Agilent Technologies

Making MIMO Measurements--Choosing and Using Tools

March 2009

This Presentation

Using and Choosing Measurement Solutions

Design & Measurement Tasks, Goals

Performance Required

Functionality Required

- RF measurements: spectrum, power, timing, phase noise
- Digital Demod: Basic mod quality or detailed analysis & troubleshooting
- Number of inputs required: 1? 2? 3? 4? More?
- System/subsystem or component test

Leveraging & Upgrading Existing Solutions

Agenda

MIMO & Measurements Overview

MIMO Measurement Examples

Signal Analysis Solutions, Comparisons

Signal Generation Solutions, Comparisons

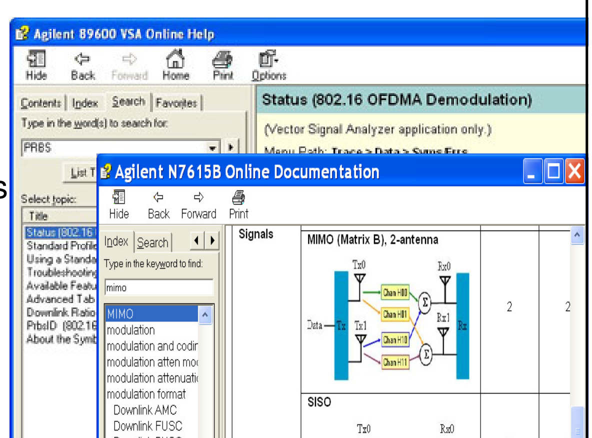
Protocol & Conformance Solutions (brief)

References, Additional Resources

Learn by Making Measurements

89601A VSA Software, Free Demo License,
Signal Studio Software, Free Simulation Mode

- Recorded signals provided: 1-4 channels, perform any kind of vector analysis or demodulation
- Simulated hardware
- Tutorials
- Troubleshooting help
- Example displays



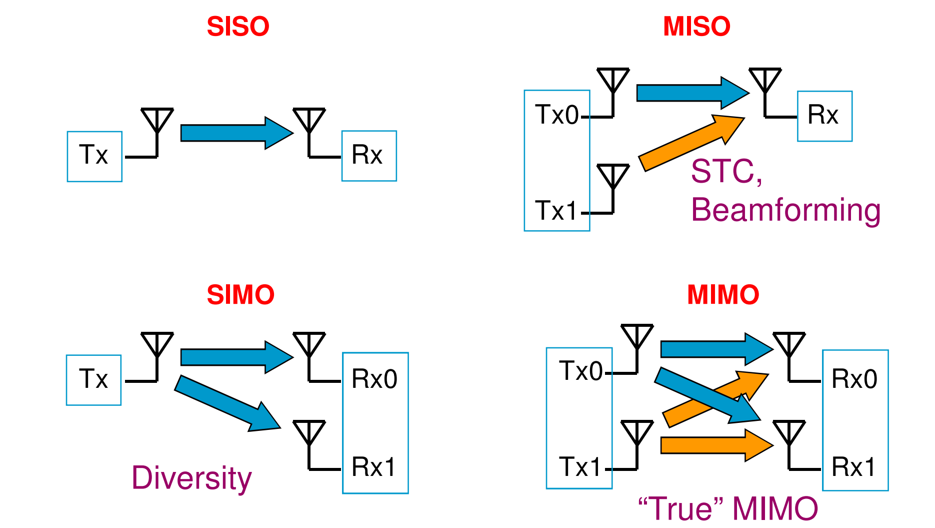
VSA & Signal Generators
14-day Free Trial Licenses

- Connect to hardware
- Generate, download & play back signals

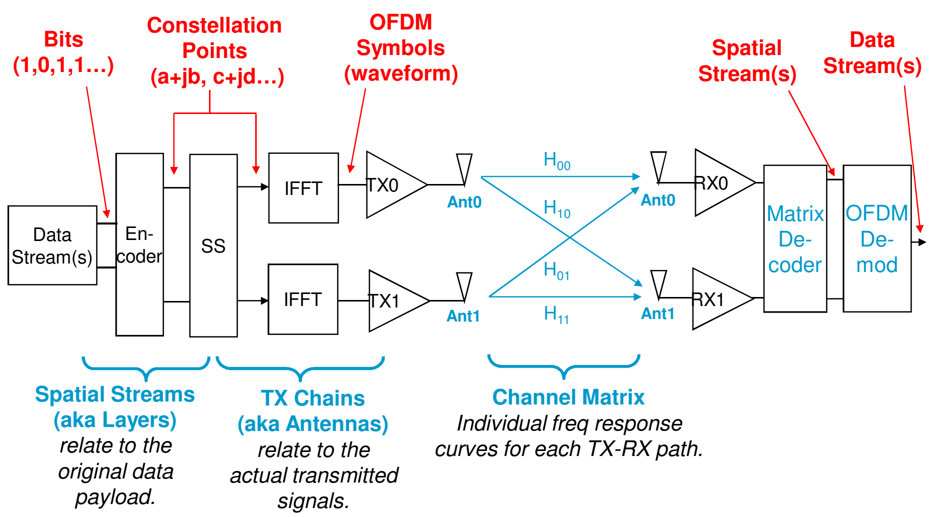
Tech Overviews, Demo Guides

System & Antenna Configurations, Terms

"Input" and "Output" Refer to the Transmission Channel



MIMO – Data & Spatial Streams, Channels
2x2 Example



MIMO Measurement Types

All the Basics, Plus More/Linked Channels

All Traditional Spectrum, Network, Power, Timing

Basic Modulation Quality

Isolation/Coupling/Crosstalk

Frequency Responses (multiple)

General Modulation Impairments

Proper MIMO Operation, Signal Content

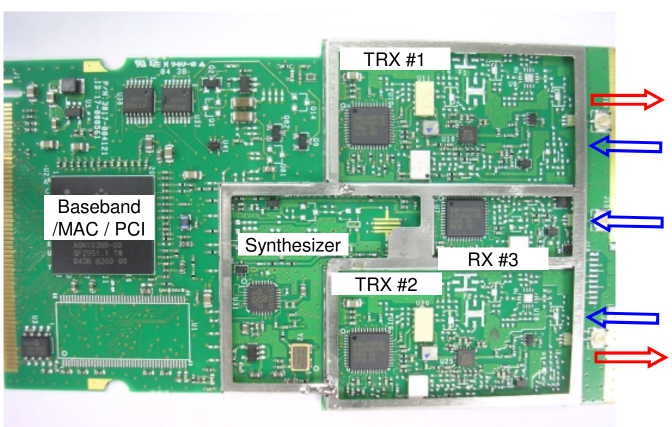
MIMO Signal Separation

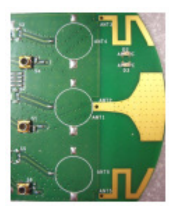
Optimization: Cost, signal quality, size, power consumption, complexity, antenna configuration

