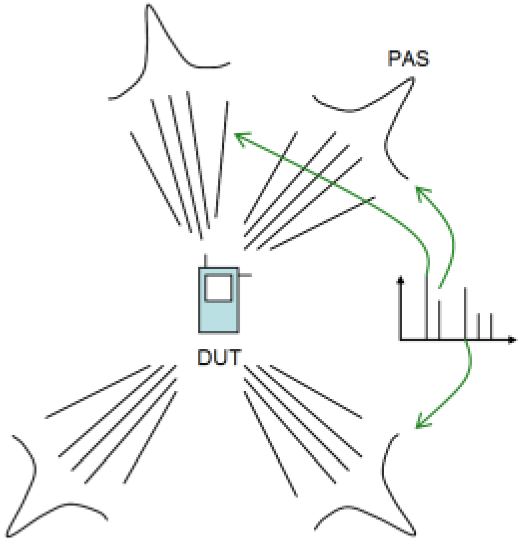
octoScope

Fundamentals of channel emulation



Mar-2012

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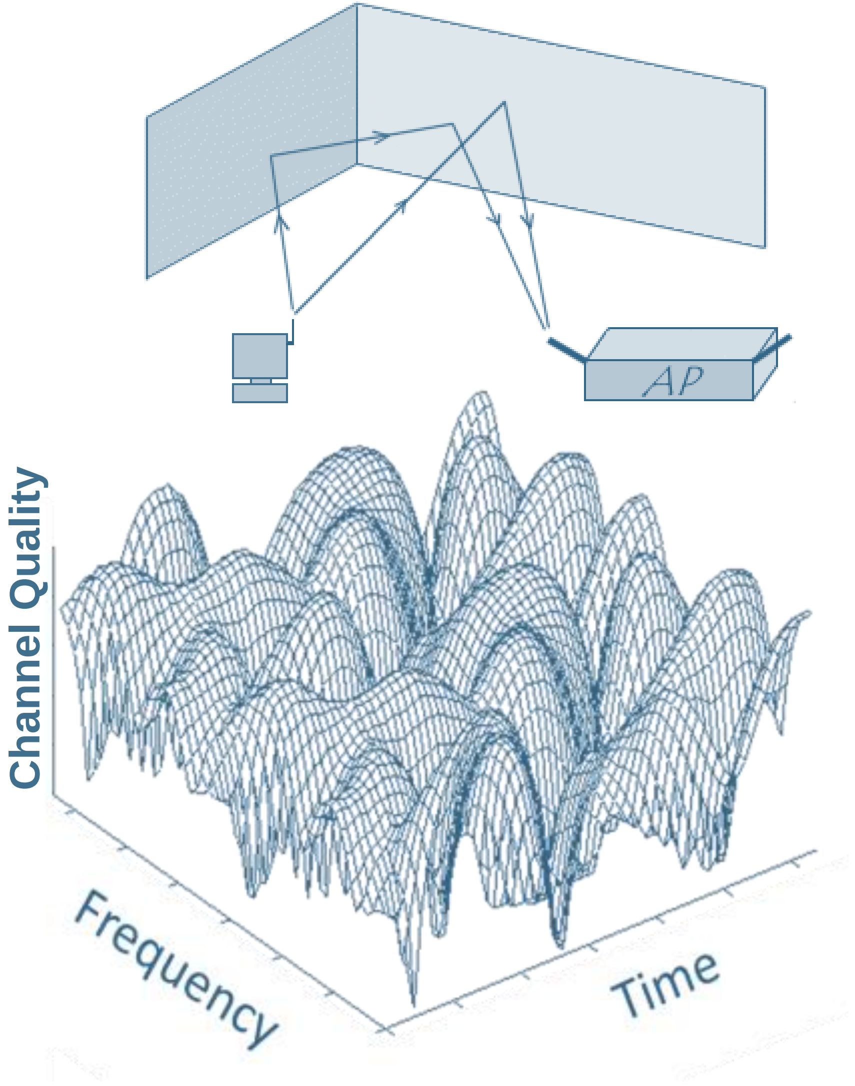
Outline

- What is channel emulation and why is it critical for MIMO systems?
- Channel modeling standards and technologies
- Channel model statistics
- MIMO/OTA
- Channel emulator implementation
- Competitive analysis

Wireless Channel

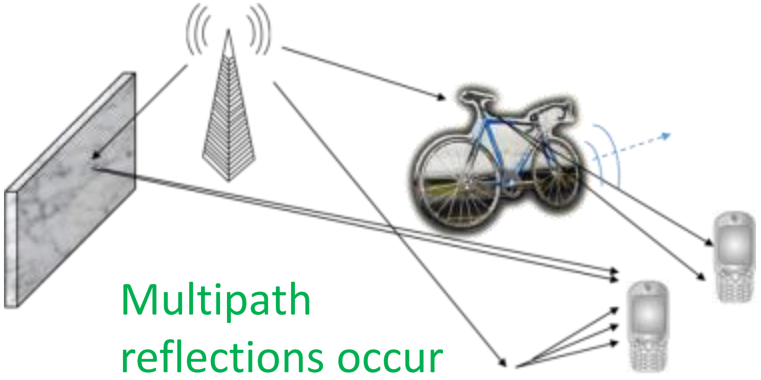
- Frequency and time variable wireless channel
- Multipath creates a sum of multiple versions of the TX signal at the RX
- Mobility of reflectors and wireless devices causes Doppler-based fading
- Multiple antenna techniques are used to optimize transmission in the presence of multipath and Doppler fading



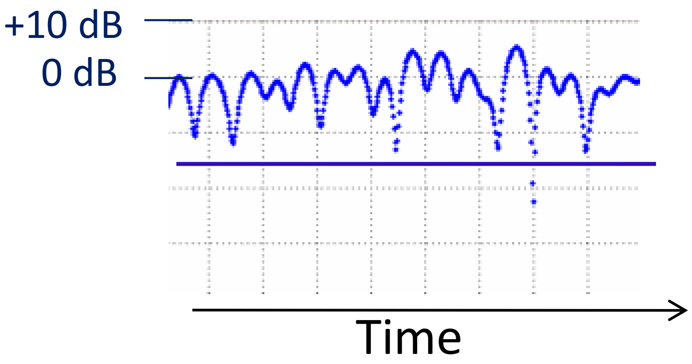
MIMO=multiple input multiple output

Multipath and Flat Fading

- In a wireless channel the signal propagating from TX to RX experiences
  - Flat fading
  - Multipath/Doppler fading



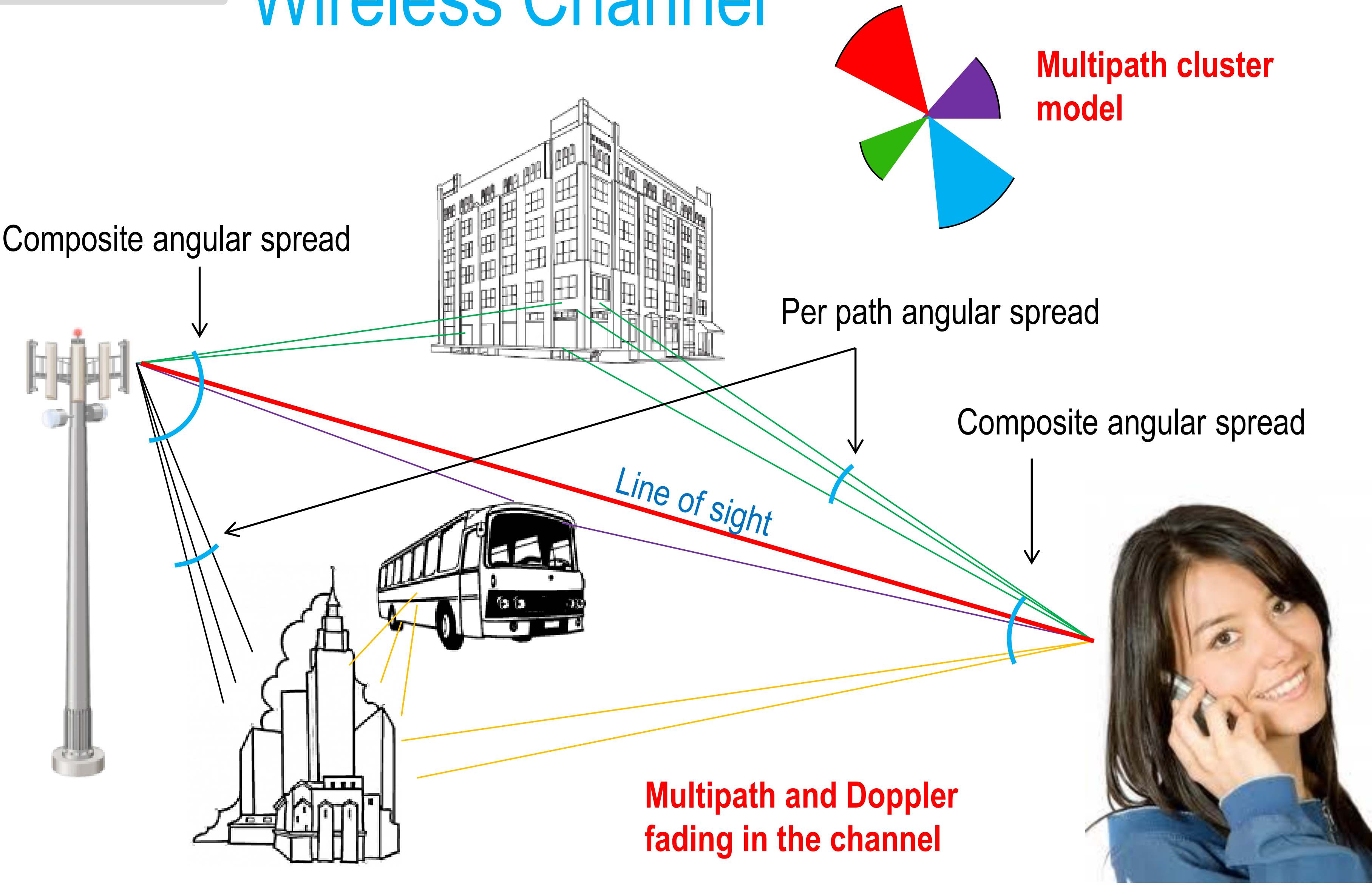
Multipath reflections occur in clusters.



Multipath fading component

-15 dB flat fading component

Wireless Channel



Multipath cluster model

Composite angular spread

Per path angular spread

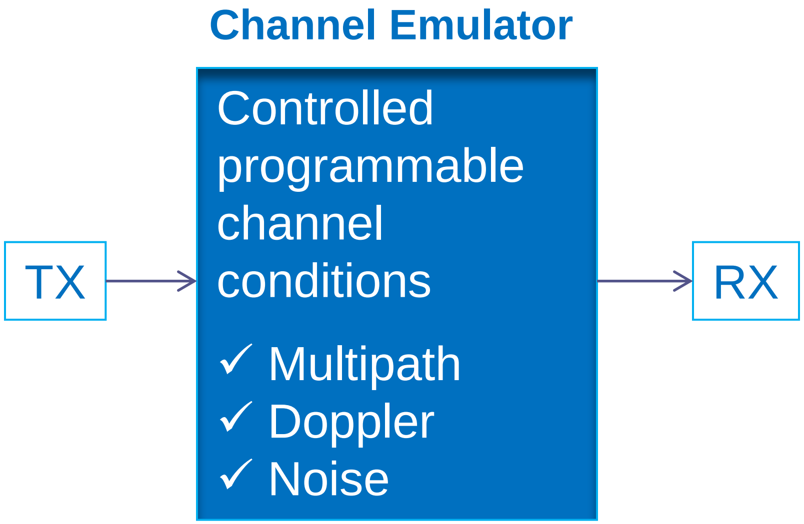
Composite angular spread

Line of sight

Multipath and Doppler fading in the channel

Validating Radio DSP

- A variety of channel conditions and complex multiple-antenna algorithms for adapting to these conditions make a channel emulator necessary for developing and testing radio DSP



Channel Emulator

TX

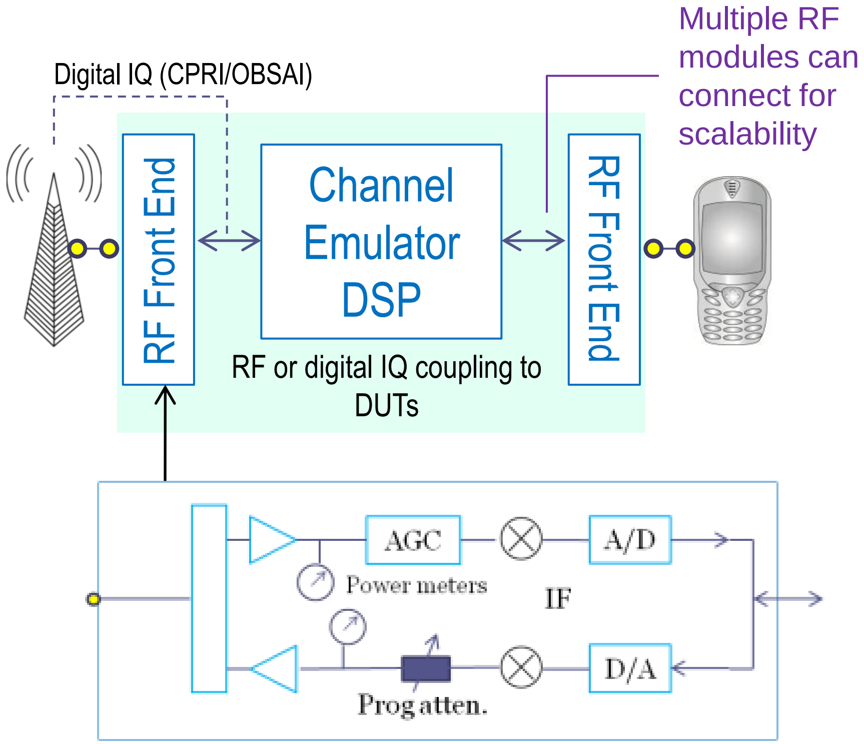
Controlled programmable channel conditions

- ✓ Multipath
- ✓ Doppler
- ✓ Noise

RX

Development and Test of MIMO

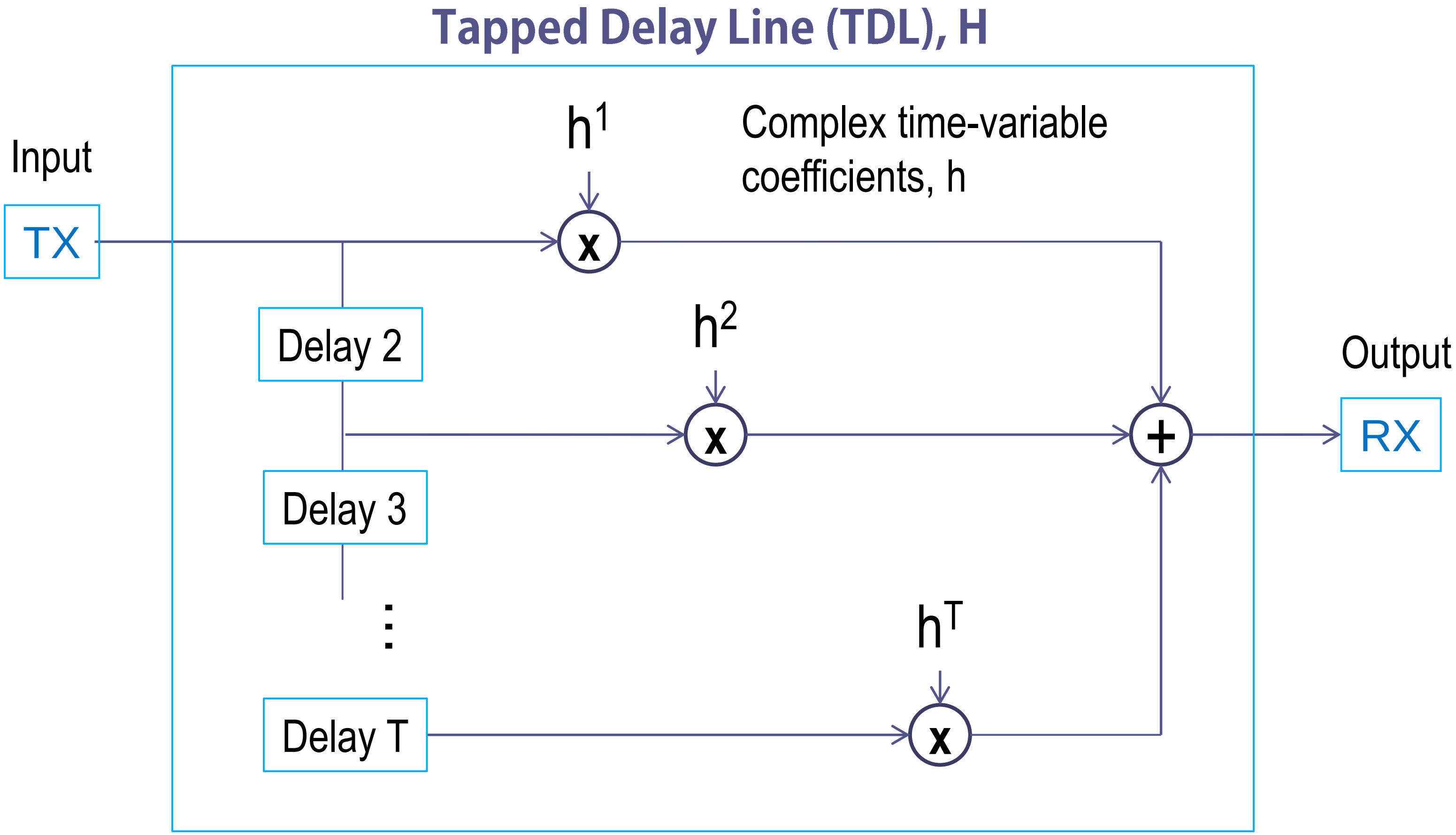
- Development and test of MIMO systems requires a channel emulator to emulate multipath and Doppler fading in a variety of wireless channels.
- Adaptive multiple antenna techniques, including TX and RX diversity, spatial multiplexing and beamforming involve sophisticated open and closed loop algorithms that must be tested under a range of controlled (emulated) channel conditions.
- Traditional channel emulators connect to DUTs conductively – without antennas. Antennas and antenna arrays are part of the channel models.



