Addressing Multi-Channel Synchronization for MIMO and Beamforming Test
Agenda

Overview of Multi-Antenna Techniques

Multi-Antenna Test Challenges

Calibration of a Multi-Antenna System

Measurement Examples
The Data Challenge

- Internet
- Email
- Navigation
- Texting
- Music
- Safety alerts
- Youtube
- TV
- Social networking
- Video/Photo Sharing
- Games
- Cloud
- Imaging
- Banking

- More connected devices
- Expanded coverage
- Explosion of mobile data
How do wireless service providers keep up with the Data Demand?

- Make better use of spectrum
  - Combine carriers with carrier aggregation
  - Wider channel bandwidths
  - Denser modulation techniques
  - Multi-antenna techniques
  - Heterogeneous networks
## Comparing Wireless Standards

<table>
<thead>
<tr>
<th></th>
<th>Cellular</th>
<th>Wireless LAN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>LTE</td>
<td>LTE-Advanced</td>
</tr>
<tr>
<td>Peak Data Rate (DL/UL)</td>
<td>300 Mbps/75 Mbps</td>
<td>1 Gbps/500 Mbps</td>
</tr>
<tr>
<td></td>
<td>Up to 20 MHz</td>
<td>Up to 100 MHz</td>
</tr>
<tr>
<td>Modulation Types</td>
<td>QPSK, 16QAM, 64QAM (256 QAM in small cell)</td>
<td>BPSK, QPSK, 16QAM, 64QAM</td>
</tr>
<tr>
<td></td>
<td>up to 4x4</td>
<td>Up to 8x8</td>
</tr>
<tr>
<td></td>
<td>N/A</td>
<td>Up to 4x4</td>
</tr>
<tr>
<td>MIMO Technology</td>
<td>DL</td>
<td>UL</td>
</tr>
<tr>
<td>Beamforming</td>
<td>Up to dual layer (DL)</td>
<td>Up to 8 layer (DL)</td>
</tr>
<tr>
<td></td>
<td>Up to 4 Tx beamforming</td>
<td>Up to 8 layers Tx beamforming</td>
</tr>
</tbody>
</table>

**Multi-Antenna techniques are a key technology used to get higher spectral efficiency and increase peak data rates**
Enhanced Multi-Antenna Techniques

- Use of multiple antennas to improve spectral efficiency - increase overall capacity and the data rate through multiple antennas
Enhanced Multi-Antenna Techniques

**Path diversity**
- Improves robustness

**Spatial multiplexing**
- Improves spectral efficiency and throughput

**Spatial multiplexing with Beamsteering**
- Increases signal robustness w/the added advantage of the improved throughput through spatial multiplexing MIMO
How does Beamsteering Work?

- Use multiple antennas to electronically steer a single data stream
- Used in radar, sonar, seismology, electronic warfare, wireless communications, radio astronomy, acoustics
- Takes advantage of multi-antenna interference to control directionality
- Multi-antenna signals are weighted relatively in both magnitude and phase to produce spatial selectivity
  
  • Constructive (in-phase) interference power gain in desired directions
  
  • Destructive (out-of-phase) interference power nulling in other directions
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Advantages and Challenges with Beamforming

Common Issues

**Advantages**

– Improved user experience through better signal quality
  
  • Beamforming selectivity
  
  • Increases the signal to noise ratio
  
  • Coherent signal gain

– Increase cell capacity with MU-MIMO

**Challenges**

– Requires more antennas

– Phase alignment of RF carrier is critical in beamforming: < 1 deg at RF frequency

– Often requires multiple, highly synchronized instruments in test
Enhanced Multi-Antenna Designs

Test Challenges

Complicated test setup for higher order MIMO including beamforming

- Complexity of connecting multiple synchronized instruments
- Control of relative phase, time and frequency of multiple channels
- Calibration of the measurement system at the device under test

Visualizing and validating the MIMO signal at the RF antenna

- Analyzing multi-antenna beamforming signals with up to 8x8 MIMO
- Simultaneous UL & DL measurements

Cost and footprint

- Test equipment cost & size
- Time consuming tests
- Development while standards evolving
Complicated Test Set-up

Need for multiple test channels

- Carrier aggregation with carriers in different frequency bands
- Multi-standard radios
- Diversity where antennas are in different frequency bands
- Spatial multiplexing MIMO up to 8x8
- Beamsteering

Considerations for Test Equipment

- Is channel testing done sequentially or in parallel?
- What level of time synchronization is needed?
- Do you need phase coherent channels?
- Calibration of the measurement system at the device under test
Critical Multi-Channel Synchronization Parameters

Time Alignment

- Use clock synchronization & triggering to ensure waveform playback and waveform captures start synchronously on all channels
  - MIMO, carrier aggregation

Phase Coherence

- Two signals are coherent if they have a constant relative phase at all instances in time
- Coherence is then a statistical property between signals
  - Beamforming
Multi-Channel Time Synchronization

Example using PXI 10 MHz CLK

- One unit designated master, synchronizes with multiple slaves
- Master uses one PXI trigger line to send to all slave units
- Slaves each use one PXI trigger line to send to master unit
- When all channels are armed, master can signal a trigger event and all units start on next 10MHz clock edge after trigger event
- A common clock reference provides time alignment but not phase coherence
Considerations for Phase Coherence

Phase Matching Issues

Two signals are coherent if they have a constant relative phase at all instances in time.

