

AGENDA

- **Wireless Trends**
- MIMO Overview
- 802.11 WLAN Overview
- MIMO Transmitter Testing
- MIMO Receiver Testing
- MIMO Test Equipment



WIRELESS TRENDS

- video + wireless connectivity =
higher wireless data rates required

Application	Max Data Rate (Mbps)
Videoconference	0.5
Streaming internet video	8
HD video	25
Blu-Ray	40
Uncompressed video	3730



WIRELESS TRENDS

- 5G Wi-Fi (WLAN)
 - 802.11ac, up to 7 Gbps, Now!
 - 160 MHz bandwidth, up to 8X8 MIMO
- 4G Cellular
 - LTE-Advanced, over 1 Gbps, 2013
 - 100 MHz bandwidth, up to 4X4 MIMO, HetNet
- WiGig
 - 802.11ad, up to 7 Gbps, 2014?
 - 2 GHz bandwidth, 60 GHz spectrum (point-to-point)



WLAN TRENDS

- Enterprise
 - WLAN replacing wired LAN
- Hotspots
 - Public & private
 - Airports, libraries, etc.
- Home
 - PC connectivity
 - Cell phones, laptops
 - Streaming video (TV, tablets, etc.)



- Anand Lal Shimpi, AnandTech



WLAN TRENDS

- Record \$1.7B WLAN infrastructure sales in Q4 2011 (14% YOY growth)
- Nearly 500,000 WLAN devices were shipped to service providers in 2011 (170% YOY growth)
- Largest vertical markets in the 2nd half of 2011: Education 22%, Healthcare 14%, Enterprise 12%
- Shipments of 802.11ac SOHO WLAN devices in 2012 and Enterprise WLAN devices in 2013

- Dell'Oro Group, Feb. 29, 2012

- In-Stat projects >1B 802.11ac devices to ship by 2015

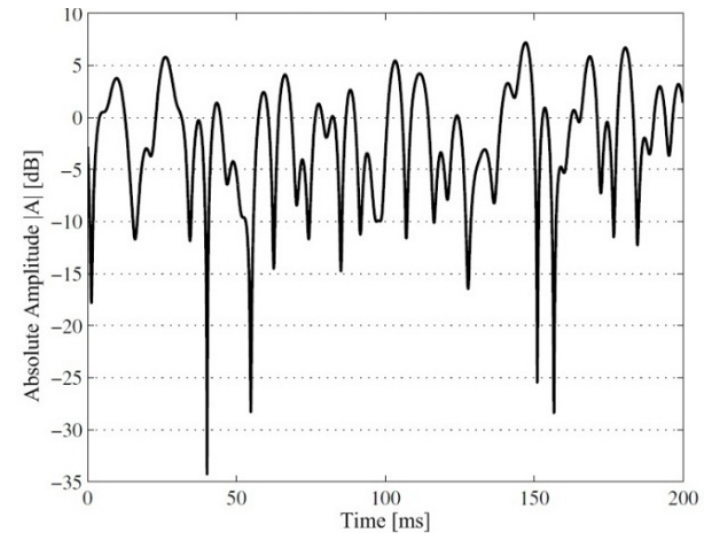
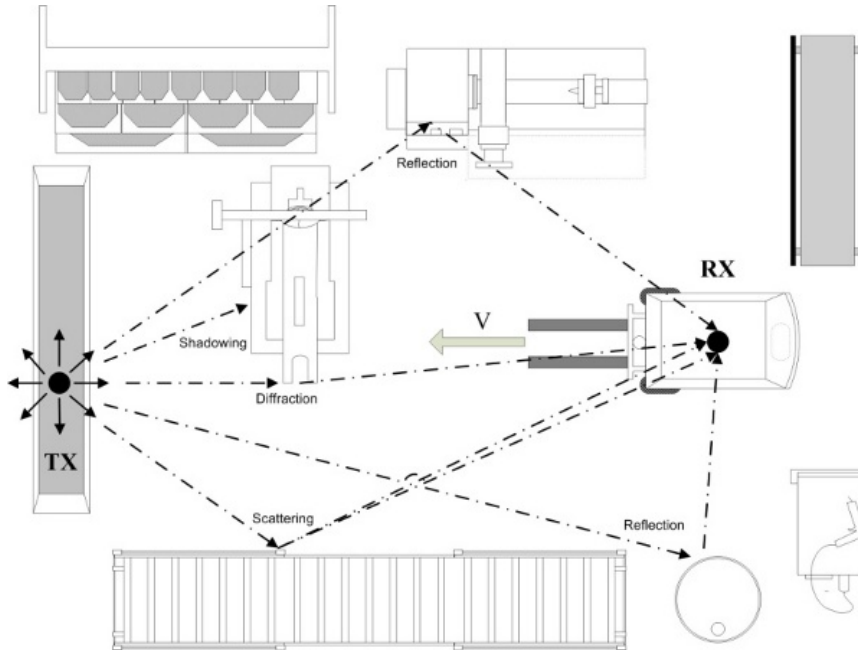


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RF ENVIRONMENT



- Aurel Buda, et. al.
University of Applied Sciences Bochum

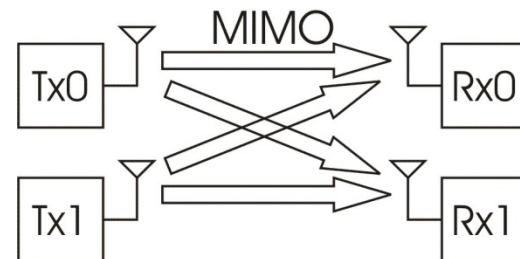
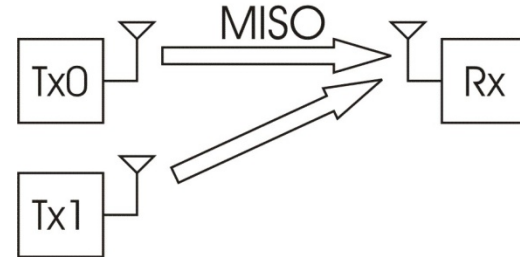
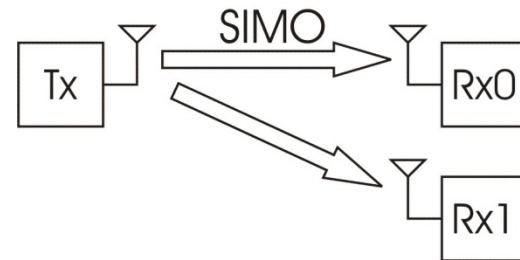
- Highly scattered environment
- Doppler & multipath fading



