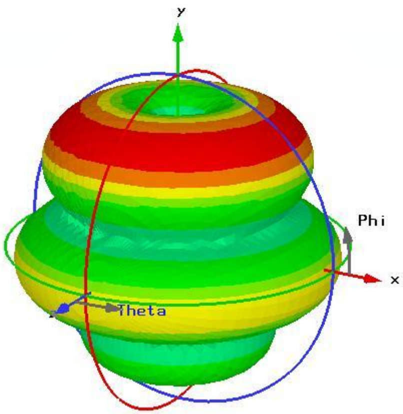
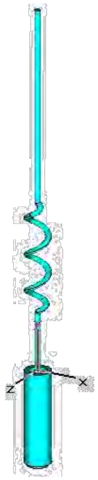




octoScope

NI Week 2011

Over the Air Wireless Test Methods and Metrics

Technical Session: TS5101
Fanny Mlinarsky
Ron Cook

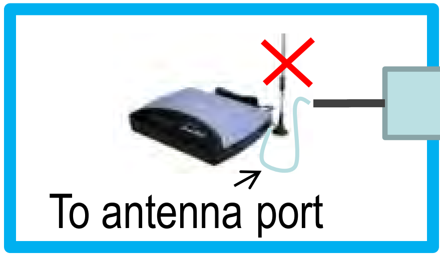
The Nature of Wireless Measurements

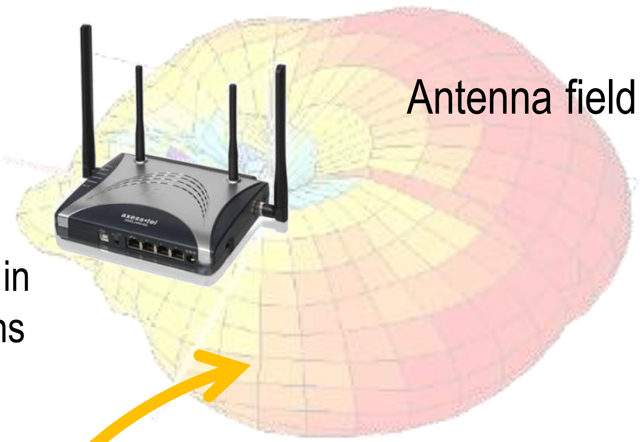
Conducted | **OTA**

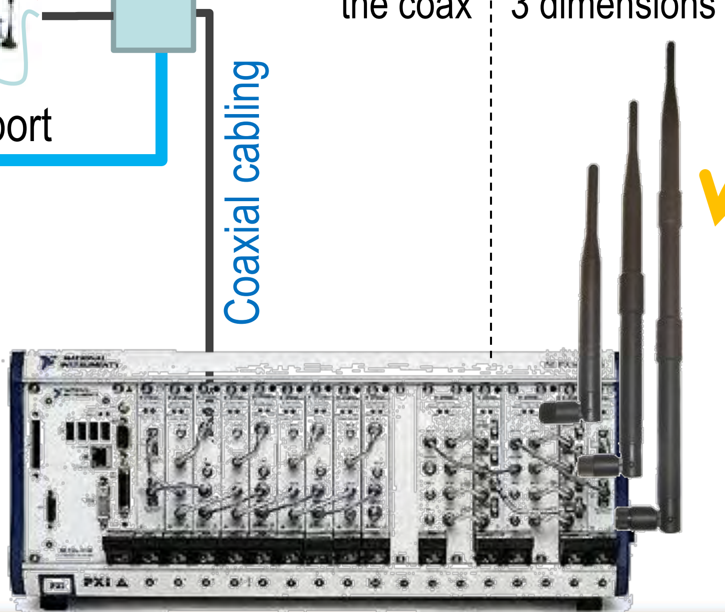
Repeatable measurements, but antennas are not included in the test; impractical to disconnect antennas for measurement in devices like smartphones and consumer electronics

All energy couples into the coax

Energy propagates in 3 dimensions



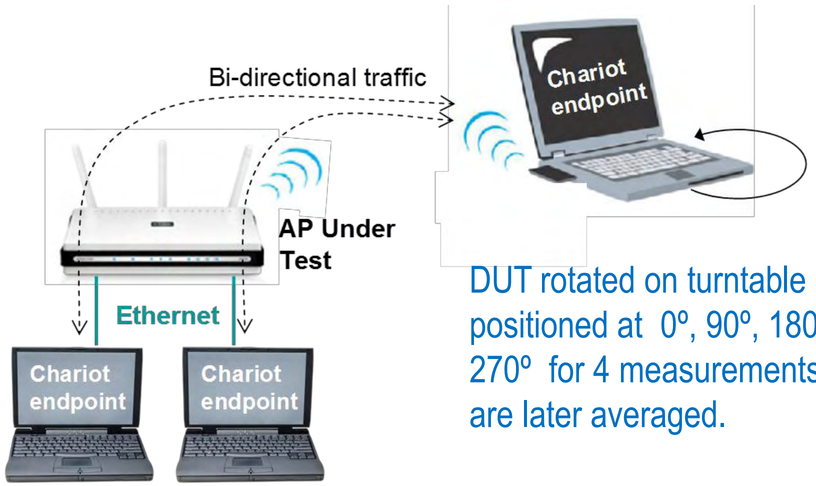




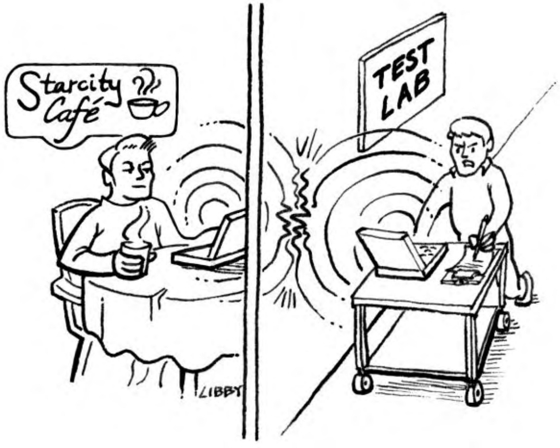
Antennas are included in the test and small devices with printed antennas can be measured through antennas, but the test set up requires controlled conditions to support 3D OTA metrics. Signal power and integrity at test antennas varies with DUT orientation, reflections and interference.

OTA = over the air
DUT = device under test

Open Air Test Methodology

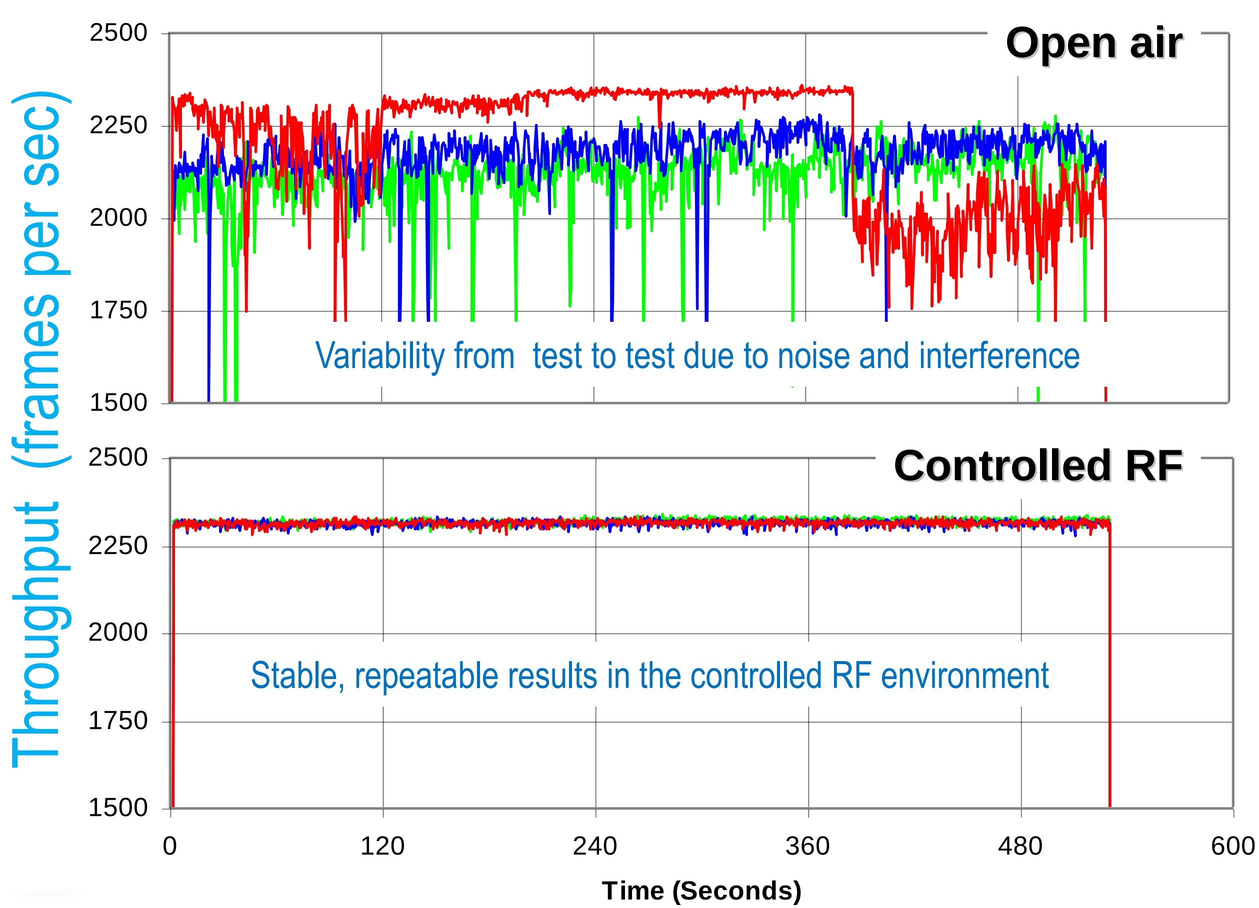


DUT rotated on turntable or positioned at 0º, 90º, 180º and 270º for 4 measurements that are later averaged.

