rf & wireless EUROPE

5G Primer for MIMO/Phased Array Antennas

Teil 1: Advances in 5G-System-Level Modeling

Diese umfangreiche Einführung in die für die Umsetzung und Nutzung von 5G erforderlichen MIMO/Phased-Array Antennen ist in folgende Themen aufgegliedert:

Teil 1: Advances in 5G System-Level Modeling

Teil 2: Platform Bridges the 5G Design/Verification Gap

Teil 3: MIMO and Beam-Steering Modeling for 5G

Teil 4: 5G and MIMO Design with Circuit/Antenna Co-Simulation

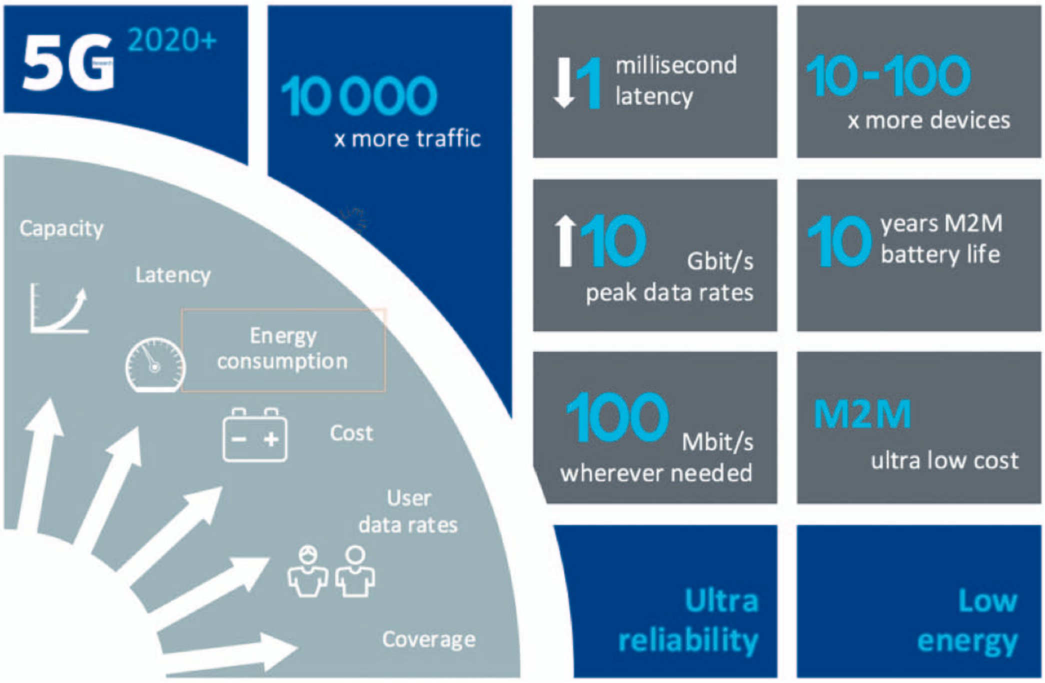

Figure 1: Goals for high-performance 5G

Introduction

Evolving communication systems are driving developments in the RF/microwave industry. The large umbrella of 5G focuses on supporting three main technologies:

- Enhanced mobile broadband, which is the natural development of long-term evolution (LTE)
- Massive machine-type communications, also known as the industrial internet of things (IIoT)
- Ultra-reliable, low-latency communications providing mission-critical infrastructure for services such as transportation, public safety, medical, and more.

Future communication systems will comprise many diverse systems that will be implemented with a wide array of solutions. Providing increased mobile broadband traffic and higher data rates, as demanded by end users, will require adding more spectrum with greater efficiency, as well as building out ultra-dense network configurations.