Multiple RF modules can connect for scalability

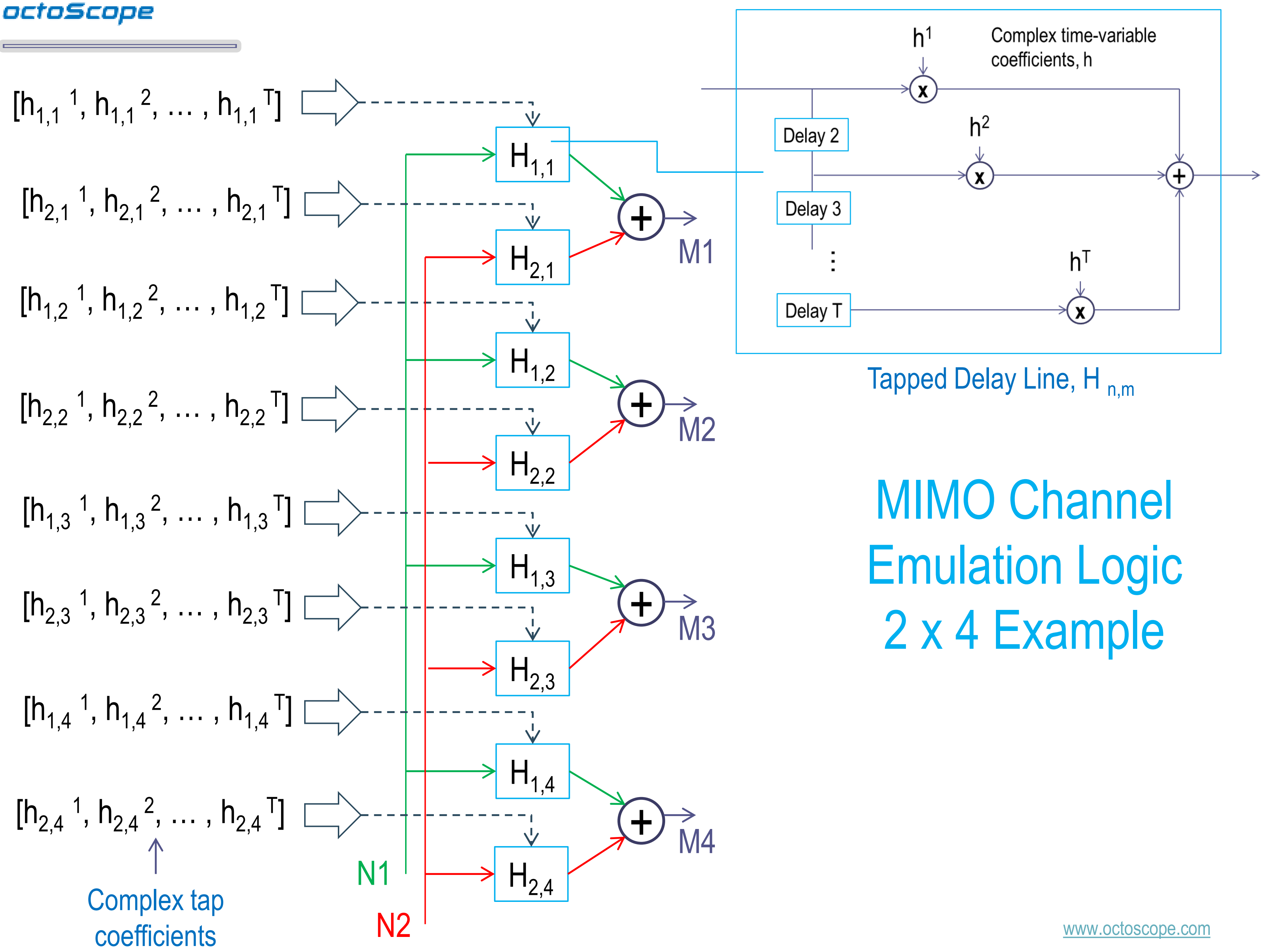
Problematic for MIMO and beamforming systems where antennas are integral to performance

SISO Channel Emulator



where **T** is the number of taps in the TDL

MIMO Channel Emulation Logic
2 x 4 Example



$[h_{1,1}^{1}, h_{1,1}^{2}, \ldots, h_{1,1}^{T}]$

$[h_{2,1}^{1}, h_{2,1}^{2}, \ldots, h_{2,1}^{T}]$

$[h_{1,2}^{1}, h_{1,2}^{2}, \ldots, h_{1,2}^{T}]$

$[h_{2,2}^{1}, h_{2,2}^{2}, \ldots, h_{2,2}^{T}]$

$[h_{1,3}^{1}, h_{1,3}^{2}, \ldots, h_{1,3}^{T}]$

$[h_{2,3}^{1}, h_{2,3}^{2}, \ldots, h_{2,3}^{T}]$

$[h_{1,4}^{1}, h_{1,4}^{2}, \ldots, h_{1,4}^{T}]$

$[h_{2,4}^{1}, h_{2,4}^{2}, \ldots, h_{2,4}^{T}]$

Complex tap coefficients

N1

N2

$H_{1,1}$ $H_{2,1}$ $H_{1,2}$ $H_{2,2}$ $H_{1,3}$ $H_{2,3}$ $H_{1,4}$ $H_{2,4}$

M1

M2

M3

M4

h^1

Complex time-variable coefficients, h

Delay 2

h^2

Delay 3

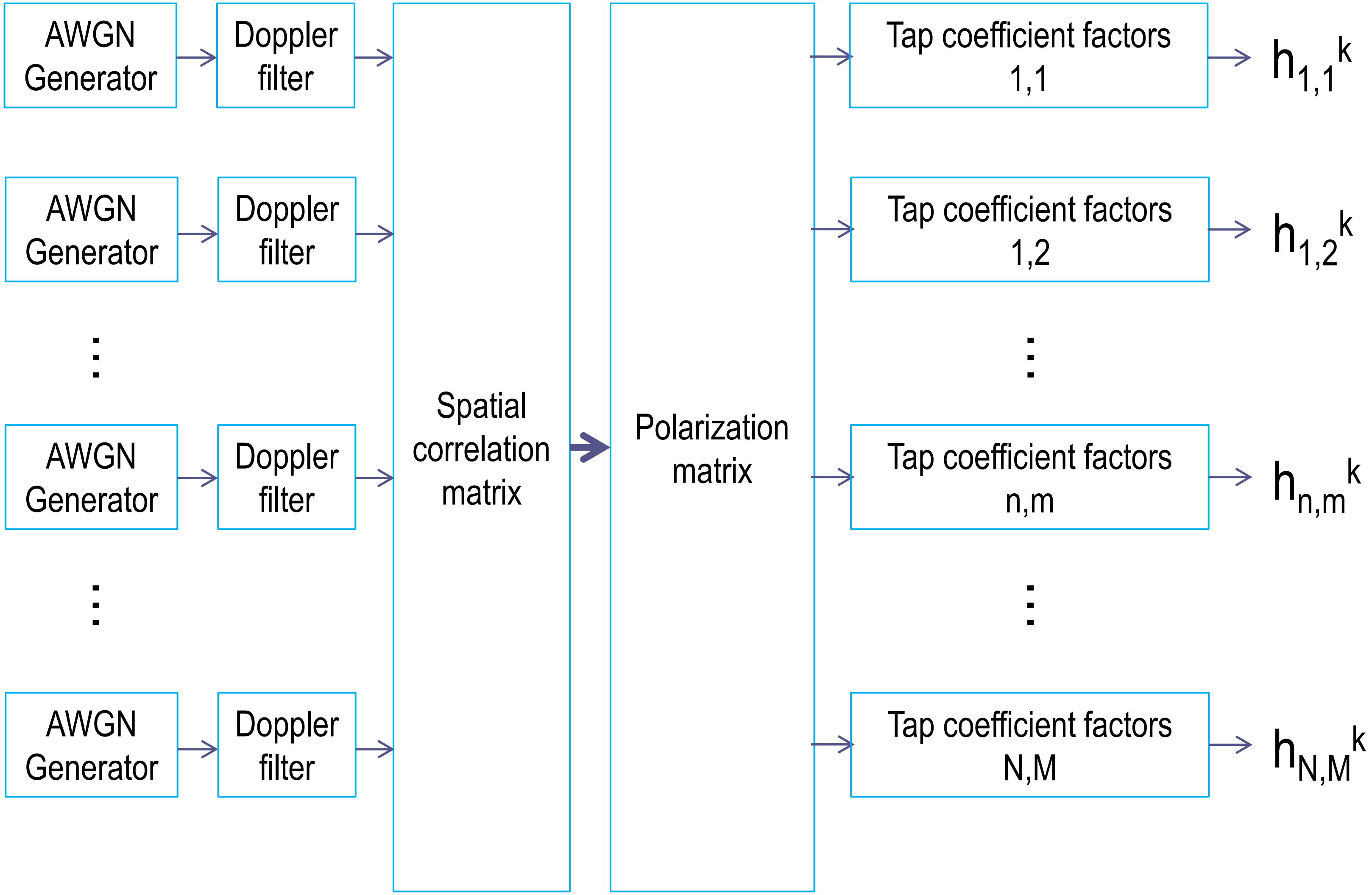
⋮

Delay T

h^T

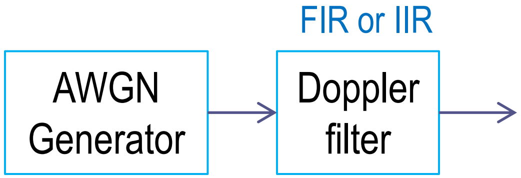
Tapped Delay Line, $H_{n,m}$

Complex Tap Coefficient Generator



where **k** is the tap number and **h** is the time-variable complex coefficient

Doppler Filter

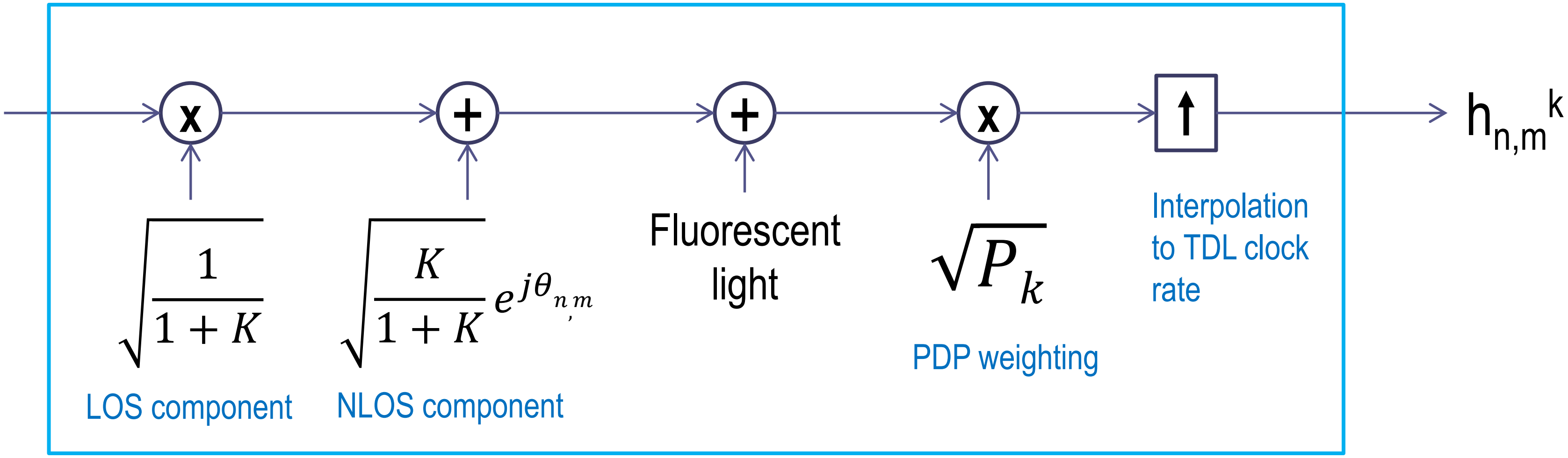


Doppler filter	Notes
Classical	Specified for most 3GPP channel models; Classical = Jakes; variations of classical filter used in the industry include Classical 3 dB and Classical 6 dB;
Bell	Specified for 802.11n channel models; variations of this filter include Bell-spike, which is used by 802.11 model F to model a 40 km/hour spike in the spectrum
Static	Models LOS on first tap; used in custom channel modeling
Flat	Can also be implemented using RF attenuators via an identity matrix (i.e. connecting inputs to outputs through attenuators)
Rounded	Variations of this filter include Rounded 12 dB
Gaussian	
Constant phase	
Butterworth	
Pure Doppler	

Notes on Doppler Filter Implementation

- AWGN sources are connected to Doppler filters that provide the desired spectral shape of the fading. The Doppler filter is IIR in the octoFade implementation.
- For 802.11n models, the filter is Bell-shaped for models A through F and Bell-Spike for model F. The Bell spectrum models fading due to walking-speed motion in the environment at an average speed of 1.2 km/hr. The spike in the Bell-Spike spectrum adds the effect of a vehicle moving at an average speed of 40 km/hr.
- For 3GPP models, the Doppler spectrum is Classical.

Tap Coefficient Factors



x

+

+

x

$h_{n,m}^{k}$

$\sqrt{\frac{1}{1+K}}$

LOS component

$\sqrt{\frac{K}{1+K}}e^{j\theta_{n,m}}$

NLOS component

Fluorescent light

$\sqrt{P_k}$

PDP weighting

Interpolation to TDL clock rate

Tap coefficient factors n,m

where **k** is the tap number, **h** is the time-variable complex coefficient, **K** is Rician K-factor

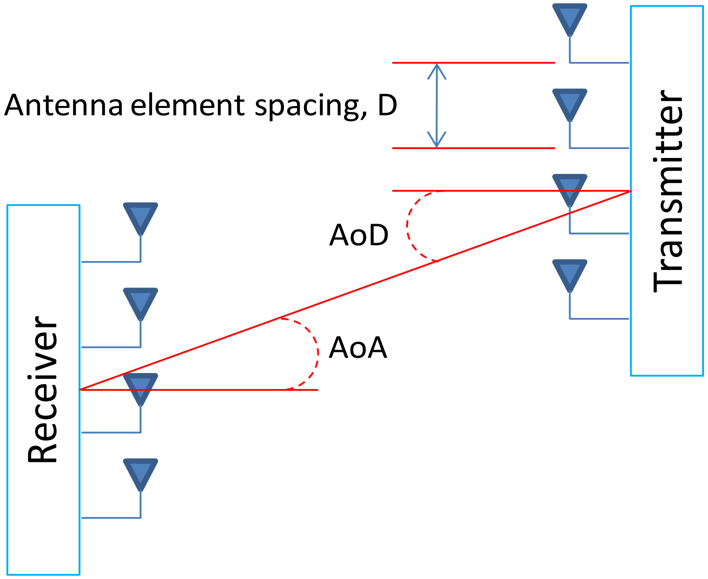
Notes on Tap Coefficient Factors

- The parameter K (Rician K-factor) determines the relative strength of the LOS and NLOS components and is set based on the chosen model.
- The $\sqrt{\frac{K}{1+K}}$ term models the LOS component. The $\sqrt{\frac{1}{1+K}}$ term models the NLOS component.
- The LOS component can only be present on the 1st tap. If the distance between the transmitter and the receiver is greater than the distance to 1st reflector (typically a wall in the indoor environment) then LOS component is not present. The presence of LOS is a configuration parameter that can be enabled or disabled.
- The first tap's LOS component isn't Doppler filtered. Thus, if LOS is present, the power spectrum on the first tap deviates from the Bell spectrum since it includes both the LOS and the NLOS components. If LOS is present, the PDF and CDF of the 1st tap are Rician. If LOS is not present the PDF and CDF on the 1st tap are Rayleigh. On all other taps the PDF and CDF are always Rayleigh.
- $\sqrt{P_k}$ represents the Power Delay Profile (PDP) weighting, summed over all the clusters that contribute power for the k_{th} tap. It reflects how strong the total power is at tap k.

802.11n/ac Correlation Matrix

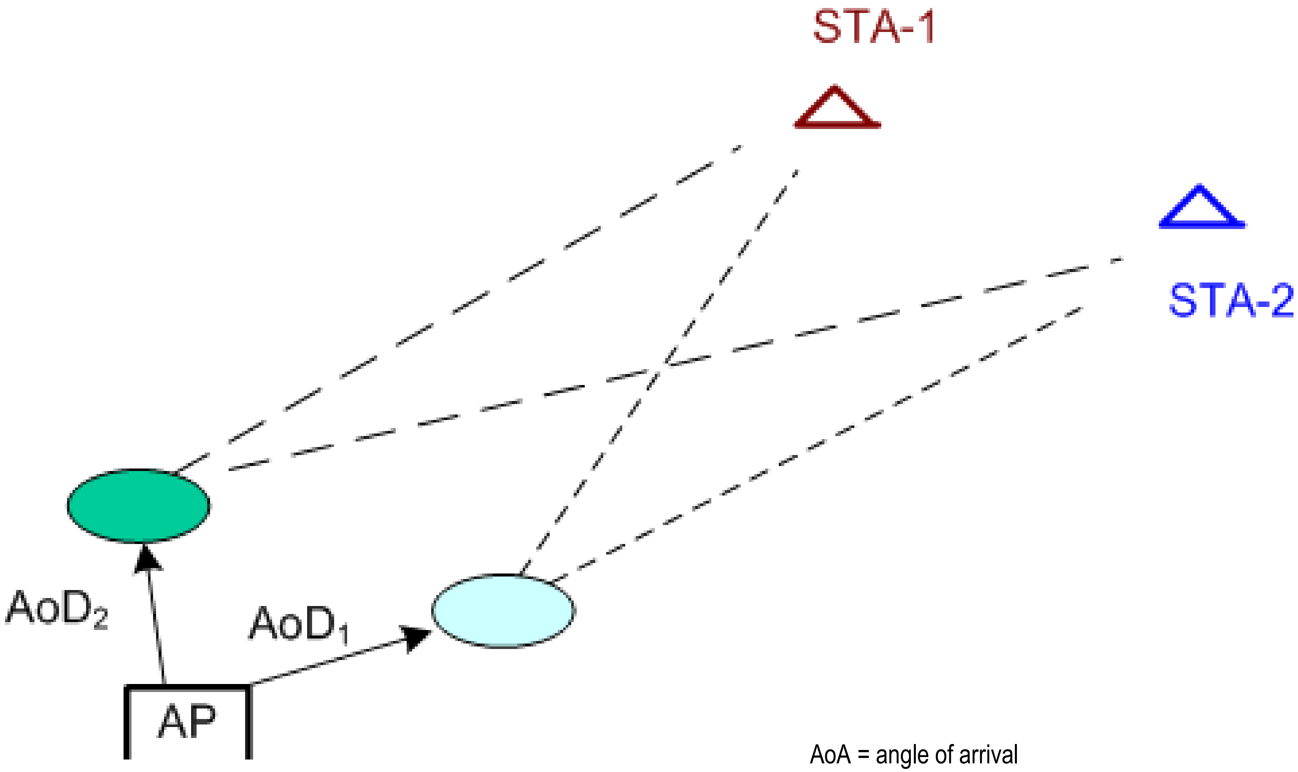
- The spatial correlation matrix is a function of the angular spread of each cluster, angle of arrival (AoA) and angle of departure (AoD). 802.11n models assume that RX and TX antenna systems are uniform linear arrays with equally spaced antenna elements.
- Spatial correlation is implemented using the Kronecker product of the transmit and receive correlation matrices, R_{tx} and R_{rx}, respectively. These matrices are comprised of correlation coefficient terms,ρ, that depend on the PAS, AoA, AoD, tap powers and distance D between antenna elements. Fox computes the real and imaginary parts, $R_{XX}(D)$ and $R_{XY}(D)$, respectively, for each ρ. This allows spatial correlation based on the complex field (i.e., using $\rho = R_{XX}(D)+jR_{XY}(D)$) or real power (i.e., using $\rho = R_{XX}^2(D) + R_{XY}^2(D)$).