However, each signal generation and measurement channel has its own phase noise.

Solution

- Use a single, shared LO for all channels to achieve True Phase Coherence.
- All channels will have a constant, relative phase error.
- Calibration is critical to remove any fixed phase offset between channels.
Source Simplified Block Diagram
Example of 2 phase coherent channels

Modulator 1
- RAM
- 90°
- ⊕
- Source output 1
  - Level control
  - Output signal 1

Modulator 2
- RAM
- 90°
- ⊕
- Source output 2
  - Level control
  - Output signal 2

Controller
- Download & definition

Synthesizer
- Local oscillator

Frequency reference
- Reference oscillator

4 LO outputs
Analyzer Simplified Block Diagram

Example of 2 phase coherent channels

Downconverter 1
- RF input attenuator
- Pre-selector, or low-pass filter
- Mixer
- IF gain
- IF filter

Digitizer 1
- Analog-digital converter

Downconverter 2
- RF input
- Pre-selector, or low-pass filter
- Mixer
- IF gain
- IF filter

Digitizer 2
- Analog-digital converter

Results & display

Controller

Synthesizer
- Local oscillator

Frequency reference
- Reference oscillator

Input signal 1
- RF input
- Pre-selector, or low-pass filter
- Mixer
- IF gain
- IF filter

Input signal 2
- RF input
- Pre-selector, or low-pass filter
- Mixer
- IF gain
- IF filter
Synchronization across Multiple Chassis
Extending PXI 10 MHz CLK to a second chassis

Example Two Chassis Receiver Configuration, two receivers per Chassis

- Front panel connections between master in each chassis
- Common 10 MHz reference shared via front panel
- Alignment of 10 MHz reference required
- Within each chassis, backplane triggers used
- Provides synchronous frequency and timing but need more for phase coherency
Agenda

- Overview of Multi-Antenna Techniques
- Multi-Antenna Test Challenges
- Calibration of a Multi-Antenna System
- Measurement Examples
Calibration of Phase Coherent Measurement Systems

Why is this important?

- Even when using a shared LO, there will be some static time and phase skew between instrument channels in the measurement system.

- Time and phase variations due to cables, connectors, and signal conditioning.

Correcting out these offsets will ensure that any measured differences is due to the signal/device under test and not the test equipment.

Uncorrected

Corrected using Keysight LTE-A Multi-Channel Reference Solution Tools
Calibration of Phase Coherent Signal Generation System

The End Goal – Perfectly Aligned in Time and Phase

- Determine channel to channel time and phase differences and apply corrections
  - Apply known signal to all channels and measure each channel relative to master source
  - Collect BB time and phase differences between channels
  - Repeat for each frequency, amplitude, and sample rate
  - Apply time and phase corrections to multi-channel phase coherent measurements
- Keysight has helpful tools to automate this process and allows for integration of deltas for design verification
Multi-Channel Calibration Methods

Traditional Source Calibration

- VSG 1
- VSG 2
- VSG 3
- VSG 4

4-channel Scope

New Source Calibration

- VSG 1
- VSG 2
- VSG 3
- VSG 4

4 Way combiner

VSA

Analyzer Calibration

- VSA 1
- VSA 2
- VSA 3
- VSA 4

4 Way splitter

• New Patent-Pending Multi-Channel Calibration Method
  - Automated for faster tests
  - Less HW & SW lowers the cost
  - For best results minimize cable length, keep cable lengths the same, and select high quality splitter, connectors, and cables.
Tips for True Phase Coherent Measurement Systems

Minimize Phase Variations and Calibrate

1. Use common LO Source
2. Use phase stable LO
3. Use low phase noise LO
4. Use reference clock synchronization to ensure waveforms and acquisitions start at the same time
5. Calibrate out any time and phase skew between generator channels or between analyzer channels
6. Calibrate out any losses and mismatches due to cables and connectors
Overview of Multi-Antenna Techniques

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Measurement Examples
Test Challenge: Complicated Test Setup

LTE-Advanced Multi-Channel Reference Solution

Accelerate LTE-A designs and gain deeper insight faster

Software

Signal Studio
N7624B & N7625B for LTE/LTE-A FDD & TDD

Multi-Channel Configuration & Correction Utilities

89600 VSA & WLA Software
(Optional X-Series measurement applications for SISO analysis)

Hardware

Available Configurations
- Analyzers, sources or both
- 2, 4, or 8 channels
- Time synchronized or phase coherent
- Chassis, controller, cables
- V2802A LO distribution

Test stimulus from VSGs

Device under test

Signal to be analyzed by VSAs
Test Challenge: Characterizing the full set of LTE/LTE-A tests, including 8x8 MIMO, cross channel measurements and multi-antenna beamforming, which typically includes 4 or 8 antenna elements.

