Keysight Technologies

Solutions for Design and Test of LTE/LTE-A Higher Order MIMO and Beamforming

Application Note

KEYSIGHT TECHNOLOGIES

Unlocking Measurement Insights

Combining Simulation with Test to Gain Deeper Design Insight into Single and Multi-Channel Designs

Overview

Consumers are now more reliant than ever on wireless devices. Increasingly, they are demanding better wireless device connectivity and higher data throughput to accommodate the wealth of innovative and useful applications entering the market. As consumers obtain even more connected wireless devices, these demands will only grow. Keeping up with these demands will require wireless service providers to make better use of spectrum through a number of different means, such as employing wider channel bandwidths and carrier aggregation to send more data. Implementation of denser modulation techniques and use of heterogeneous networks to offload users to picocells are other options. Enhanced multi-antenna techniques like higher order Multiple-Input, Multiple-Output (MIMO) technology (e.g., 8x8 MIMO) and beamforming, offer wireless service provider another means of increasing cell capacity. MIMO specifies the manner in which multiple transmit and receive antennas (two or more) can be used to communicate through the radio channel, while beamforming generates a steering matrix that focuses resources in the direction of a target device.

Long Term Evolution-Advanced (LTE-A), with the specification of 1-Gbps data rates in the downlink and 500 Mbps in the uplink, is one 4G standard that makes use of enhanced multi-antenna techniques like 8x8 MIMO and beamforming, as well as a number of other enhancements, to obtain higher spectral efficiency and increase peak data rates. These enhancements are captured in Releases 8/9 and 10 of the LTE standard. Release 10 specifies a multi-layer transmission mode for the downlink—Transmission Mode 9 (TM9)—which enables MIMO with up to eight spatial streams and antennas (8x8 MIMO) and 4x4 MIMO in the uplink. It also specifies up to 8 layers in the downlink for beamforming.

Enhanced multi-antenna techniques like 8x8 MIMO and beamforming are key to improving the robustness of the connection and amount of data that can be sent between the base station and wireless devices. Having the ability to effectively test these techniques is critical to enabling the ecosystem to advance. Moreover, with advances in multi-antenna techniques like higher order (spatial multiplexing) MIMO and beamforming, multi-channel test becomes more important for characterizing wireless devices.

Problem

The 8x8 MIMO scheme poses a number of design and test challenges for the system engineer, primarily because TM9 is far different than the transmission modes for 2x2 or 4x4 LTE systems. Because of these differences, existing 2x2 and 4x4 MIMO test solutions are not effective for designing and testing 8x8 MIMO.

A key difference is that TM9 is based on non-codebook-based precoding. This concept is an extension of the dual-layer beamforming technique in TM7 and TM8, although TM9 adds up to eight layers and, therefore, requires additional antenna ports to handle the eight-layer transmissions. TM9 signals are also constructed much differently than those from the 4×4 MIMO in Release 8. TM9 includes new User Equipment (UE)-specific reference signals and cell-specific reference signals. The addition of the UE-specific reference signals eliminates the overhead of transmitting additional cell-specific reference signals on the newly added antenna ports to support the additional layers in TM9. The UE uses the UE-specific reference signals as a phase reference for demodulation and channel estimates. However, since the new antenna ports do not transmit cell specific reference signals, a new Channel State Information Reference Signal (CSI-RS) was introduced to allow the UE to make channel estimates (e.g., in cases when it is not receiving a downlink shared channel). Other new aspects of TM9 include the ability to do beamforming for up to eight-layers and seamlessly switch from single-user MIMO to multi-user MIMO.

Another challenge of multi-channel operation is the synchronization requirements. These systems use multiple, spatially separated antennas to provide increased throughput and better integrity of transmitted data. Some of the signal may be reflected from nearby objects and take a less direct path to the receiving antenna. The signals may combine destructively or constructively. If they combine destructively, there will be no energy at the receiving antenna. When a second antenna is used and placed at the appropriate physical separation from the main antenna, the signals can combine constructively and much more energy will be at the receiving antenna.

This complicated operation places tighter requirements (e.g., tight time synchronization requirements to ensure channel measurements start at the correct time) on the overall system and forces engineers to have to consider magnitude and phase differences across the measurement system. Phase-coherent signal generation and measurement systems are, therefore, needed to accurately recreate the operational environment and achieve accurate inter-channel magnitude and phase measurements. Signals must be created in a way that they will coherently combine to simulate the real world. Additionally, new measurement techniques are required to augment the single-channel tests being done today.