5G is driving many of the requirements for products today and achieving the aggressive goals of 5G is being addressed in several areas. Spectral usage, which includes variations on orthogonal frequency-division multiplexing (OFDM) based waveforms that were introduced with LTE Release 8 and inter- and intra-band carrier aggregation is important, especially for spectrum below 6 GHz, where continuous unused bandwidth is rare. Another goal is enhancing over-the-air (OTA) efficiency with the expansion of multiple-in-multiple-out (MIMO) and beam-steering antenna technologies. A third goal is moving to higher frequencies, particularly above 6 GHz and into the centimeter and millimeter-wave (mmWave) range.

As 5G pushes into these higher frequencies, beam-steering antennas will be required to direct radiated energy from the base station antenna array to the end user, while overcoming the higher path losses that occur at these frequencies. Fortunately, the shorter wavelength translates into smaller antennas, which, in turn, drives more integrated circuit (IC) based antenna array solutions.

NI AWR Design Environment
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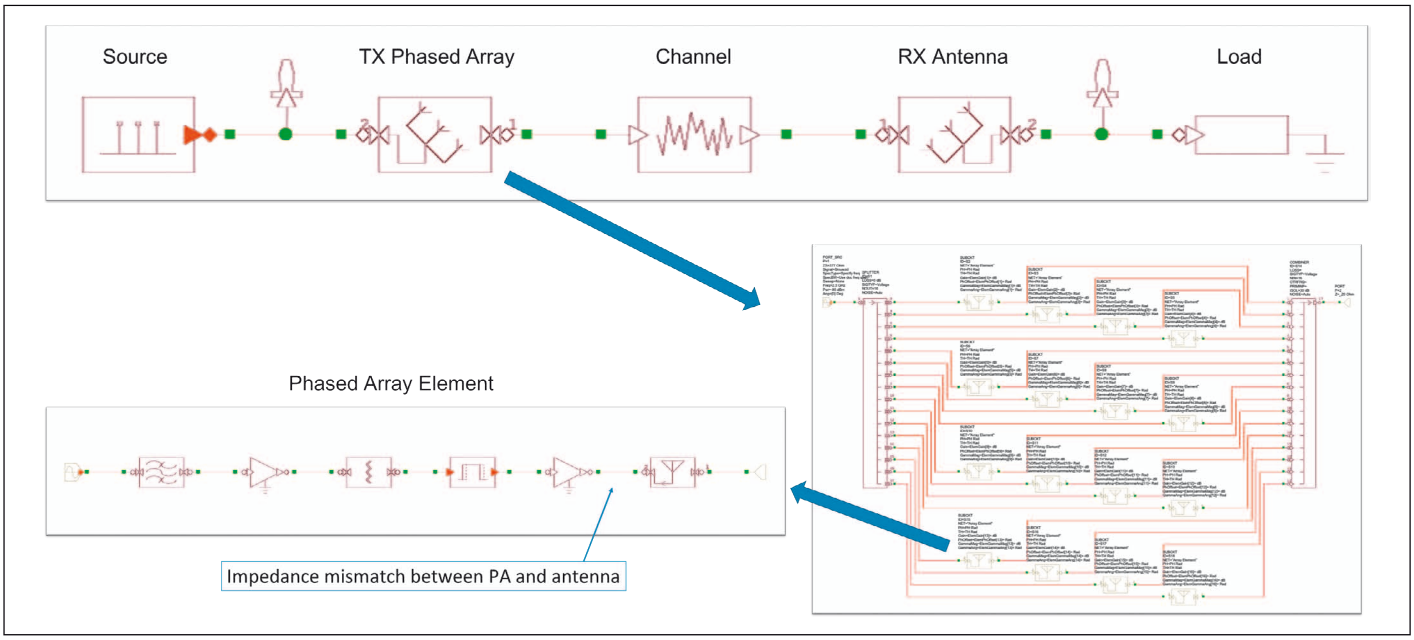

Figure 2: One of the challenges of designing systems is the impedance matching between the PA and the antenna.

Monolithic microwave IC (MMIC) and RFIC design will play an important role in future beam-steering technologies for 5G systems operating at mmWave frequencies. As wireless communications systems evolve, smaller devices with better performance will be required that incorporate multi-technology-based module designs with different IC and printed circuit board (PCB) process technologies. This primer examines some of the simulation technologies available that support the design of MIMO and beam-steering phased-array antennas.