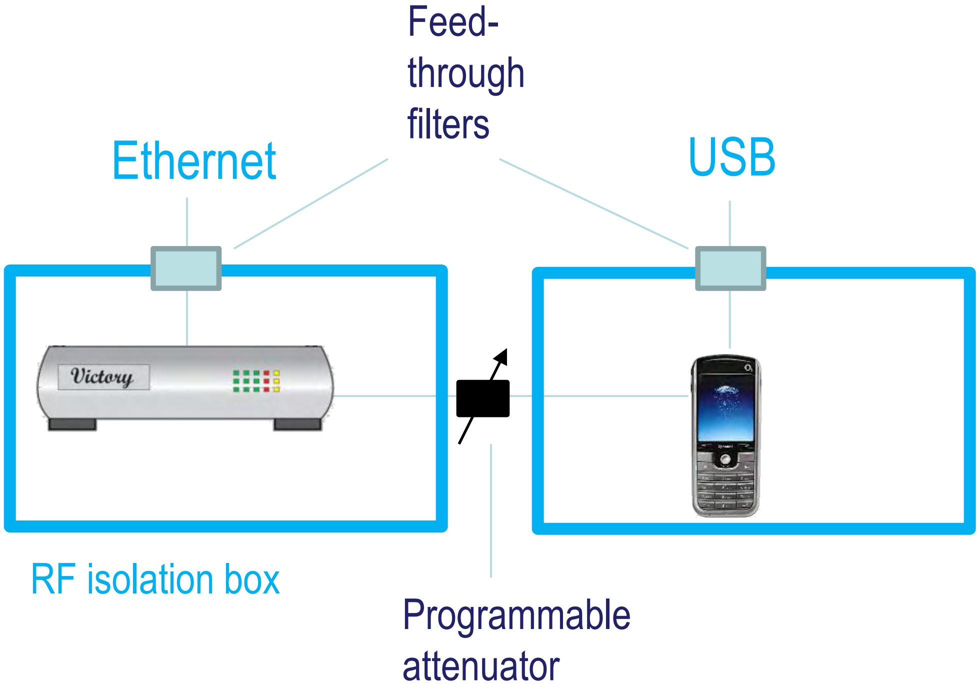


- Open air testing (e.g. performance vs. distance) requires averaging results
  - … vs. time - to cancel variability due to noise
  - … vs. DUT orientation - to compensate for antenna field asymmetries

Open Air vs. Controlled Environment



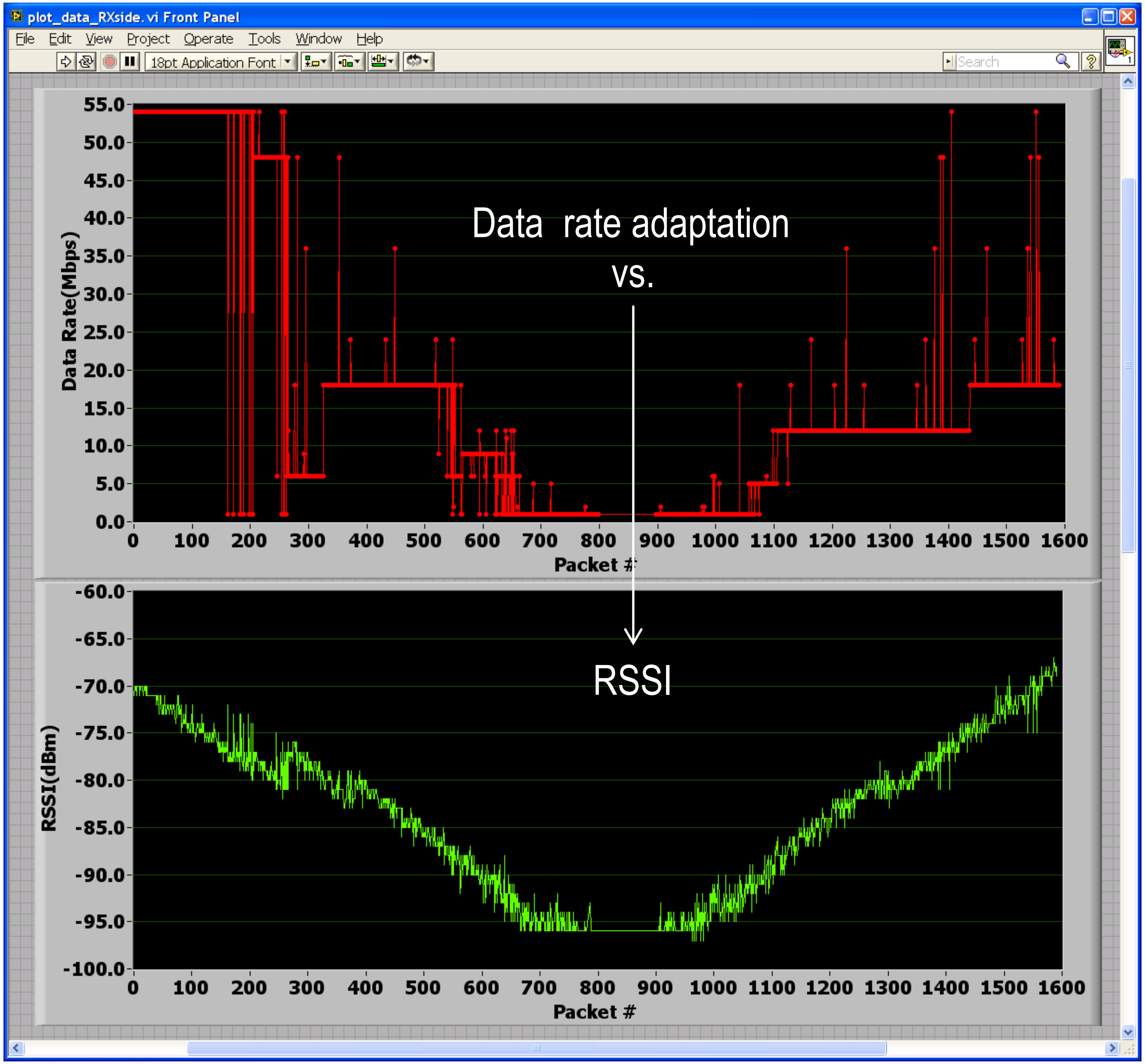
Controlled Environment Conducted Test



Signal coupled via cabling, antennas are removed

Distance and motion emulated using a programmable attenuator to model path loss (flat fading) or a channel emulator to model multipath and Doppler fading

Master and DUT are isolated from each other to achieve wide dynamic range of the measurement by eliminating crosstalk



Controlled Environment Measurement Example

Noise, interference and Master to DUT coupling must be well below intended signal level at DUT for metrics such as rate/MCS adaptation or roaming performance

802.11b (DSSS-CCK)
- 1, 2, 5.5, 11 Mbps; 2.4 GHz

802.11a (OFDM)
- 6, 9, 12, 18, 24, 36, 48, 54 Mbps; 5 GHz

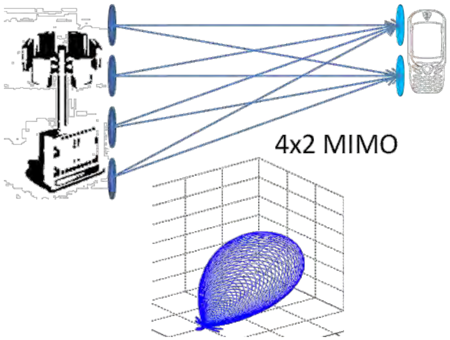
802.11g
- both 11b and 11a rates; 2.4 GHz

802.11n
- up to 600 Mbps; 2.4 and 5 GHz

RSSI = receive signal strength indicator

Market Need for Controlled Over the Air (OTA) Test

- With wireless radios dropping in cost, wireless interfaces are now incorporated into a variety of consumer products, including phones, cameras, games, PCs, APs, base stations, etc.
- OTA testing is starting to displace traditional conducted testing because
  - Low-cost consumer devices typically have integrated antennas that are impractical to access and remove for testing
  - New generation MIMO and beamforming devices have antennas that play an integral role in device performance



MIMO and beamforming require OTA testing…

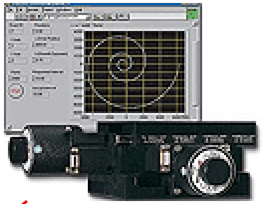
Bluetooth
Wi-Fi
CDMA
WCDMA/HSxPA
GSM
LTE

… and so do multi-radio smartphones that typically lack antenna connectors

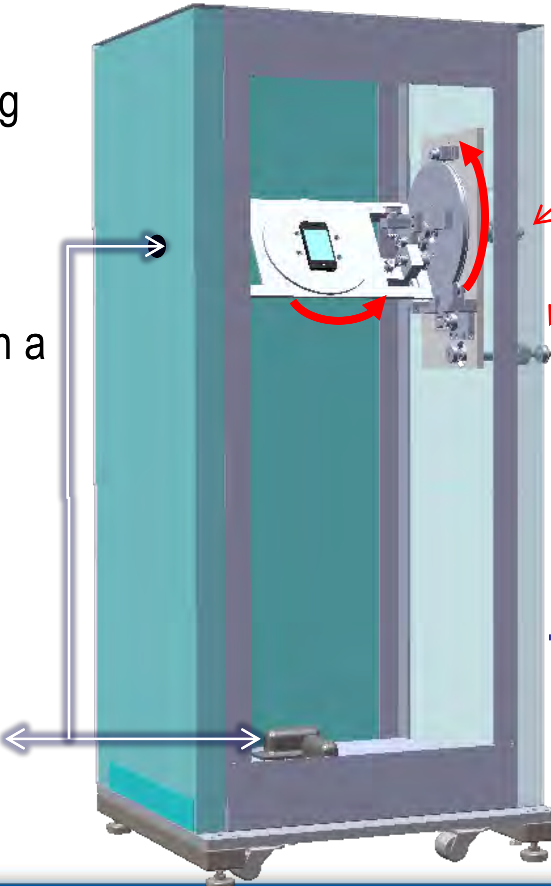
Controlled Environment OTA Test

- Controlled anechoic OTA environment yields repeatable results
  - Fast measurements, little averaging needed with stable signal
  - May still want to average vs. DUT orientation (e.g. average RX throughput over a sphere) to obtain a single performance metric
- 3D metrics include
  - TX power
  - RX sensitivity, packet error rate, etc.

