rf&wireless EUROPE

5G Primer for MIMO/Phased Array Antennas

Teil 2: Platform Bridges the 5G/Verification Gap

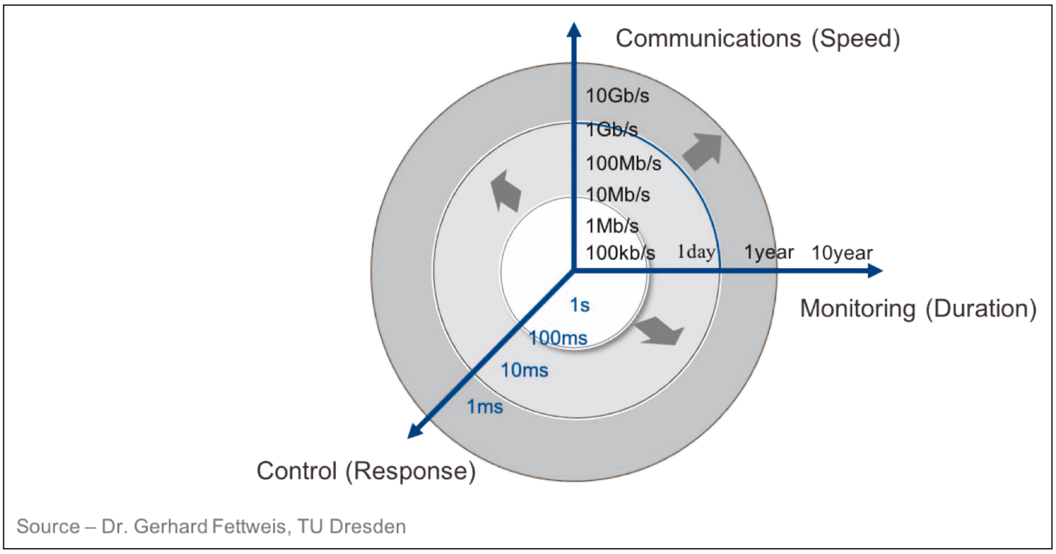

Figure 1: 5G goals for communication speeds and latency to support wireless control called for with the IoT and IIoT

The emerging third phase of information connectivity will change the use of wireless technology dramatically. The first phase connected homes and businesses through wired telephony and the early internet via dial-up modems. Over the last few decades, the development of communication networks has been superseded by wireless mobile technology connecting people instead of places. Today, there are over seven billion mobile devices in the world connecting over 3.8 billion people - the next frontier will be to connect things through the developing IoT concept. It has been well published that within the next decade at least 10 times the number of things as people will be connected.

This new era will usher in a host of new wireless technologies to support IoT and the underlying 5G infrastructure currently in the early conceptual phase. The promise of increased information bandwidth and faster response times (low latency) for real-time wireless control with minimal power consumption are highly attractive system goals, as shown in Figure 1. Achieving these goals will pose a significant challenge to design teams working on the enabling semiconductor technology and infrastructure that will define the physical (PHY), medium access control (MAC), and routing layers of future 5G networks. Although the technical requirements necessary to make 5G and IoT a commercial success are demanding, the economic potential and business opportunities are enormous. Thus, billions of dollars are being poured into industry and academia research.

5G networks will likely be based on multi-radio access technology (multi-RAT) using existing cellular base stations to ensure broad coverage and high mobility and interspersed small cells for capacity and indoor service. These future networks will use a combination of small-cell and macrocell base stations, as well as cellular and wireless networking (WiFi), with considerable research into using WiFi for cellular traffic offloading. Although there is not yet full agreement on which technology will address the 5G challenge, researchers are converging on four vectors:

- massive MIMO technology - dramatically increases the number of antennas a base station employs for mobile device coverage, as well as high-speed backhaul links
- Network densification – includes space (dense deployment of small cells to achieve greater coverage using more nodes) and spectral (utilizing larger portions of radio spectrum in diverse bands