Angle of arrival (AoA),
Angle of departure (AoD)
Antenna spacing, D



802.11ac Correlation and Polarization

- MU-MIMO modeled for AoD and AoA
- Polarization matrix added since 802.11ac devices are expected to have cross-polarized antennas



AoA = angle of arrival
AoD = angle of departure

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802.11n Channel Models - Summary

Model [1]		**Distance to 1st wall (avg)**	**# taps**	**Delay spread (rms)**	**Max delay**	**# clusters**
A*	test model		1	0 ns	0 ns	
B	Residential	5 m	9	15 ns	80 ns	2
C	small office	5 m	14	30 ns	200 ns	2
D	typical office	10 m	18	50 ns	390 ns	3
E	large office	20 m	18	100 ns	730 ns	4
F	large space (indoor or outdoor)	30 m	18	150 ns	1050 ns	6

* Model A is a flat fading model; no delay spread and no multipath

The LOS component is not present if the distance between the transmitter and the receiver is greater than the distance to 1st wall. The presence of LOS is a configuration parameter that can be enabled or disabled.

802.11ac Channel Models

- 802.11ac channel models are an extension of 802.11n models [2]

System Bandwidth W	Channel Sampling Rate Expansion Factor	Channel Tap Spacing
W ≤ 40 MHz	1	10 ns
40 MHz < W ≤ 80 MHz	2	5 ns
80 MHz < W ≤ 160 MHz	4	2.5 ns
W > 160 MHz	8	1.25 ns

3GPP Certification Channel Models

	Model Name	**Document**
LTE	EPA 5Hz; EVA 5Hz; EVA 70Hz; ETU 70Hz; ETU 300Hz; High speed train; MBSFN	3GPP TS 36.101 V10.5.0 (2011-12) Annex B
GSM	RAx; HTx; TUx; EQx; TIx	3GPP TS 45.005 V10.3.0 (2011-11) Annex C
3G	Case1, Case2, Case3, Case4, Case5, Case6, Case8, PA3; PB3; VA30; VA120; High speed train; Birth-Death propagation; Moving propagation; MBSFN	3GPP TS 25.101 V11.0.0 (2011-12) Annex B

Other 3GPP Channel Modeling Documents

- 37.976 Test Plan for MIMO/OTA
  - More on this methodology in the MIMO/OTA section below
  - Requires SCME per 25.996
  - Referenced in Verizon ODI LTE_3GPP_Band13_Data Throughput Test Plan
- 25.996 Spatial channel model for Multiple Input Multiple Output (MIMO) simulations
- 36-521-1 UE Conformance Specification, Annex B
  - References 36.101
- 36.141 Base station conformance test, Annex B
- 36.814 Further advancements for E-UTRA physical layer aspects (LTE-A), Annex B
  - Remote radio head, femtocell and outdoor relay channel models
- WIM2 model for LTE-A from ITU

WIM2 = WINNER Phase II Model
WINNER = Wireless World Initiative New Radio
OTA = over the air
ODI = open developer initiative
SCME = spatial channel models enhanced

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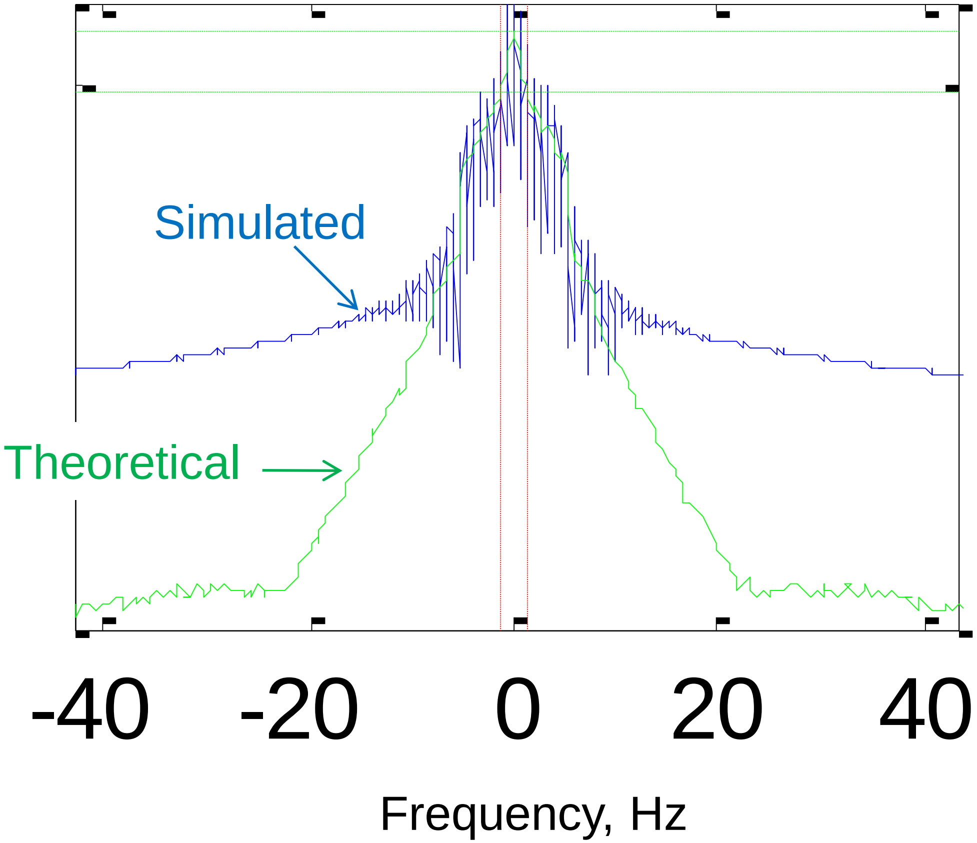
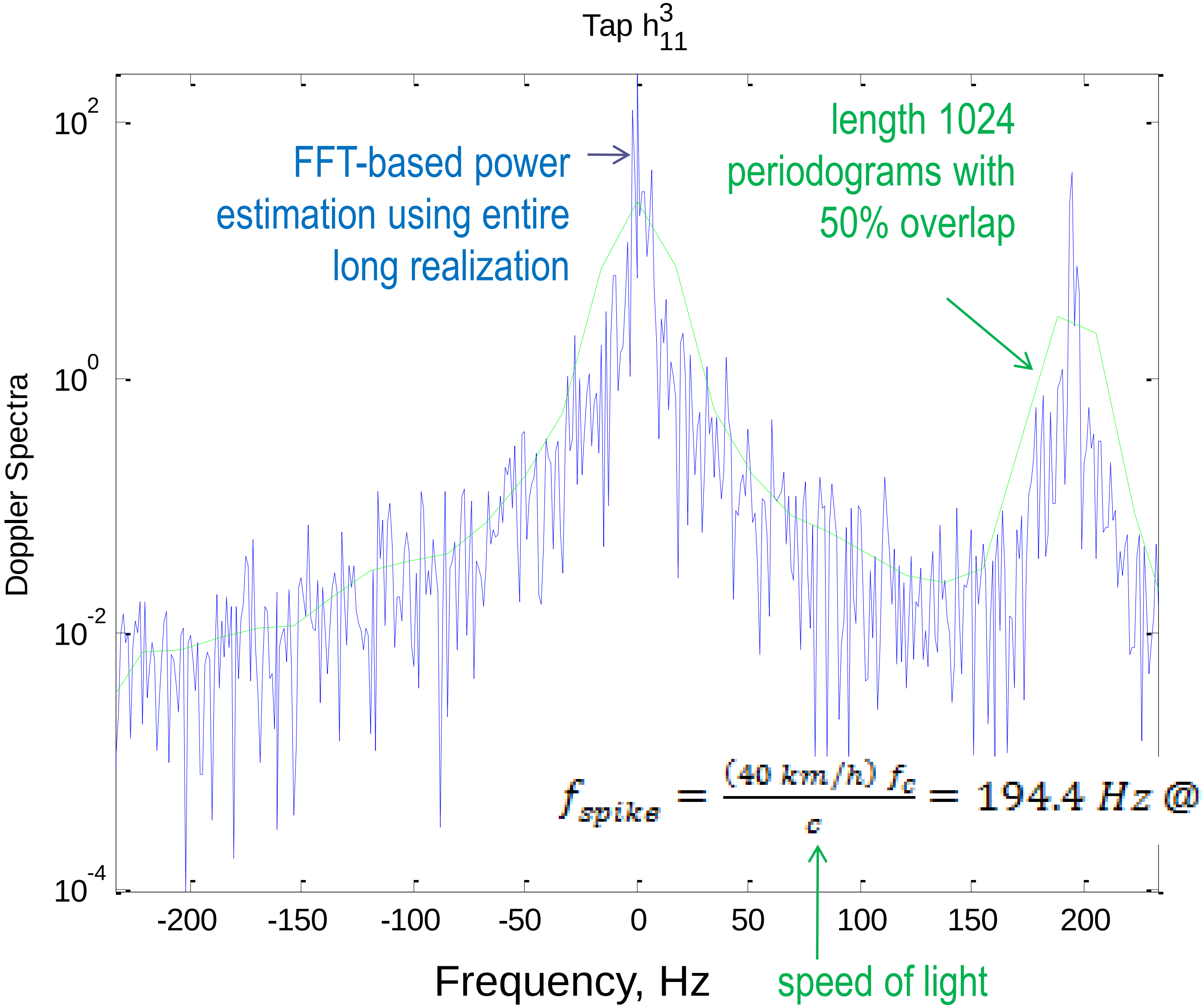
Doppler Spectrum – 802.11n Model F



- Example of Doppler spectrum plots for IEEE 802.11n model F
  - Environment velocity is 1.2 km/hour and is modeled on all taps for all models
  - Tap 3 for model F includes automotive velocity spike at 40 km/hour

The Doppler spread is 3 Hz at 2.4 and 6 Hz at 5.25 GHz for environment speed of 1.2 km/hour

Doppler Spectrum – 802.11n Model F, Tap 3



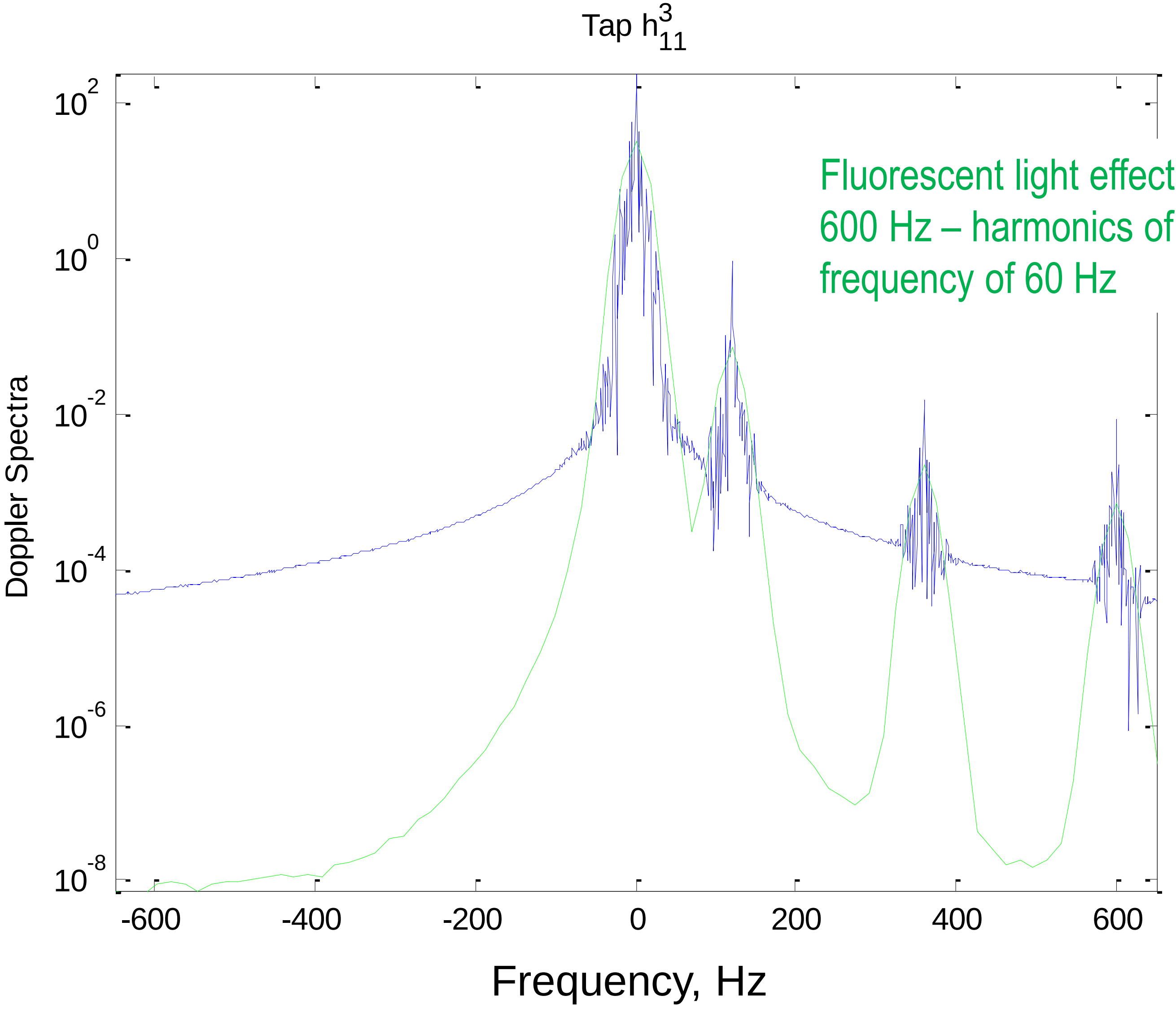
FFT-based power estimation using entire long realization

length 1024 periodograms with 50% overlap

$$f_{spike} = \frac{(40\ km/h)\ f_c}{c} = 194.4\ Hz\ @\ f_c = 5.25\ GHz$$

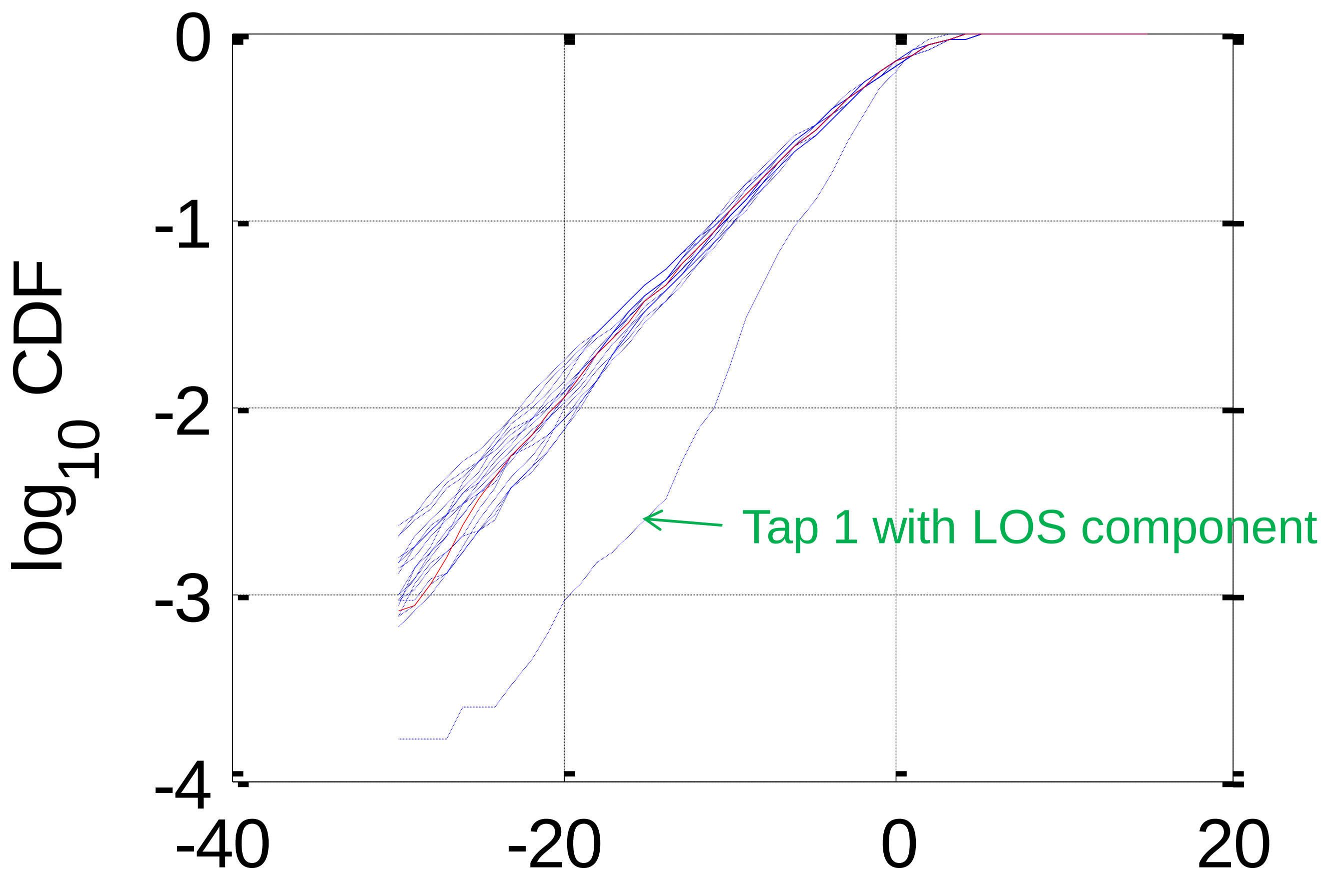
speed of light

Doppler Spectrum – 802.11n Model E, Tap 3



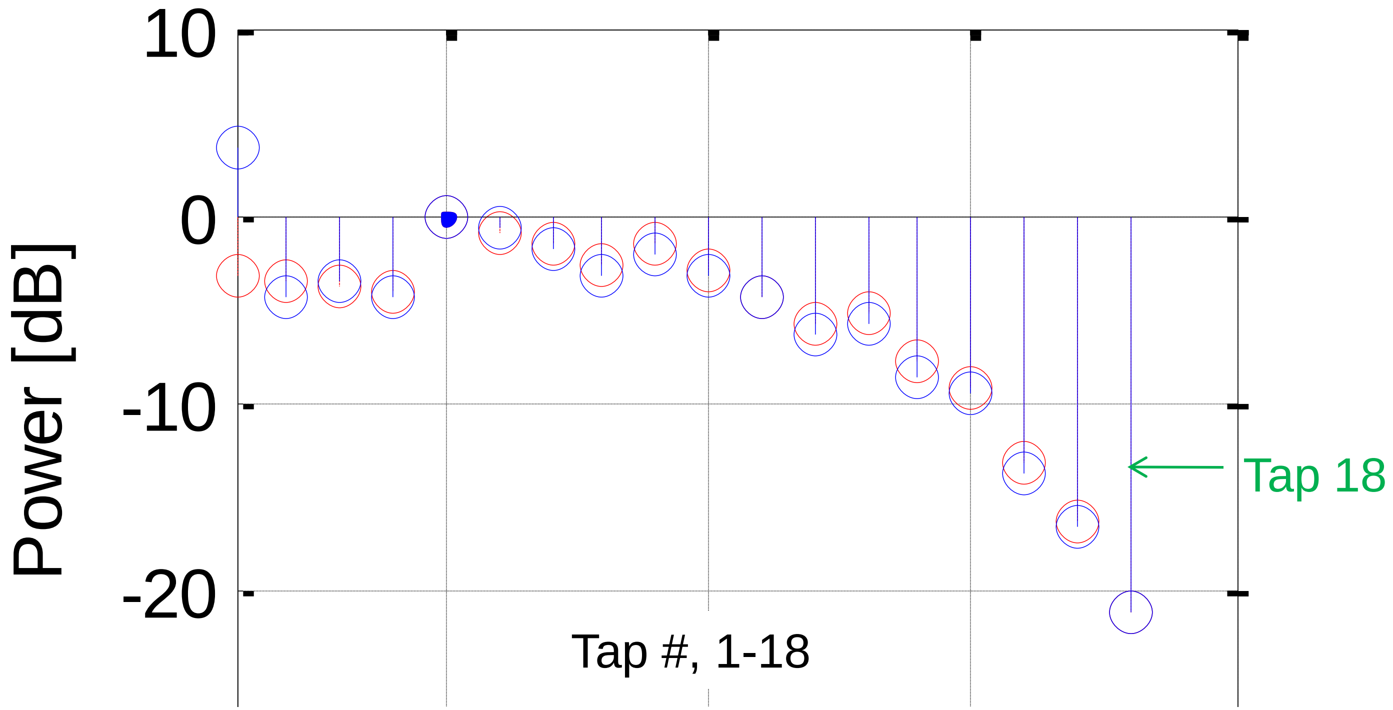
Fluorescent light effects at 120, 360, and 600 Hz – harmonics of the power line frequency of 60 Hz