Physical Implications:

Antenna Spacing, Crosstalk, Real Estate

All Affect Signal Quality, MIMO Operation





Compact Antennas, Connections

One example configuration: 2Tx, 3Rx

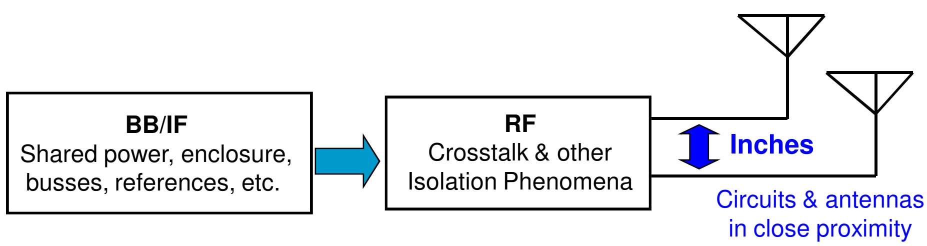
Design Issues – Antenna & Channel

The antennas form part of the channel

The antenna design process is a combination of simulation, intuition, trial & ~~error~~ refinement

Simple channel measurements often a mixture of conventional swept VNA style, and those using Multi-tones

MIMO Transmitter Measurement Problem



Need Traditional & Cross-Channel Measurements

Need 40+ dB Measurements in a 20 dB Environment

Analysis Approaches

Switch Off One Channel

- Simple, generally less expensive
- Use established equipment, approaches
- Results with limited applicability

Single-Input Measurements of 2 - 4 Transmitters

- Transmitters combined deliberately or incidentally
- Some signals can be separated by frequency or time
- No Matrix decoder

Multi-Channel Measurements, Two or More

- Signal processing to restore 40+ dB measurements
- Measure cross-channel parameters and how they vary with configuration changes

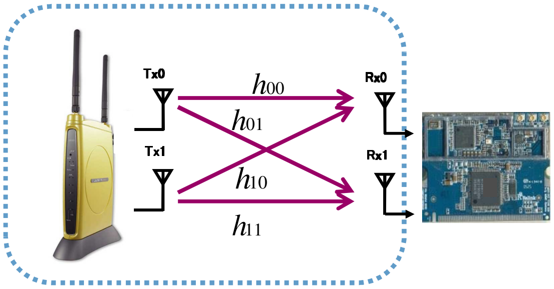
Principal MIMO Applications

All use OFDM transmission schemes

IEEE 802.11n Wireless LAN

IEEE 802.16 OFDMA WiMAX® (wireless MAN)

3GPP LTE (4th Generation Mobile)

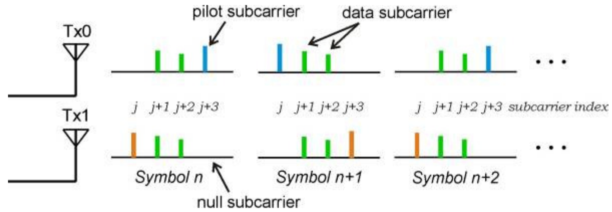


"WiMAX," "Mobile WiMAX" and "WiMAX Forum" are trademarks of the WiMAX Forum

MIMO Signal Recovery: Measuring Matrix Coefficients

Recovering the channel coefficients

(WiMAX Wave 2 example)



In WiMAX and LTE, more subcarriers are allocated as pilots

Pilot location changes from symbol to symbol

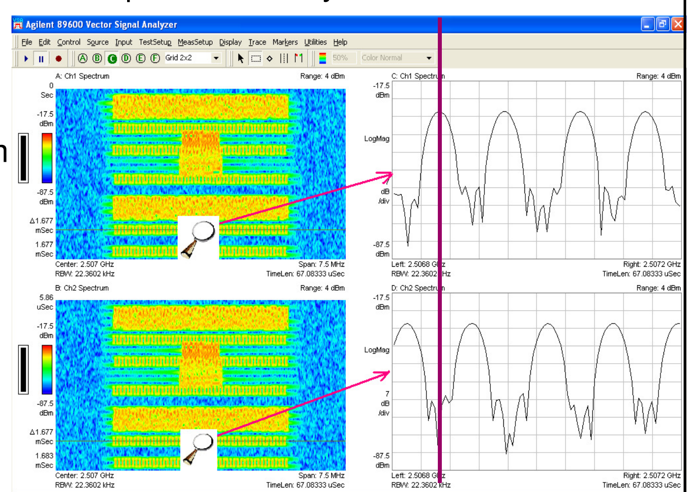
Pilot power is boosted to ensure errors from recovering the training signal do not dominate the demodulator performance

MIMO Signal Recovery – Spectrum View

The traces in this LTE signal show how the Reference Signals (pilots) are on different frequencies at any instant in time

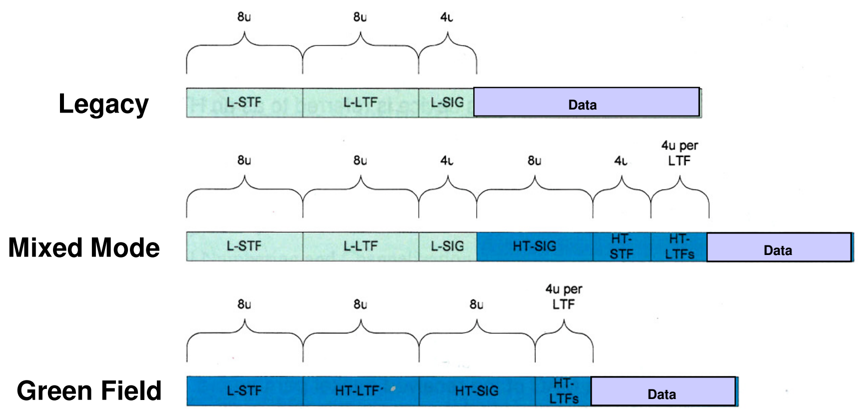
Spectrograms on left show spectrum versus time (time is vertical axis)