MIMO TOPOLOGIES

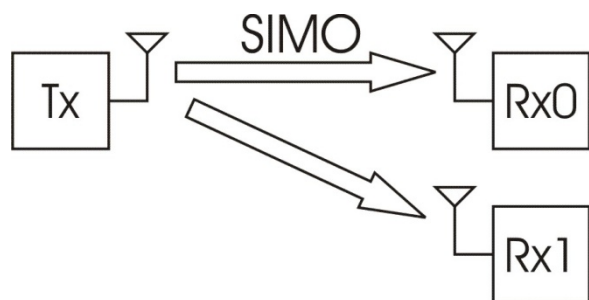
Why MIMO?

- Highly scattered multipath environment
- Antennas separated by $>\lambda/2$
- Improve signal robustness
- Increase distance & directionality
- Increase channel capacity
(Channel = all MIMO streams)



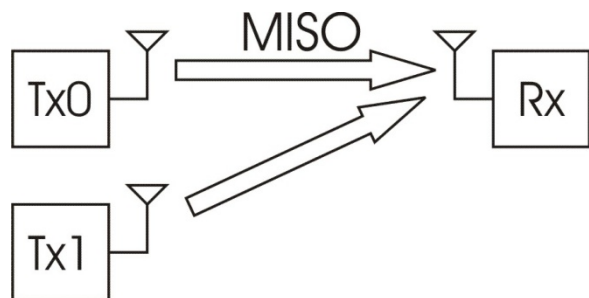
DIVERSITY

- SIMO or MISO with identical data streams
- Reduces channel fading



SIMO

- Selective Combining
- Equal Gain Combining
- Maximal Ratio Combining



MISO

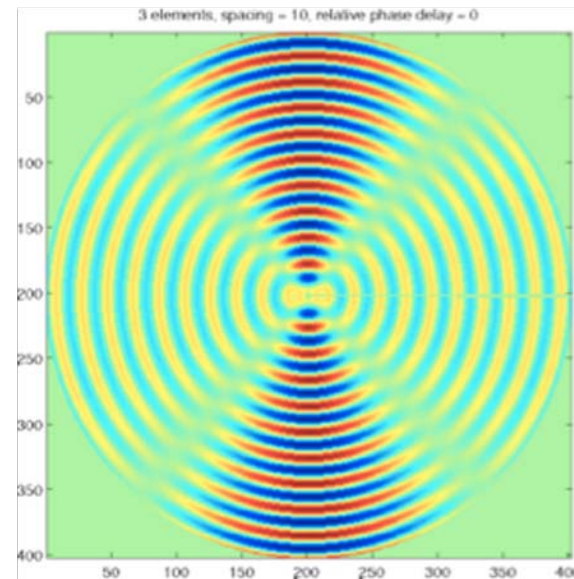
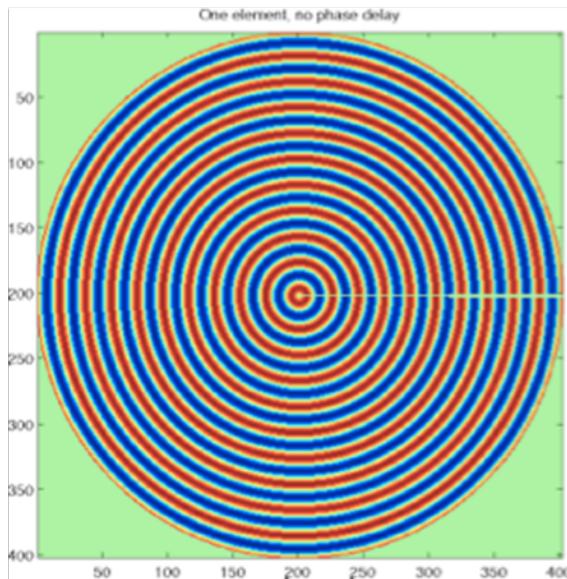
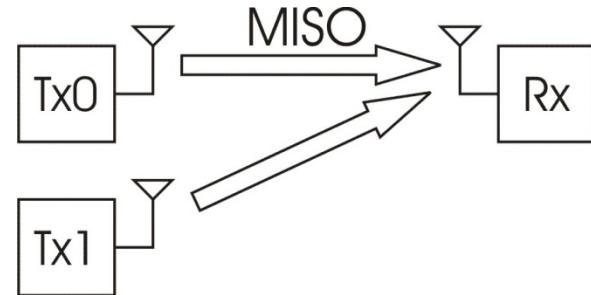
- Space Time Block Coding (STBC)
- 50-200 ns between transmitters



BEAMFORMING



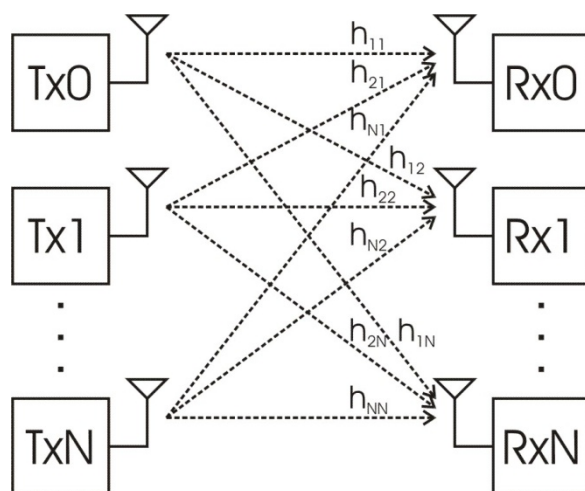
- MISO with identical data streams
- Extends distance and directivity