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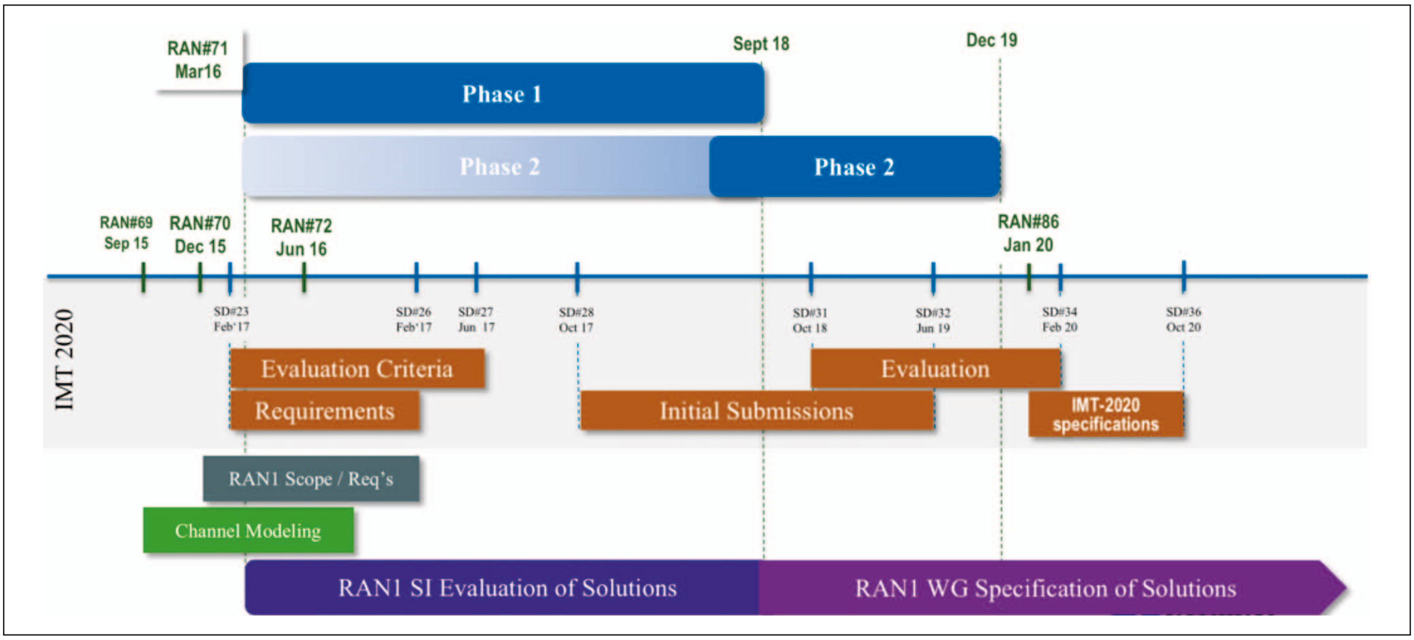

Figure 2: 3GPP and ITU timeline for 5G standards specification

- 5G waveforms – increases bandwidth utilization through structural improvements of signals and modulation techniques
- mmWave frequencies - new spectrum (3-300 GHz) frequency ranges to provide very large bandwidths capable of delivering multi-Gbps data rates, as well as the extremely dense spatial reuse to increase capacity

Every radio component, from PAs to filters and antennas, will play a key role in realizing 5G/IoT connectivity. System performance will require that these electrical components function as mini systems with ever-increasing levels of integration and functional density. Figure 2 shows a combination of the 3rd Generation Partnership Project (3GPP) and the International Telecommunications Unit's (ITU) 5G standards specification timeline. Phase 1 has been defined as looking at the sub-40 GHz frequency bands and with bandwidths greater than 100 MHz. However, Phase 2 includes research up to 100 GHz. Phase 2 is only 15 months, which is a very short amount of time. If researchers want to be successful during Phase 2 and have relevant work to submit for the IMT 2020 specifications, work needs to begin now.