Solutions

Moving the industry forward with development and deployment of LTE systems as the technology evolves to 8x8, requires appropriate LTE analysis and signal generation solutions. However, these solutions must be capable of effectively dealing with the differences created by the 8x8 MIMO scheme.

One of the challenges associated with operating eight radios simultaneously in a small space, for example, is the potential for interference and crosstalk issues that could degrade system performance. Any test equipment will, therefore, need to support up to eight ports for complete testing. Additionally, to ensure proper operation of the Release 10 standard's functionality, the test equipment will need to support UE-specific reference signals, cell-specific reference signals and CSI-RS signals, as well as, techniques like beamforming and switching from single-user MIMO to multi-user MIMO.

Prime examples of LTE analysis and signal generation instrumentation enabling this mix of functionality are Keysight Technologies' Signal Studio software with LTE-Advanced option; 89600 vector signal analysis software with the PXI Vector Signal Analyzer (VSA); MXG signal generator, and SystemVue Electronic System Level (ESL) design software. Signal Studio is used for signal creation, while the 89600 VSA software running on the PXI signal analyzer performs signal analysis by processing and measuring simulation data. SystemVue provides an alternative solution for 8x8 MIMO coding and signal generation, but is also capable of more system-level tasks. Once the 8x8 MIMO test signals have been created, either using Signal Studio or SystemVue, they are modulated by the MXG and subsequently analyzed by the 89600 software and PXI signal analyzer (Figure 1).

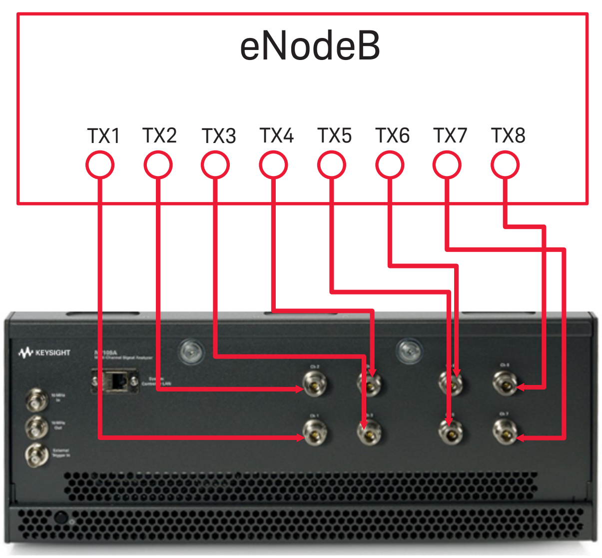


FIGURE 1. Keysights' comprehensive LTE-Advanced 8x8 MIMO signal-generation and analysis solutions fully support generation and analysis of FDD and TDD signals compliant with the 3GPP Release 10 standard. In this case, 8 ports is shown connected to the PXI VSA for analysis.

Signal Studio provides effective signal creation for accurate 8x8 MIMO receiver testing and evaluation of receiver performance with its ability to automatically generate eight-layer LTE signals and synchronize multiple signal generators. It also enables designers to determine if the UE is reporting the correct channel conditions under different propagation conditions. The quick configuration of transport channel-coded TM9 signals, including the new port definitions for 8-layer transmissions, UE-specific reference signals, and the CSI-RS is supported through the software's graphical user interface (Figure 2). Complex antenna weights can also be customized for each antenna port, which allows specific beam patterns to be created for each user and enables complete testing of UE capabilities. With Signal Studio's LTE-Advanced option, designers can perform receiver tests with fully channel-coded waveforms.

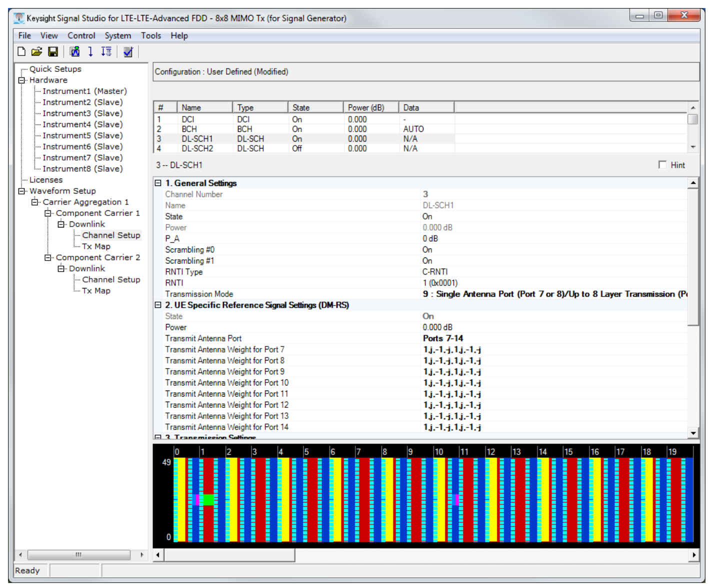


FIGURE 2. Shown here is a sample configuration of a Release 10 signal with eight layers configured for one user