Unlike 802.16 OFDMA, the LTE RS (pilots) not present on all symbols



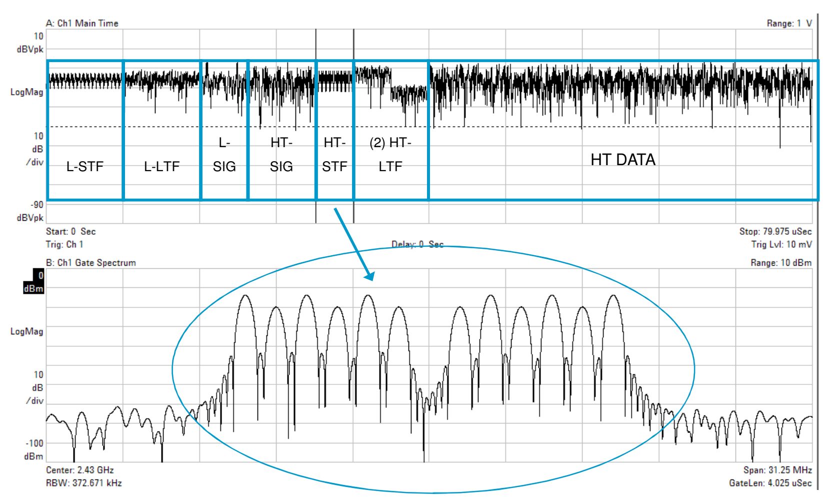
IEEE802.11n Phy layer

Sync, Training/EQ, Channel Measurement in Preamble



L=legacy, **STF**=short training field, **LTF**=long training field, **SIG**=signal field, **HT**=high throughput

Frequency vs. Power in Burst: 802.11n



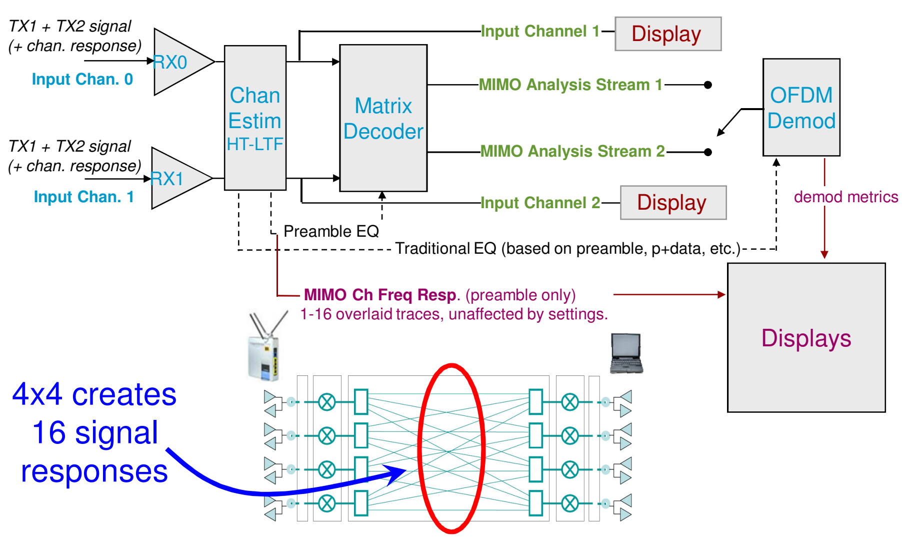
Channel Training Varies with Technology

3GPP LTE	WiMAX	11n Wireless LAN
Reference signals (pilots) use different subcarriers for each transmitter The QPSK Reference signals are transmitted every 3rd or 4th symbol, mixed with data	BPSK Pilot subcarriers use different frequencies. Their positions vary symbol by symbol within a subframe, but are constant from frame to frame. Subcarrier coverage builds over several symbols, allowing interpolation Details depend on the zone type (e.g. PUSC, AMC)	A preamble is used for training. The same subcarriers are used for all transmitters. Signals are separated by a CDMA code 4 orthogonal QPSK pilots are used (6 for 40MHz), sharing the same subcarriers. They are never transmitted without data

HSPA+ uses code channels on the Common Pilot Channel, CPICH, with unique symbol bit patterns having different locations in the OVSF code domain

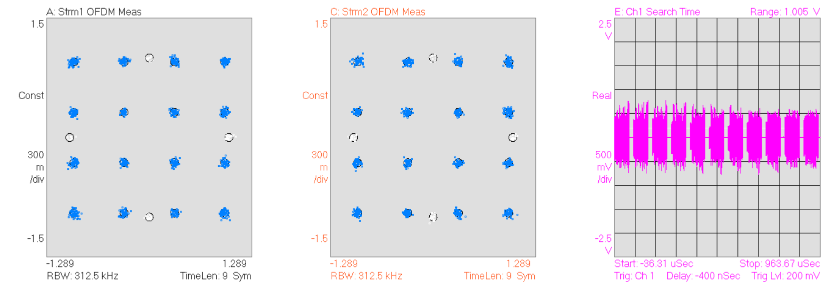
VSA MIMO Signal Analysis

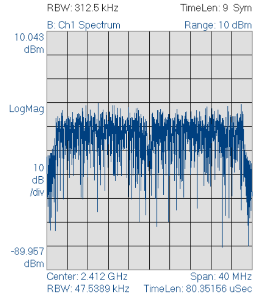
Conceptual Model--Only 2x2 shown for clarity



Demodulation Results

Constellation, Time, Spectrum, Tabular





D: OFDM Error Summary

	Ch1	Ch2	Ch3	Ch4	Av
EVM	-24.643	-31.046	-31.436	***	-27
EVMPeak	-16.29	-21.138	-22.253	***	-16
PilotEVM	-25.426	-31.105	-32.599	***	-28
DataEVM	-24.603	-31.043	-31.379	***	-27
FreqErr	***	***	***	***	-30
SymClkErr	***	***	***	***	-1.
CPE	***	***	***	***	0.9
IQOffset	-47.548	-48.226	-44.807	***	-46
IQQuadErr	3.199	0.02671	0.21635	***	1.1
IQGainImb	0.42360	-0.0744	-0.0402	***	0.1
CrossPwr	0.00089	-0.0073	0.01824	***	0.0
SyncCorr	0.98756	1	1	***	0.9