Fortunately, advancements in microwave and signal processing technologies such as gallium nitride (GaN) transistors, new MMIC/extreme MMIC devices, heterogeneous "More-than-Moore" integration, cost reductions for front-end modules/packaging, new mmWave silicon ICs, and advanced antenna integration/electronic beam steering will enable new wireless technology standards such as 802.11ax, Wireless Gigabyte Alliance (WiGig), and the ambitious goals being outlined for 5G. The challenges in IC and system design include the nonlinear distortion of PAs, phase noise, IQ imbalance, highly-directional antenna design, and more.

Electronics targeting 5G/IoT applications will incorporate novel materials, new semiconductor devices, interconnect technology, and circuit architectures within existing and evol-

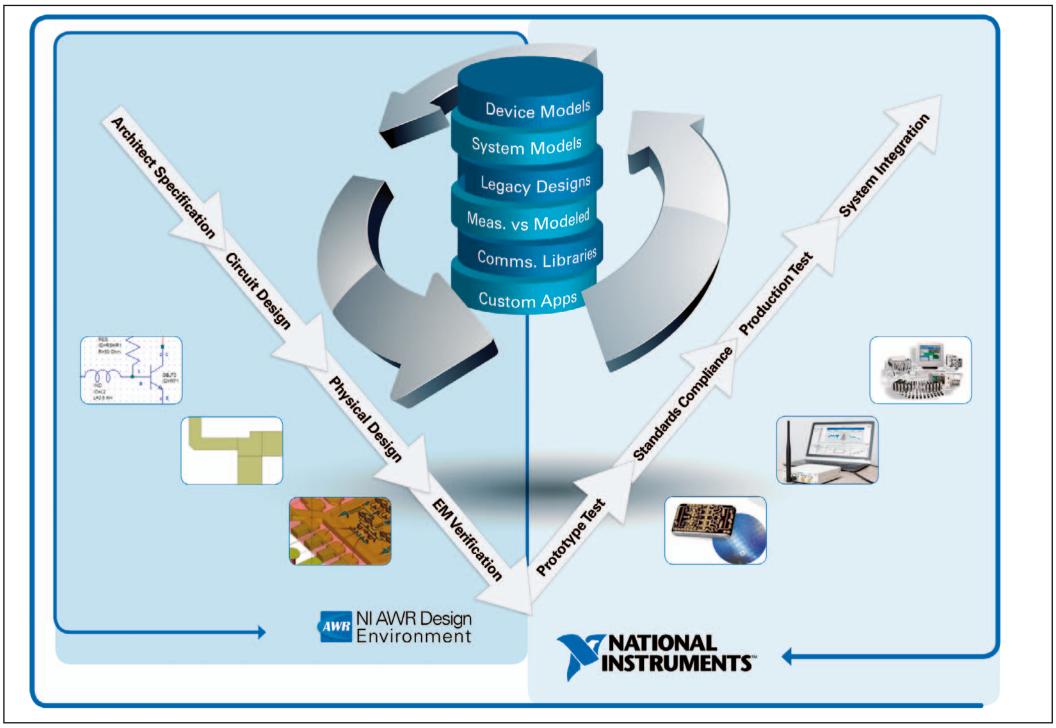

Figure 3: High-frequency product development flow accelerated through shared data models and design automation using NI AWR Design Environment and LabVIEW design platforms