The 89600 software is an eight-channel TM8 (for FDD) and TM9 solution, offering support for TM9 up to 8x8 MIMO (both FDD and TDD), UE-specific reference signals and CSI-RS (Figure 3). The PXI signal analyzer enables full analysis of LTE-A standards on next-generation antennas, base stations and user equipment. Its modular and software-defined building blocks, including the ability to seamlessly integrate with VSA software, provide flexible system configurations to meet diverse test needs. Working with the 89600 software, the PXI vector signal analyzer provides for phase-synchronous and cross-channel measurements with up to four RF channels in a single mainframe. The 89600 software and PXI signal analyzer also enable testing of the CSI-RS signal quality, as well as, the proper placement in time and frequency.

Using Signal Studio and the 89600 software, designers can start testing physical layer implementations of LTE-A devices with greater insight and confidence, while gaining a deeper understanding of the root causes of design problems. The MXG, with its fast switching speed (≤ 1.2 ms in SCPI mode), industry-best ACPR, high power, small form factor, and simplified self-maintenance, provides designers with a fast, reliable, accurate vector signal generator that rounds out Keysight's already comprehensive 8x8 MIMO signal generation and analysis solutions.

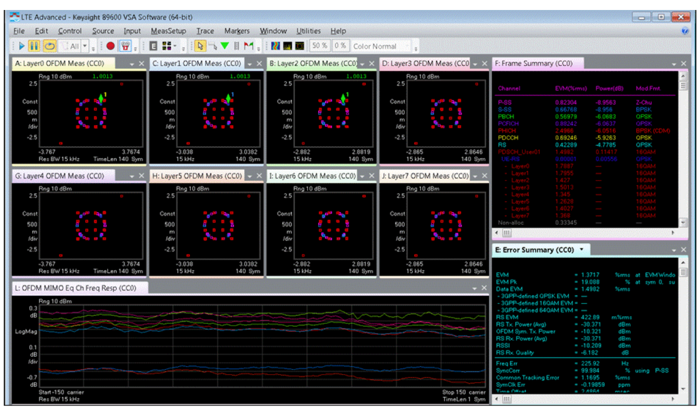


FIGURE 3. Shown here is a screenshot of 8x8 MIMO demodulation in the 89600 VSA software.

LTE-A Beamforming for Base Stations

Beamforming, a key technology in 4G LTE-A, is designed to improve signal quality, cell coverage and reduce interference. Because SystemVue not only provides 8x8 MIMO coding with virtual MIMO over-the-air propagation and fading effects, but also models base station beamforming and evaluates system-level throughput performance, it provides a total solution for 4G LTE-A beamforming from antenna array design, verification and final beamforming performance evaluation.

The design flow for 4G beamforming in SystemVue is shown in Figure 4 and is as follows:

1. Use an antenna synthesis tool to calculate the set of excitations needed for a linear antenna array to match a desired radiation pattern.
2. Using the 89600 VSA, test the radiation pattern in simulation and a real RF signal environment.
3. Evaluate the LTE-A throughput performance in SystemVue. Note that users can also include RF impairments, MIMO channel scenarios and the synthesized antenna pattern.
4. Download any waveforms from the simulation environment into an MXG or other Keysight vector signal generator for realization of the signals in the test environment.