Advances in 5G System-Level Modeling

The exploration phase for high-performance 5G communication systems is well under way with ongoing investigations into enabling technologies that will support the use of more spectrum and mmWave frequencies, smaller high-density cells, improved device power efficiency, new modulation schemes for diverse device coexistence, and high directivity over-the-air (OTA) transmission made possible through the implementation of massive MIMO antenna arrays and beam steering technologies.

5G On the Way

The goals for 5G communications are very ambitious: 10,000 times more traffic, 1,000 times increased capacity, much lower latency, very high peak and sustained data rates, much longer battery life, and lower device cost. As the infographic in Figure 1 conveys, the planned requirements for 5G mobile networks include:

- Peak data rate: 10 gigabits per second
- Reaction speed (latency): less than 1 millisecond
- Network reliability: 99.999 percent
- Number of devices: more than 1 million per square mile
- Energy efficiency: 10 percent of current consumption
- Max speed of reliable coverage: 300 miles per hour

Unique 5G Design Challenges

In support of 5G, the range of mobile communication frequencies will be extended to include new spectrum allocations below 6 GHz, as well as higher frequency bands that will complement the lower bands by providing additional system capacity and very wide transmission bandwidths on the order of 1 GHz or more for bands above 30 GHz. These higher frequency ranges will provide the very wide bandwidths necessary for extreme data rates in dense deployments. However, since frequencies above 30 GHz have inferior propagation properties (higher loss), the lower bands will be more commonly used, serving as the backbone for 5G mobile communication networks.

Massive MIMO and Beamforming Antenna Arrays

Massive MIMO and beamforming signal processing is expected to play a critical role in 5G as it greatly enhances coverage and user experience across the entire range of frequency bands. Massive MIMO, a term coined by the 5G community to describe antennas with many elements (up to 128), will contribute significantly to the required 5G capacity increase. Massive MIMO will employ beamforming technology, which will then enable 5G systems to pinpoint and steer the signals to specific users and track these users so they always have good coverage. It will also enable simplified receivers on the user equipment side.

Another benefit offered by beamforming is the ability to transmit considerably less power due to the array gain, which in turn results in certain reductions in hardware complexity. For example, the power amplifiers (PAs) and supporting circuitry in a traditional base station dominate power consumption at about 1 kW for three sectors because of their need to provide high-RF output power and their low efficiency when operating at considerable back off to achieve linearity requirements. In massive MIMO a similar range can be covered with a total power consumption of 15 W for 100 antennas. Massive MIMO also helps counteract the impact of the higher propagation losses at mm-Wave frequencies by directing energy more efficiently over the channel.

In addition, beamforming improves the radio environment by limiting interference to small fractions of the entire space around a transmitter and likewise limiting the impact of interference on a receiver to infrequent stochastic events. The use of beamforming will also be an important technology for lower frequencies; for example,