SDM

Space Division Multiplexing

- True MIMO with unique data streams
- Increased channel capacity within same RF spectrum
- Estimate of channel matrix H using training sequence
- Singular values of H = strength and separation of MIMO streams



$$\begin{bmatrix} \text{Rx0} \\ \text{Rx1} \\ \vdots \\ \text{RxN} \end{bmatrix} = \begin{bmatrix} h_{11} & h_{21} & \dots & h_{N1} \\ h_{12} & h_{22} & \dots & h_{N2} \\ \vdots & \vdots & \ddots & \vdots \\ h_{1N} & h_{2N} & \dots & h_{NN} \end{bmatrix} \begin{bmatrix} \text{Tx0} \\ \text{Tx1} \\ \vdots \\ \text{TxN} \end{bmatrix}$$



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802.11 WLAN OVERVIEW

Legacy

L-STF	L-LTF	L-SIG	Data
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Mixed Mode

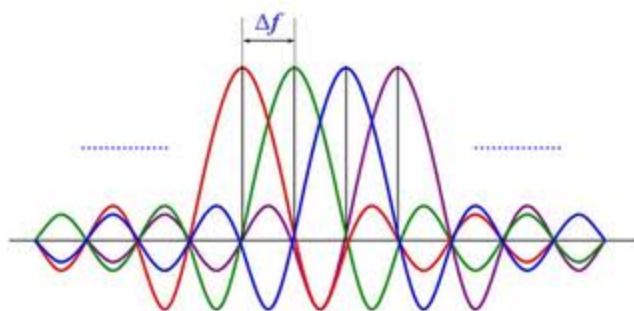
L-STF	L-LTF	L-SIG	HT-SIG	HT-STF	HT-LTF	Data
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Green Field

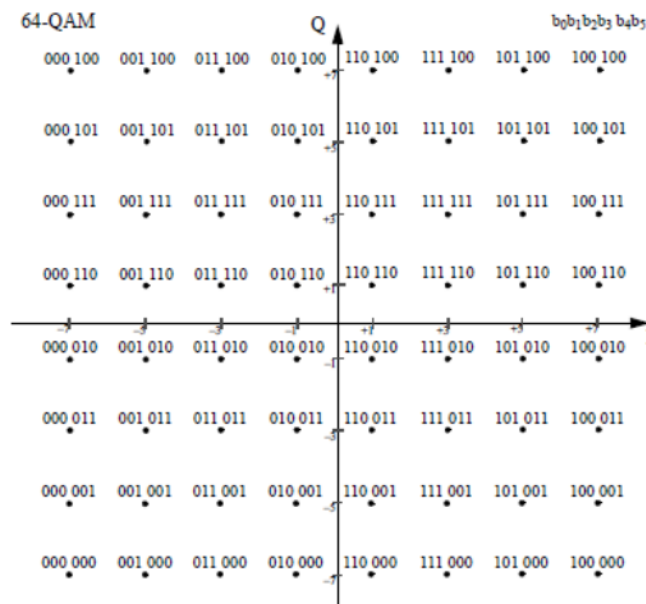
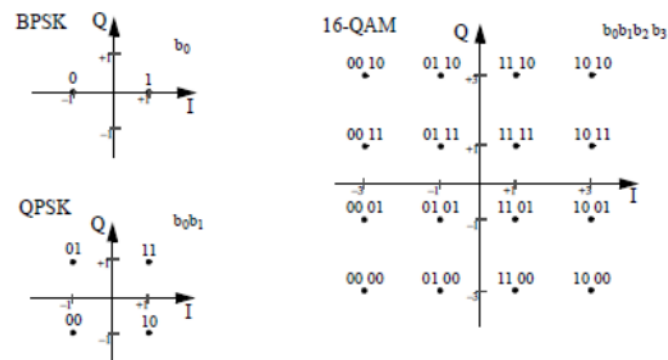
HT-STF	HT-LTF	HT-SIG	HT-LTF	Data
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VHT Mixed Mode

L-STF	L-LTF	L-SIG	VHT-SIG-A	VHT-STF	VHT-LTF	VHT-SIG-B	Data
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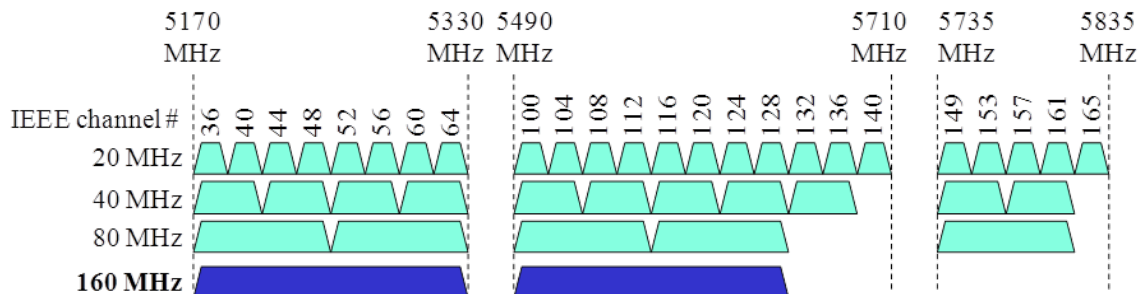
OFDM Subcarriers



802.11ac OVERVIEW

- Up to 6.93 Gb/s (160 MHz, MCS 9, 8 streams, short Guard Interval)
- Uses less crowded 5 GHz spectrum

802.11ac Features		
Item	Mandatory	Optional
Channel Bandwidth	20 MHz, 40 MHz, 80 MHz	160 MHz, 80+80 MHz
Data Subcarriers	52, 108, 234	468
Modulation Coding Schemes	MCS 0 to 7	MCS 8 & 9
Modulation Types	BPSK, QPSK, 16QAM, 64QAM	256QAM
PPDU Format	Very High Throughput (VHT)	
MIMO Streams	1	2 to 8
MIMO Features	Beamforming	Multi-User MIMO