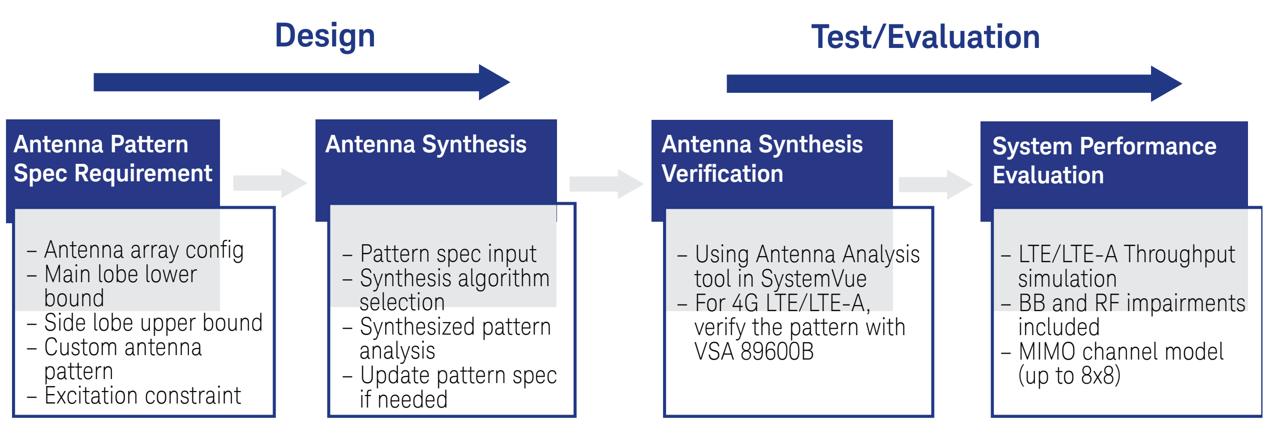
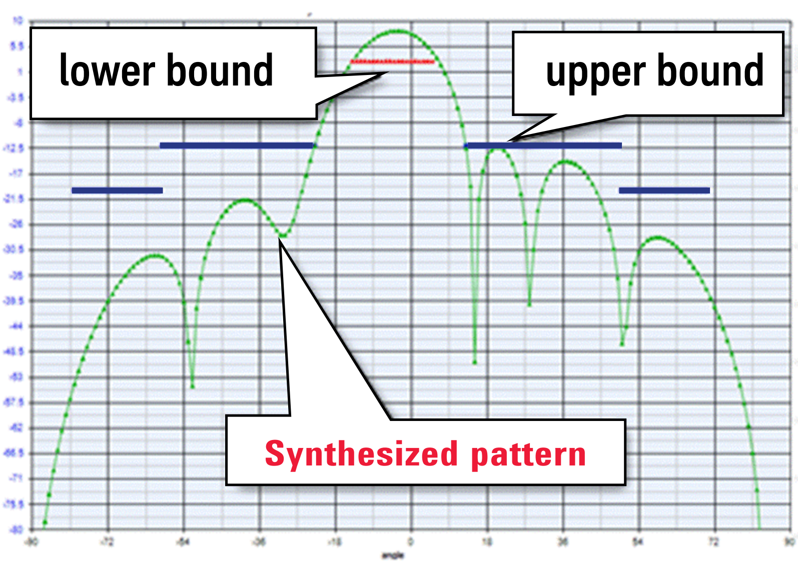


FIGURE 4. SystemVue's libraries support antenna array design, verification and beamforming performance evaluation phases as shown in this design flow for 4G beamforming.

SystemVue's beamforming techniques maximize the Signal-to-Interference-plus-Noise Ratio (SINR) of received signals by controlling the excitations on the antenna array to generate specific steering and sidelobe far-field antenna patterns. These beam-forming and 8x8 MIMO propagation models are part of SystemVue's W1715 MIMO Channel option. Up to 8x8 MIMO coding and throughput simulations are included with SystemVue's W1918 LTE-Advanced library.

As an example, consider the 10-element uniformly spaced antenna array shown in Figure 5. The excitations generated from the antenna synthesis can be input to LTE-A sources to form the desired LTE-A beamforming case, with RF impairments and fading added. The resulting array of signals may then be connected to 89600 VSA co-simulation with SystemVue, to measure the results of detected excitations, antenna radiation and other metrics. The signals may also be rendered in hardware using signal generators, run through RF components, measured on a signal analyzer, and visualized using the same 89600 VSA algorithms for direct comparison.



|W|	∠W (°)
0.326	-25.444
0.571	-33.391
0.777	-23.241
1	-7.119
1	7.117
0.777	23.246
0.572	33.383
0.326	25.449

FIGURE 5. This graph shows the given lower bound of the main beam (red curve), upper bound of the side beam (blue curve) and the synthesized pattern result (green curve) for a 10-element uniformly spaced antenna array. Excitations are on the right.

Testing Multi-Channel Designs

Testing multi-channel systems (e.g., creation and analysis of multi-channel signals) is a complex process. Since these systems require multiple channels with a known phase relationship between them, testing their operation requires at least a phase stable or even phase coherent test environment. To be phase coherent, the measurement equipment must have a specific and definable phase relationship. It must also be highly synchronized and support multi-channel test.

In addition to a phase-coherent signal generation and measurement system, multiple sources and analyzers are often required to accommodate verification of the multi-channel system's cross-channel performance during design. And to ensure the measurement system produces accurate results, precise channel-to-channel synchronization and calibration are essential. Modular instruments combined with signal generation and analysis software are ideal for providing a compact, accurate solution that enables engineers to gain deeper insight into complicated multi-channel designs.