NI Motion

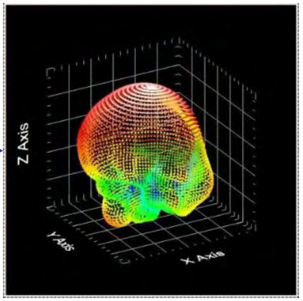


octoBox II anechoic chamber with 2-axis positioner



Motors

Motorized 2-axis positioner spins the DUT as measurements are taken over a virtual sphere around the DUT

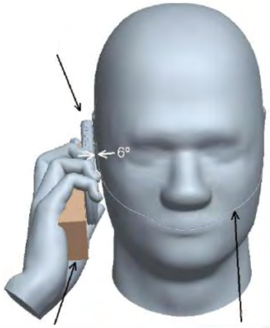


NI Chassis

CTIA Certification – TIS/TRP

- CTIA certification includes TIS and TRP measurements [4]
  - 3D RX and TX performance measurements
- Testing performed in an anechoic chamber
- Phantom head and hand used as test fixtures

Phone under test on a phantom head



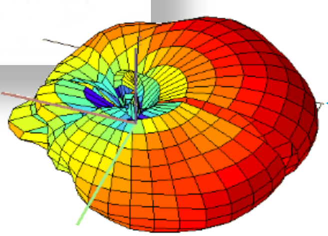
Typical anechoic chamber

CTIA Certification

A Division of CTIA–The Wireless Association™

Test Plan for Mobile Station Over the Air Performance

Method of Measurement for Radiated RF Power and Receiver Performance

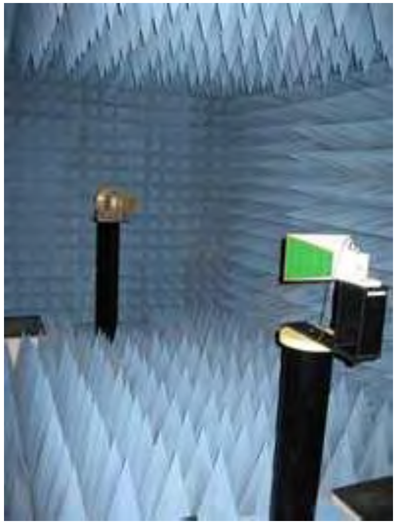


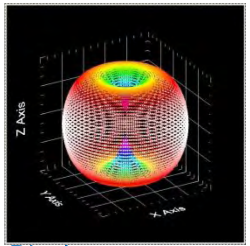
CTIA = Cellular Telecommunications & Internet Association
TRP = Total Radiated Power
TIS = Total Isotropic Sensitivity

Reverberation vs. Anechoic Chamber

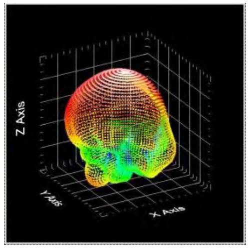
Reverberation chamber

- Reflective metal walls
- Metal 'stirers' scatter energy which enters the antennas uniformly from all directions
- Impossible to discern the shape of the field pattern, but total energy can be measured





Dipole antenna pattern



Typical pattern against a phantom head

Anechoic chamber

- Absorptive walls minimize standing waves that cause signal fluctuation
- Far-field conditions ensure predictable power vs. distance
- 3D field pattern measurements done using DUT rotation

Examples of Radio Performance Metrics

R&D	Certification	QA	Production
RX sensitivity EVM Interference, blocker test Data rate/MCS adaptation Throughput vs. noise and channel impairments Roaming behavior	RX sensitivity EVM Interference, blocker test Spectrum mask TIS/TRP SAR	Regression testing Data rate/MCS adaptation Throughput vs. noise and channel impairments Roaming behavior	Fast functional test to find process-related faults Speed and test coverage are key Test late in the process – fully assembled units High yields – minimize false failures while optimizing coverage

Blue = anechoic or conducted
Green = anechoic only
Black = conducted only

The tests listed here are examples, actual tests vary with device type, wireless standard, etc.

EVM = error vector magnitude
MCS = modulation coding scheme
SAR = specific absorption rate

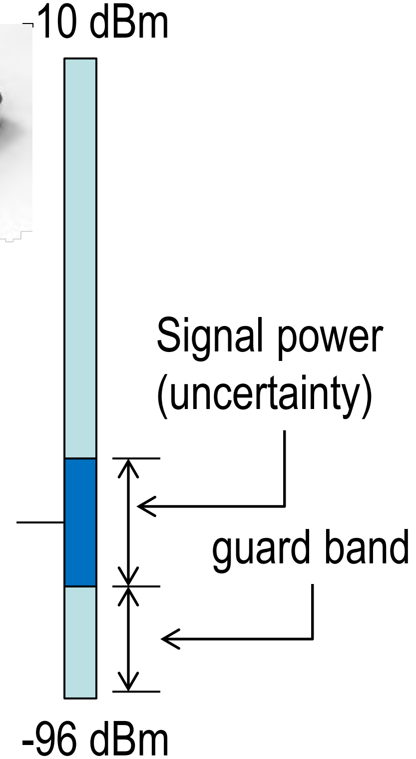
TRP = Total Radiated Power
TIS = Total Isotropic Sensitivity

Production Test

- Fast test to find process related faults (e.g. tombstone components, bad solder joints)
- To maximize probability of fault detection, test DUT RX at lowest signal level
- To minimize probability of false failures, maintain a guard band at the bottom of the RX dynamic range and make RX test signal level high enough to accommodate signal power fluctuations.

Setting RX power too low will result in false failures. Setting RX power too high will lower probability of fault detection. The less fluctuation in signal power, the easier it is to achieve these objectives and thus maximize test coverage and efficiency.

DUT RX dynamic range



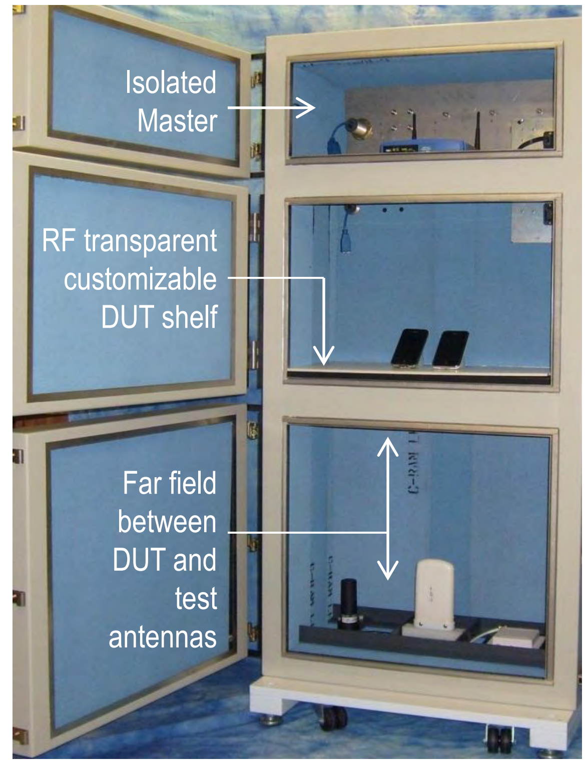
Example

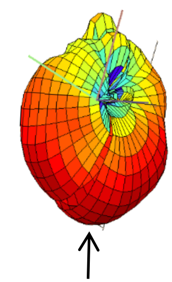
Keeping the radiated signal stable and repeatable for each DUT insertion is key for an OTA production test setup.

How to Stabilize OTA Measurements?