F: OFDM Data Burst Info

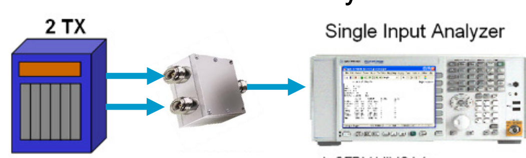
	ModFmt	Len(sym)	Pwr(dBm)
L-STF	QPSK	2	-2.0398
HT-LTF	BPSK	2	-1.9315
HT-SIG	BPSK	2	-2.3267
HT-LTF	BPSK	3	-1.8662
HT-Data	16QAM	9	-1.7672
Total	***	18	-1.8908

Format 40 MHz HT-greenfield 3 streams
HT-SIG CRCPassed
L-SIG None

Some Cross Channel Measurements Can Be Made With a Single Input Analyzer

Applies to LTE, WiMAX

Using a power combiner removes ANY uncertainty due to timing jitter or calibration



A: OFDM MIMO Info

Type	= STC_2			
Matrix	= B			
Antenna	= 0			
DataScPwr	= -0.047	dB		
RefScPwr	= -46.702	dBm		
	Tx0/Rx0		Tx1/Rx0	
PilotPwr	-23.39	dBm	-65.72	dBm
PilotScPwr	5.528	dB	-36.8	dB
PilotRCE	-44.559	dB	0.672	dB
CPE	81.3	m%rms	92.09	%rms
Timing	0.0000	sec	-188.	nsec
Phase	0.0000	deg	77.528	deg
SymbClk	2.8036	ppm	-219.4	ppm
Freq	199.11	Hz	1.0076	kHz

The demodulation process recovers the time and phase relationship between the transmitters at the power combiner input

Cable calibration may still be required

Modulation Analysis: Tabular Results

Symbol / Error table - Channel

- EVM parameters
- Freq / clock errors
- Common pilot error
- I/Q parameters

D: OFDM Error Summary

	Ch1	Ch2	Avg	
EVM	-14.161	-13.707	-13.928	dB
EVMPeak	3.3985	2.9038	3.3985	dB
PilotEVM	-13.606	-10.422	-11.728	dB
DataEVM	-14.206	-14.102	-14.154	dB
FreqErr	***	***	-3.5656	kHz
SymClkErr	***	***	75.791	ppm
CPE	***	***	42.403	%rms
IQOffset	-59.38	-45.757	-48.582	dB
IQQuadErr	-0.10975	-0.35088	-0.23032	deg
IQGainImb	0.01970	-0.03760	-0.00890	dB
CrossPwr	1.9424	1.577	1.7635	dB
SyncCorr	0.89341	0.89108	0.89225	

Symbol / Error table - Stream

- EVM parameters
- CPE
- Raw bits

E: Strm1 OFDM Syms/Errs

StrmEVM	= -34.03	dB
StrmEVM	= 1.9884	%rms
StrmEVM Pk	= 7.4445	%
CPE	= 821.50	m%rms
StrmPilotEVM=	-33.048	dB
StrmDataEVM	= -34.091	dB

```
  0 F33AC 6E D4923DA0 DC7DBD8B 70F1CC48 2 FE4D50
 40 A03BA94  22F421D2 E    5553 3AF23 95 765EB630
 80 10C 5F4B 236CDFE0 3F88D434 563101D  ACF94A77
120 6B 3B60B B4B03512 E9853452 D6A8F7 F AFBAB10C
160 4888 F6B 2E019D    FCEBA1B A3 39806 7D30E80C
200  BE3FC3F 9C3F366C 64ED2595 CA7F BD6 B07A4DE
```


Signal Content: Tabular Results

F: OFDM Data Burst Info

	ModFmt	Len(sym)	Pwr(dBm)	EVM(dB)
L-STF	QPSK	2	-24.962	***
L-LTF	BPSK	2	-24.687	***
L-SIG	BPSK	1	-24.516	***
HT-SIG	BPSK	2	-24.64	***
HT-STF	QPSK	1	-24.501	***
HT-LTF	BPSK	2	-24.345	***
HT-Data	16QAM	26	-24.388	-33.994
Total	***	36	-24.452	-33.994

HT-SIG CRCPassed

Data Burst Info Table

Shows the modulation type, length, power, and EVM of data payload AND the preamble

E: OFDM HT-SIG Info

HT-SIG CRCPassed

MCS:	12	BW:	40MHz	HTLen:	2048
Smooth:	Y	NotSnd:	Y	Resrvd:	1
Aggreg:	Y	STBC:	0	AdvCode:	N
ShortGI:	N	NumHTLTF:	1	CRC:	0x64
Tail:	0x0				

HT-SIG Info

Shows the contents in the High throughput Signal Symbol

Demodulation Results

Measurements by Transmitter

D: OFDM Error Summary

	Ch1	Ch2	Ch3	Ch4	Av
EVM	-24.643	-31.046	-31.436	***	-27
EVMPeak	-16.29	-21.138	-22.253	***	-16
PilotEVM	-25.426	-31.105	-32.599	***	-28
DataEVM	-24.603	-31.043	-31.379	***	-27
FreqErr	***	***	***	***	-30
SymClkErr	***	***	***	***	-1.
CPE	***	***	***	***	0.9
IQOffset	-47.548	-48.226	-44.807	***	-46
IQQuadErr	3.199	0.02671	0.21635	***	1.1
IQGainImb	0.42360	-0.0744	-0.0402	***	0.1
CrossPwr	0.00089	-0.0073	0.01824	***	0.0
SyncCorr	0.98756	1	1	***	0.9