A prime example of one such solution fitting this criteria is Keysight Technologies' LTE/LTE-A Multi-Channel Reference Solution. The solution combines phase coherent, 8-channel PXI multi-channel VSGs and VSAs, with Signal Studio, SystemVue and 89600 VSA software, and configuration and calibration tools (Figure 6). The PXI VSG operates from 1 MHz to 3/6 GHz, with a ± 0.4-dB absolute amplitude accuracy and a 10-µs switching speed, while the PXI VSA operates from 9 kHz to 27 GHz with an absolute amplitude accuracy of ± 0.15 dB and a frequency switching speed of less than 150 µs. Both the PXI VSG and VSA deliver up to 160 MHz of RF modulation bandwidth and analysis bandwidth, respectively. The 89600 VSA software is used with the multiple phase-coherent PXI VSAs to provide a rich set tools to quickly analyze signals. Likewise, Keysight's Signal Studio or SystemVue software can also be used with phase-coherent PXI VSGs to generate the complex signals needed to support multi-channel LTE-A.

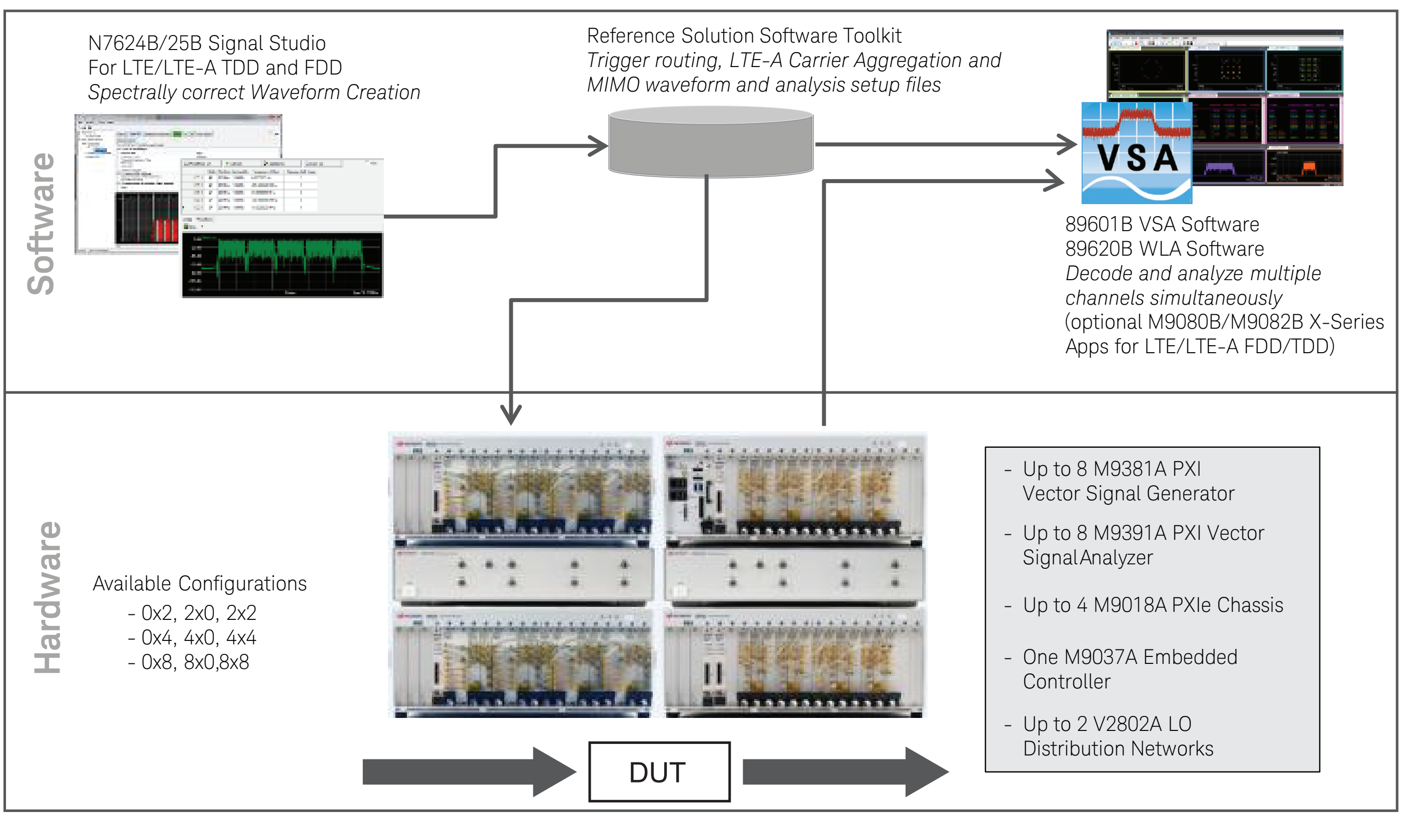


FIGURE 6. The LTE/LTE-A Multi-Channel Reference Solution provides the precise synchronization needed to simulate MIMO or beamforming transmission. By using the PXI VSG and VSA, which also offer multi-channel configuration and calibration tools, engineers can more quickly accelerate test set up and gain deeper insight into their complex LTE/LTE-A designs.

Channel-to-Channel Synchronization and Calibration

With any phase-coherent measurement solution used to test multi-channel systems, the key to getting accurate results is precise channel-to-channel synchronization and calibration. This can be achieved by following these tips:

For synchronization:
- Tip 1. Use a common Local Oscillator (LO) source
- Tip 2. Use a phase stable LO
- Tip 3. Use a low phase noise LO

For calibration:
- Tip 1. Use a reference clock synchronization to ensure waveforms and acquisitions start at the same time
- Tip 2. Calibrate out any time and phase skew between generator channels or between analyzer channels
- Tip 3. Calibrate out any losses and mismatches due to cables and connectors

Synchronization