- Isolation
  - Prevents errors caused by noise and by crosstalk between Master and DUT
- Absorption
  - Eliminates standing waves that cause nulls in the signal
  - Nulls result in high power gradients vs. antenna position - up to 10 dB changes in power measurement observed in some enclosures while moving the DUT by < 1”
- Far field conditions
  - Create predictable and stable power levels vs. range
- DUT orientation for optimum antenna field stability

octoBox™ small anechoic chamber

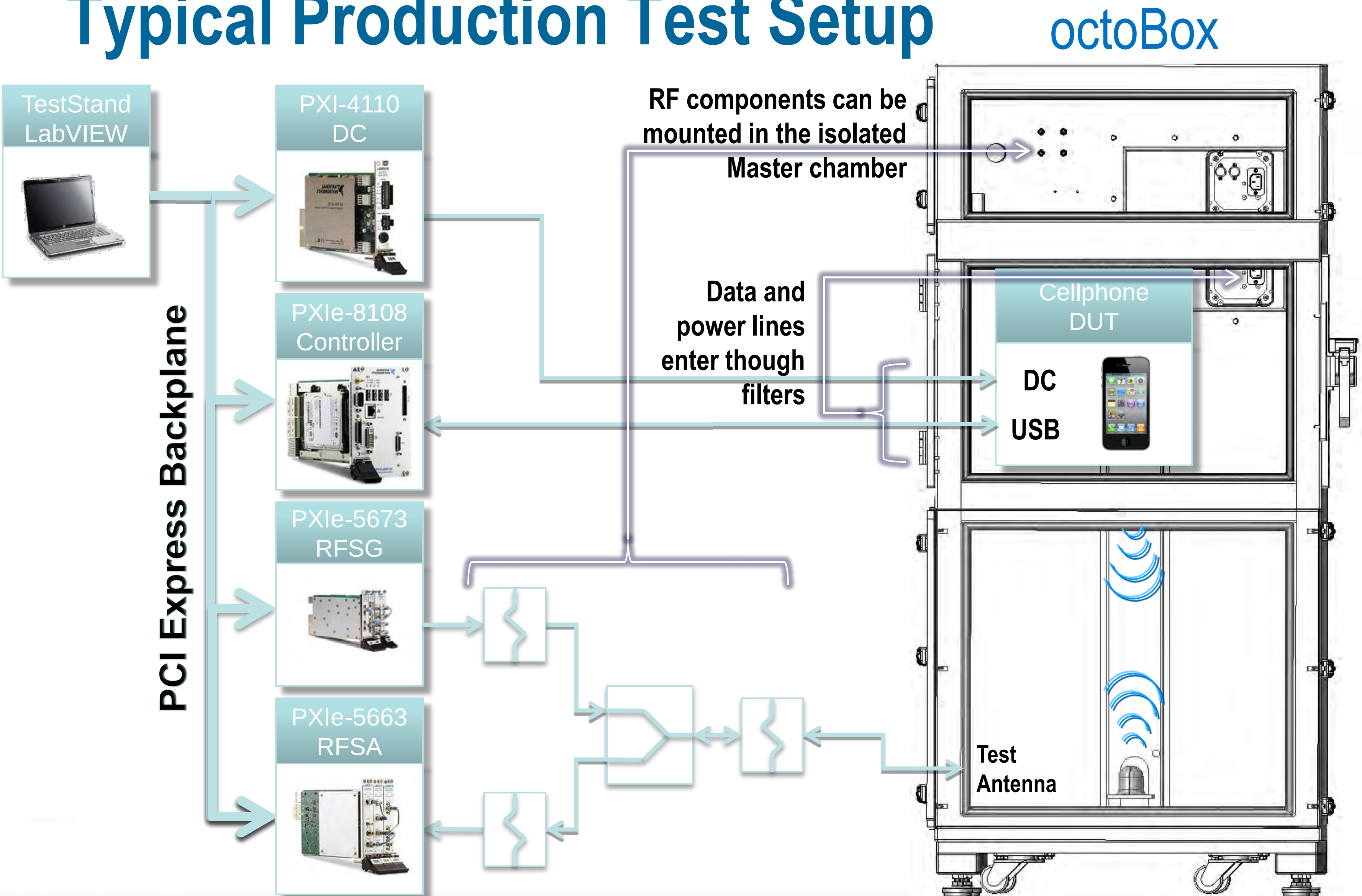




Uniform lobe

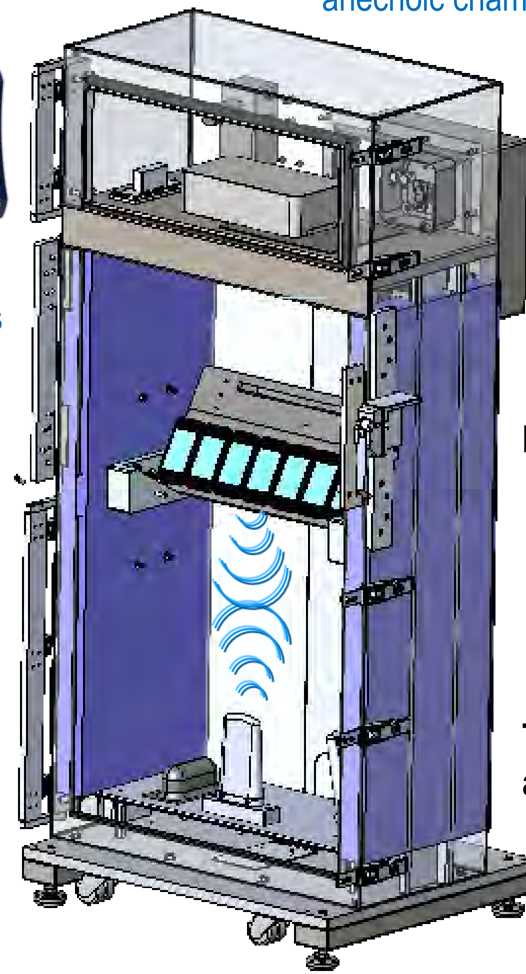
Orient DUT for stability of coupling

Typical Production Test Setup

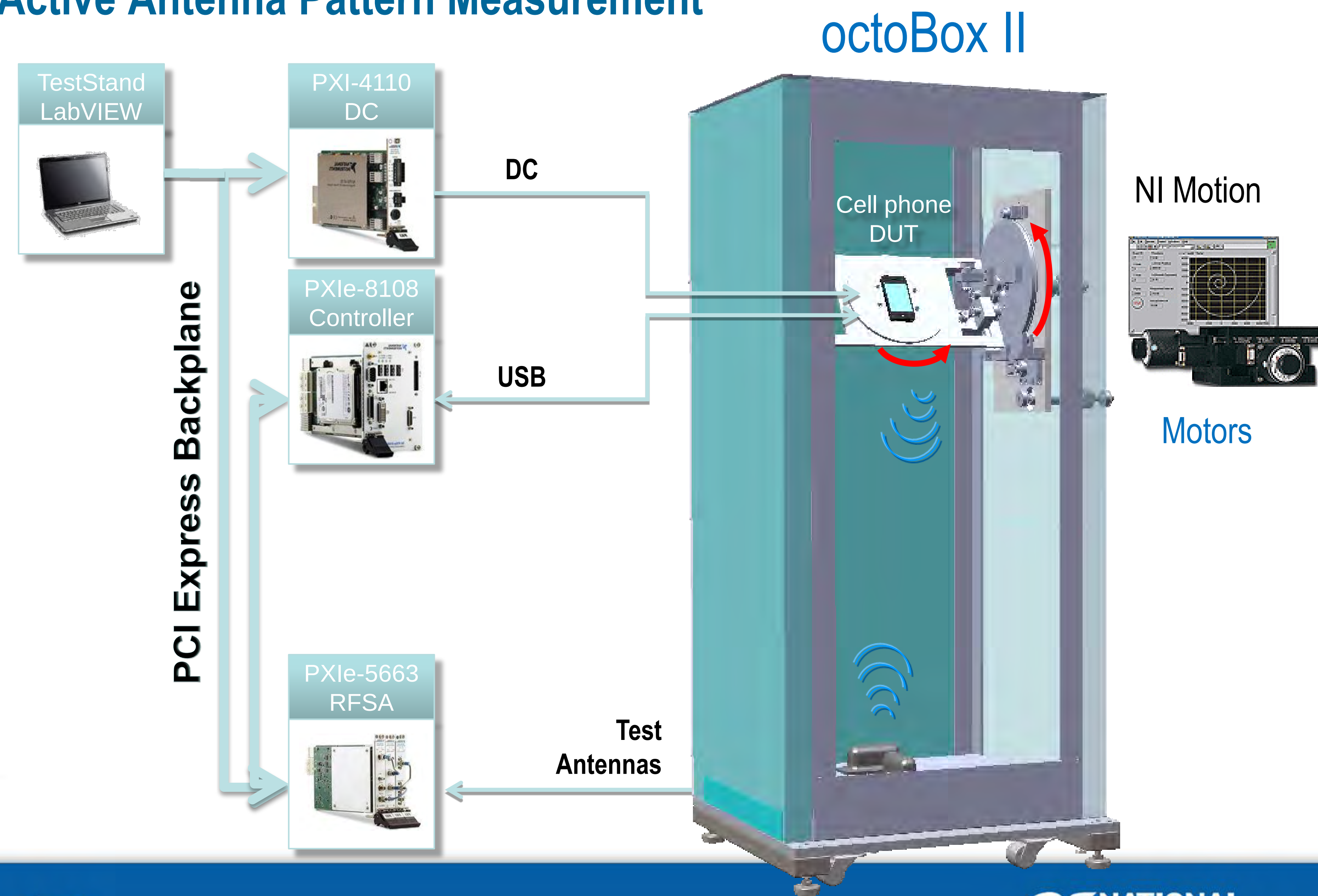


Fast and Efficient Production

- To speed up production
  - Test multiple devices or multiple radios within each device simultaneously
  - Minimize false failures and maximize fault detection by optimizing stability of the radiated signal within the test chamber