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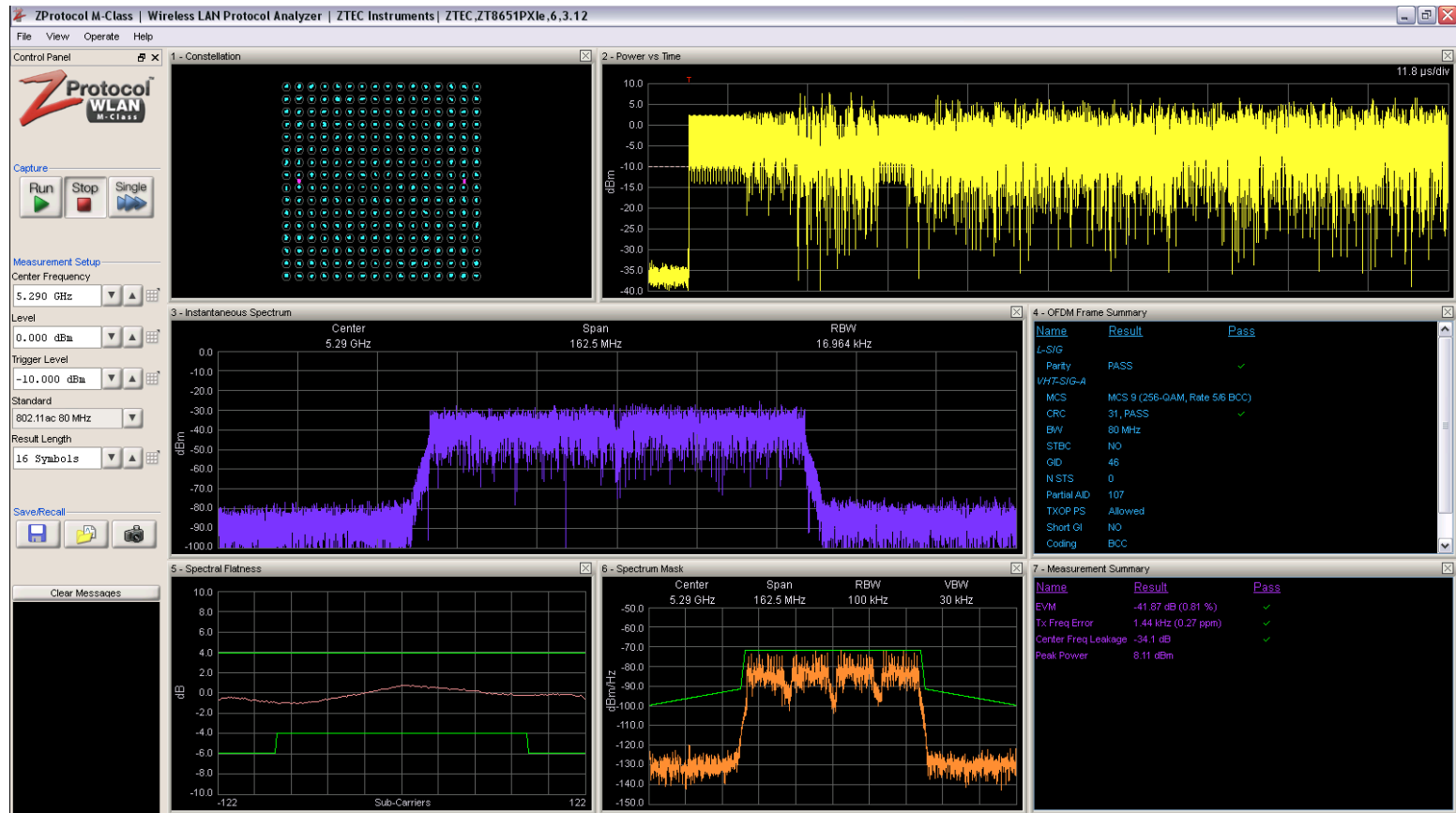
TX COMPLIANCE TESTING

- Spectrum Mask
- Spectral Flatness
- Peak Power
- Center Frequency Error
- Symbol Clock Frequency Error
- Center Frequency Leakage
- Error Vector Magnitude (EVM)

Modulation	Coding Rate	Relative Constellation Error or EVM
BPSK	1/2	-5 dB (56.2%)
QPSK	1/2	-10 dB (31.6%)
QPSK	3/4	-13 dB (22.4%)
16-QAM	1/2	-16 dB (15.8%)
16-QAM	3/4	-19 dB (11.2%)
64-QAM	2/3	-22 dB (7.94%)
64-QAM	3/4	-25 dB (5.62%)
64-QAM	5/6	-27 dB (4.47%)
256-QAM	3/4	-30 dB (3.16%)
256-QAM	5/6	-32 dB (2.51%)