To achieve multiple phase coherent instruments, a phase stable relationship must be established between all of the channels. The simplest way to achieve a degree of phase stability between instruments is to lock the 10-MHz reference of multiple chan-nels. This provides a frequency-locked reference whereby each instrument is locked to a common 10M-Hz clock. The multiple channels track against the same time base, but they use separate internal oscillators, so each channel has its own phase noise. Any uncorrelated noise will contribute to additional errors.

An example of synchronization using a common 10-MHz clock to start capture or playback simultaneously on all channels being synchronized in a PXI system is shown in Figure 7. It relies on some initial setup and initialization of the instrument clocks and uses the PXI backplane triggers to synchronize the multiple instruments.

In this multi-channel time synchronization example, the PXI M9300A reference module drives the backplane 10-MHz reference, as well as the 10-MHz alignment on multiple chassis if more than one chassis needs to be synchronized. Here the master uses one PXI trigger link to send to all slaves, and when all channels are armed, the master signals a trigger event. All units then start on the next 10-MHz rising edge. The performance of this reference is important because it impacts the relative phase stability of the system.

While this provides synchronization alignment between channels, it does not necessary provide phase coherency. To achieve phase coherency, a common LO reference, or shared reference, must be used across multiple instruments. This will ensure the same phase reference on each channel and therefore, each channel will have the same characteristics in terms of phase noise that can be shifted in time between channels. As a result, phase instabilities within the measurement system become common between the multiple channels and they no longer an issue because each channel has the exact same phase noise. In other words, the relative phase instabilities are essentially removed. For shared LO reference, the signal-to-noise ratio in the instrument is the largest contributor to channel-to-channel phase noise. The higher the phase noise, the lower the coherency factor possible between channels