Cumulative Distribution Function (CDF)



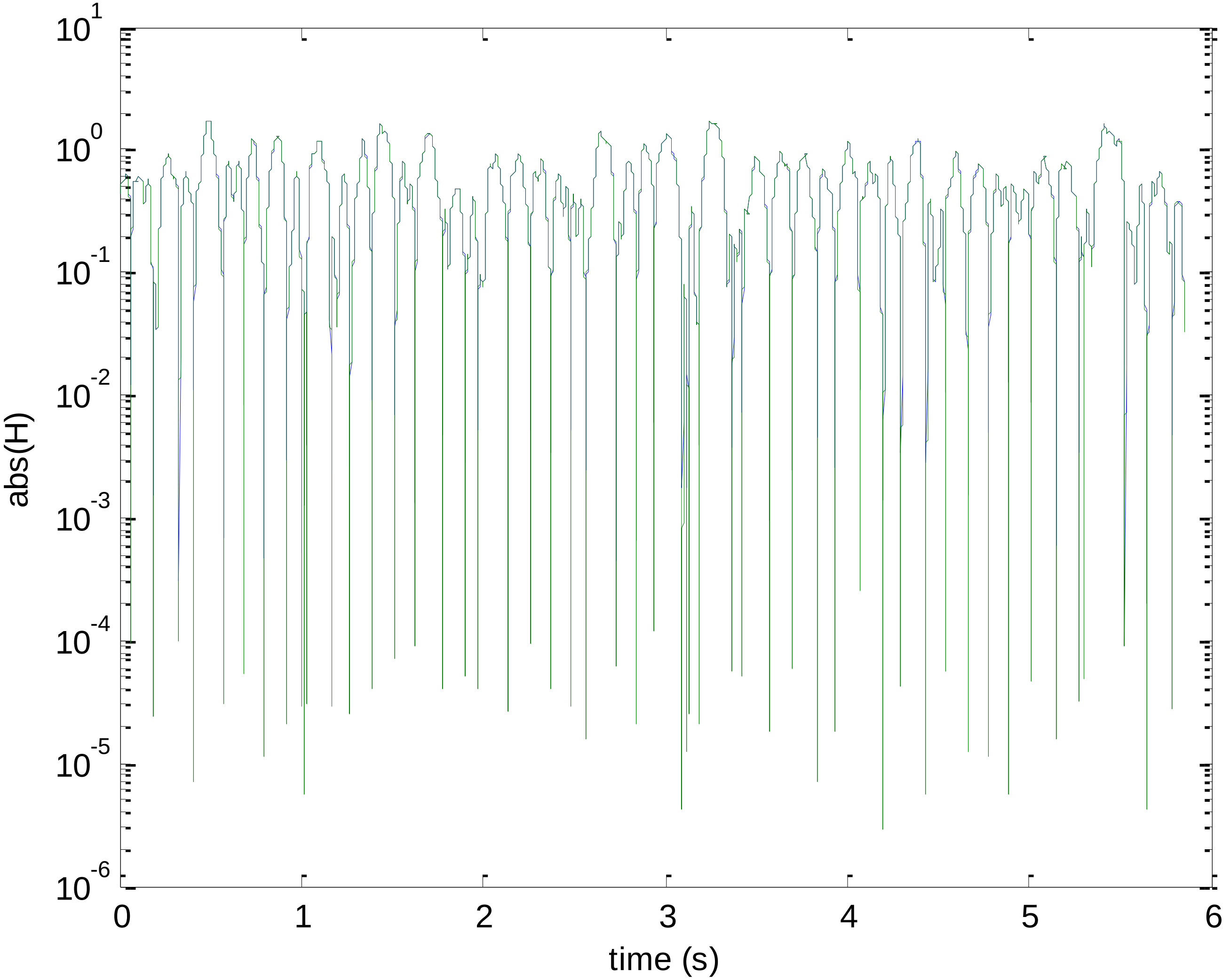
- IEEE 802.11n, Model F, CDF for 18 taps

Power Delay Profile (PDP) – Model F



- Power decreases with increasing tap delay.
- Red points are for the normalized PDP under NLOS conditions. Blue points are simulated normalized PDP under LOS conditions.

Channel Impulse Response



- Impulse response, IEEE 802.11n model F

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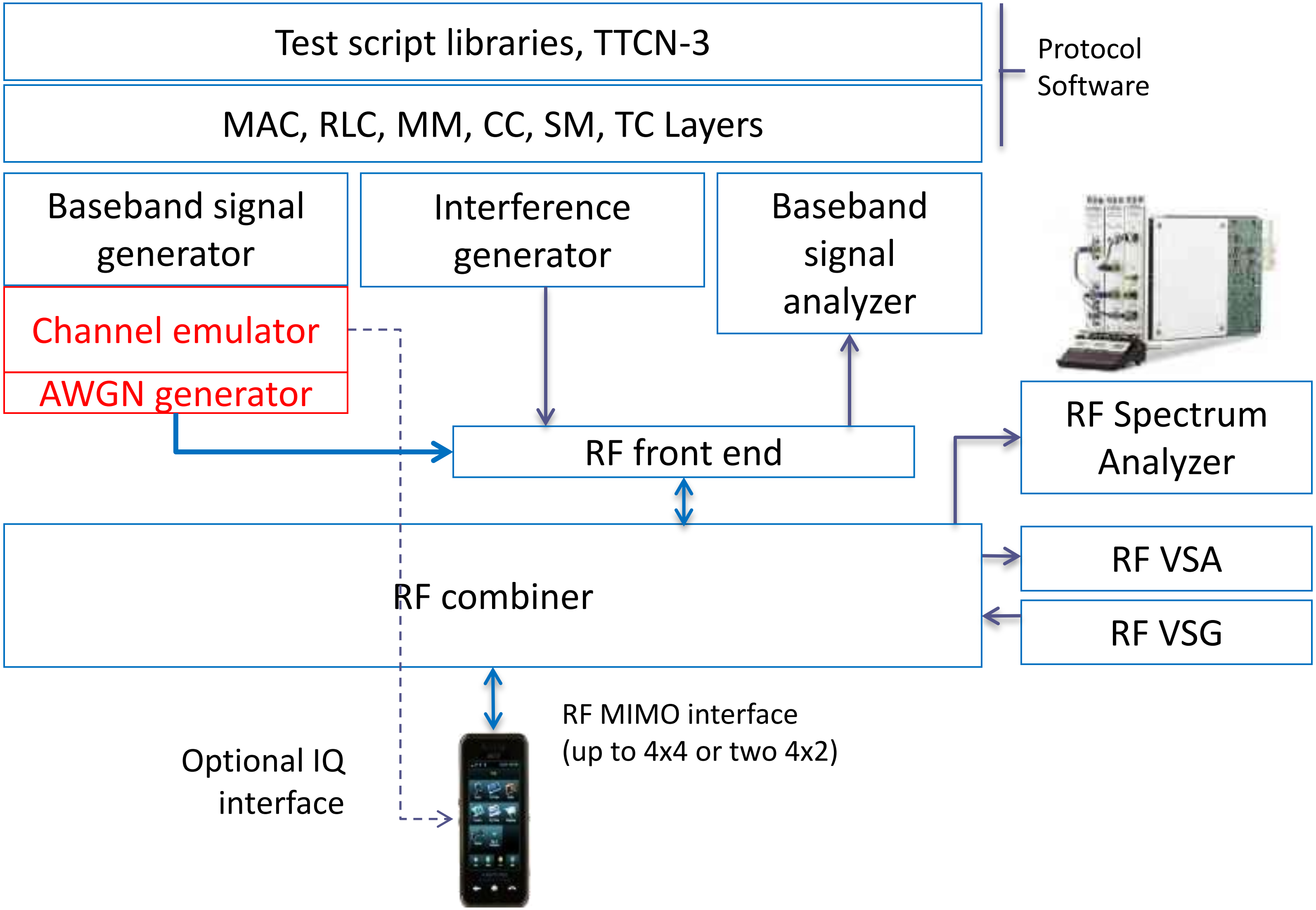
Typical LTE Certification Configuration



Test script libraries, TTCN-3

MAC, RLC, MM, CC, SM, TC Layers

Protocol Software

Baseband signal generator

Interference generator

Baseband signal analyzer

Channel emulator

AWGN generator

RF front end

RF Spectrum Analyzer

RF combiner

RF VSA

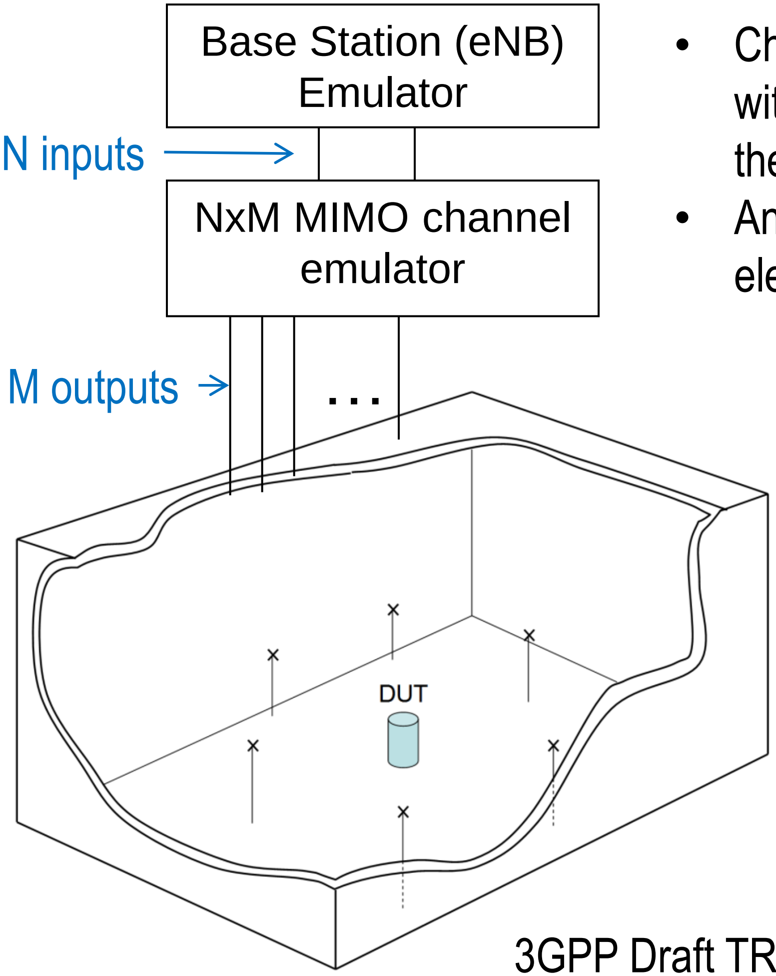
RF VSG

Optional IQ interface

RF MIMO interface (up to 4x4 or two 4x2)

MIMO/OTA Standardization Efforts

- Channel emulator performs NxM DL emulation with N typically being 2 and M being equal to the number of probe antennas
- Antennas are typically cross polarized (with 2 elements each: vertical and horizontal)



Base Station (eNB) Emulator

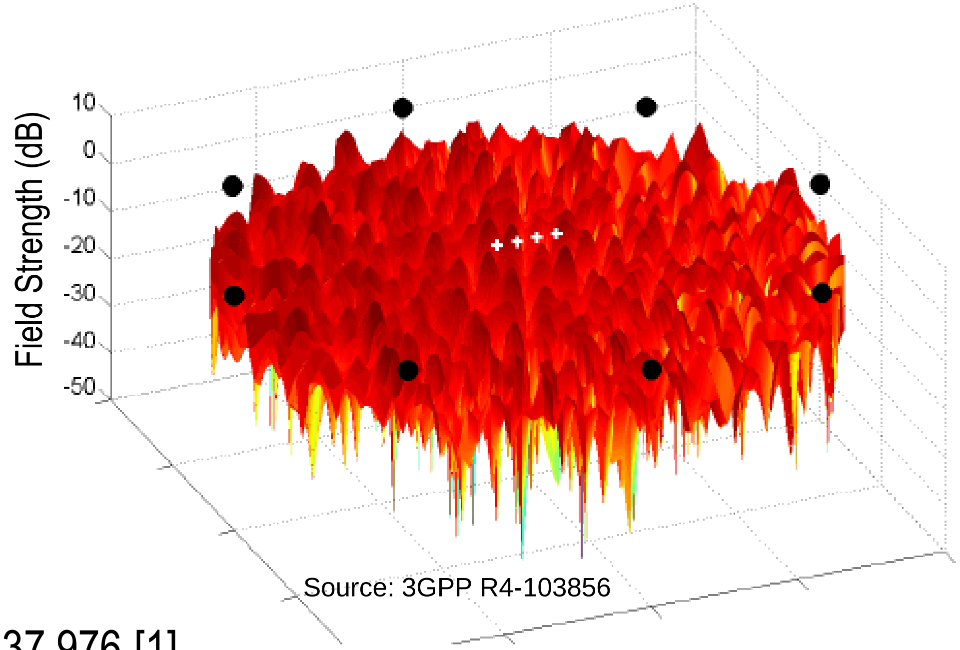
N inputs

NxM MIMO channel emulator

M outputs

. . .

3GPP Draft TR 37.976 [1]

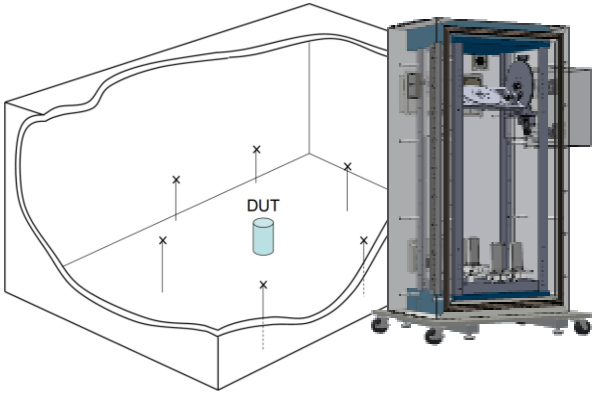


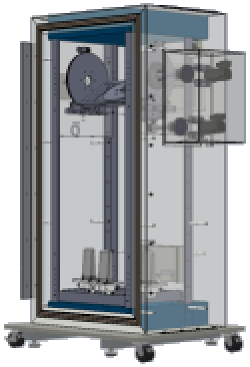
Source: 3GPP R4-103856

MIMO/OTA Standards Organizations

- 3GPP (International)
  - MIMO/OTA specification development [1]
  - Driven by TSG RAN WG4 in collaboration with CTIA & COST
- CTIA (US)
  - SISO OTA certification standard [4]
  - Recently formed MIMO/OTA Sub-Working Group (MOSG) is driving effort to update current standard [4] for MIMO/diversity
- COST (Europe)
  - Recently formed ICT COST IC1004 Action: “Cooperative Radio Communications for Green Smart Environments”; Formerly COST 2100 Action: “Pervasive Mobile & Ambient Wireless Communications”
  - Contributions driven by SWG2.2: “Compact Antenna Systems for Terminals”

Proposed MIMO OTA Test Methods

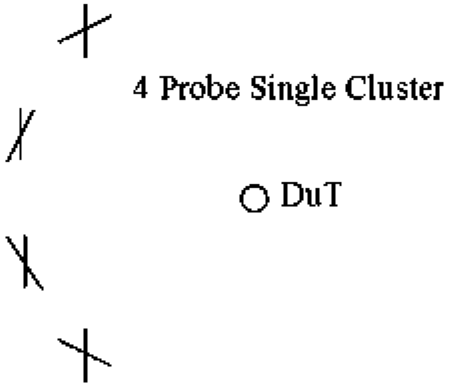


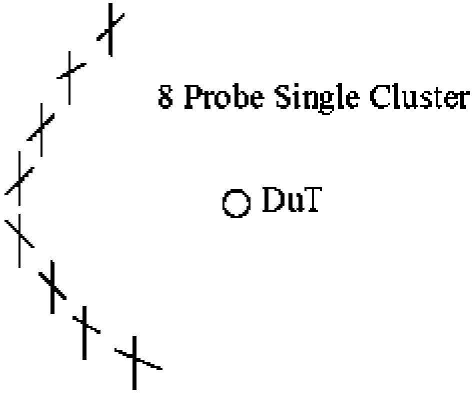


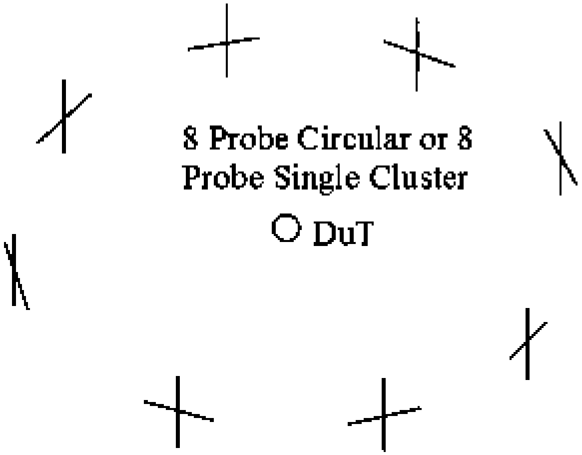
- Anechoic chamber
  - DUT is surround by multiple antenna elements inside the chamber in conjunction with external channel emulator/fader and a BS emulator
  - Various antenna numbers/positions and model permutations are being evaluated
- Reverberation chamber
  - Mode-stirrer(s) within DUT chamber are used to generate channel fading environment in conjunction with an external BS emulator
  - An external channel emulator can be added to provide higher power delay profiles, faster Doppler shifts and multipath fading correlation
- Two-stage method
  - 3-D far-field patterns for the DUT's antenna array are measured OTA in an anechoic chamber (w/ VNA or w/BS emulator & on-DUT measurements)
  - Antenna patterns are mathematically incorporated into the channel models
  - DUT is then tested in a conducted fashion with BS and channel emulators

LTE channel models in the draft [1]: SCME Urban Macro (UMa), Urban Micro (UMi), WINNER II Outdoor-to-indoor and EPA.