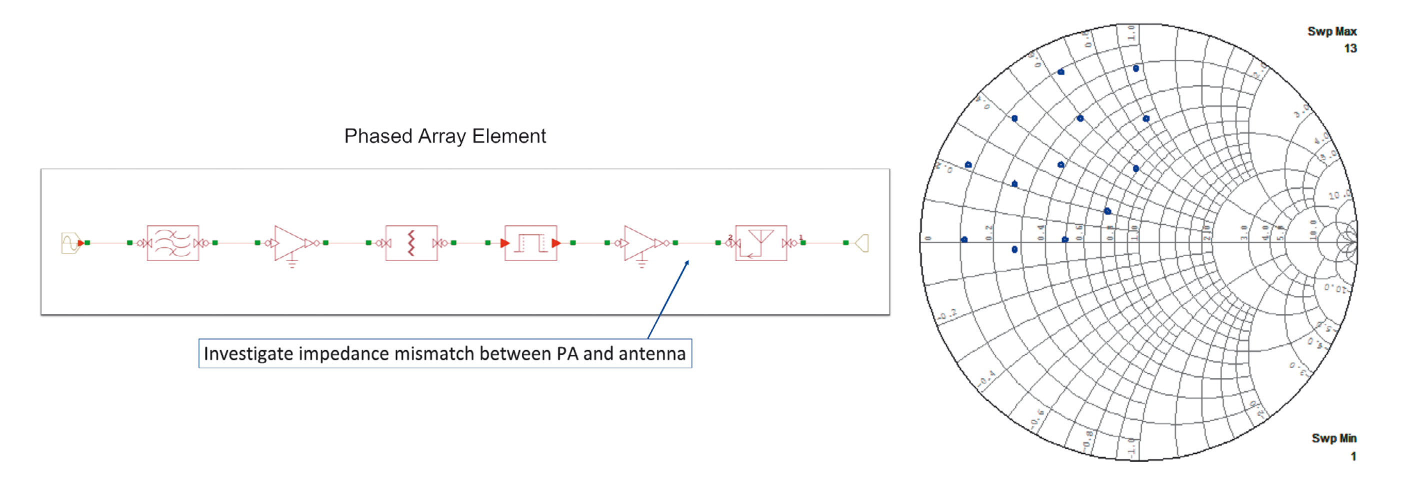

Figure 3: The impedance mismatch between the PA and the antenna was investigated by setting a range of impedance values on a Smith Chart

to extend coverage and to provide higher data rates in sparse deployments.

Another goal is to provide within the MIMO technology itself spatial-multiplexing capabilities that increase user throughput. By using arrays with hundreds of antennas at base stations that simultaneously serve many tens of low-complexity terminals in the same time frequency resource through closed-loop spatial multiplexing/de-multiplexing (multi-user MIMO precoding/decoding), a 10x or more increase in gross throughput can be achieved with massive MIMO. Perhaps even more important is the significant gain in reliability due to flattening out of deep fades, hardening of the channel, and array gain.

MIMO RF-System Design and Analysis Using VSS

In order to cope with moving terminals, the base station employing beamforming must be able to track the terminal (user device) and adaptively steer its beam in the direction of the terminal. Such adaptive beamforming can be implemented with a phased-array antenna, which consists of various interconnected individual transmitters. With a variable and intelligent arrangement of the individual transmitters, the resulting antenna pattern achieves high directivity and the resulting beam can be flexibly adjusted to moving users and varying capacity needs.

Achieving the goals for massive MIMO poses several unique design challenges. Any large antenna system, and especially a MIMO system, is complex to design and difficult to analyze. As communications systems move to higher and higher frequencies, RF impairments become ever more significant. MIMO system modeling includes antenna elements in the phased array as well as the RF links of the individual elements. Since each element has its own RF links in MIMO, it is important to include the RF link impairments in the overall performance of the antenna so that meaningful results are obtained that closely match the final measured results of the device once it is built. The effects of the specific RF links for each of the elements in the antenna pattern of the overall system need to be investigated. This design process will also define the matching network requirements for the system.

New phased-array modeling capabilities in NI AWR Design Environment platform, specifically Visual System Simulator (VSS) system design software,