Solution

89600 VSA Software

Spectrum measurements like SEM, OBW, power, spurs, ACPR
Isolation/cross-channel skew crosstalk, time alignment error (TAE)
MIMO and beamforming measurements with beamforming weightings per antenna
Modulation quality with EVM per layer
LTE/LTE-A FDD/TDD UL & DL, WLAN including 802.11ac

M9391A VSAs provide up to 8 LO locked phase coherent, time aligned analyzers, 160 MHz BW
8x2 BF modulation analysis example

MIMO/BF – Downlink

Antenna beam patterns

C-RS propagation matrix, etc

UE-RS BF weights etc
Testing the Receiver Side

**Test Challenge:** Ability to generate complex MIMO and beamforming signals that have relative phase, time and frequency characteristics to adhere that the latest wireless standards

**Solution**

- MIMO signal generation solutions that can be used with RF fading simulators
- Can be combined with carrier aggregation

**Signal Studio**

- Support for the latest WLAN and cellular multi-channel signals including 802.11ac and LTE-Advanced TDD and FDD
- Select transmission mode including diversity, spatial multiplexing, beamforming up to 8x8 MIMO and carrier aggregation
- Define, generate and export waveform files

Up to 8x8 LO locked phase coherent, time aligned generators, 160 MHz BW

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From Simulation to Manufacturing

- Model new LTE/LTE-A and WLAN 802.11ac MIMO design
- Verify interpretations of the standard
- Rapid proto-typing and integrated measurements
- Use in design simulation, verification and testing
- New 5G libraries available
Case Study – Xidian University, China
Application: Research Verification

*Need 8x8 system with wide bandwidth and phase coherent channels*

**Key Test Challenges:**
- Complexity and size of integrating 8 sources and 8 analyzers
- Phase coherency between channels to test beamforming
- Characterizing wireless communications

**Solution provides:**
- Compact size
- Automatic routing of triggers
- Reduced complexity

**8x8 implementation**
- 8 PXI VSGs, 6 GHz, 160 MHz
- 8 PXI VSAs, 6 GHz, 160 MHz
- MATLAB
- 89601B VSA SW
- 4 PXI Chassis with 1 embedded controller plus LO distribution unit (not shown)
Keysight Solution for MIMO Throughput Test
LTE/LTE-A 4x4 MIMO waveform generation, EVM, throughput test

SystemVue Software to create LTE-A FDD or TDD channel & capture measurements via 89600 VSA software

LTE-A Multi-Channel Reference Solution
- PXI chassis w/ embedded controller
- 4 M9381A PXI VSGs
- 4 M9391A PXI VSAs
- Configuration & Correction Tools
Configuration and Calibration Demo

Accelerate LTE-A designs and gain deeper insight faster

Software
- Signal Studio N7624B & N7625B for LTE/LTE-A FDD & TDD
- Multi-Channel Configuration & Correction Utilities
- 89600 VSA & WLA Software (Optional X-Series measurement applications for SISO analysis)

Hardware
- Available Configurations
  - Analyzers, sources or both
  - 2, 4, or 8 channels
  - Time synchronized or phase coherent
  - Chassis, controller, cables
  - V2802A LO distribution
- Test stimulus from VSGs
- Device under test
- Signal to be analyzed by VSAs

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Newer carrier aggregation, spatial multiplexing, beamforming applications require tightly synchronized, phase-coherent channels for accurate test.

Channel-to-Channel phase and time alignment and calibration is critical in the multi-antenna measurement system.

Keysight provides in-depth signal generation & analysis solutions for advanced technology & research.
Thank You !!!

Questions and Answers
LTE / LTE-Advanced Design and Test Solutions

- Signal Studio Software
- Signal Generators
- Baseband Generator and Channel Emulator
- RF Module Development
  - RF Proto
  - RF Chip/module
- BTS and Mobile BB Chipset Development L1/PHY
  - FPGA and ASIC
- Protocol Development L2/L3

- RF and BB Design Integration L1/PHY
  - DigRF v4
  - BTS or Mobile

- System Design Validation System Level RF Testing

- Pre-Conformance
- Conformance
- Manufacturing
- Network Deployment

- LTE UE Signalling, RF, Protocol and Functional Test
- RF Handheld Analyzers
- Power Measurement
- Manufacturing Test
- Systems for RF and Protocol Conformance

- 89600 VSA/WLA
  - For Signal Analyzers, Scopes, LA SystemVue and ADS

- 3D EM Simulation
  - SystemVue (BB) ADS/GG (RF/A)

- Battery Drain Characterization

- 3-year repair warranty coverage on all instruments
- Optional Calibration and Repair Service Plans

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