Anechoic Chamber - Cluster Modeling

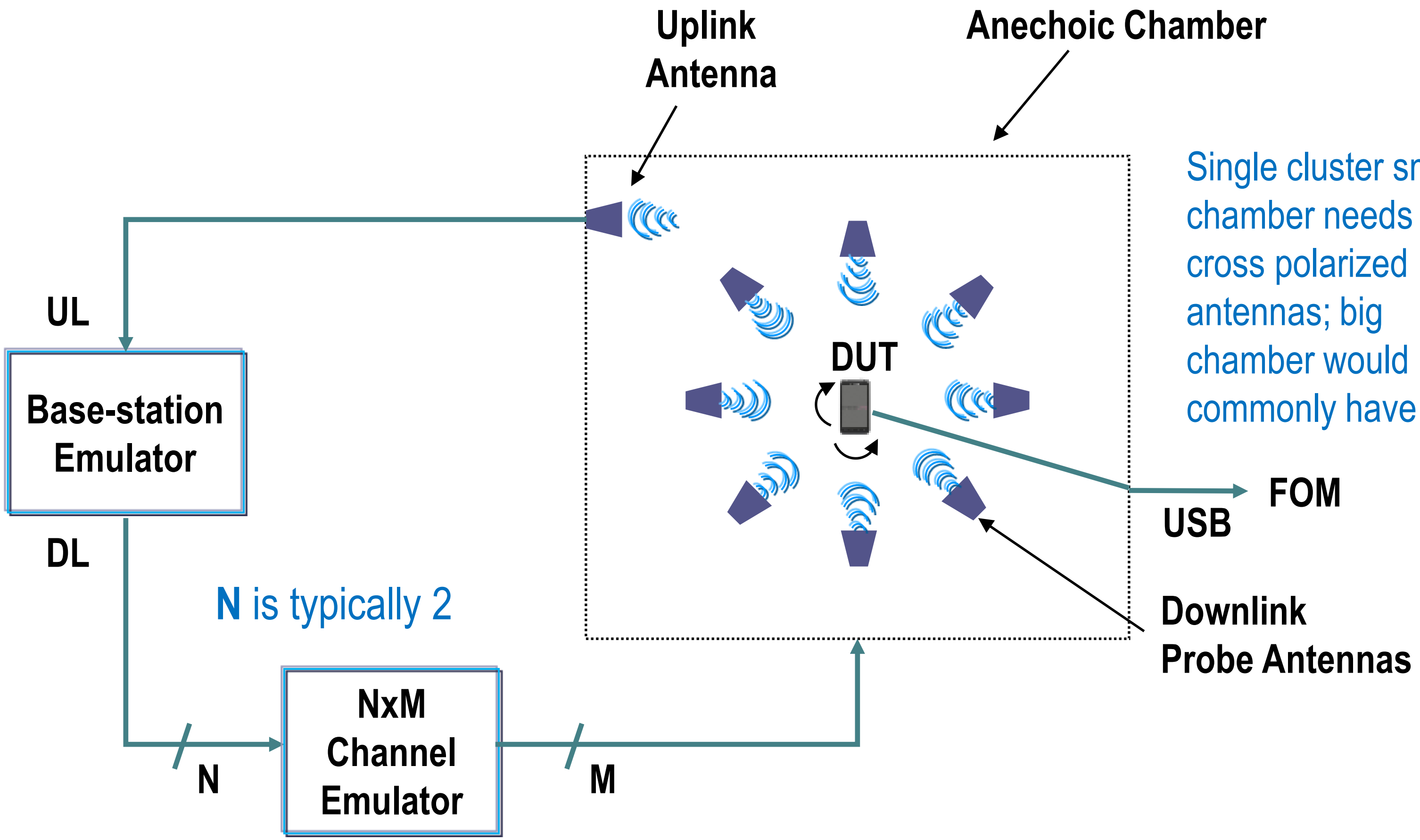






- MIMO/OTA modeling can be done in a large anechoic chamber with probes surrounding the DUT or in a small chamber modeling a single cluster
- 8 channel emulator DL RF ports are needed for 4 cross polarized probes modeling a cluster (configuration on left)

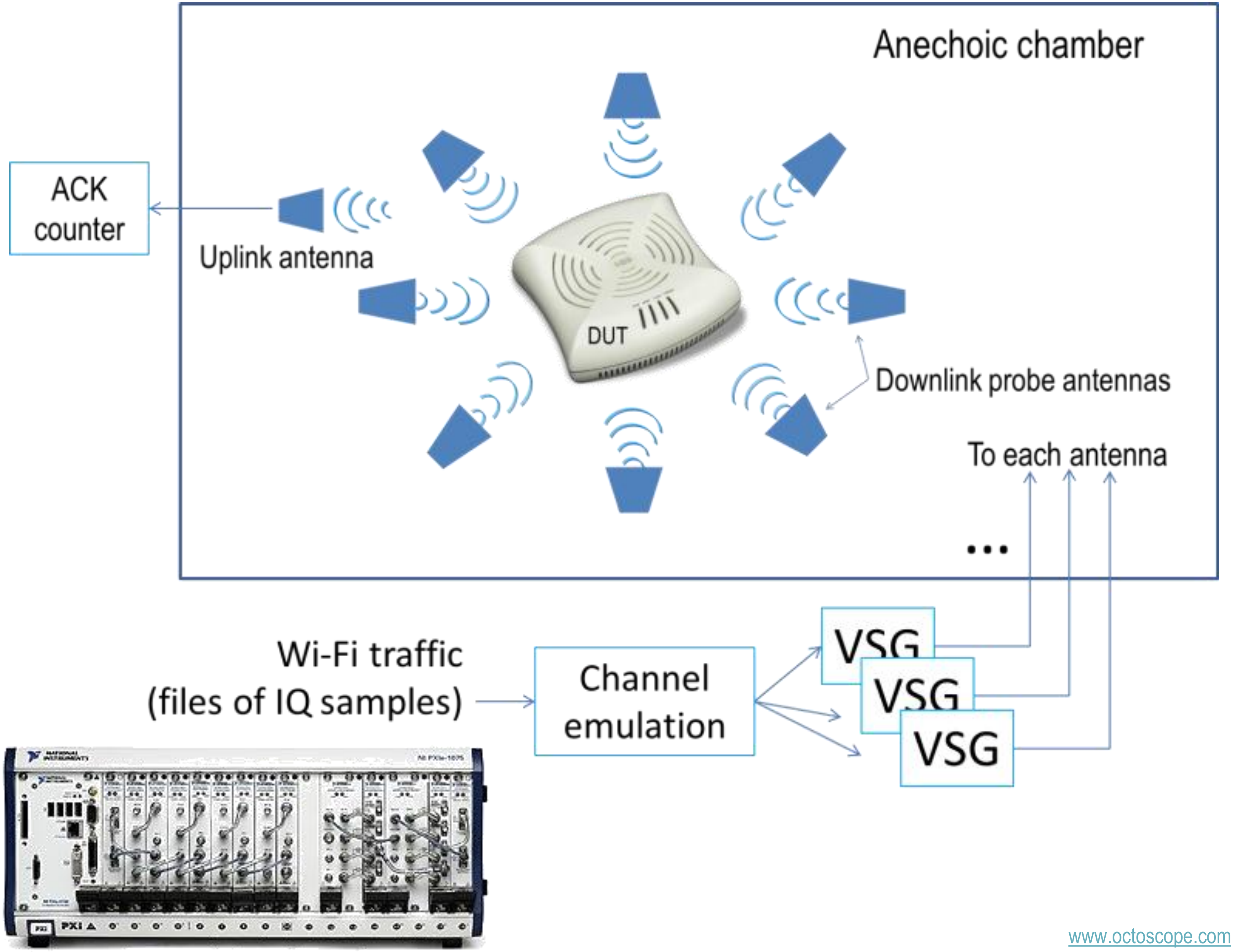
Anechoic Chamber Setup



Single cluster small chamber needs 4 cross polarized antennas; big chamber would commonly have 8

N is typically 2

Possible Wi-Fi Anechoic Chamber Setup



Anechoic chamber

ACK counter

Uplink antenna

DUT

Downlink probe antennas

To each antenna

…

Wi-Fi traffic (files of IQ samples)

Channel emulation

VSG

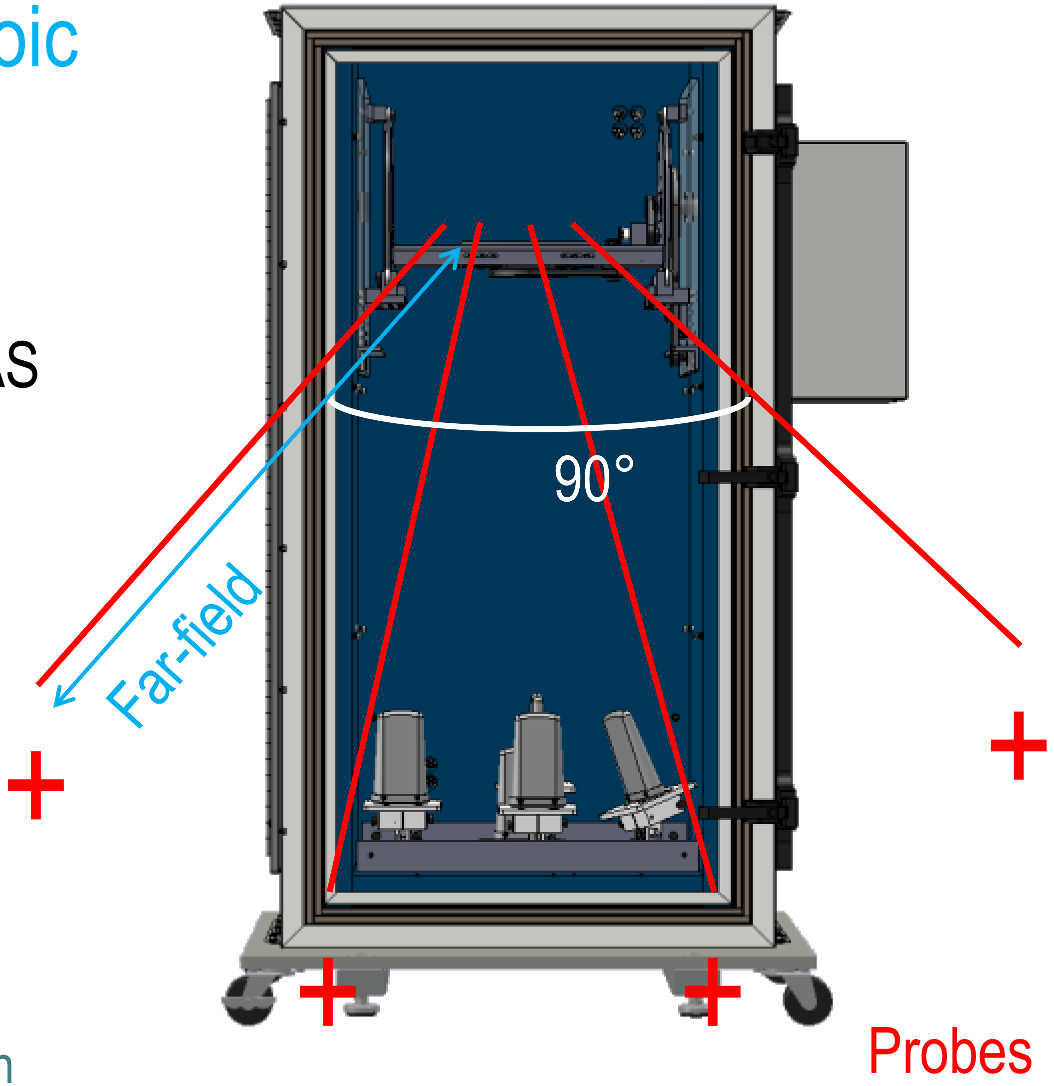
VSG

VSG

Single Cluster Setup Using octoBox II

Single Cluster Anechoic Chamber Test

- Chamber geometry is determined by cluster AS and by the far-field distance
- TR 37.976 [1] specifies single cluster AS of 35° rms, or about …
  - 90° peak to peak for Laplacian distribution
  - 50° peak to peak for non-Laplacian distribution

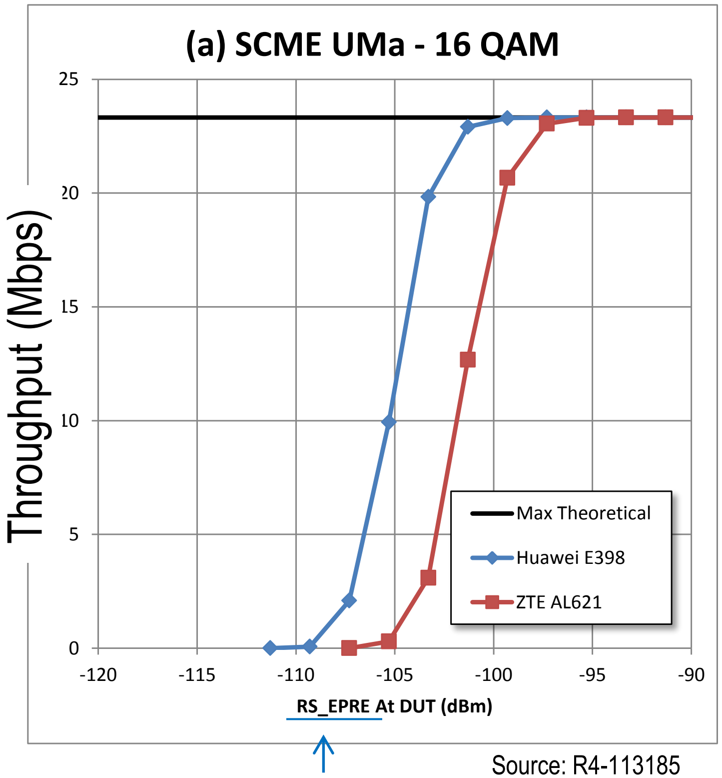


AS = angular spread

MIMO/OTA Test Figure of Merit (FOM)

- Predominant MIMO/OTA FOM is averaged MIMO OTA throughput
  - Indicator of end-to-end link capacity
  - Measured actively with a BS emulator in a fading environment
  - Measured at top of UE LTE/HSPA physical layers
  - Performed with fixed or variable RCs (reference channels)
  - Typically measured while varying RX input power (sensitivity), SNR (co-channel interference), channel models and DUT orientation

Example MIMO/OTA Measurement

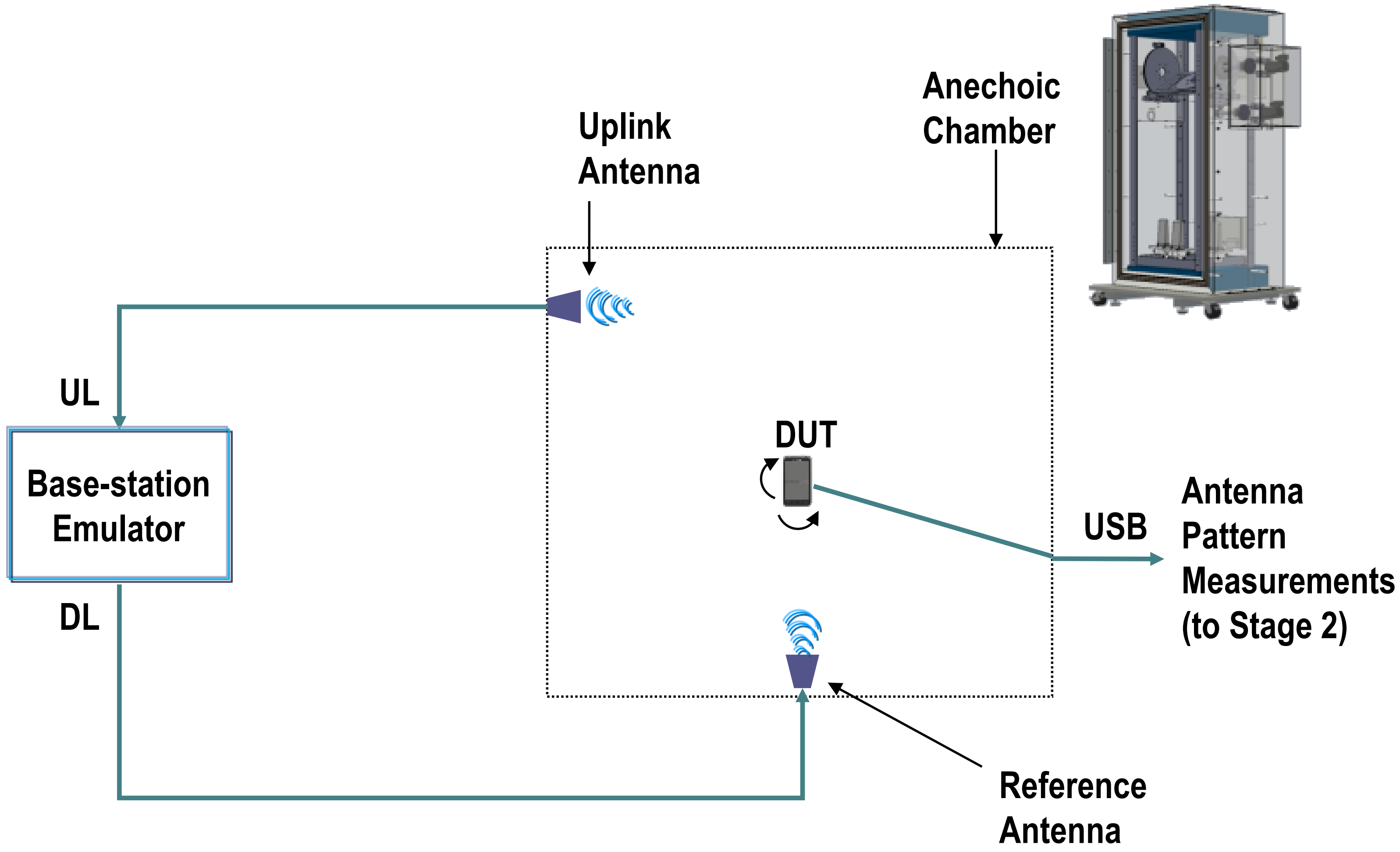


Source: R4-113185

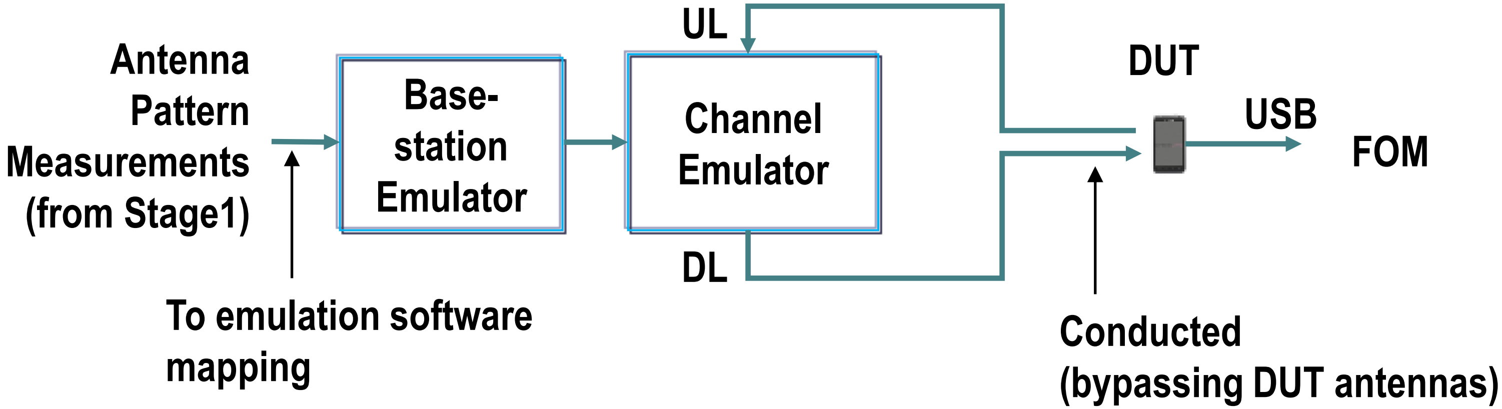
Energy at DUT per LTE subcarrier
(i.e. per 15 kHz)