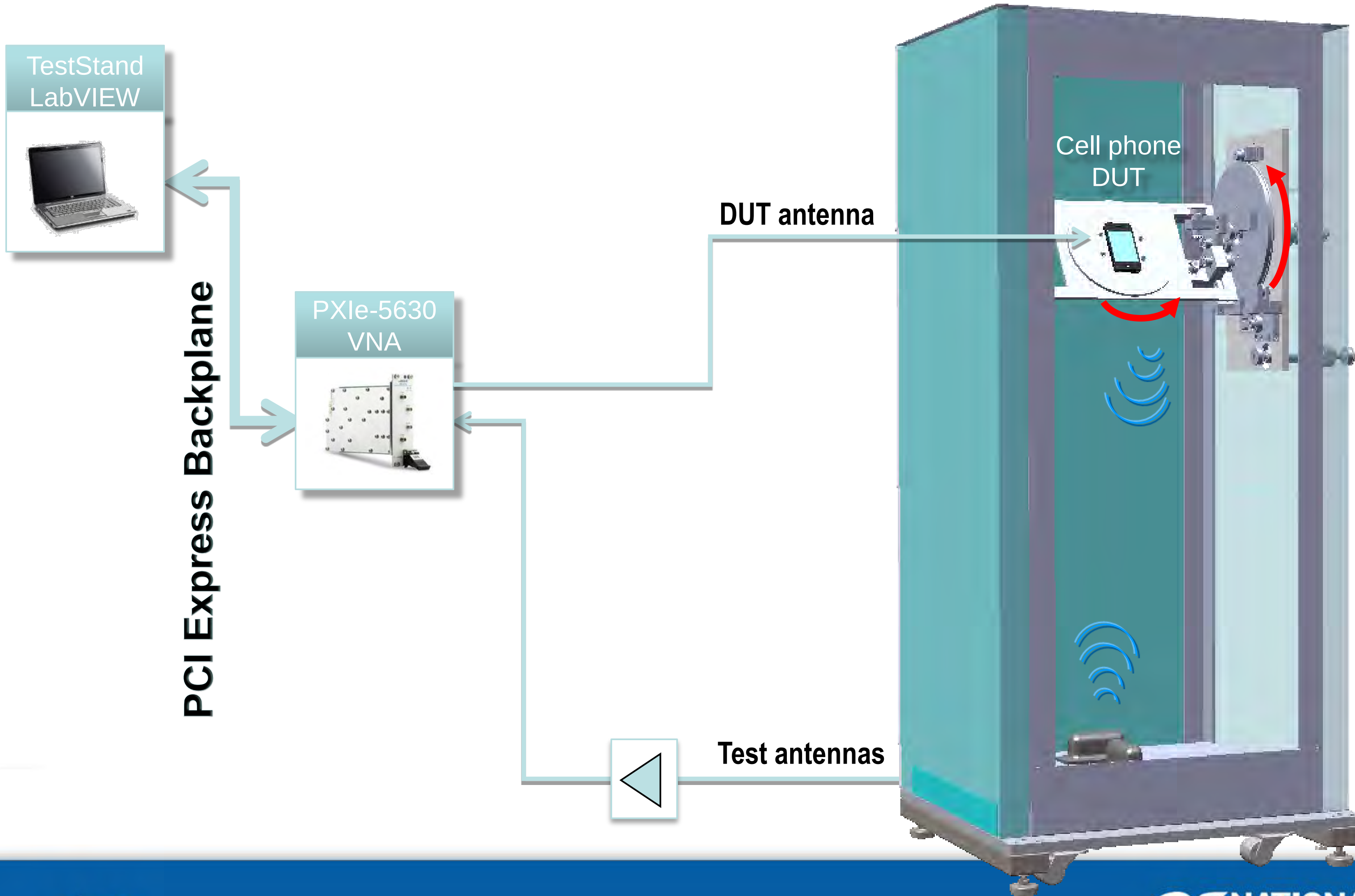


Active Antenna Pattern Measurement



Passive Antenna Pattern Measurement

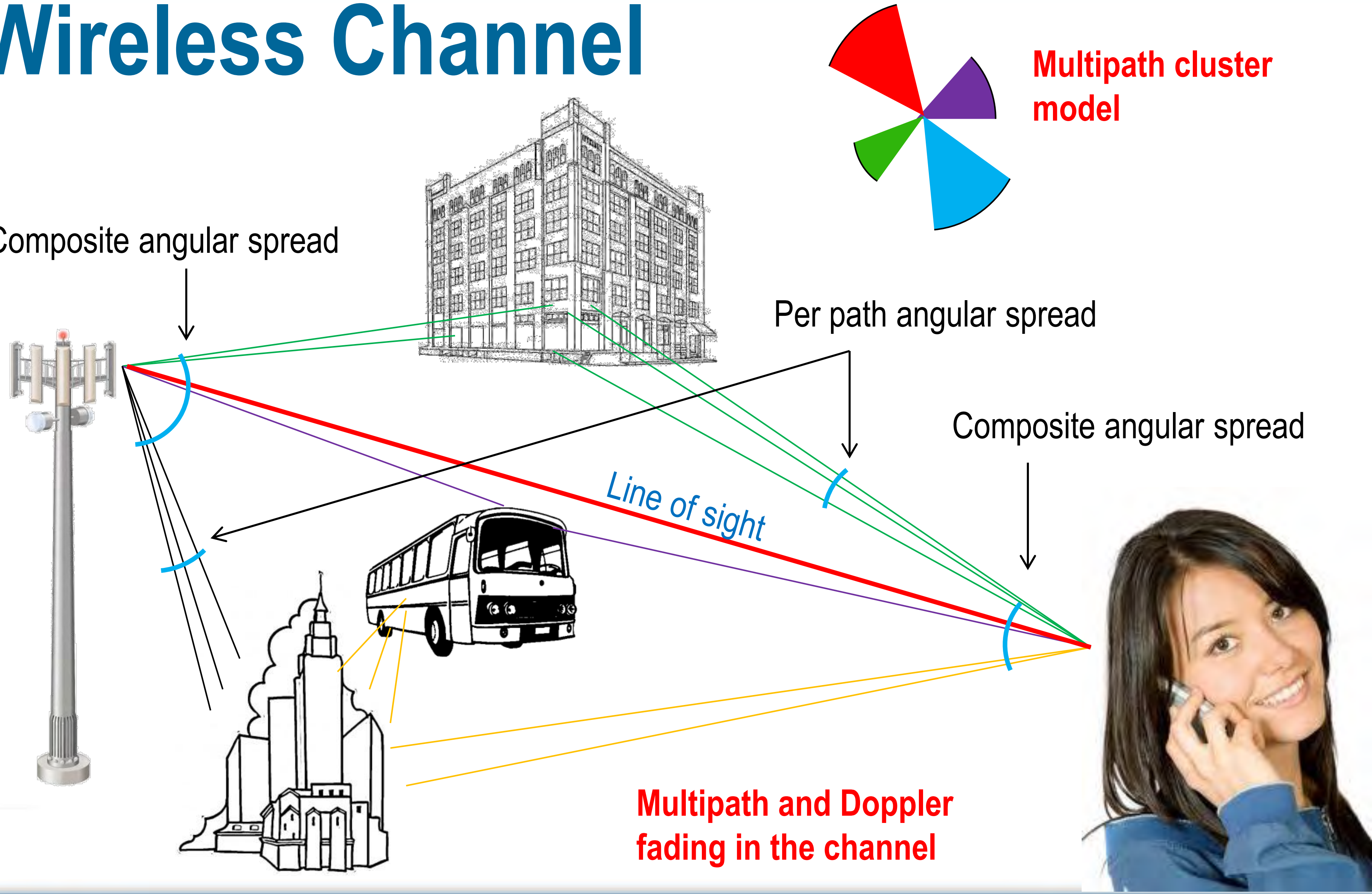
octoBox II



MIMO / OTA

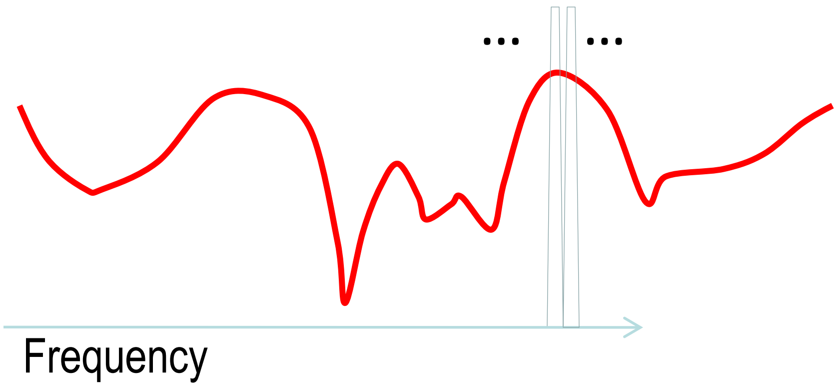
MIMO = multiple input multiple output
OTA = over the air

Wireless Channel



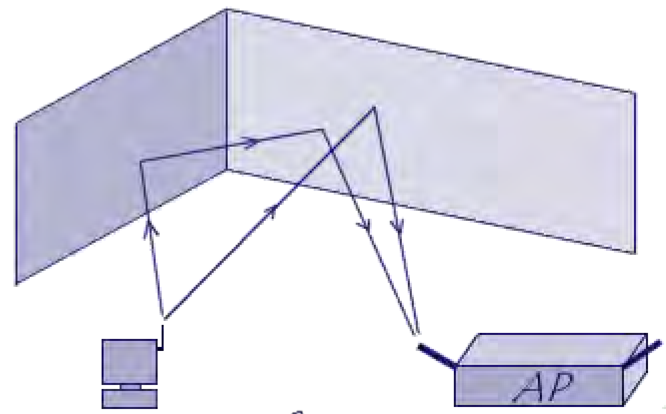
OFDM and MIMO

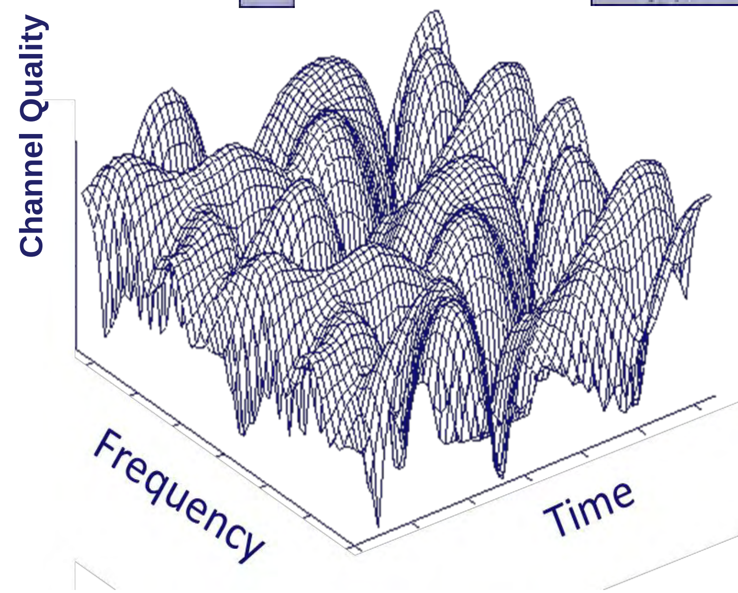
OFDM transforms a frequency- and time-variable fading channel into parallel correlated flat-fading channels, enabling wide bandwidth operation



Frequency-variable channel appears flat over the narrow band of an OFDM subcarrier.