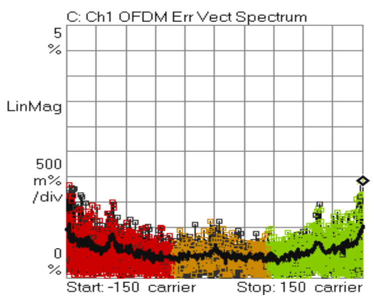
Detected Signal Content

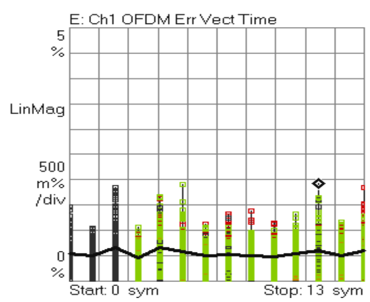
F: OFDM Data Burst Info

	ModFmt	Len(sym)	Pwr(dBm)
L-STF	QPSK	2	-2.0398
HT-LTF	BPSK	2	-1.9315
HT-SIG	BPSK	2	-2.3267
HT-LTF	BPSK	3	-1.8662
HT-Data	16QAM	9	-1.7672
Total	***	18	-1.8908

Format	40 MHz HT-greenfield	3 streams
HT-SIG	CRCPassed	
L-SIG	None	

Orthogonal Modulation Analysis Results





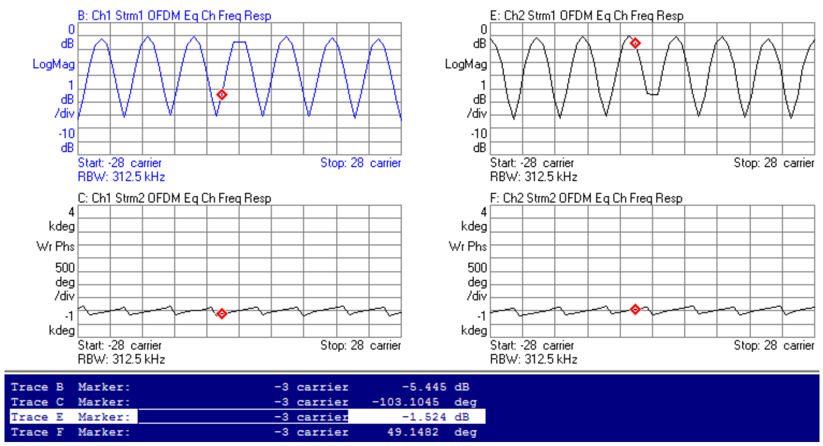
Error Vector Spectrum

Shows the EVM detail by carrier for every symbol time along with the average EVM per carrier (heavy line):

Error Vector Time

Shows the EVM detail by symbol time (EVM for every carrier during that symbol time) along with the average EVM per symbol time (heavy line)

Frequency Response by Channel & Stream



Channel frequency responses

Shows the transfer functions (mag & phase) for each channel. Available for all data streams.

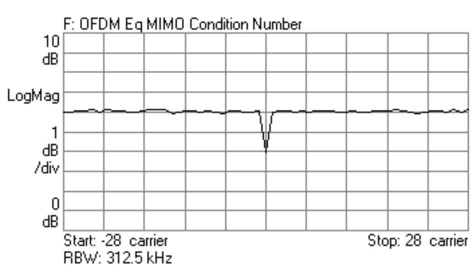
MIMO Condition Number

What it is:

a) A way to see if your MIMO system is functioning correctly

b) A short term indication of the SNR you need to recover a MIMO signal

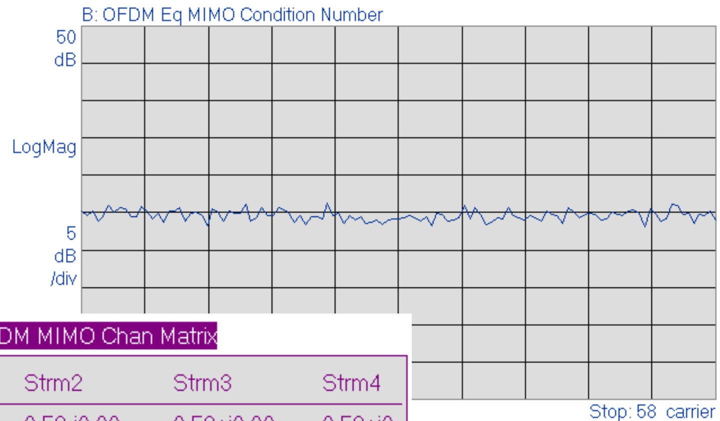
How you calculate it: Find the *singular values* of the channel matrix, and take the ratio of the highest / lowest



Matrix condition number

Ratio of max/min singular values of a matrix. Value always ≥1 (or ≥ 0 dB). If this value is greater than signal SNR it is likely the MIMO separation of data streams will not work correctly.