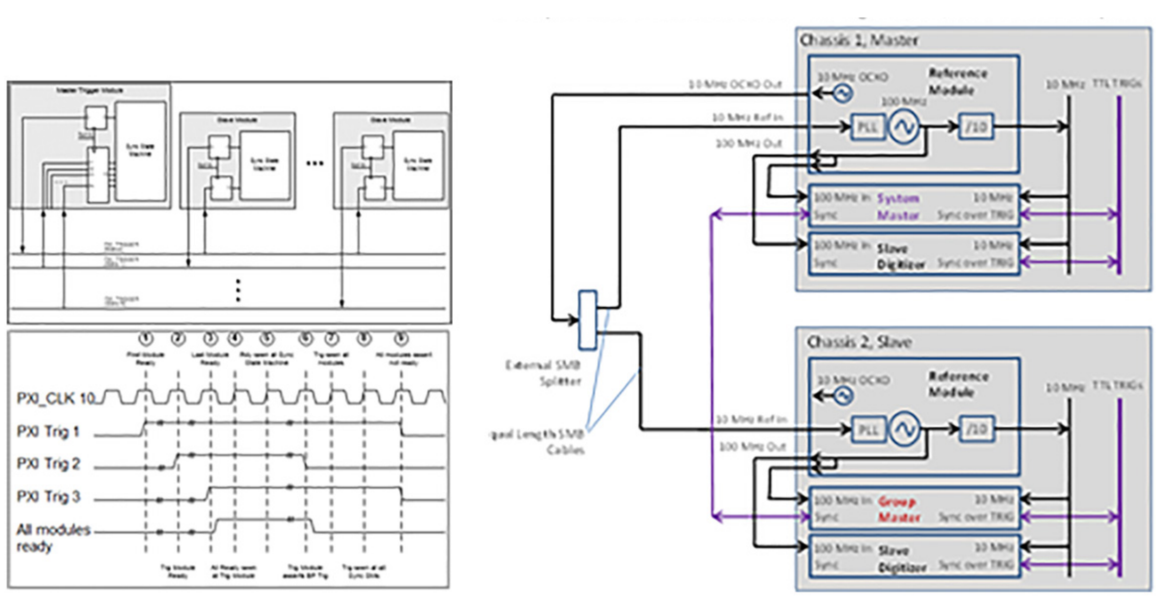


FIGURE 7. The image on the left is an example of a multi-channel time synchronization using a PXI 10-MHz clock. On the right is an example of synchronization across multiple chassis. Here, the synchronization signals are extended via the front-panel Sync connector on one of the digitizers or modulators in each chassis. Backplane PXI triggers are then used for the synchronization of the channels within each chassis. A 10-MHz reference must also be applied to the Ref In of the M9300A reference module in each chassis. An additional alignment step must be performed to align the phases of the 10-MHz reference signal in each chassis.

Channel-to-Channel Synchronization and Calibration continued

Calibration

In a multi-channel test system, the variation in magnitude and phase between channels greatly impacts the accuracy of measurement results (Figure 8). Even small differences between the cable lengths and connectors can create delays or phase shifts that will destroy the phase relationship. Ultimately, the goal is for all channels to look the same at the Device-Under-Test (DUT), with perfectly aligned delay and phase, so that the signal-of-interest and not variations in the test equipment is being measured. Accomplishing this goal requires calibration.

Essentially, the engineer needs to capture the magnitude, time and phase deltas between channels and then correct for any channel-to-channel differences or corrections from mismatch effects inherent in the measurement cables, connectors, splitters, and attenuators. By doing so, direct, corrected measurements of the antenna beamforming performance can be observed at the RF antenna output.

The key steps to calibrating a phase coherent system are:

- Step 1. Apply a signal to all channels and measure each channel relative to the master source or analyzer.
- Step 2. Collect correction values for time and phase differences between channels.
- Step 3. Repeat for each frequency, amplitude and sample rate.
- Step 4. Apply phase delay, amplitude and flatness corrections to multi-channel phase coherent measurements.

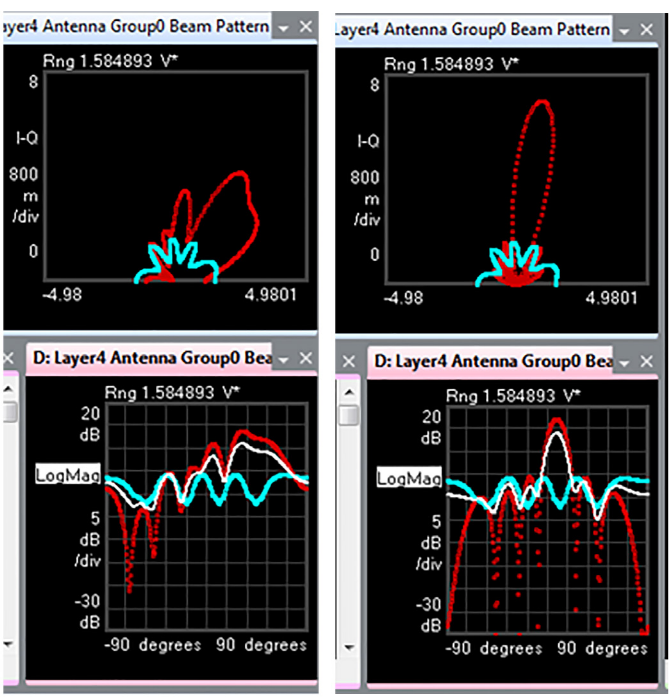


FIGURE 8. In this graphic, an uncorrected beamforming signal is shown on the left. Notice that the main lobe is deformed and the side lobes are greater than they should be. In the corrected (calibrated) measurement on the right, the beam pattern is much more prominent with greater beamforming gain.