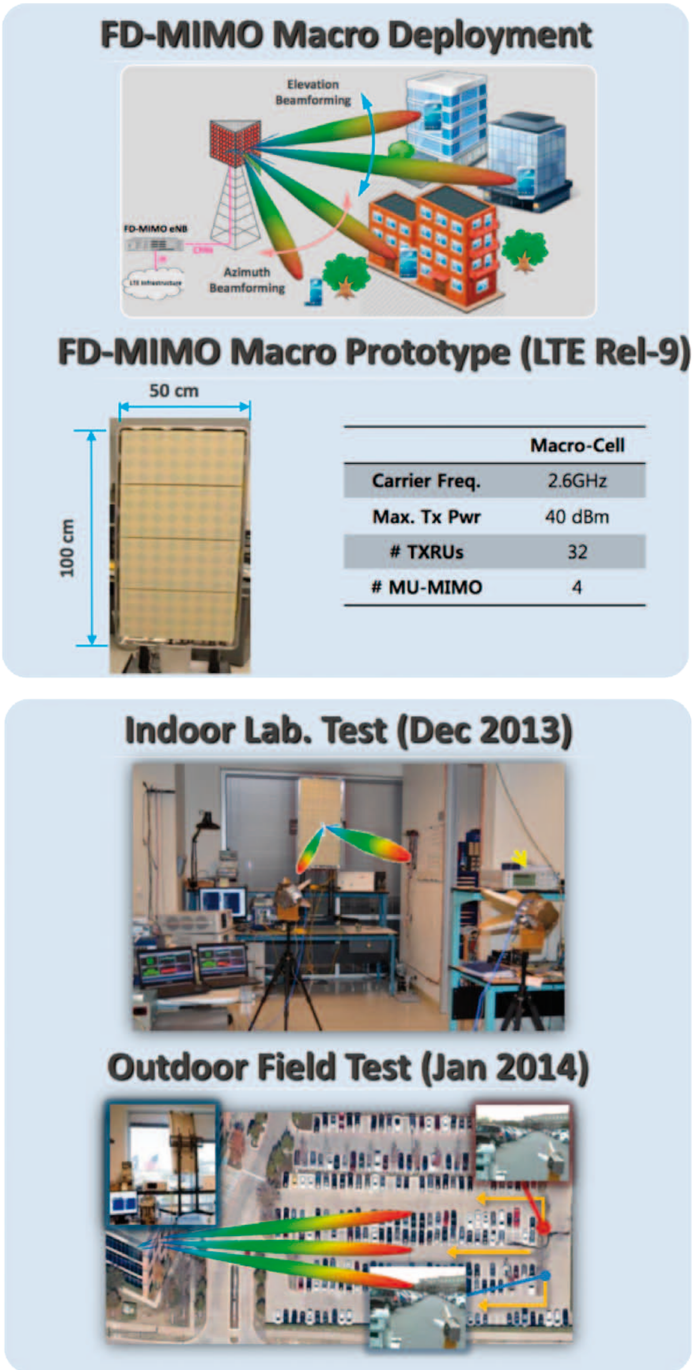

Figure 4: Samsung FD-MIMO 3D beamforming prototyping system implemented with four NI USRP RIO software receivers

ving platforms such as modules and sub-systems.

The task of developing and integrating this new technology is easier said than done. Technology integration at this level is implemented by numerous design groups and engineering disciplines working in unison.

Coordinating design activity requires a pragmatic, top-down/bottom-up approach cognizant of overall system performance while maintaining awareness of the detailed electrical interactions between structures channeling high-frequency/speed signals within the physical design.

Design trends in high-frequency component integration are steering engineers to approach electronic design differently than in the past.

The challenge for product development teams targeting 5G/IoT opportunities will be to shorten the design cycle and reduce failure through proper up-front planning, specifying realistic radio-block performance, outlining detailed circuit requirements, verifying via electromagnetic (EM) (and possibly multi physics) simulation, and performing early prototype testing with the ability to incorporate results back into the system simulation. For organizations of any size, the top-down/bottom-up approach calls for design tool integration that includes a system-level understanding of overall performance based on data representing individual components from a range of simulation and/or measurement sources.