4x4 Channel Matrix & Condition Number

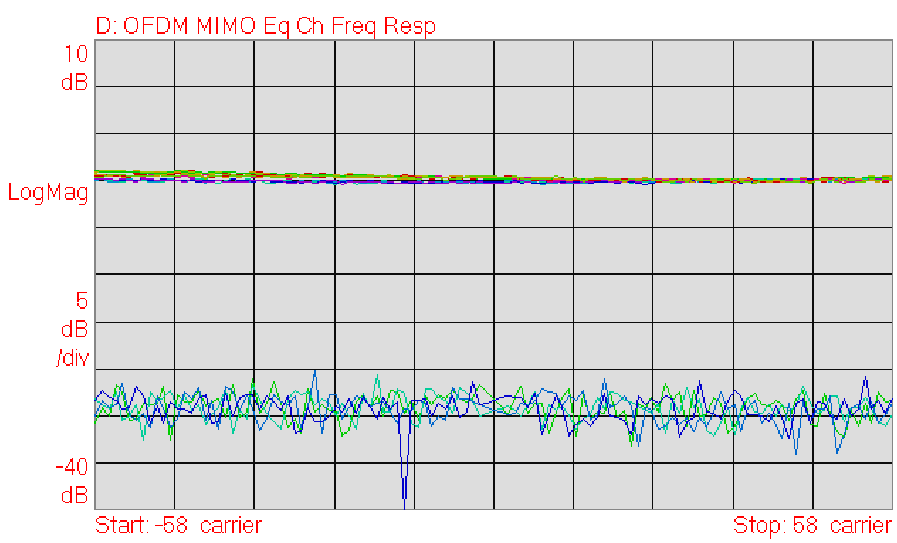


F: OFDM MIMO Chan Matrix

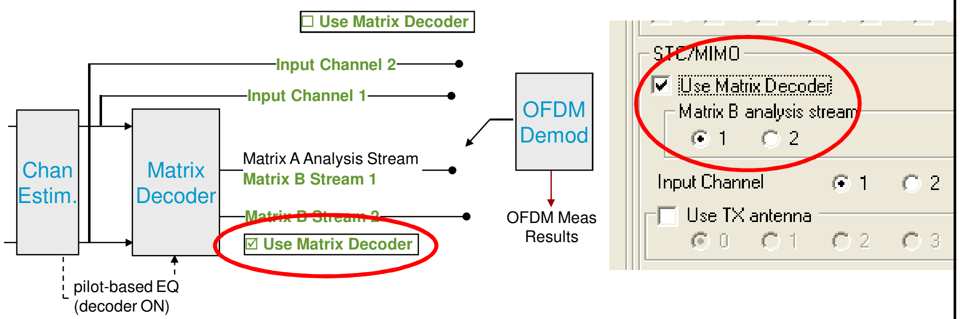
	Strm1	Strm2	Strm3	Strm4
Ch1	0.59+j0.00	0.59-j0.00	0.59+j0.00	0.59+j0.
Ch2	-0.51+j0.22	0.51-j0.22	-0.52+j0.22	0.52-j0.
Ch3	0.51-j0.26	0.27+j0.52	-0.51+j0.26	-0.26-j0.
Ch4	-0.01+j0.03	0.03+j0.01	0.01-j0.03	-0.03-j0.

MIMO 4x4 Frequency Response

802.11n Example: One Weak Channel



Matrix Decoder & Crosstalk



Measurements Made Without Matrix Decoder

- Effects of crosstalk are included in measurement
- Crosstalk degrades EVM
- Error due to crosstalk can hide other errors

Measure Both Ways to Understand Error Contribution of Crosstalk

Signal Analysis Solutions, Comparisons

Vector Signal Analysis Software

Spectrum/Signal Analyzers

Digital Oscilloscopes

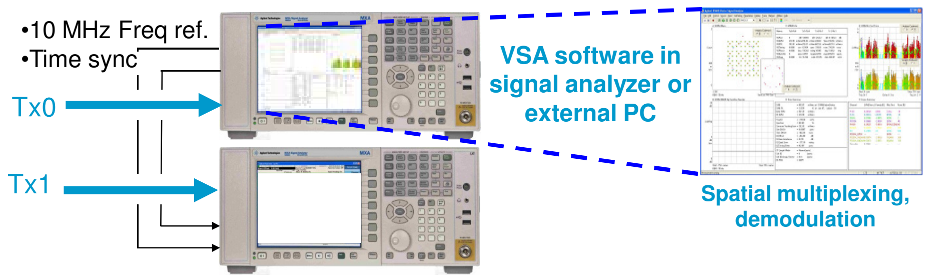
Modular VXI

Design & Simulation Software

- Agilent ADS
- Matlab

Dual RF Signal Analyzer MIMO Solution

Agilent MXA, EXA

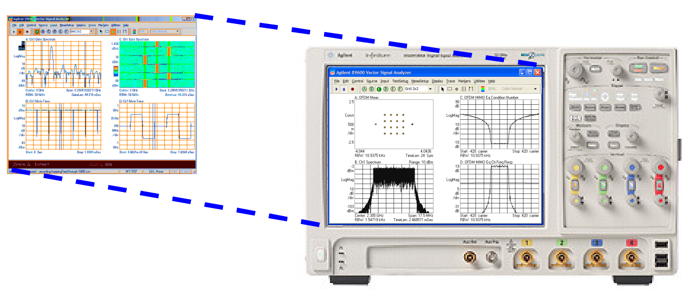


- VSA software controls, coordinates both analyzers
- References locked, time-synchronized, LOs not shared
- True MIMO analysis, matrix decoding; phase-stable (over a packet), not phase coherent
- Signal/spectrum analyzers can be used independently

Digitizing Oscilloscopes

Agilent Infiniium, InfiniiVision

Direct RF Input to 13GHz

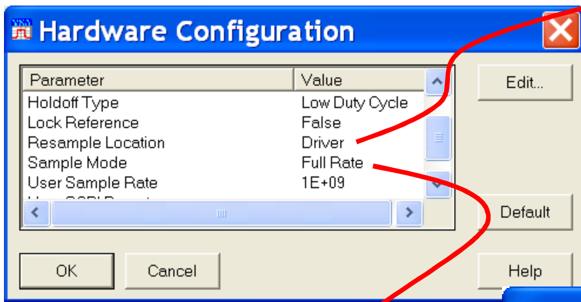


2 - 4 Ch. VSA operates in oscilloscope or connected PC

Oscilloscope + VSA software use covered in detail in ap-notes (see references)