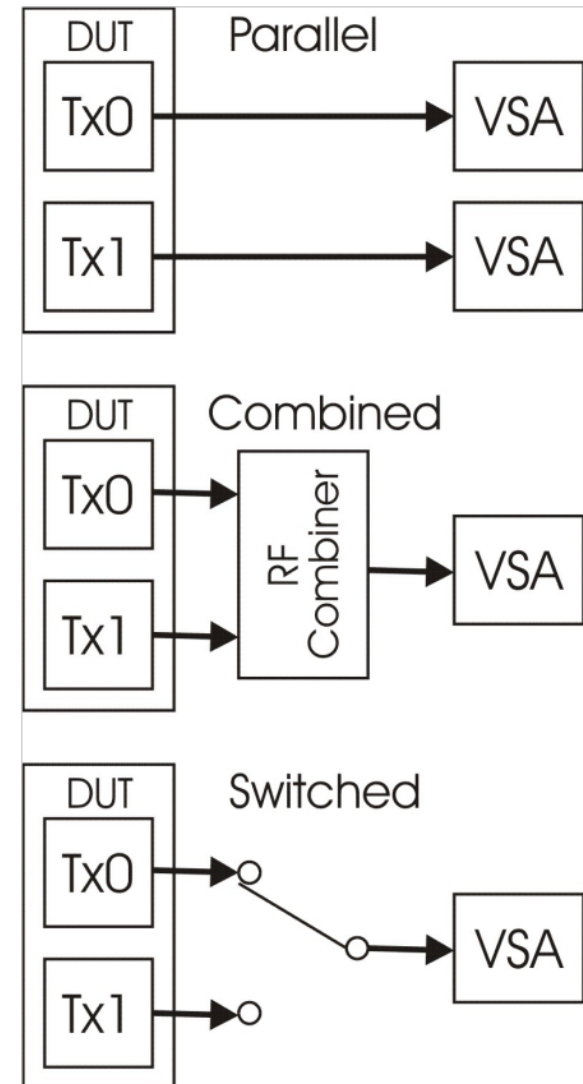
TX COMPLIANCE TESTING



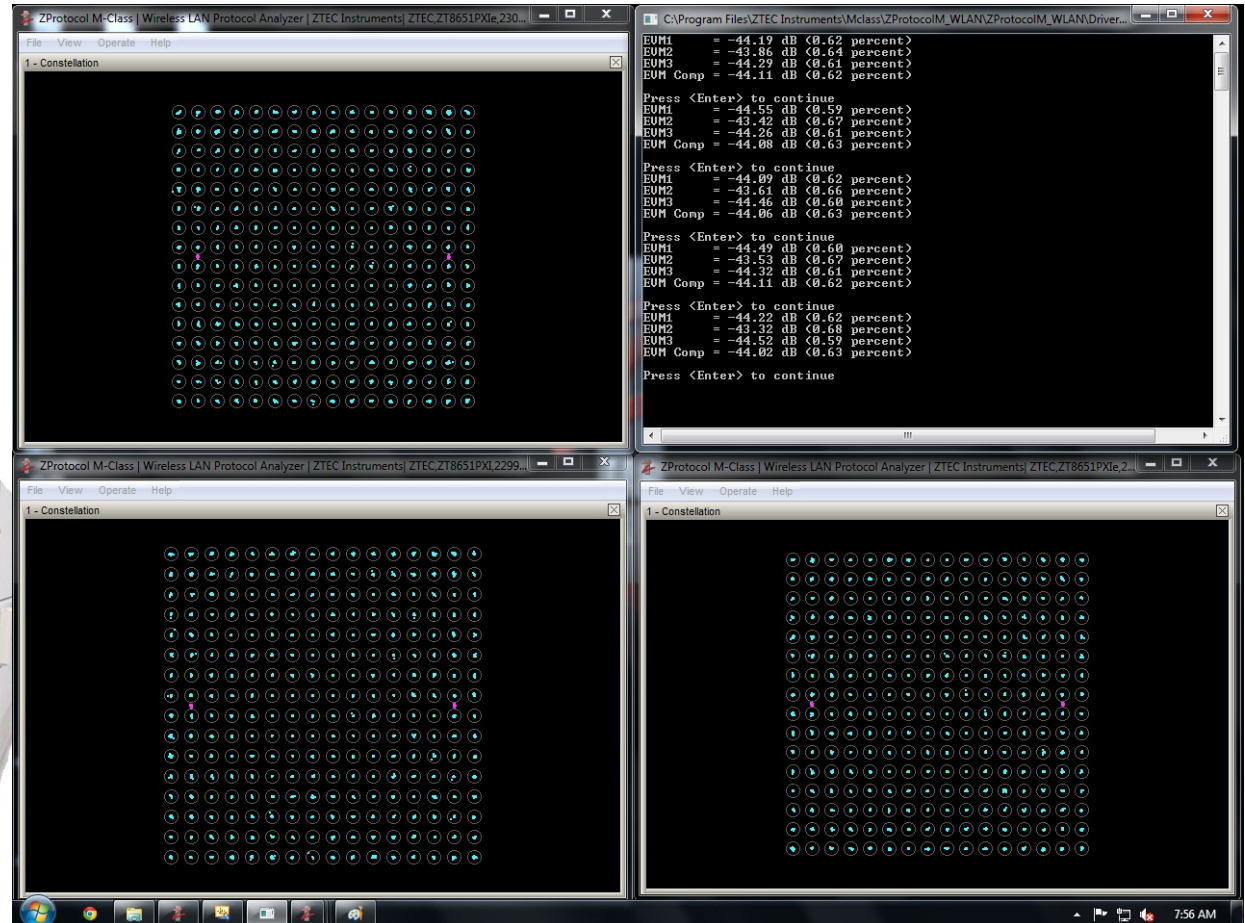
Vector Signal Analyzer (VSA) + Protocol Analysis Software

MIMO TX TESTING

- Parallel VSA
 - Compliance tests (Composite EVM)
 - Interleaved subcarrier test
- Combined VSA
 - Composite EVM
 - STBC simulation
 - SDM cannot be simulated
- Switched VSA
 - Multiple sequential captures
 - STBC & SDM simulation
 - Timing jitter & phase variations
 - Longer test time



MIMO TX TESTING



X3 MIMO Transmitter Test (Composite EVM)