Managing the design project through system simulation helps guide the early development process and enables integrators to generate a link budget (accounting for losses and gains through the signal chain), define the component specifications, and monitor the overall performance. Design detail from circuit/EM simulation and/or measurement is added as it becomes available. A design platform that supports system-level data management of circuit/EM simulation and/or measurement-based results should be able to directly access this data through tool interoperability.

For the process described, research and development (R&D) teams will be able to manage the overall development project using a data flow specific to their process technology (foundries, vendors) and integrating their simulation (optimization, yield analysis), physical design (layout, PDKs, design rules) and verification (electromagnetic, test) across all design software/measurement phases. The electrical design phase is best served by a unified design platform that integrates physical design (layout and process stack-up) with the following capabilities:

- High-frequency circuit linear, steady-state nonlinear (frequency-based harmonic balance) and transient (non-steady-state time domain)
- Communication systems - behavioral component models, waveform sources, digital modulation
- EM analysis of electrical behavior of 2D (planar) and 3D structures excited with high-frequency signals. Electrical interaction between radio blocks is more prevalent when they are tightly integrated into a small form factor without the benefit of distance and/or shielding to prevent performance-crippling behavior from EM coupling.
- Manufacturing analysis such as yield and corner analysis to access the impact of manufacturing tolerances
- Interoperability between physical design tools (layout), manufacturer/IC fab device models, measurement data, and multi-physics verification

NI, a leading collaborator with top industry and academic 5G researchers, offers this interoperability through its RF/microwave design software and hardware/software measurement solutions. NI AWR Design Environment platform offers a complete platform, integrating Visual System Simulator™ (VSS) system design software, Microwave Office circuit simulation software, AXIEM planar EM simulation, Analyst 3D finite element method (FEM) EM simulation, and links to third-party EM simulators from Sonnet and ANSYS, as well as computer-aided design (CAD) tools from Cadence, Mentor Graphics, and Zuken. The platform also provides a link from simulation to prototype testing through interoperability with NI's LabVIEW a system-design platform and development environment, which supports test instrument control, data acquisition, and industry automation (Figure 3).

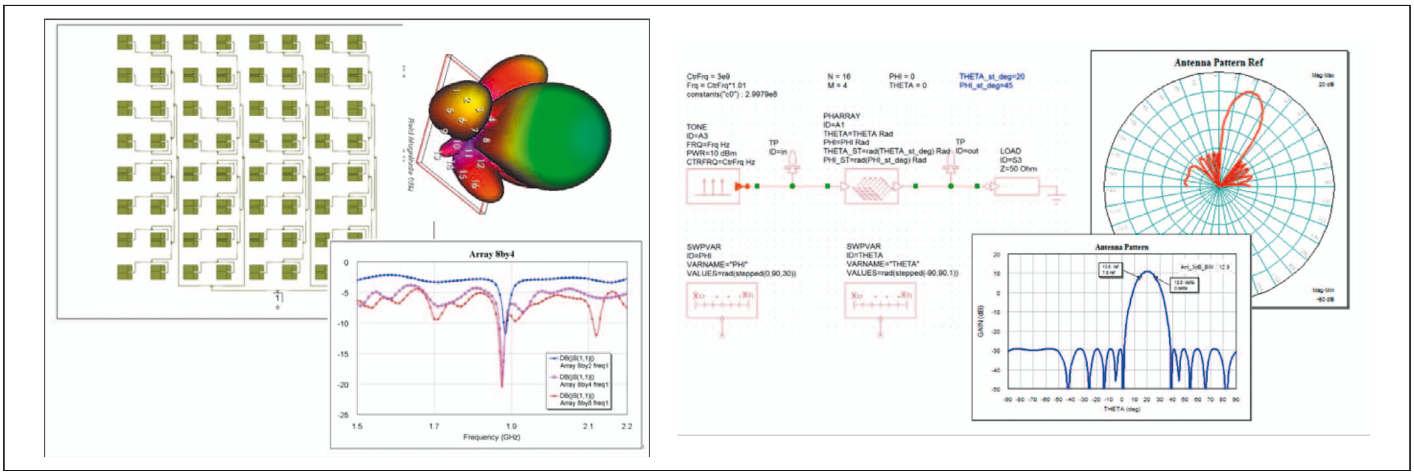

Figure 5: a) patch antenna array design using AXIEM simulation for planar EM simulation and b) system-level simulation of a phased array