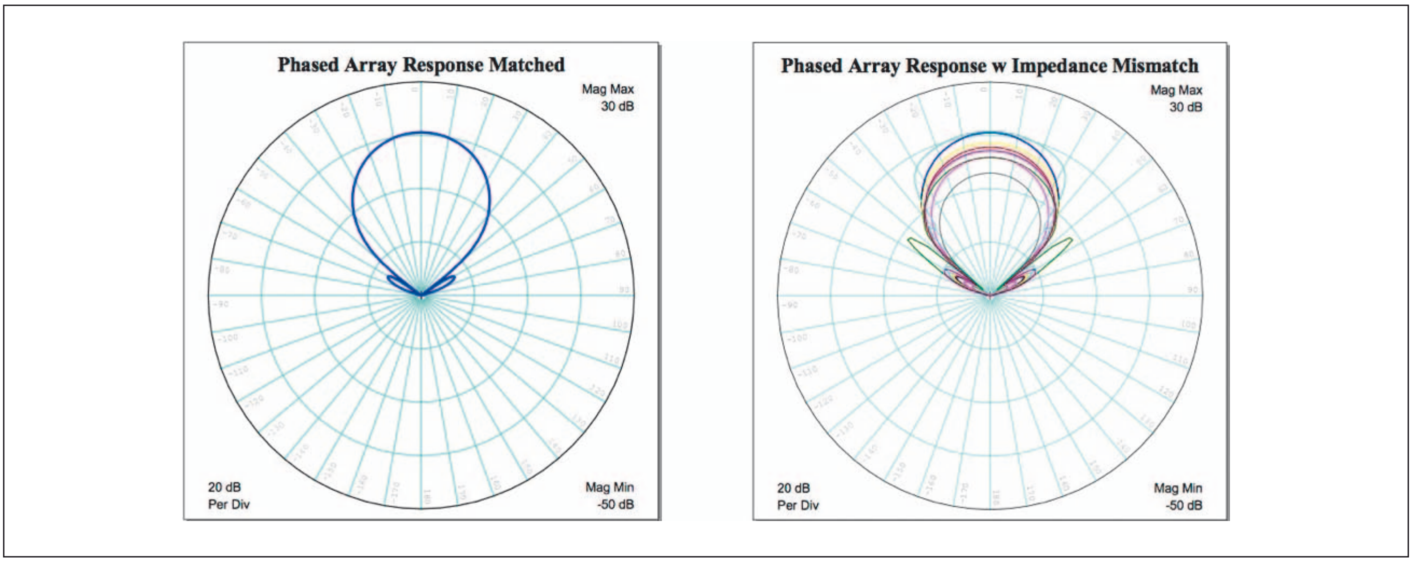

Figure 4: The blue curve on the left graph shows the array response for perfect matching between the PA and the antenna elements and the right graph shows results for each of the impedance points on the Smith Chart from Figure 3

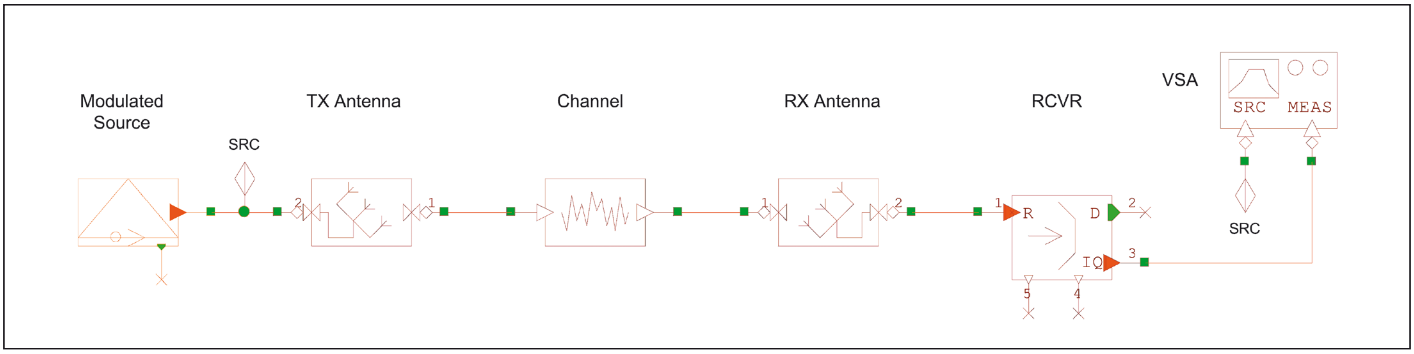

Figure 5:Along with antenna array response, system level measurements can be taken from the same system

provide ease of configuration and reduced overhead, as well as shorter design and simulation times. These capabilities enable designers to configure the array's geometry using either a standard layout pattern or a custom-created one. The radiation patterns of individual elements can be specified via simulations or real-world measurements and can be included in the performance evaluation of the phased array. Such an approach yields much more accurate results compared to simple, idealized, isotropic sources. Furthermore, the system simulator can model the individual RF components in the phased array so that designers can obtain a realistic performance of the overall system. The following example demonstrates these new capabilities in the design of a 4x4 phased-array antenna.