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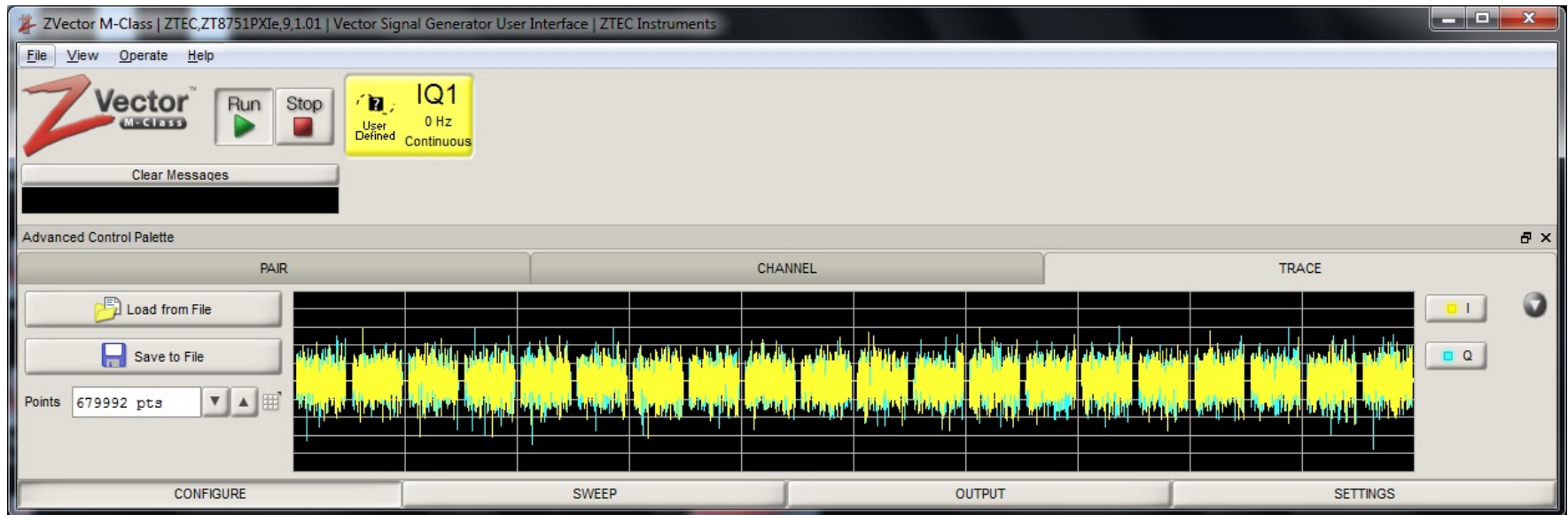
RX COMPLIANCE TESTING

- Minimum Input Level Sensitivity
- Maximum Input Level
- Adjacent Channel Rejection (ACR)
- Non-Adjacent Channel Rejection
- Clear Channel Assessment (CCA) Sensitivity

Modulation	Coding Rate	Minimum Sensitivity			
		20 MHz	40 MHz	80 MHz	160 MHz
BPSK	1/2	-82 dBm	-79 dBm	-76 dBm	-73 dBm
QPSK	1/2	-79 dBm	-76 dBm	-73 dBm	-70 dBm
QPSK	3/4	-77 dBm	-74 dBm	-71 dBm	-68 dBm
16-QAM	1/2	-74 dBm	-71 dBm	-68 dBm	-65 dBm
16-QAM	3/4	-70 dBm	-67 dBm	-64 dBm	-61 dBm
64-QAM	2/3	-66 dBm	-63 dBm	-60 dBm	-57 dBm
64-QAM	3/4	-65 dBm	-62 dBm	-59 dBm	-56 dBm
64-QAM	5/6	-64 dBm	-61 dBm	-58 dBm	-55 dBm
256-QAM	3/4	-59 dBm	-56 dBm	-53 dBm	-50 dBm
256-QAM	5/6	-57 dBm	-54 dBm	-51 dBm	-48 dBm



RX COMPLIANCE TESTING

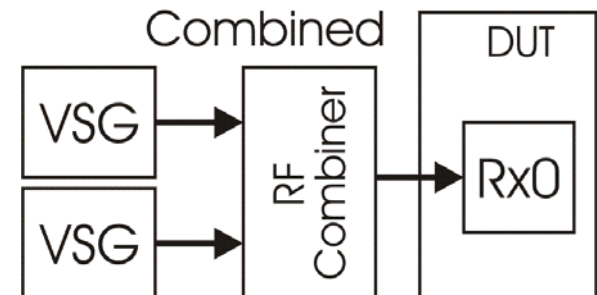
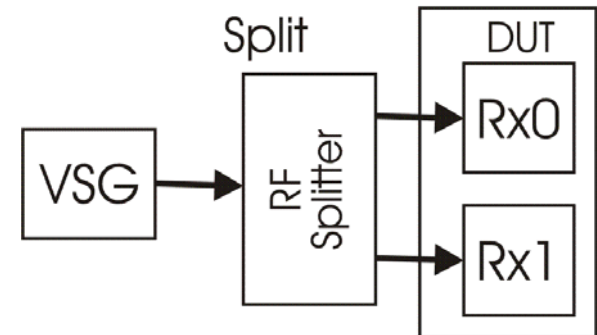
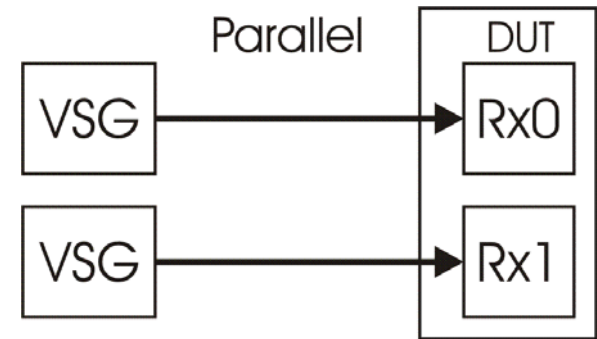