SCME = spatial channel model enhances
UMa = Urban Macro
Umi = Urban Micro

Two-Stage Method Setup (Stage 1)

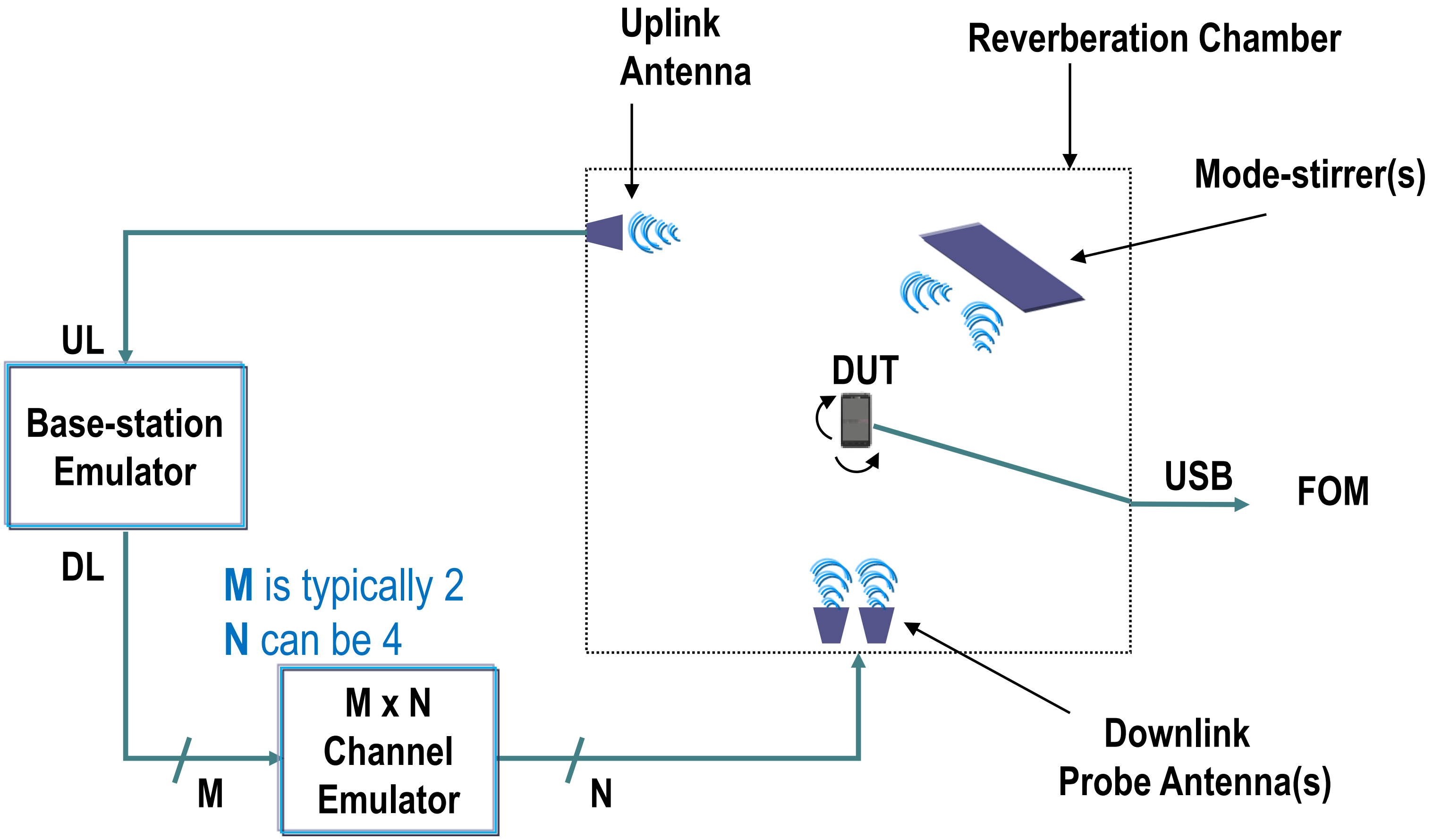


Two-Stage Method Setup (Stage 2)



FOM = figure of merit

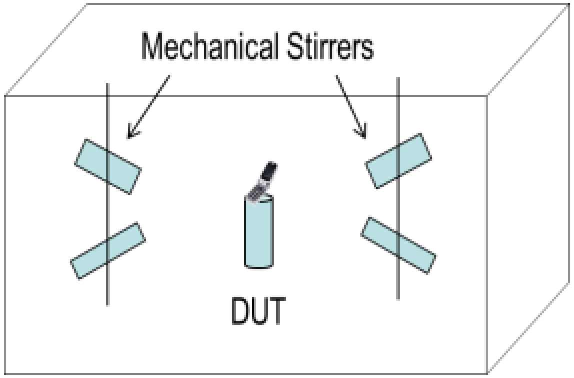
Reverberation Chamber Setup



M is typically 2
N can be 4

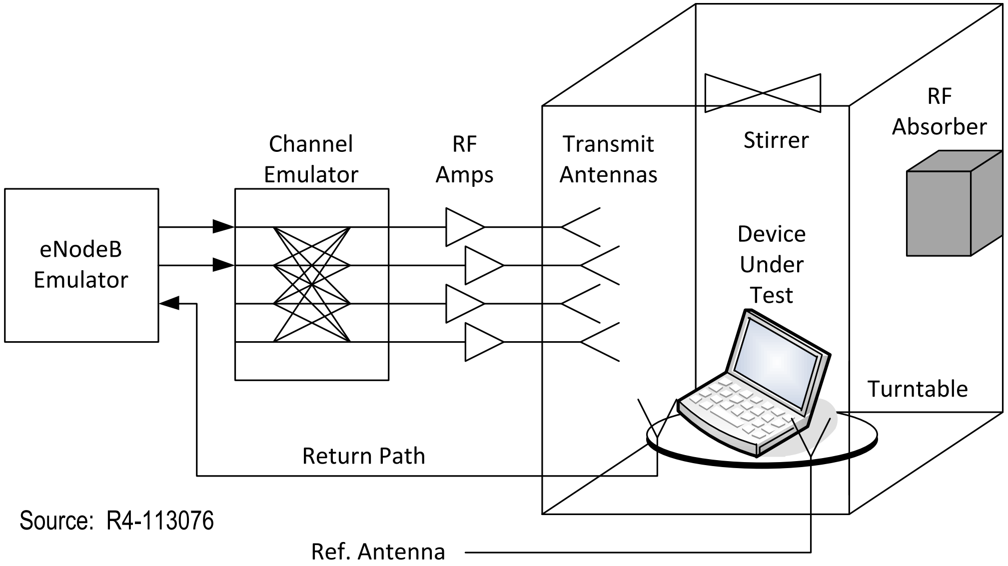
FOM = figure of merit

Reverberation Chamber Setup Example



Traditional reverb configuration
Doppler effects are modeled by stirrers

Uniform angular spread; difficult to reproduce a standards based model

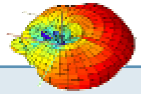


Source: R4-113076

3GPP MIMO/OTA proposal
Doppler effects are modeled by stirrers; channel emulator provides more realistic Doppler

One of the 3GPP RAN4 round-robin test DUTs

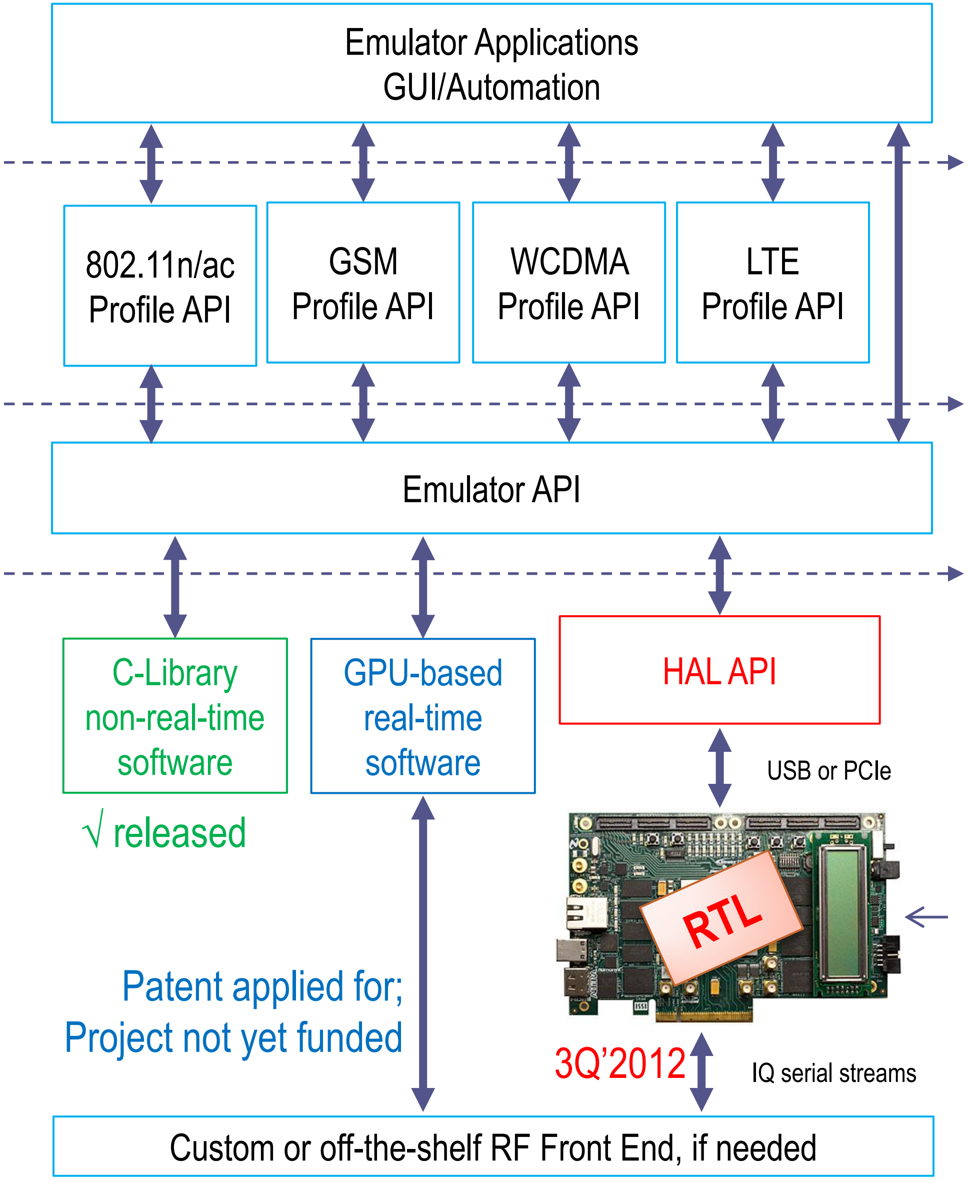
Small Anechoic vs. Reverb Chamber

Metric	**Small anechoic**	**Reverb chamber**	**Notes**
TIS/TRP certification	Y	?	e.g. BLER, TX Power metrics [4]
3D FOM plots 	Y		3D plots of antenna fields & RX sensitivity
Conducted metrics	Y		Range, RX sensitivity, TX spectrum, channel emulation, interference, etc.
3GPP PHY certification	Y		UE or eNB; typically performed at labs like 7Layers, CETECOM and AT4
MIMO/OTA single cluster method	Y		
MIMO/OTA 2-stage method	Y		
MIMO/OTA reverb method		Y	
GPS test	Y		Requires superior isolation
Production	Y		Multi-radio smartphones, APs, base stations
Simultaneous production test of multi-radio DUTs	Y		Test radios simultaneously (fast production, radios interference test)
FCC/ECC regulatory pretest	Y		e.g. radiated emissions

Outline

- What is channel emulation and why is it critical for MIMO systems?
- Channel modeling standards and technologies
- Channel model statistics
- MIMO/OTA
- Channel emulator implementation
- Competitive analysis

System Architecture



Emulator Applications
GUI/Automation

802.11n/ac Profile API

GSM Profile API

WCDMA Profile API

LTE Profile API

Emulator API

C-Library non-real-time software

√ released

GPU-based real-time software

Patent applied for;
Project not yet funded

HAL API

USB or PCIe

RTL

3Q'2012

IQ serial streams

Custom or off-the-shelf RF Front End, if needed

- Standard-specific functions that translate propagation model profiles to generic emulator function calls
  - i.e. LTE_set_model(), WCDMA_enable_birthdeath(), etc.
- Generic emulator functions that translate emulator block configurations to register settings
  - i.e. octoFade_ConfigureMIMOChannels(), octoFade_ConfigureTDLPaths(), octoFade_ConfigureCorrelationMatrix, etc.
- Hardware abstraction layer that programs register values to a specific platform or writes register values to file to support modeling & simulation efforts
  - i.e. write_register (), read_register (), etc.

Off-the-shelf FPGA hardware (e.g. Stratix IV GX FPGA Dev Kit 530 shown)

octoFade Solution

- octoFade is a fully verified library of standards-based channel models and generic fader building blocks
- Implemented in C-software and RTL
- Ideal for building into existing systems requiring channel emulation
- octoScope provides
  - Sales of software or RTL
  - Customization and integration services

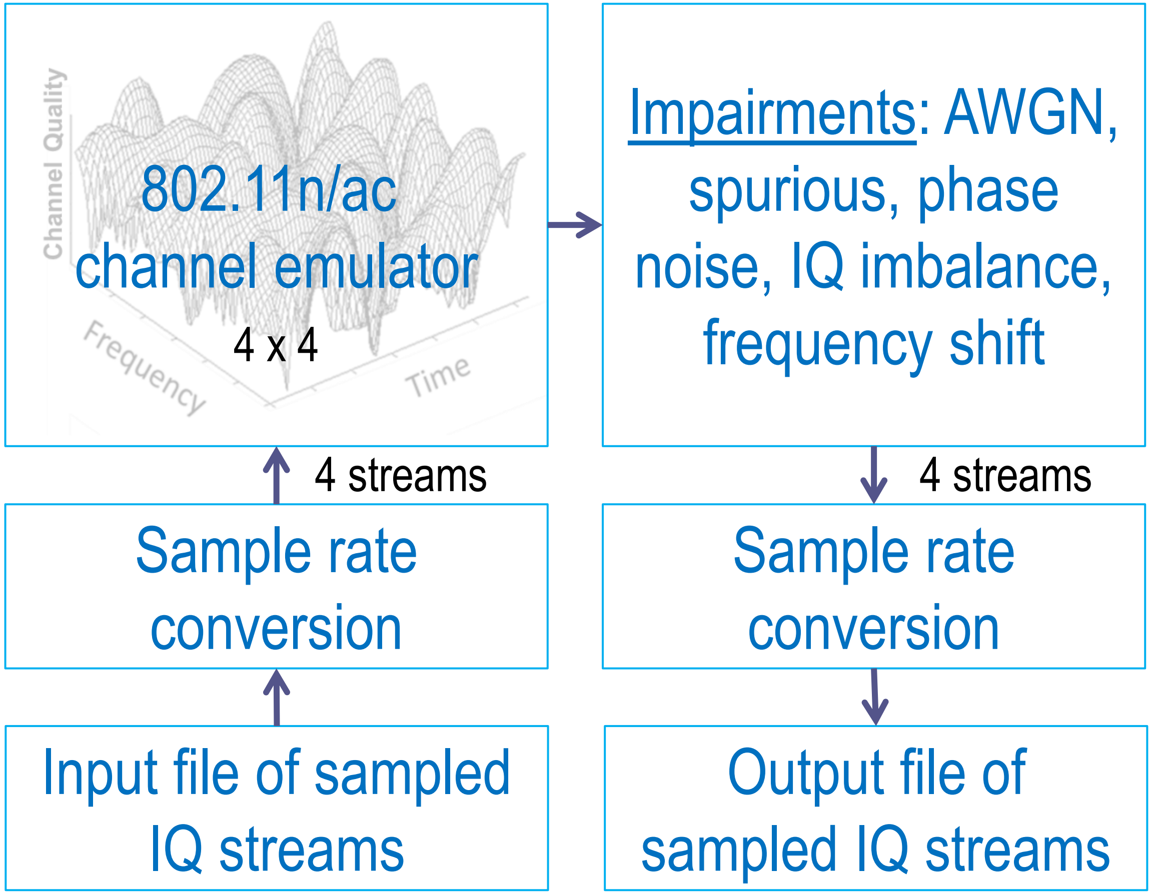
Custom or off-the-shelf RF Front End

Commercial off the shelf computing hardware (FPGA and GPU)