For design verification purposes, it's also helpful to introduce a known delta or variations between channels to analyze the response in the MIMO system. Three options exist for performing this multi-channel calibration (Figure 9). The most common method (method a) is to use a multi-channel scope oscilloscope with good channel-to-channel alignment. The second method (method b) relies on a Keysight-patented routine that extracts the signal data and calculates the timing and phase skew between each channel. A known reference signal is played on each source and fed through a 4-way passive power combiner. The combined signal is then fed to a signal analyzer for analysis.

With the third method (method c), a wideband modulated reference signal is played out on a single source and fed through a 4-way power splitter. The splitter splits the single source signal and connects to each of the analyzer channels to be calibrated. The delay and phase skew are measured using the same technique in the second method. Once the frequency response and skew is known for each channel, compensation can be applied using various methods. Note, however, that the quality of the corrections will be determined by the quality of the power combiner or power splitter used in the configuration. These measurements should be made with the external fixturing and signal conditioning in place so that the calibration plane will be at the inputs and outputs of the DUT. The benefit of this calibration method is that less equipment is required.

In the LTE/LTE-A Multi-Channel Reference Solution, the routines used in this third method are automated. The corrections are stored in the BasebandDelay and BasebandPhase properties and automatically applied at the time of the multi-channel measurement.

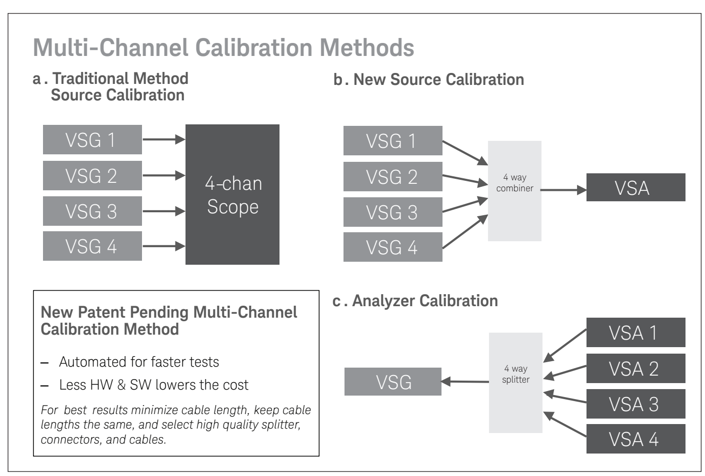


FIGURE 9. Shown here are the three different methods that can be used to perform multi-channel calibration of a test system.

Summary of Results

While 8×8 MIMO is still very much in the developmental phase, being able to effectively test it is critical to enabling the ecosystem to advance. Accomplishing that goal requires signal-generation and analysis solutions that are fully compliant with the 3GPP Release 10 standard and, therefore, support TM9 and its' up to 8-layer transmissions. Keysight's comprehensive LTE-A 8x8 MIMO solutions are well equipped to address this challenge head on. Signal Studio with the LTE-A option and SystemVue provide signal generation capabilities, while the 89600 VSA software and PXI signal analyzer enable effective signal analysis. Combined with the power of an MXG X-Series signal generator, these solutions provide design engineers with the fast, reliable, accurate 8x8 MIMO test solution they need to design and evaluate transmitters, receivers, base-bands, and components for LTE-Advanced base stations and mobile terminals.

When multi-antenna techniques like higher order MIMO and beamforming are employed in wireless devices, multi-channel testing becomes critical. Precise channel-to-channel synchronization and calibration are required to obtain accurate measurement results. Keysight's LTE/LTE-A Multi-Channel Reference Solution combines modular signal generators and analyzers with signal generation and analysis software to give today's engineers the phase coherent measurement solution with automated calibration they need for accurate and simplified multi-channel testing.

The Power to Accelerate Wireless Design and Test

Keysight is a leader in wireless test, focused on the highest-performance design and test of wireless devices and networks, with application-focused platforms optimized for existing and emerging standards. Adding to this optimal R&D and field support, Keysight allows engineers to better understand the intricacies of the continuously evolving wireless industry so you can accelerate your development of products.

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- W1715 MIMO Channel Builder,
  Keysight Application Note 5990-6535EN,
- W1918 LTE-Advanced Baseband Verification Library,
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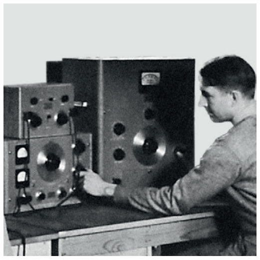

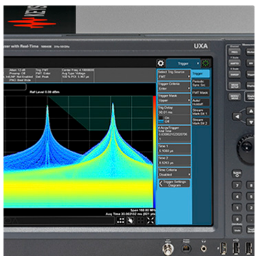

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