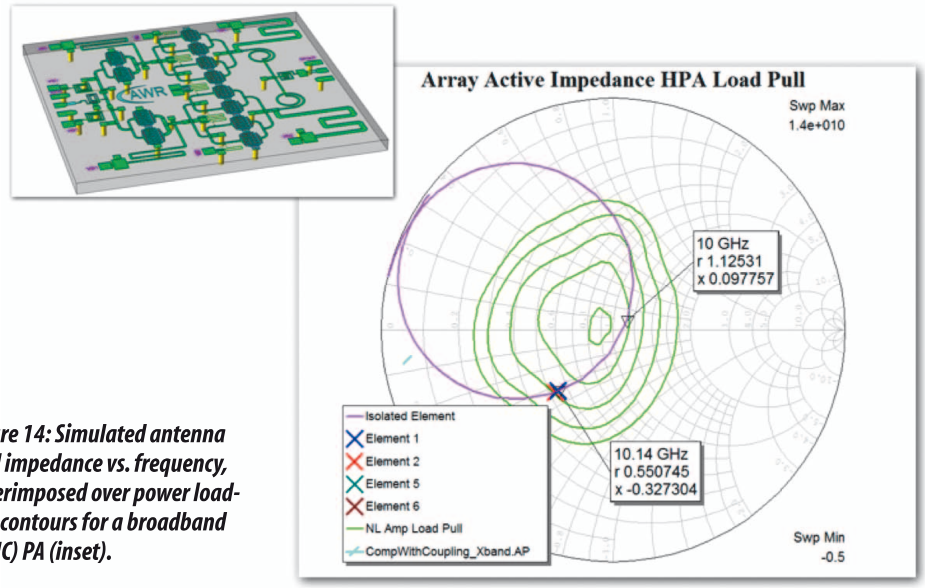

Figure 14: Simulated antenna feed impedance vs. frequency, superimposed over power load-pull contours for a broadband MMIC) PA (inset).

Mutual coupling characteristics (previously discussed).

One common challenge is that not all RF links should be equal. For example, gain tapers are commonly used in phased arrays; however, when identical RF links are used for all antenna elements, elements with higher gains may operate well into compression while others operate in a purely linear region, causing undesired array performance.

To avoid this problem, designers often use different RF link designs for different elements. While this is a more complicated task, VSS phased-array modeling enables them to achieve this, resulting in more efficient phased arrays. To assist the design team creating the feed network and providing the RF link to the systems team, VSS software includes the capability to automatically generate the characteristics of the phased-array element link defined by the data tables.

The designer starts by creating a schematic-based link design per the system requirements. A "measurement" extracts the design characteristics, which can include circuit-level design details (nonlinearities), through Microwave Office co-simulation and saves a properly-formatted data file for use with the phased-array assembly model.

In-Situ Nonlinear Simulations

An accurate simulation must also account for the interactions that occur between the antenna elements and the driving feed network. The problem for simulation software is that the antenna and the driving feed network influence each other. The antenna's pattern is changed by setting the input power and relative phasing at its various ports. At the same time, the input impedances at the ports change with the antenna pattern. Since input impedance affects the performance of the nonlinear driving circuit, the changing antenna pattern affects overall system performance.

In this case, the input impedance of each element in the array must be characterized for all beam-steering positions. The array is only simulated once in the EM simulator. The resulting S-parameters are then used by the circuit simulator, which also includes the feed network and amplifiers. As the phase shifters are tuned over their values, the antenna's beam is steered. At the same time, each amplifier sees the changing impedance at the antenna input to which it is attached, which affects the amplifier's performance.

In this final example, the power amplifiers (PAs) are nonlinear, designed to operate at their 1-db compression point (P1dB) for maximum efficiency. They are, therefore, sensitive to the changing load impedances presented by the array. The beam of a 16-element array is steered by controlling the relative phasing and attenuation to the various transmit modules (Figure 13). In practice, the harmonic balance simulation in Microwave Office software used to characterize the power amplifiers takes substantial time to run with 16 PAs. Therefore, the beam is steered with the amplifiers turned off. The designer then turns on the individual PA for specific points of interest once the load impedance from the directed antenna has been obtained.

At this point the designer can directly investigate the PA nonlinear behavior as a function of the load (antenna) impedance. With the load-pull capability in Microwave Office software, PA designers can investigate output power, compression, and any other number of nonlinear metrics defining the amplifier's behavior, as shown in Figure 14.

With a detailed characterization of the RF links for each individual element, the overall system simulation is able to indicate trouble areas that would have previously gone undetected until expensive prototypes were made and tested in the lab (Figure 15).

Conclusion

The capability to design and verify the performance of the individual components, along with the entire signal channel that defines the AESA radar, is a necessity as element counts increase and antenna /electronics integration advances. Through a sophisticated design flow that encompasses circuit simulation, system-level behavioral modeling, and EM analysis operating within a single design platform, development teams can investigate system performance and component-to-component interaction prior to costly prototyping. ◄

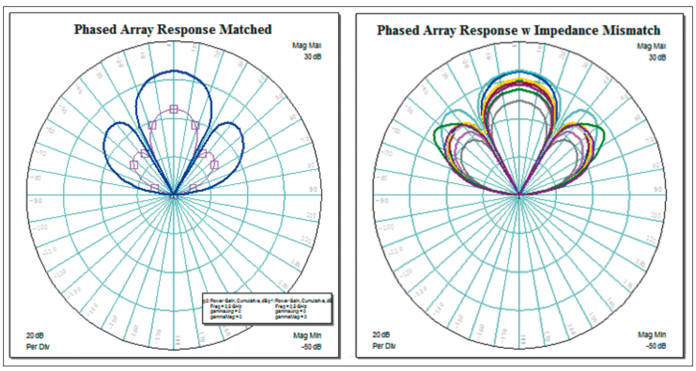

Figure 15: Phased-array simulations with RF link effects, including the impact of impedance mismatch between PA and steered antenna array.

www.nssl.noaa.gov/publications/mpar_reports/LMCO_Consult2.pdf