RTL = register transfer level

octoFade Software

Up to 4x4 MIMO configuration



802.11n/ac channel emulator

4 x 4

Impairments: AWGN, spurious, phase noise, IQ imbalance, frequency shift

4 streams

4 streams

Sample rate conversion

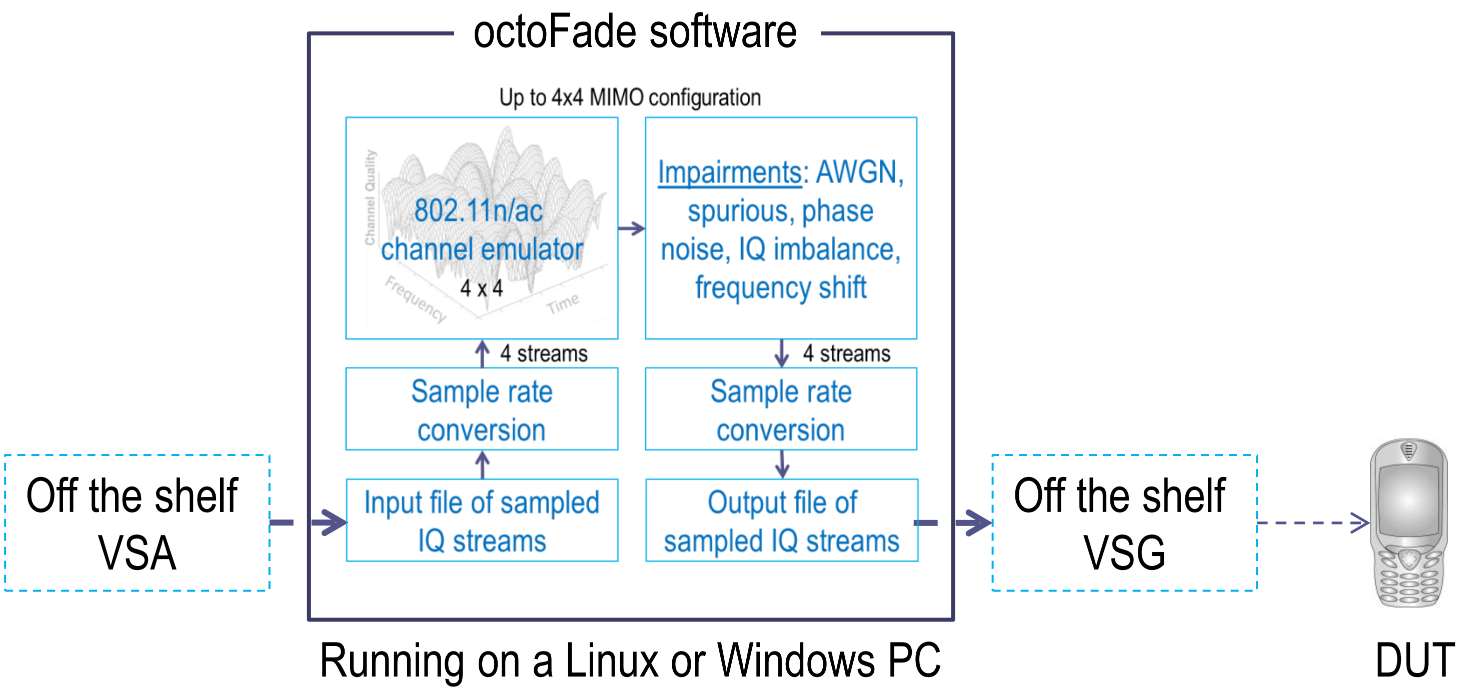
Sample rate conversion

Input file of sampled IQ streams

Output file of sampled IQ streams

AWGN = average white Gaussian noise

Use octoFade Software with Off-the-shelf Equipment



octoFade software

Up to 4x4 MIMO configuration

802.11n/ac channel emulator 4 x 4

Impairments: AWGN, spurious, phase noise, IQ imbalance, frequency shift

4 streams

Sample rate conversion

Input file of sampled IQ streams

Output file of sampled IQ streams

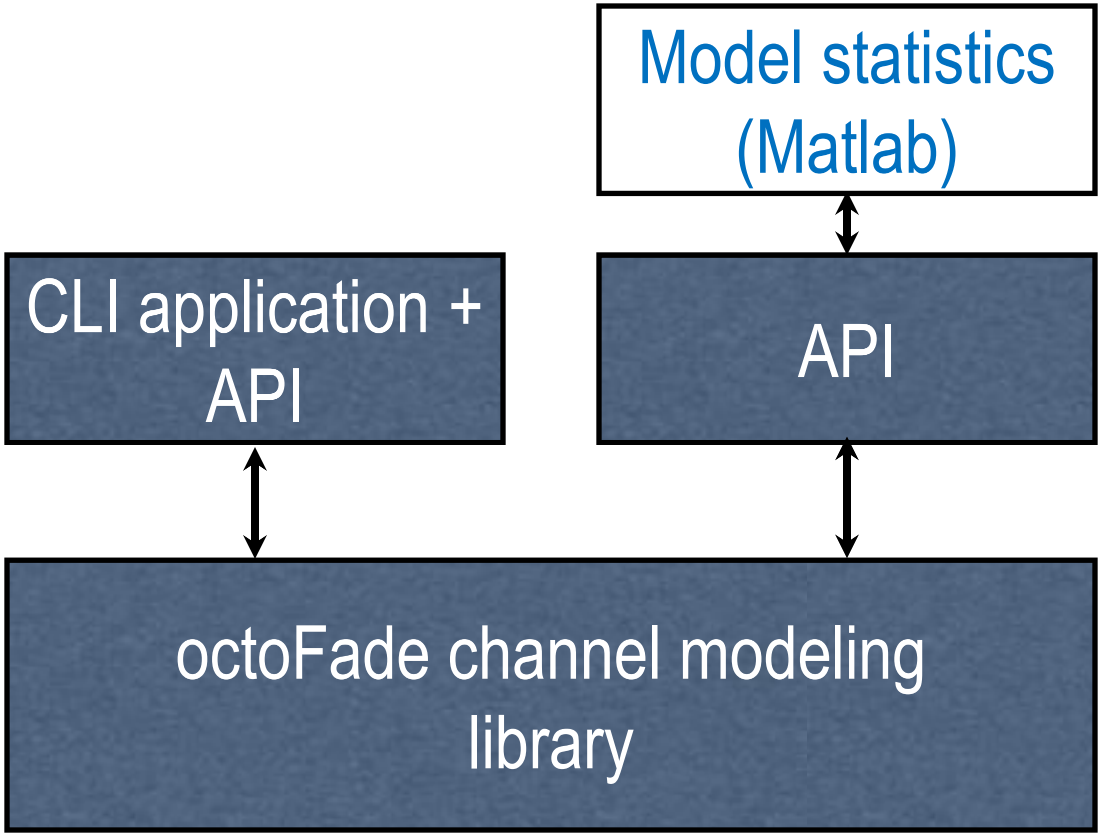
Off the shelf VSA

Off the shelf VSG

Running on a Linux or Windows PC

DUT

octoFade Software Architecture



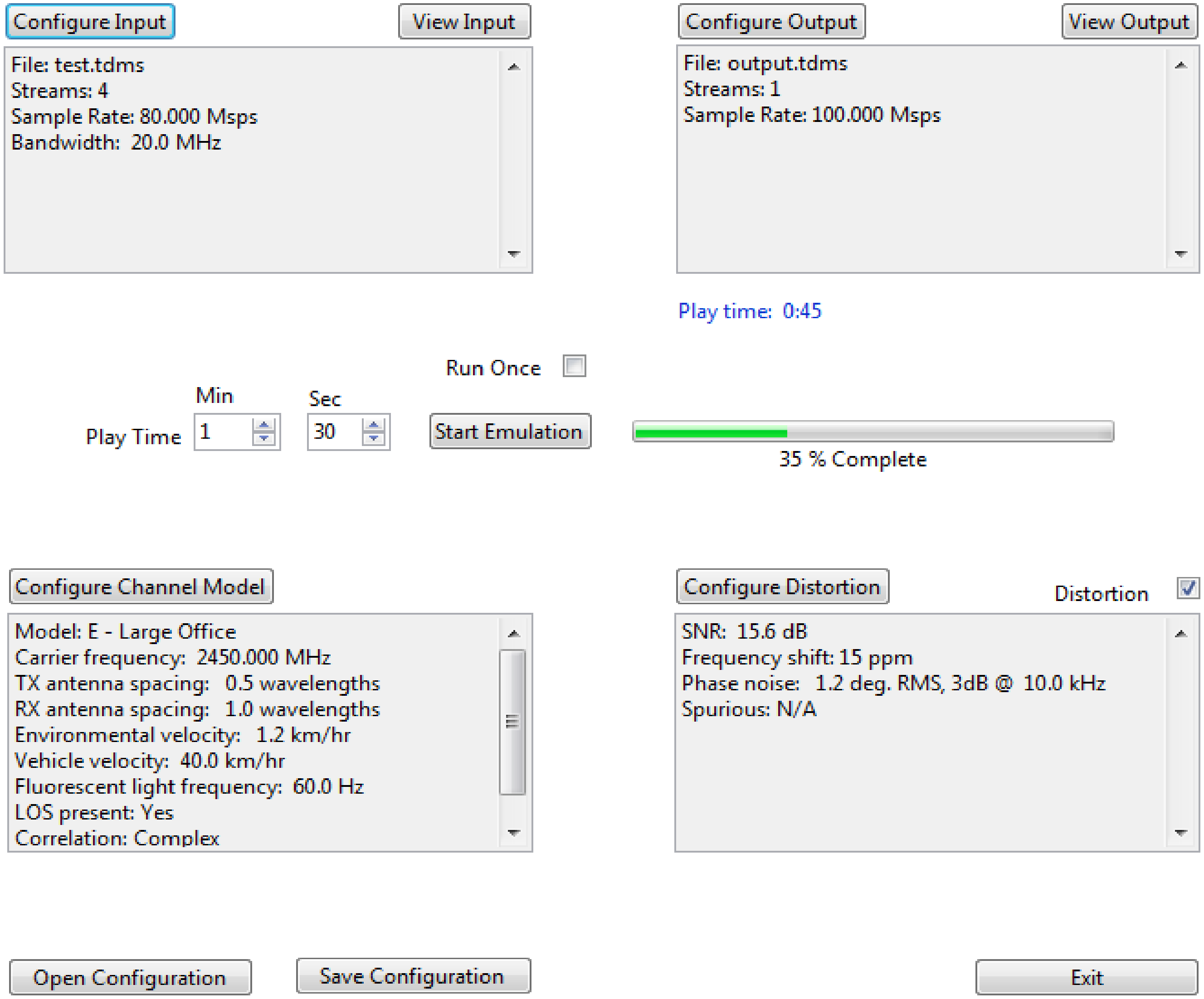
Model statistics (Matlab)

CLI application + API

API

octoFade channel modeling library

National Instruments LabVIEW Console



File: test.tdms
Streams: 4
Sample Rate: 80.000 Msps
Bandwidth: 20.0 MHz

File: output.tdms
Streams: 1
Sample Rate: 100.000 Msps

Play time: 0:45

Play Time: 1 Min, 30 Sec

35 % Complete

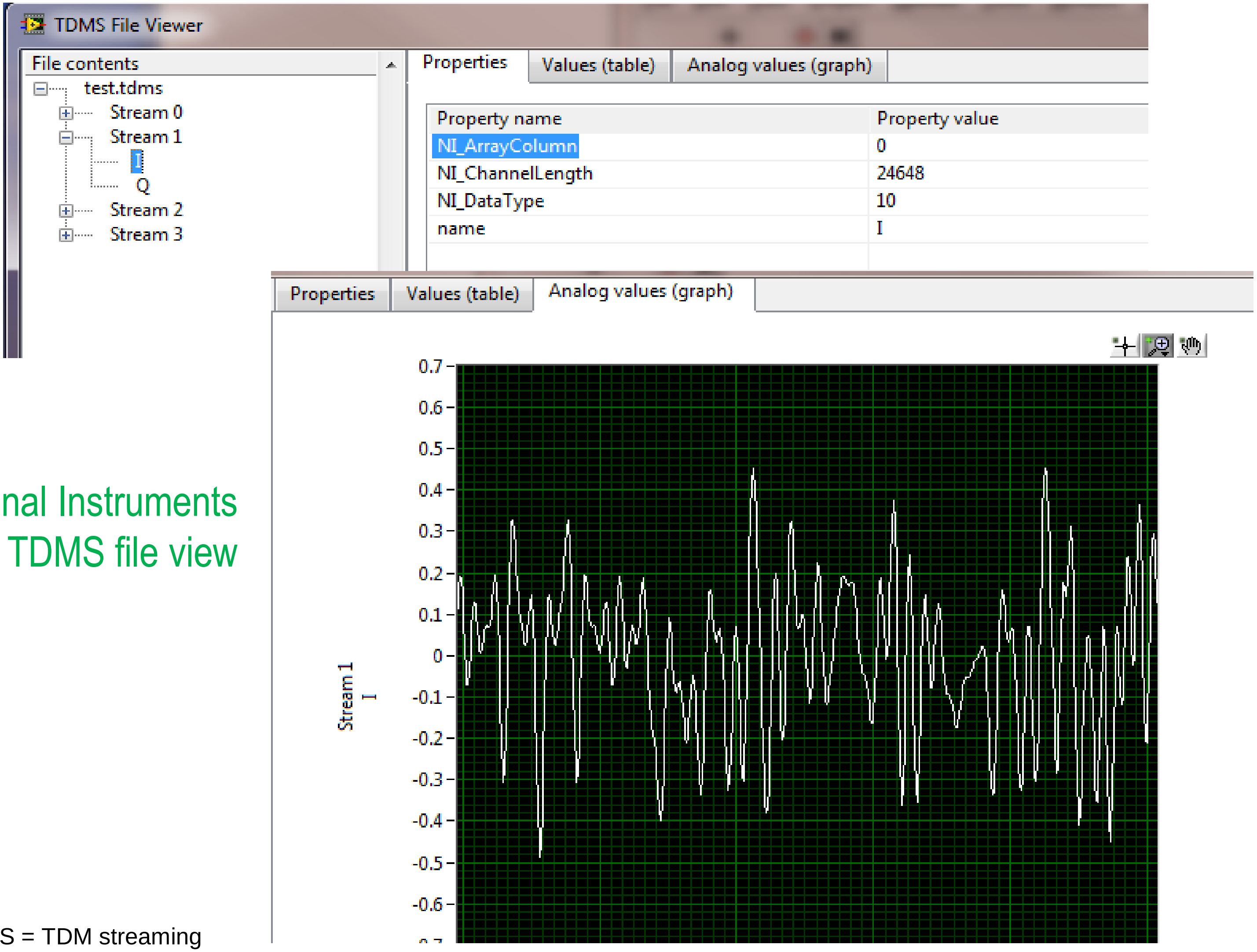
Model: E - Large Office
Carrier frequency: 2450.000 MHz
TX antenna spacing: 0.5 wavelengths
RX antenna spacing: 1.0 wavelengths
Environmental velocity: 1.2 km/hr
Vehicle velocity: 40.0 km/hr
Fluorescent light frequency: 60.0 Hz
LOS present: Yes
Correlation: Complex

SNR: 15.6 dB
Frequency shift: 15 ppm
Phase noise: 1.2 deg. RMS, 3dB @ 10.0 kHz
Spurious: N/A

National Instruments LabVIEW application

Graphical programming environment

Viewing Input and Output Streams



TDMS File Viewer

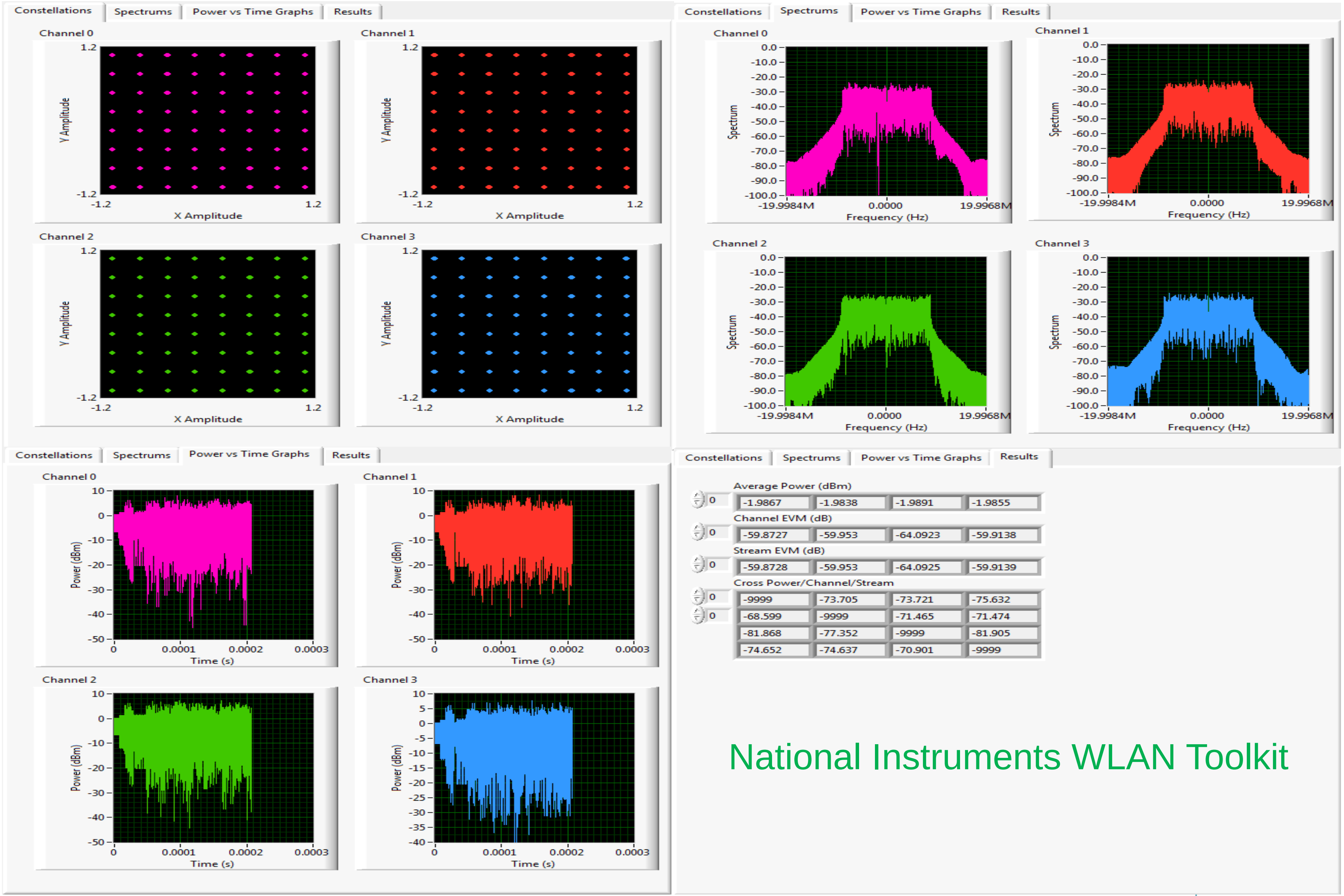
File contents
- test.tdms
  - Stream 0
  - Stream 1
    - I
    - Q
  - Stream 2
  - Stream 3

Property name	Property value
NI_ArrayColumn	0
NI_ChannelLength	24648
NI_DataType	10
name	I

National Instruments
TDMS file view

TDMS = TDM streaming
TDM = technical data management

Waveform Analysis



Average Power (dBm)

0	-1.9867	-1.9838	-1.9891	-1.9855

Channel EVM (dB)

0	-59.8727	-59.953	-64.0923	-59.9138

Stream EVM (dB)