The integration of simulation technologies, system prototyping tools, and automated test equipment by NI AWR Design Environment and LabVIEW platforms is critical for addressing the complexity of developing 5G wireless technology. In these cases, design teams will need to rely on a combination of simulation and prototype testing in order to ensure design robustness. Although simulation is essential to design a test bed or prototype, measurement is often needed to validate assumption made before fabrication, and to convince others of design viability.

Gary Xu, director of research at Samsung, showcased one of the first public demonstrations of a prototype for a 5G full-dimensional MIMO (FD-MIMO) base station at NIWeek 2015 in Austin, TX. The demo comprised a small base station containing the FD-MIMO antenna array and four NI reconfigurable I/O (RIO) and universal software radio peripheral (USRP) receivers, which emulated into four "5G" handled terminals. One of the key technologies of the demonstration was Samsung's new 3D beamforming algorithms. The prototype demonstrated that 3D beamforming enabled higher throughput and an increase in the number of supported users. In this instance, the system improved from enabling 2 Mbps for one user to 25 Mbps for four users with the use of 3D beamforming. Dr. Xu's demonstration, shown in Figure 4, is an excellent example of radio prototyping as an important tool for proving the viability of a given system design.

On the simulation side, NI AWR Design Environment platform helps engineers develop radio components such as PAs, filters, antennas, sources such as voltage-controlled oscillators (VCOs), control circuits such as mixers, converters, and switches, and interconnect technologies before fabrication. For example, 5G will require significant use of advanced antenna technologies. Because of the high-bandwidth, low-power requirements and considerable channel losses at mmWave frequencies, antenna designs will be needed with multiple, directed beams and polarization diversity and control (as in Figure 4). Phased arrays are an obvious candidate to meet these requirements. This, in turn, requires the circuit simulation and system environments to support phased array simulations.

Traditionally, the phased array is simulated in an EM simulator and the resulting S-parameter file is embedded into the circuit simulator to complete the design. The integrated circuit and EM simulators allow the designer to investigate how the antenna and circuit interact with each other. In particular, the impedance of the array's ports changes with the scan angle of the beam. In turn, the performance of the PA driving the antenna is severely affected by the port impedances. The designer must often go back and forth between the antenna simulation and circuit simulation to accurately model this behavior. Microwave Office software can now automatically couple the two simulations.

The PA "sees" the changing port impedance and the antenna scans its beam as the input power and phasing to the input ports is changed. Along with saving time and reducing errors, the designer can now optimize and perform yield analysis on circuit/antenna systems. Figure 5 shows how EM co-simulation will continue to play an important role in the development of densely populated high-frequency electronics and interconnect characterization.

Recent work from Université du Québec à Rimouski (UQAR) students led by Dr. Chan-Wang Park provides an example of simulation and test data being applied together in a 5G design. The design team developed a 6-watt, 1 GHz PA for use with 5G MIMO multi-carrier signals. Because they wanted to linearize the PA in the future, the team intended to correct the nonlinearity of the PA by using a neural network pre-distortion linearizer, Volterra, or polynomial pre-distortion linearizer developed with NI AWR Design Environment and LabVIEW platforms. A digital pre-distorter in the baseband will be used to create an expanding nonlinearity that is complementary to the compressing characteristic of the PA.

Figure 6: a) Load/source pull data and test set-up diagram used for model verification and impedance matching (fundamental and 3rd harmonic) and b) PXI-based RF measurement platform for 4x4 MIMO.