Multipath in a wireless channel

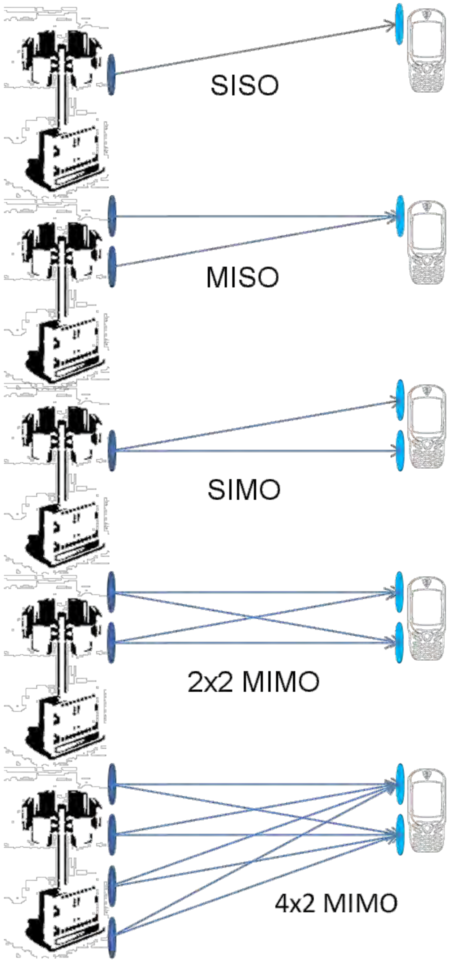




OFDM = orthogonal frequency division multiplexing
MIMO = multiple input multiple output

Multiple Antenna Techniques

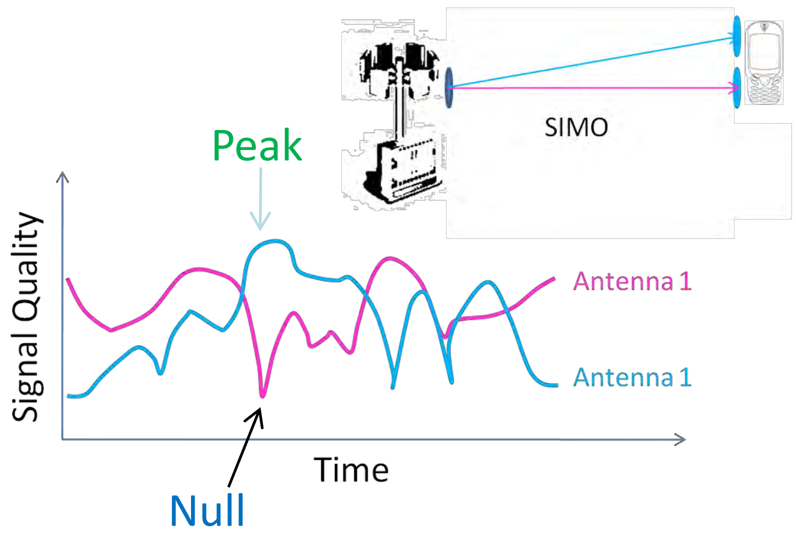
- SISO (Single Input Single Output)
  - Traditional radio
- MISO (Multiple Input Single Output)
  - Transmit diversity (STBC, SFBC, CDD)
- SIMO (Single Input Multiple Output)
  - Receive diversity, MRC
- MIMO (Multiple Input Multiple Output)
  - SM to transmit multiple streams simultaneously; can be used in conjunction with CDD; works best in high SNR environments and channels de-correlated by multipath
  - TX and RX diversity, used independently or together; used to enhance throughput in the presence of adverse channel conditions
- Beamforming



SM = spatial multiplexing
SFBC = space frequency block coding
STBC = space time block coding
CDD = cyclic delay diversity
MRC = maximal ratio combining
SM = Spatial Multiplexing
SNR = signal to noise ratio

MIMO Based RX and TX Diversity

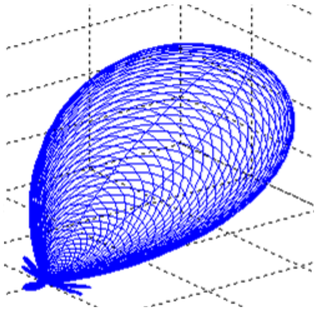
- When 2 receivers are available in a MIMO radio MRC can be used to combine signals from two or more antennas, improving SNR
- MIMO also enables transmit diversity techniques, including CDD, STBC, SFBC
- TX diversity spreads the signal creating artificial multipath to decorrelate signals from different transmitters so as to optimize signal reception

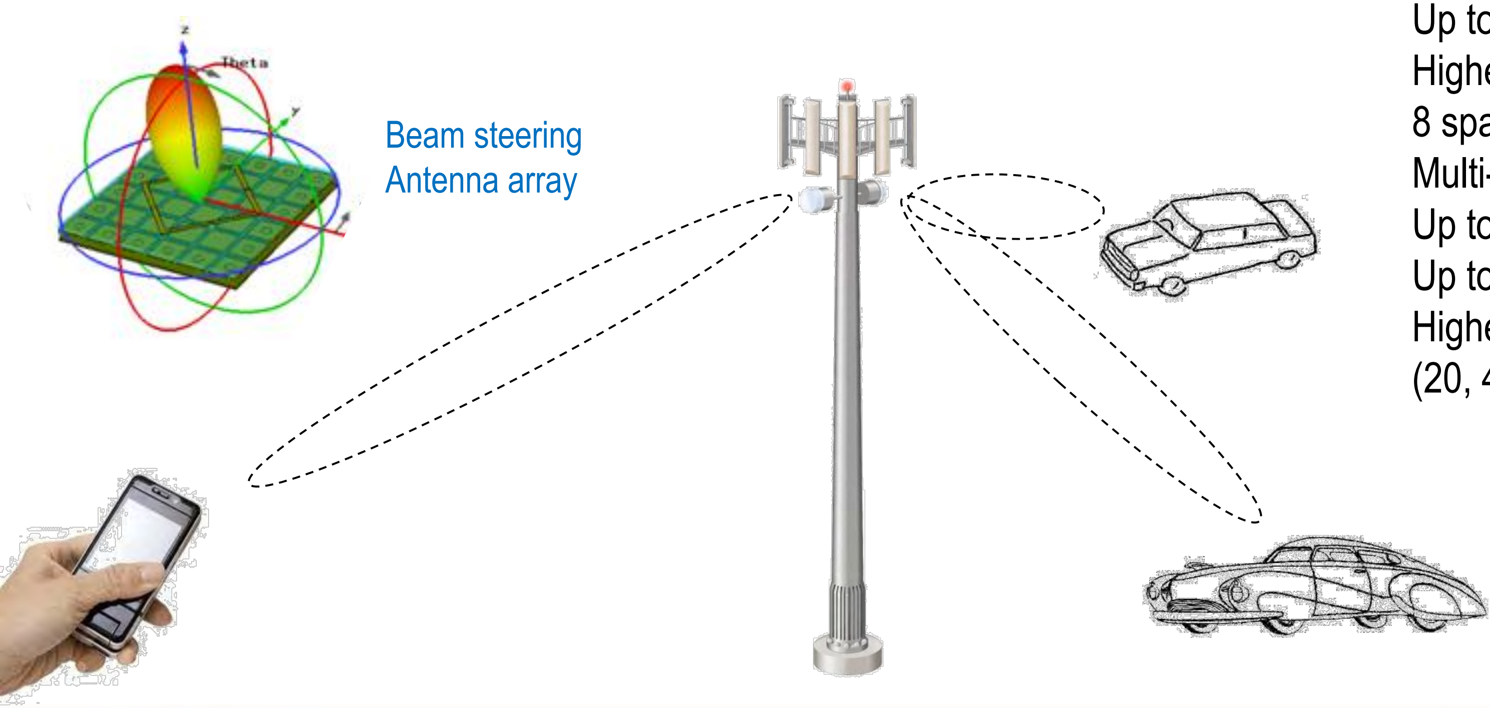


MIMO = multiple input multiple output
SIMO = single input multiple outputs
SFBC = space frequency block coding
STBC = space time block coding
CDD = cyclic delay diversity
MRC = maximal ratio combining
SM = Spatial Multiplexing
SNR = signal to noise ratio

Beamforming and MU-MIMO

LTE Advanced and IEEE 802.11ac/ad will support beamforming and MU-MIMO spatial multiplexing techniques to make efficient use of scarce spectrum