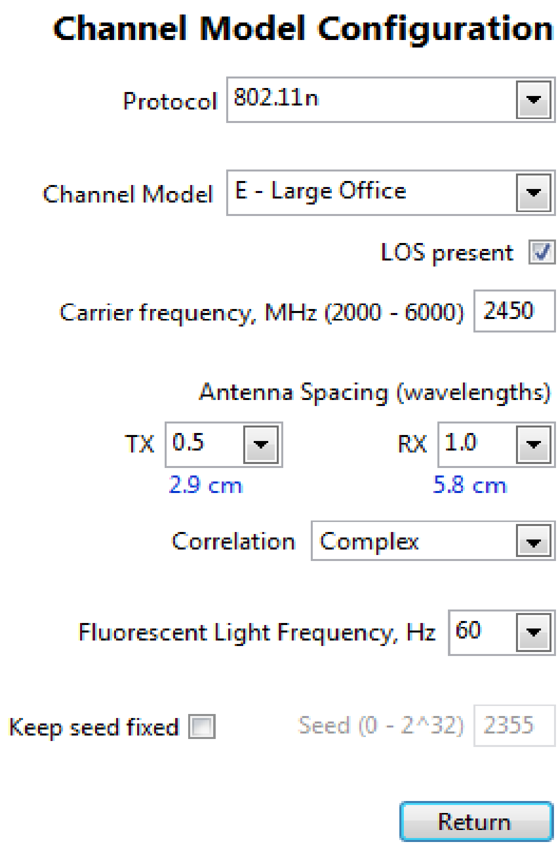
0	-59.8728	-59.953	-64.0925	-59.9139

Cross Power/Channel/Stream

0	-9999	-73.705	-73.721	-75.632
0	-68.599	-9999	-71.465	-71.474
	-81.868	-77.352	-9999	-81.905
	-74.652	-74.637	-70.901	-9999

National Instruments WLAN Toolkit

Channel and Distortion Settings



Channel Model Configuration

Protocol: 802.11n

Channel Model: E - Large Office

LOS present ☑

Carrier frequency, MHz (2000 - 6000): 2450

Antenna Spacing (wavelengths)

TX: 0.5 (2.9 cm)

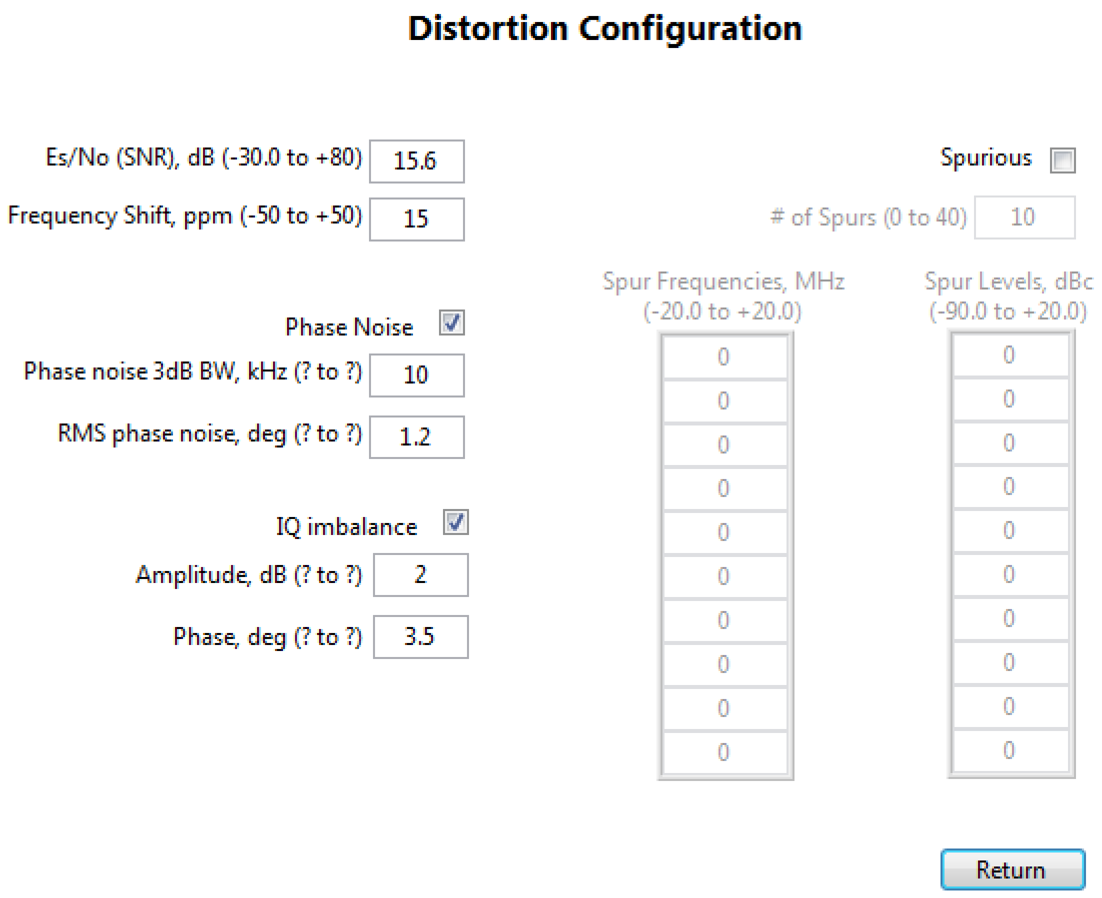
RX: 1.0 (5.8 cm)

Correlation: Complex

Fluorescent Light Frequency, Hz: 60

Keep seed fixed ☐

Seed (0 - 2^32): 2355



Distortion Configuration

Es/No (SNR), dB (-30.0 to +80): 15.6

Frequency Shift, ppm (-50 to +50): 15

Phase Noise ☑

Phase noise 3dB BW, kHz (? to ?): 10

RMS phase noise, deg (? to ?): 1.2

IQ imbalance ☑

Amplitude, dB (? to ?): 2

Phase, deg (? to ?): 3.5

Spurious ☐

# of Spurs (0 to 40): 10

Spur Frequencies, MHz (-20.0 to +20.0)	Spur Levels, dBc (-90.0 to +20.0)
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0
0	0

Supported Models and Building Blocks

Parameter	Model Name	References and Notes
3GPP Models (RTL)	**LTE:** EPA 5Hz; EVA 5Hz; EVA 70Hz; ETU 70Hz; ETU 300Hz; High speed train; MBSFN	3GPP TS 36.521-1 V10.0.0 (2011-12) Annex B 3GPP TS 36.101 V10.5.0 (2011-12) Annex B
	GSM: RAx; HTx; TUx; EQx; TIx	3GPP TS 45.005 V10.3.0 (2011-11) Annex C
	3G: PA3; PB3; VA30; VA120; High speed train; Birth-Death propagation; Moving propagation; MBSFN	3GPP TS 25.101 V11.0.0 (2011-12) Annex B 3GPP TS 25.104 V11.0.0 (2011-12) Annex B
IEEE 802.11n/ac Models (software)	A, B, C, D, E, F	IEEE 802.11-03/940r4; IEEE 11-09-0569
Static Models (software and RTL)	Identity matrix	Static bypass
	Butler matrix	Static, minimum correlation
Channel modelling building blocks (RTL)	Tap: delay, Doppler, PDP weight Path: list of taps System: NxM, correlation matrix	

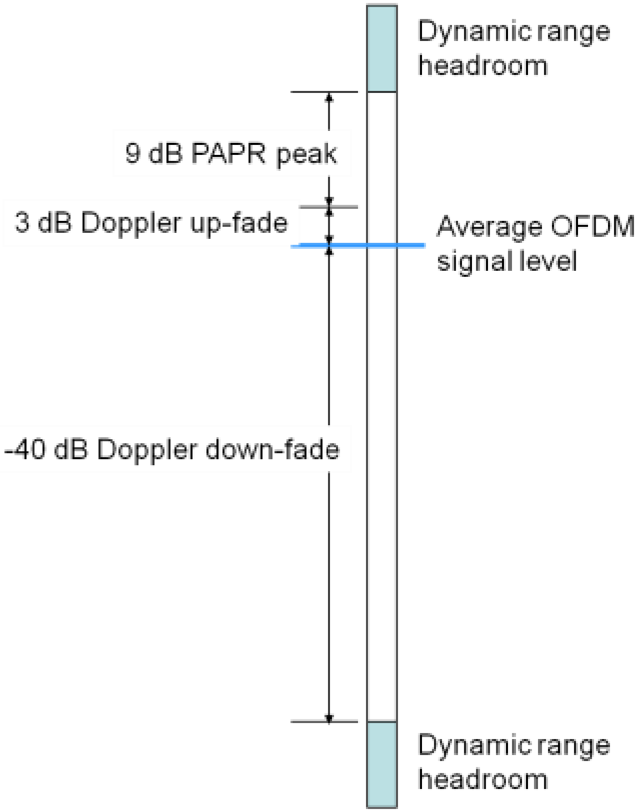
RTL DSP Specifications

Parameter	Specification	Notes
Number of IQ input paths	1-8	Unused inputs disabled where applicable
IQ input data format	18-bit	
Number of IQ output paths	1-8	Unused outputs set to zero where applicable
IQ output data format	18-bit	
Input/output sample rate	Up to 400 MHz	Current capability: 100 MHz
Channel bandwidth	Up to 160 MHz	Current capability: 40 MHz
Maximum number of total taps	FPGA resources-dependent	N x M x taps_per_TDL
Number of TDL blocks	Up to 64	
Number of taps per TDL block	FPGA resources-dependent	
Tap delay range	FPGA resources-dependent	Current capability: 30 usec
Minimum tap delay resolution	2.5 ns	Current capability: 10 ns
Tap weight range	0 to -50 dB	
Tap weight resolution	0.1dB	
Doppler shift	2 kHz	To support high speed train
SNR setting	-10 to +35 dB, average +/- 0.1 dB accuracy	
Noise filter bandwidth	Up to 160 MHz	Equal to preconfigured channel bandwidth

Subject to the availability of FPGA resources, octoScope can customize any of these specifications.

RF Front End Considerations

Parameter	Specification	Notes
MIMO configuration	8 x 8	To support emerging 802.11ac and LTE beamforming configurations
Bidirectionality	Important	To support beamforming
Bandwidth	160 MHz	To support emerging 802.11ac
Dynamic range (RF dynamic range, converter and DSP resolution)	Accommodate 52 dB of output signal dynamic range with little distortion	Signal fluctuation: +9 dB for PAPR +3 dB for up-fade -40 dB for down-fade
EVM	About 6 dB higher than EVM required for RF signal	For example, channel emulator's EVM should be at least 36 dB over the entire dynamic range to minimize distortion of a 30 dB EVM 802.11n signal



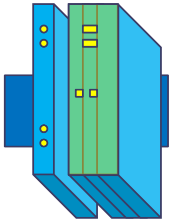
Outline

- What is channel emulation and why is it critical for MIMO systems?
- Channel modeling standards and technologies
- Channel model statistics
- MIMO/OTA
- Channel emulator implementation
- Competitive analysis

Competitive Positioning – Flexibility/Integration

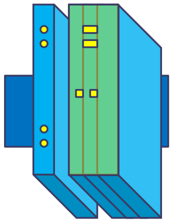
- Flexibility and design for custom integration
  - Integration into any size FPGA logic, for example to support a multiport mesh topology requiring extensive logic resources
  - Integration with custom or off-the-shelf RF front end to support required frequencies and channel widths instead of overpaying for a wideband front end (possibly with non-optimum performance) offered by mainstream competing products
- Although competing products support custom channel models, their architecture typically lacks flexibility when it comes to
  - Topology (i.e. port interconnections), which sometimes limits configurations (e.g. product may offer support for one 4x4 MIMO link or two 2x2 links, but not full mesh of SISO links)
  - Custom channel models (e.g. limited Doppler velocity or tap timing resolution, etc.)
  - Non-standard frequency bands and channel widths (e.g. may not offer 5 MHz channel width or higher sampling rate needed for 802.11ac operating in 160 MHz channels)
  - Real-time reconfiguration of fading parameters (e.g. Doppler changing vs. time)
- octoFade can address the needs of applications that mainstream emulators are unable to meet due to their closed and rigid architecture

Competitive Landscape

	 octoFade	 Azimuth ACE	 Spirent VR5	 Elektrobit Propsim
MIMO config	Up to 8x8 bi-directional	4x4 uni- and bi-directional	8x8 uni- and bi-directional	4x4 uni- and bi-directional
Bandwidth	160 MHz	40 MHz	100 MHz	135 MHz
Freq range	Optional customizable RF Front End	450-2700 MHz 3300-3850 MHz 4900-5900 MHz	380-3850 MHz 4100-6000 MHz	350-3000 MHz 350-6000 MHz
Wi-Fi, LTE, 3G, GSM	Y	Y	Y	Y
Models **Custom**	Doppler filter, TDL, PDP, correlation matrix, flexible topology; multi-cell	Doppler filter, TDL, PDP, correlation matrix	Doppler filter, TDL, PDP, correlation matrix	Doppler filter, TDL, PDP, correlation matrix
ASP (bi-directional)	$50k (8x8) RTL $35k (2x2) RTL $20k software	$300-400k (4x4) >$100k (2x2)	$300-400k (8x8) >$100k (2x2)	$300-400k (4x4) >$100k (2x2)

Application Suitability

- 🔴 Excellent
- ◒ Good
- ○ Average
- ◓ Poor
- ● Unacceptable

	 octoFade	 Azimuth ACE	 Spirent VR5	 Elektrobit Propsim	
3GPP (2G/3G/LTE)	🔴	🔴	🔴	🔴	
802.11n	🔴	🔴	🔴	🔴	
802.11ac	🔴	◓			1
DSRC (802.11p)	🔴	●	○	○	2
Mesh networks	🔴	◓	○	◓	3
UHF white spaces	🔴	◒	◒	◒	4
Custom RF	🔴	●	●	●	5
Custom topology	🔴	●	●	●	5

Notes on competitive shortcomings:

1. MU MIMO support and 400 Msps sampling unavailable
2. DSRC channel models not implemented
3. Mesh network testing requires more ports than available
4. UHF white spaces requires custom models
5. Unavailable

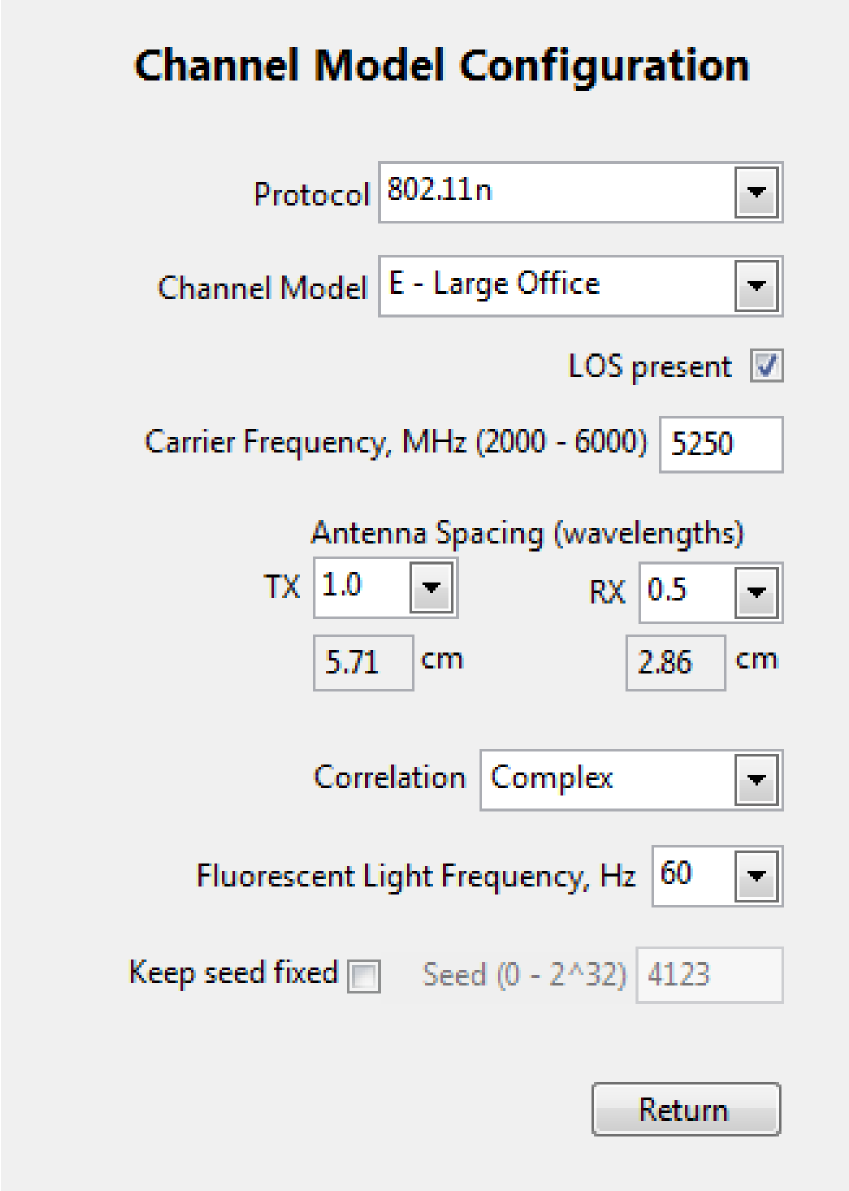
DSRC Application - Requirements

- High number of RF ports
  - 2x2 MIMO
- Symmetric channel; point to point
- 5.9 MHz
- Channel width 5, 10, 20 MHz
- V2V, V2I, etc. (V2X) communications

V2V = vehicle to vehicle
V2I = vehicle to infrastructure
DSRC = direct short-range communications

octoFade Summary

- Flexible channel emulation solution
  - C software (non-real-time)
  - GPU software (real-time
  - Hardware (real-time)
- Support for
  - Standards-based 802.11n/ac, LTE, 3G and GSM fading models
  - Custom fading models
  - Custom topology
  - Custom or off-the-shelf RF front end
- Fully verified implementation; customer references available



Channel Model Configuration

Protocol: 802.11n

Channel Model: E - Large Office

LOS present ☑

Carrier Frequency, MHz (2000 - 6000): 5250

Antenna Spacing (wavelengths)

TX: 1.0 — 5.71 cm

RX: 0.5 — 2.86 cm

Correlation: Complex

Fluorescent Light Frequency, Hz: 60

Keep seed fixed ☐ Seed (0 - 2^32): 4123

References

1. IEEE, 802.11-03/940r4: TGn Channel Models; May 10, 2004
2. IEEE, 11-09-0569 , “TGac Channel Model Addendum Supporting Material”, May 2009
3. Schumacher et al, "Description of a MATLAB® implementation of the Indoor MIMO WLAN channel model proposed by the IEEE 802.11 TGn Channel Model Special Committee", May 2004
4. IEEE 802.11-09/0308r12, “TGac Channel Model Addendum”, March 18, 2010
5. IEEE, 11-09-0334-08-00ad-channel-models-for-60-ghz-wlan-systems
6. Schumacher et al, "From antenna spacings to theoretical capacities - guidelines for simulating MIMO systems"
7. Schumacher reference software for implementing and verifying 802.11n models - http://www.info.fundp.ac.be/~lsc/Research/IEEE_80211_HTSG_CMSC/distribution_terms.html
8. 3GPP 36-521, UE Conformance Specification, Annex B
9. 3GPP TR 25.996, "3rd Generation Partnership Project; technical specification group radio access networks; Spatial channel model for MIMO simulations“
10. IST-WINNER II Deliverable 1.1.2 v.1.2, “WINNER II Channel Models”, IST-WINNER2, Tech. Rep., 2008 (http://projects.celtic-initiative.org/winner+/deliverables.html)
11. 3GPP TR37.976, MIMO OTA channel models
12. 3GPP TS 34.114: “User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) Antenna Performance Conformance Testing”
13. CTIA, “Test Plan for Mobile Station Over the Air Performance - Method of Measurement for Radiated RF Power and Receiver Performance”, Revision 3.1, January 2011

Thank you!

- View octoBox information
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