The design team was able to achieve first-pass PA design success through detailed circuit/EM co-simulation using Microwave Office and AXIEM software, along with scalable high-frequency Modelithics models of the Cree GaN transistor, imported multi-harmonic source and load-pull data (for impedance matching and model validation) from Focus Microwave, and the NI PXI RF instruments automated with LabVIEW for fast test results of the PCB-based prototype, shown in Figure 6. The team was able to develop a simplified solution for future 5G MIMO telecommunication system standards using a pre-distortion linearizer, which will be implemented in NI LabVIEW software and executed on a Xilinx Virtex-6 field-programmable gate array (FPGA). Together these interoperable platforms will give design teams the power and flexibility to realize the high-frequency electronics that will drive 5G and IoT.

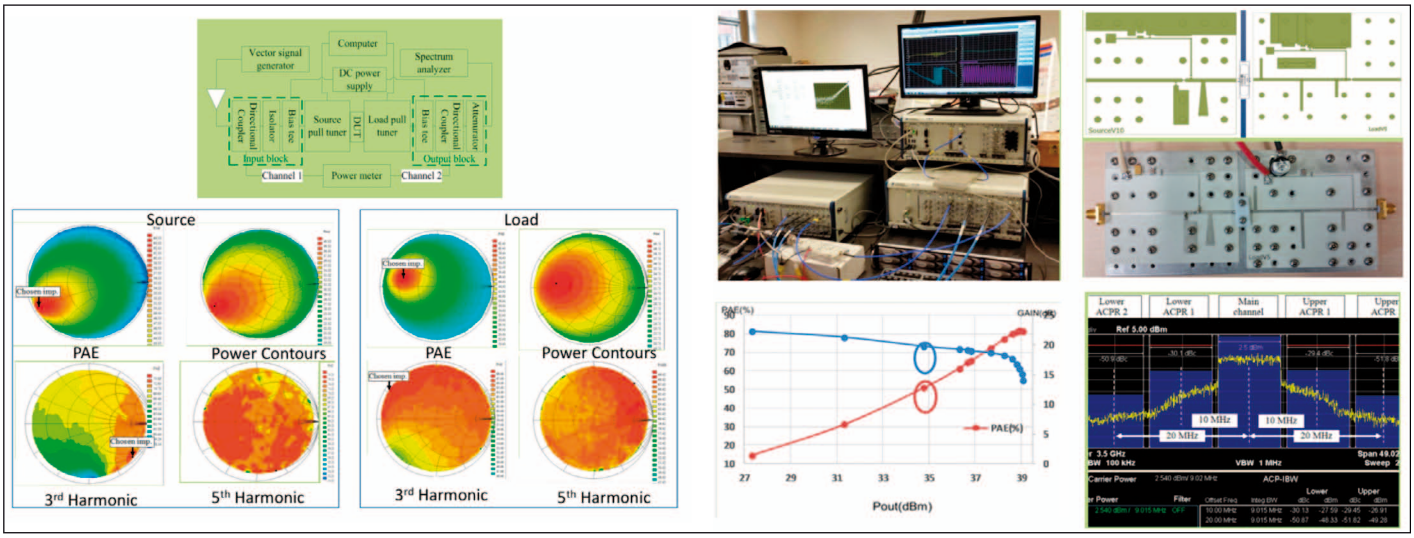

Figure 6: a) Load/source pull data and test set-up diagram used for model verification and impedance matching (fundamental and 3rd harmonic) and b) PXI-based RF measurement platform for 4x4 MIMO

Summary

The emerging third phase of information connectivity will usher in a host of new wireless technologies to support 5G and IoT infrastructure. Increased bandwidth and low latency with minimal power consumption are desirable goals, however achieving these goals will pose significant design challenges. This chapter has examined some of these challenges and has demonstrated how NI AWR Design Environment software and NI hardware/software measurement solutions will help designers conquer these challenges. ◄