Vector Signal Generator (VSG) + Protocol Generation Software



MIMO RX TESTING

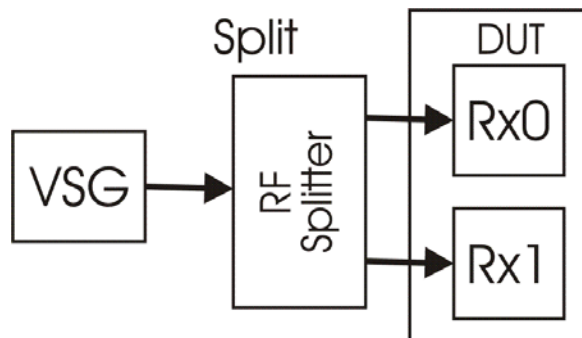
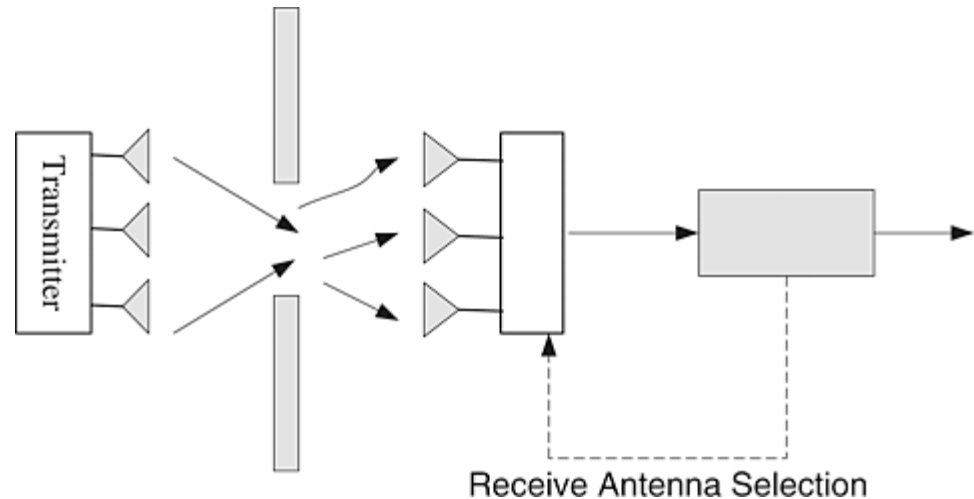
- Parallel VSG
 - Compliance tests
 - SDM & STBC simulation
 - Fading channel simulation
- Split VSG
 - Input sensitivity gain
 - Keyhole effect testing
 - STBC & SDM cannot be simulated
- Combined VSG
 - Broadband adjacent channel and non-adjacent channel testing
 - Broadband Digital Pre-Distortion (DPD)



MIMO RX TESTING

Keyhole Effect

- Single transmission path (no multi-path effects)
- Should result in ideal channel matrix
- Non-ideal matrix elements determine DUT quality (isolation & noise floor)



$$\begin{bmatrix} \text{Rx0} \\ \text{Rx1} \\ \vdots \\ \text{RxN} \end{bmatrix} = \begin{bmatrix} 1 & 0 & & 0 \\ 1 & 0 & \ddots & 0 \\ & \ddots & \ddots & \ddots \\ 1 & 0 & & 0 \end{bmatrix} \begin{bmatrix} \text{Tx0} \\ \text{Tx1} \\ \vdots \\ \text{TxN} \end{bmatrix}$$



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MIMO TEST EQUIPMENT

X4 VSA Test Set

- Four 6 GHz VSAs
- PXIe modular instruments
- PXIe throughput (250 MB/s)
- Fast embedded processing
- Open-source software
- Backplane synchronization



Processor	20 MHz MCS8	40 MHz MCS8	80 MHz MCS9	160 MHz MCS9
Laptop Intel Core i7 @ 2.67 GHz	35 ms	64 ms	73 ms	120 ms
Embedded Intel Core i5 @ 2.4 GHz	26 ms	43 ms	52 ms	100 ms