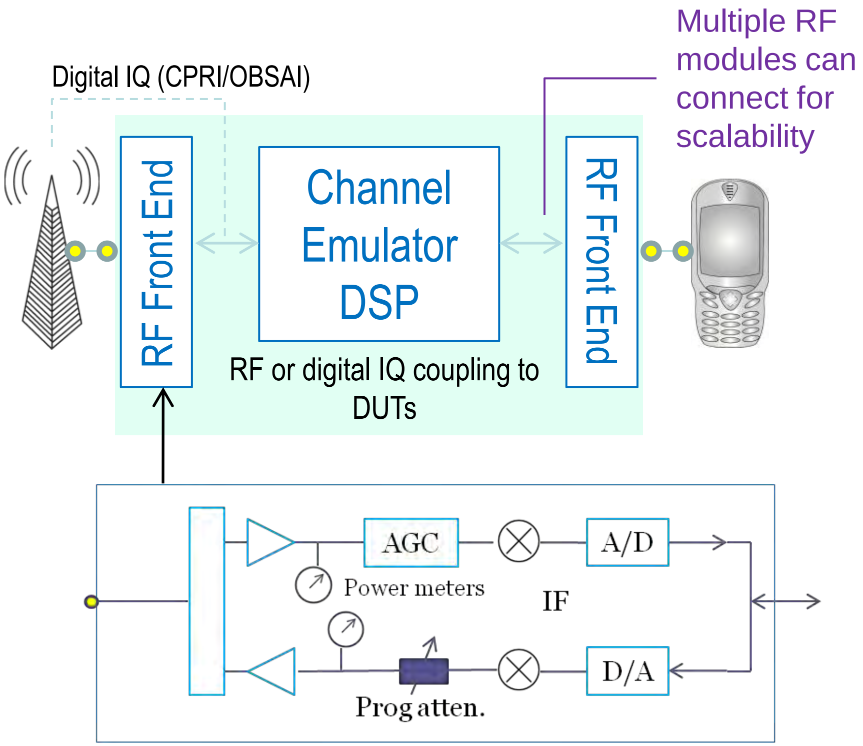
Draft 802.11ac

Up to 6.9 Gbps
Higher order MIMO (> 4x4)
8 spatial streams
Multi-user (MU) MIMO
Up to 4 users
Up to 4 streams per user
Higher bandwidth channels
(20, 40, 80, 80+80, 160 MHz)

MU-MIMO = multi-user MIMO

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.

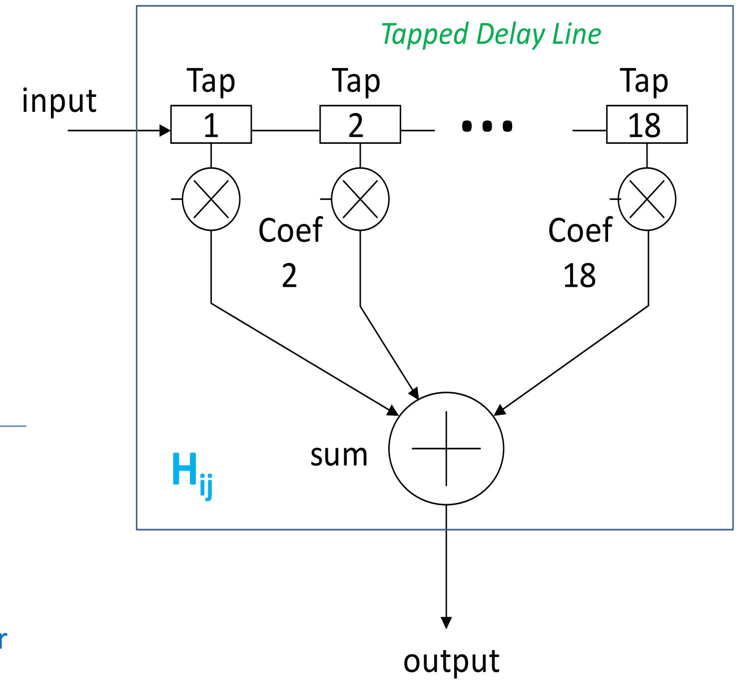


Problematic for MIMO and beamforming systems where antennas are integral to performance

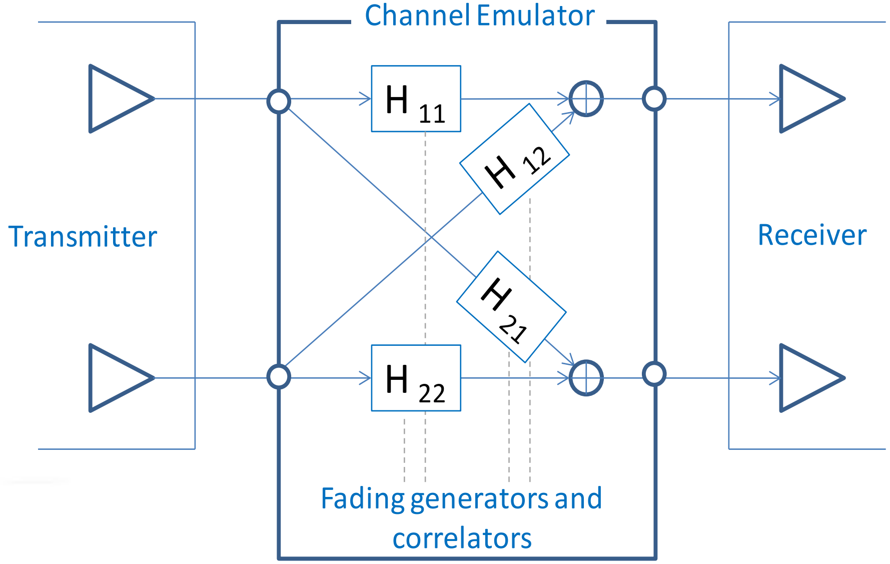
Modeling Multipath Doppler Fading Channel

A SISO channel is modeled by a single TDL

A MIMO channel is modeled by multiple TDLs with spatially correlated coefficients, each representing a MIMO path



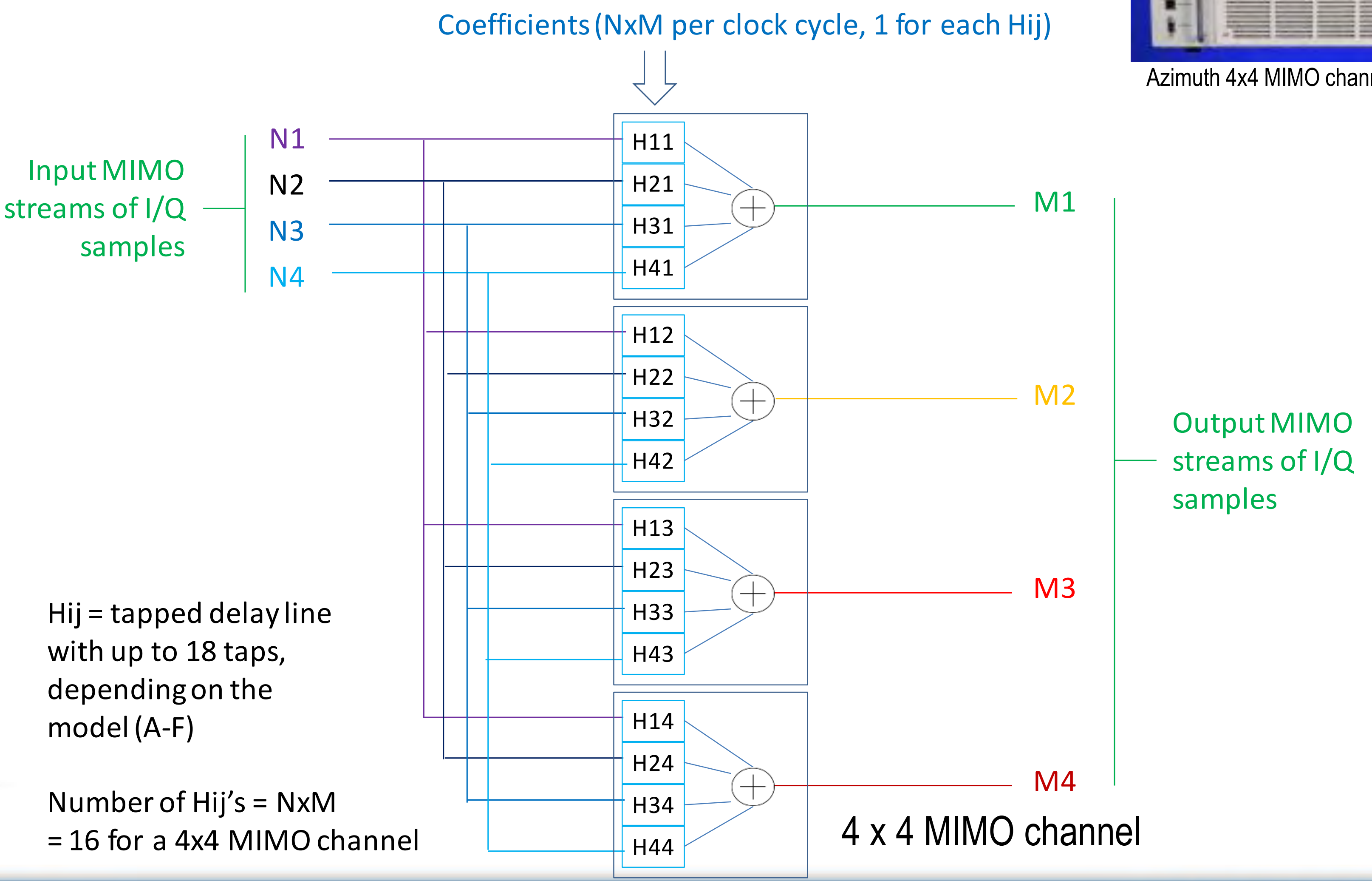
2 x 2 MIMO channel



Connections are made to coaxial ports and antennas are part of the models.