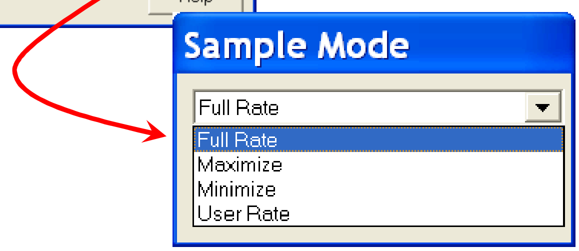
Digitizing Oscilloscopes

Driver & Integration, More Than Simple Data Transfer

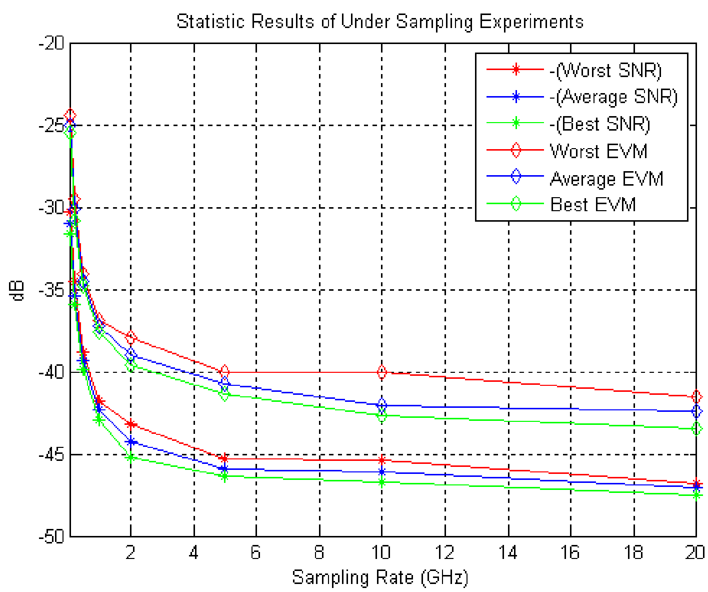


Resample in Driver

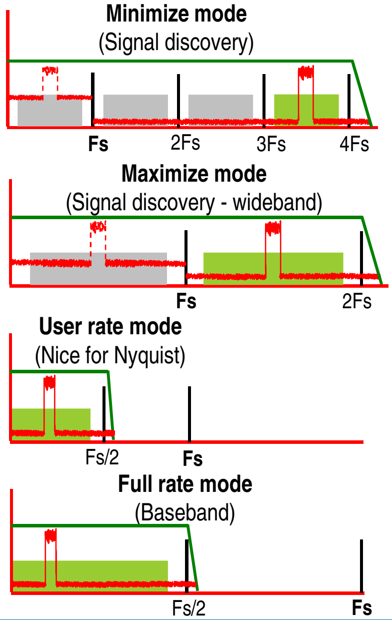
- Decimation, resampling performed before measurement process
- Improves memory limitations, measurement speed



Sampling Rate vs. Performance



Oscilloscope Baseband Sampling Modes



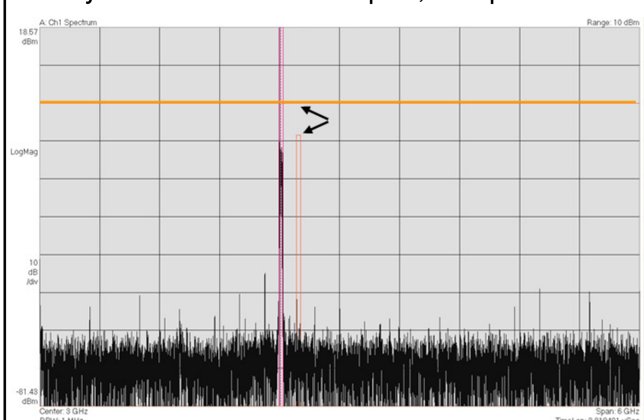
Scope sample mode	Meas. Speed	Signal acquire length*	EVM (noise floor)
Minimize ***(Max under-sample)***	★★★★	★★★★	★
Maximize ***(Least under-sample)***	★★★	★★★	★★
User Rate ***(Any rate, nice for Nyquist)***	★★	★★	★★★ (Recom-mended)
Full Rate ***(No aliases)***	★	★	★★★★

Alias Checking, Anti-Alias Filters

Alias Exposure Zone Checker Macro

- Measured & marked by automatically
- Any combination of CF span, sample rate

Anti-Alias Filters:
Lowpass, Bandpass



4 Channel Oscilloscopes, Agilent Examples

Model #	Sample rate	Freq Range
DSO 91304	40 GSa/s	13 GHz
DSO 90604	20 GSa/s	6 GHz
DSO 90404	20 GSa/s	4 GHz
DSO 90254	20 GSa/s	2.5 GHz
DSO 7104A	4 GSa/s	1 GHz
DSO 6104A	4 GSa/s	1 GHz
DSO 80000 Series	40 GSa/s	2-13 GHz

} External Downconversion, Filtering (DSO 7104A, DSO 6104A)

Comparison: Spectrum/Signal Analyzers and Digital Oscilloscopes with VSA Software

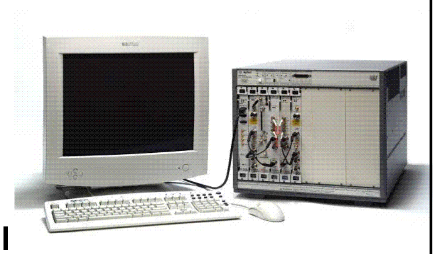
Spectrum/Signal Analyzers

- Best dynamic range, EVM
- All traditional single-channel measurements
- Re-deploy analyzers as needed
- Measurement applications for distortion, phase noise
- Linked analyzers provide true MIMO analysis, demodulation
- Faster demodulation results

Digital Oscilloscopes

- Four simultaneous channels
- Full phase coherent analysis, best for channel modeling & beamforming
- Widest bandwidth
- Most cost-effective per channel for 3 - 4 channels
- Simpler physical configuration
- Very good EVM (at higher sample rates)

VXI Modular 2 Channel Vector Signal Analysis



89600 VSA Software

Shared ADC Sample Clock

Upgradable 1 Channel - 2 Channel

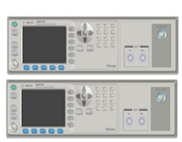
Selectable Channel Triggering

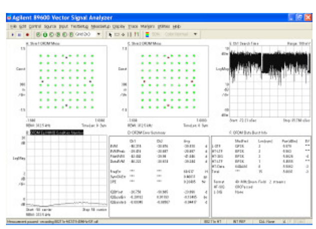
Common LO to 2.7GHz

- **Phase coherent to 2.7 GHz**
- **Phase *stable (over the course of a packet)* to 6 GHz**

Multi-Input Alternative

Agilent N4010 for 802.11n





Measurement software gathers IQ information simultaneously from multiple receivers

Measurement software gets data sequentially from a multiplexing switch

Measurements & Number of Inputs

	Number of measurement inputs required		
Measurement objective	1	2	> 2
SISO & MISO errors due to phase noise, timing errors and amplitude clipping	Y		
Spectrum Mask, Harmonics and Spurious	Y		
RF Phase and Baseband Timing Alignment, using pilot-based measurements	Using a power combiner.	No combiner needed but errors from second analyzer input will contribute to result	
Cross Channel Isolation. Using RS-based measurement	Y	Similar measurements to single input. Can connect to two transmitters at the same time	
Interference, Grounding, Transient settling	Y		
Transmit Diversity Space Time Coding (Specific channels)	Y		
MIMO Spatial Multiplexing (with unwanted coupling) and coding verification	Individual (Direct Mapped) streams	Y	If > 2 streams