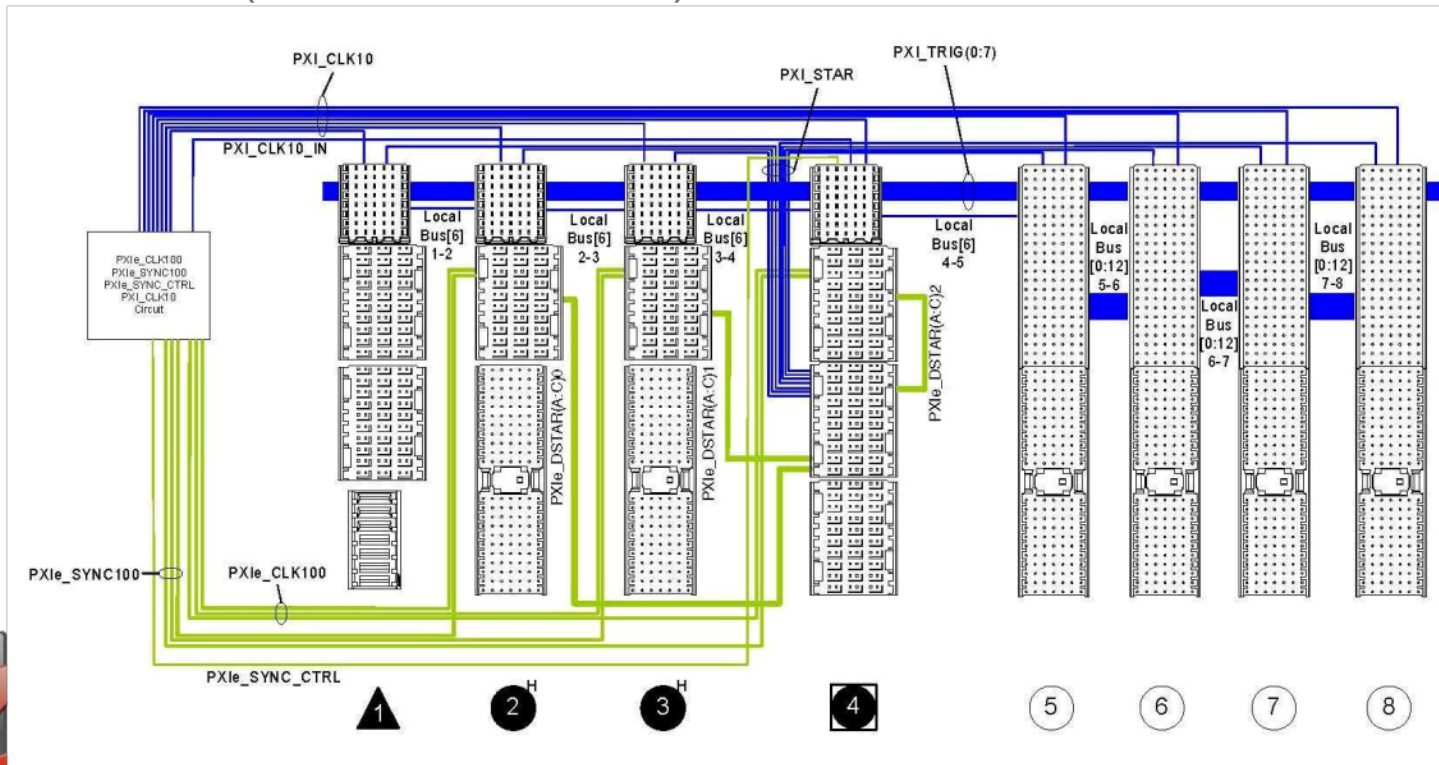




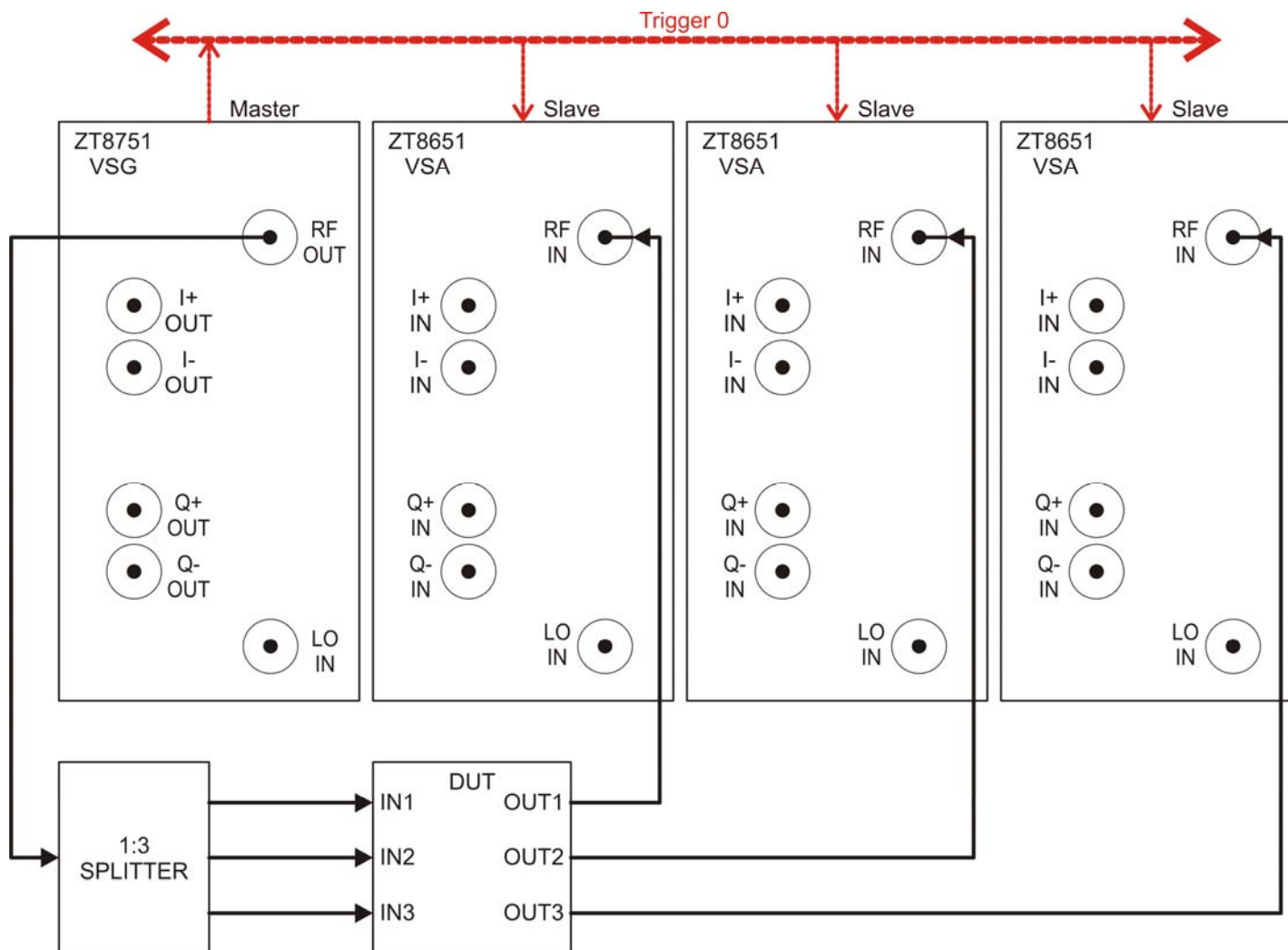
MIMO TEST EQUIPMENT

Multiple-Instrument Synchronization

- PXI/PXIe Backplane
 - Triggers
 - Timebase (10 MHz & 100 MHz)



MIMO TEST EQUIPMENT



MIMO TEST EQUIPMENT

Packet Synchronization

- VSG master
- VSA slaves
- Backplane Trigger0 identifies packets to capture
- High RF rep rate for thermal equilibrium
- MIMO processing every few 100 ms



CONCLUSION

- MIMO adds reliability (reduces fading, adds directionality & distance)
- MIMO adds channel capacity (SDM)
- MIMO adds complexity for design & test
- Integrated synchronization and software need to be considered for RF instruments
- Modular instruments (such as PXIe) are particularly well-suited to MIMO applications



Q&A

- Questions?
- Contact Information
 - Chris Ziomek, czimek@ztecinstruments.com
 - Dr. Matthew Hunter, mhunter@ztecinstruments.com
- Supplemental Application Note
 - www.ztecinstruments.com/WLAN_MIMO.pdf
- Thank You!