MIMO System Design Example

This example examines a base-station MIMO. There is a source, which goes to a transmitter phased array, then to a channel, and then to a receiver antenna. Looking at the transmitter phased array in Figure 2, it can be seen that it is a simple 4x4 phased array containing 16 elements. Each of the elements has its own RF link. One of the challenges of designing systems is the impedance matching between the power amplifier (PA) and the antenna.

While traditional approaches may be sufficient for smaller phased arrays, larger, more complex arrays require significantly more processing time and power. The new phased-array functionality in VSS software enables users to design and analyze very large phased arrays with thousands of elements and facilitates the implementation of various array geometries, tapers, imperfections, and degradation. VSS software offers enhanced modeling of element radiation patterns and mutual coupling, as well as characterization of RF links for individual array elements.

It is well known that the impedance mismatch between the PAs and their corresponding antenna element varies based on the scan angle of the array. In this example, the designer investigated the impedance mismatch between the power amplifier and the antenna by setting a range of impedance values on a Smith chart and then using VSS software to evaluate the performance of the design over the range of impedance values. Different measurements were run and evaluated, and from the measurements the requirements were drawn for the matching networks (Figure 3).

A simple 4x4 rectangular array with ?/2 element spacing was used for the phased-array configuration in this case, and a Dolph-Chebyshev gain taper and patch elements were used for the antenna array elements. The blue curve on the left in Figure 5 shows the array response when there is perfect matching between the PA and the antenna elements. The graph on the right in Figure 4 shows results for each of the impedance points on the Smith chart from Figure 4. It can be seen that there is a wide variation in mismatch effects. Both the main lobe and side lobes change significantly in terms of main lobe gain, beam width, and side lobe suppression. One quantity that can be calculated is the antenna array response; however, much more can be gleaned through system-level measurements. The same system can be driven with modulated signals, system-level measurements for error vector magnitude (EVM), adjacent channel power ratio (ACPR), and more can be performed, and measurement contours can be plotted on a Smith chart. The performance of matching networks can be investigated, and these system-level measurements can be used to derive the requirements for the matching networks, as shown in Figure 5.

VSS software also offers an automated analysis flow, enabling users to define the system architecture (modulation and more), configure the antenna array, set up the RF links, define gamma or impedance points that will be used for analysis, configure desired measurements, and, finally, run the automated analysis.

EVM and ACPR or other measurements are calculated. The results of the automated analysis are shown in Figure 6 with ACPR contours on the left and EVM contours on the right. The measurement contours are plotted on a Smith chart, and regions where the requirements are met are identified, giving the definitions for the matching networks. The designer is now able to go back and intelligently design the matching networks, ensuring that the overall system will perform well.

Summary

Emerging technologies being developed for 5G communications and new modulation schemes are being considered. The simulation capabilities in VSS software help designers overcome the associated design challenges with new advances in phased-array design and analysis and the ability to capture the real-world interactions that occur between phased-array antennas and their driving circuitry.

While the antenna example discussed is simple, there was actually a large amount of processing and analysis behind the final design. The capabilities in VSS enable users to design very large phased arrays and simplify array design and configuration. Element radiation patterns for individual elements and mutual coupling are included, as well as the RF model links for individual array elements. VSS software enables designers to evaluate the effects of matching networks in overall system performance, including array response and system-level measurements that will be used for evaluating the overall system. Automated analysis enables users to quickly configure a complex 5G system for particular requirements and obtain results in a short amount of time in order to follow up with further design work. ◄