Signal Generation Solutions, Comparisons

Signal Generation Software

- Agilent Signal Studio, single channel & MIMO

RF Signal Generators

- Agilent ESG series, MXG series

MIMO Receiver Tester

- Agilent PXB

Design & Simulation Software

- Agilent ADS
- Matlab

Linked RF Sources, MIMO-Capable Software

Arbitrary Waveforms Generated by Signal Studio

Software Generates Arbitrary Waveforms for Baseband

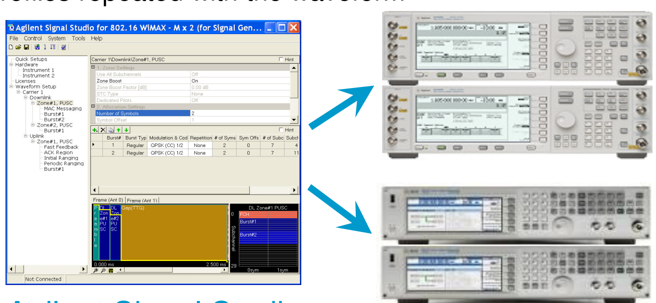
- Modulation, coding, frequency & power, signal generator coordination

Signal Generators Produce IF, RF Signals

- Can include impairments such as IQ errors, noise, phase noise

Some Fading

- Fading Profiles repeated with the waveform

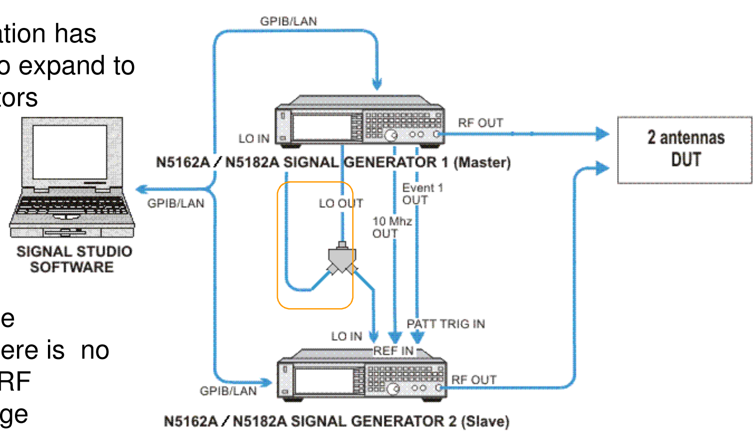


Agilent Signal Studio

Agilent MXG Phase Coherence

Reference Lock Provides Phase Stability (for a packet)
Shared LO Where Absolute Phase Needed (beamforming)

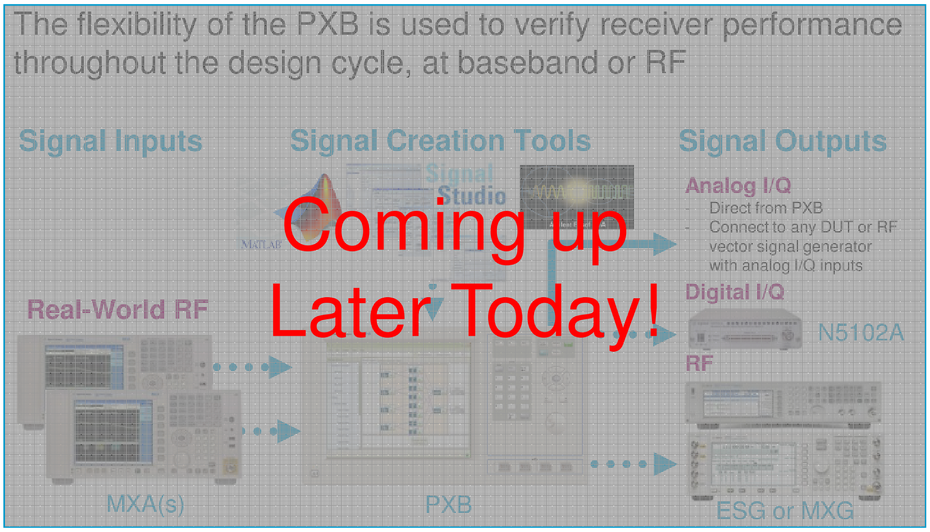
This configuration has the flexibility to expand to 3 or 4 generators



Using separate generators, there is no constraint on RF frequency range

Timing synchronization is dealt with by instrument firmware

N5106A PXB MIMO Receiver Tester: Connectivity for Real-World Fading



Comparison: MIMO Receiver Tester and RF Signal Generator(s) with ARBs

Signal Generators with ARBs

- Direct BB, IF, RF signal gen.
- Re-deploy sources as needed
- Produce fully coded signals
- Produce signals with IQ errors, noise
- Basic fading - fading profiles repeated with waveform (limited fade length not appropriate for slow fading)

MIMO Receiver Tester

- Four simultaneous channels
- Configurable channel correlation
- Signal input from Signal Studio, design/simulation programs, real-world RF capture
- Direct analog & digital BBIQ outputs, RF outputs through ESG, MXG signal generators
- Fast, precise, automated digital power calibration
- Fast, easy configuration changes
- Standards-compliant signals

Test Types & Number of Sources

Issue	1 Channel	2 Channels
Input Sensitivity (BER or PER) due to noise floor, phase noise, RF signal Interference	Y	
Signal Path response matching Amplifier characterization	Y	
Interference, Grounding, Transient settling, dynamic performance, e.g. AGC operation	Y	Y
Cross Channel Isolation	(Y)	Y
MIMO operation and Interoperability Full Channel model Testing		Y

Protocol & Conformance Test

Real-time LTE and WiMAX base station emulation for mobile development

Anite SAT LTE Protocol Tester with Development Toolset built on the Agilent E6620A

Agilent E6651A WiMAX

Additional Resources

www.agilent.com/find/mimo

Webcast: Ten Things You Should Know About MIMO
http://seminar2.techonline.com/s/agilent_Oct0808

Webcast: MIMO Channel Modelling and Emulation Test Challenges
http://www.techonline.com/learning/webinar/210603655

MIMO WLAN PHY layer Operation and Measurement AN1509
http://cp.literature.agilent.com/litweb/pdf/5989-3443EN.pdf

Video: Single-channel measurements for WiMAX matrix A and B
http://wireless.agilent.com/vcentral/viewvideo.aspx?vid=366

Webcast: WiMAX Wave 2 Testing - MIMO & STC
http://www.techonline.com/learning/livewebinar/204203534

Vector Signal Analyzer & Oscilloscope Performance Guides:

- 6000 & 7000 series: Literature no. 5989-4523EN
- 80000 & 90000 series: Literature no. 5988-4096EN