Data Flow Through Emulator

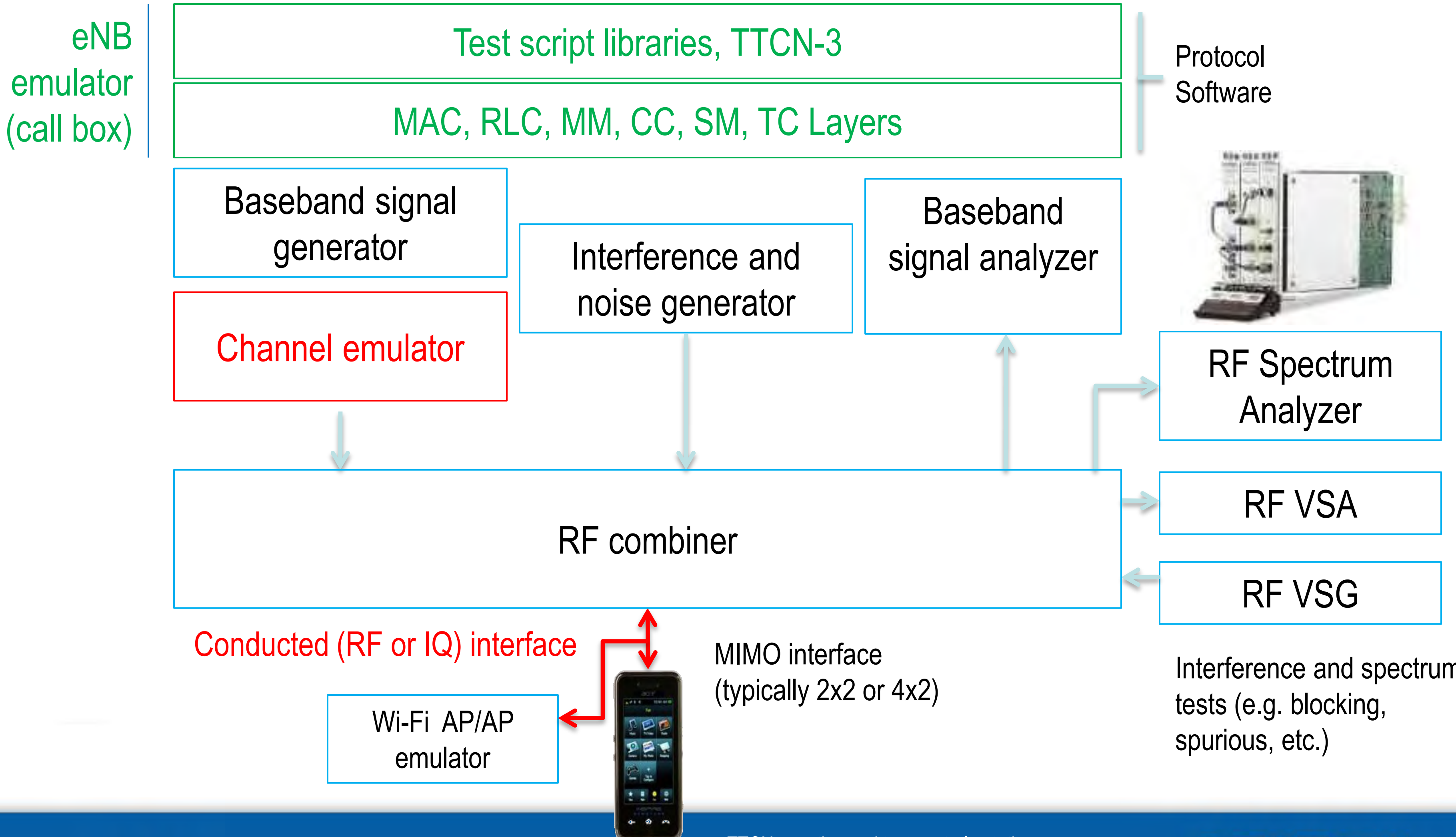
Azimuth 4x4 MIMO channel emulator



Hij = tapped delay line with up to 18 taps, depending on the model (A-F)

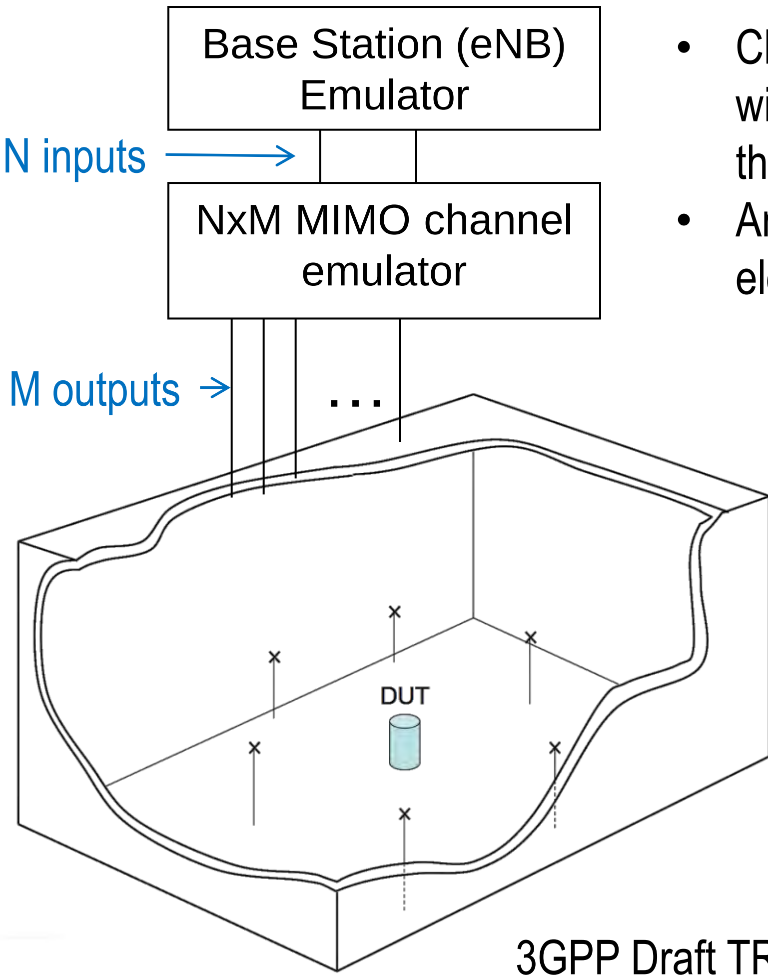
Number of Hij's = NxM
= 16 for a 4x4 MIMO channel

Typical UE Certification Test Setup

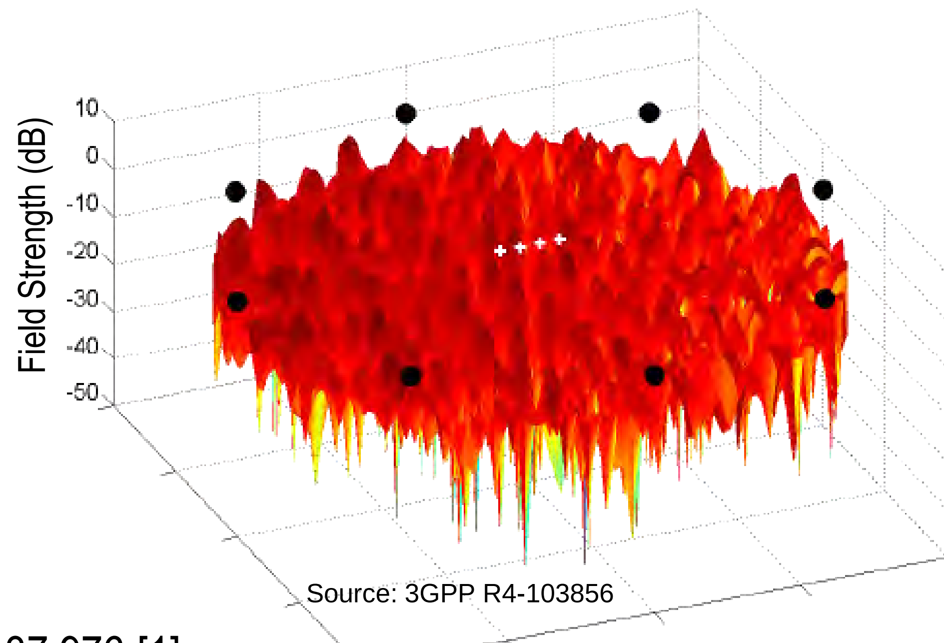


TTCN = testing and test control notation
UE = user equipment

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)



Source: 3GPP R4-103856

3GPP Draft TR 37.976 [1]

eNB = enhanced Node B
DL = downlink

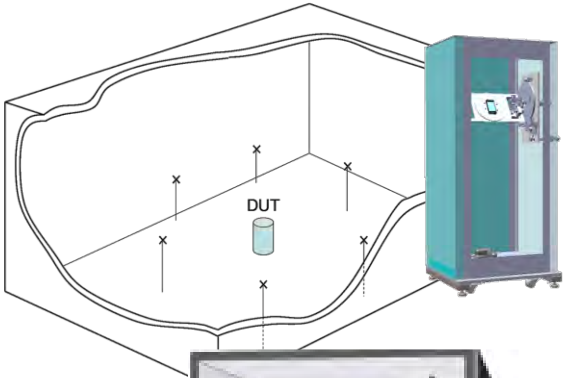
MIMO/OTA Standards Organizations

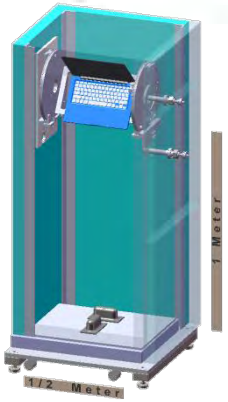
- 3GPP (International)
  - MIMO/OTA specification development [1]
  - Driven by TSG RAN WG4 in collaboration with CTIA & COST
- CTIA (US)
  - SISO OTA certification standard [4]
  - Recently formed MIMO/OTA Sub-Working Group (MOSG) is driving effort to update current standard [4] for MIMO/diversity
- 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”

3GPP = 3rd generation partnership project
CTIA = cellular telecommunications industry association
COST = European Cooperation in Science and Technology

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



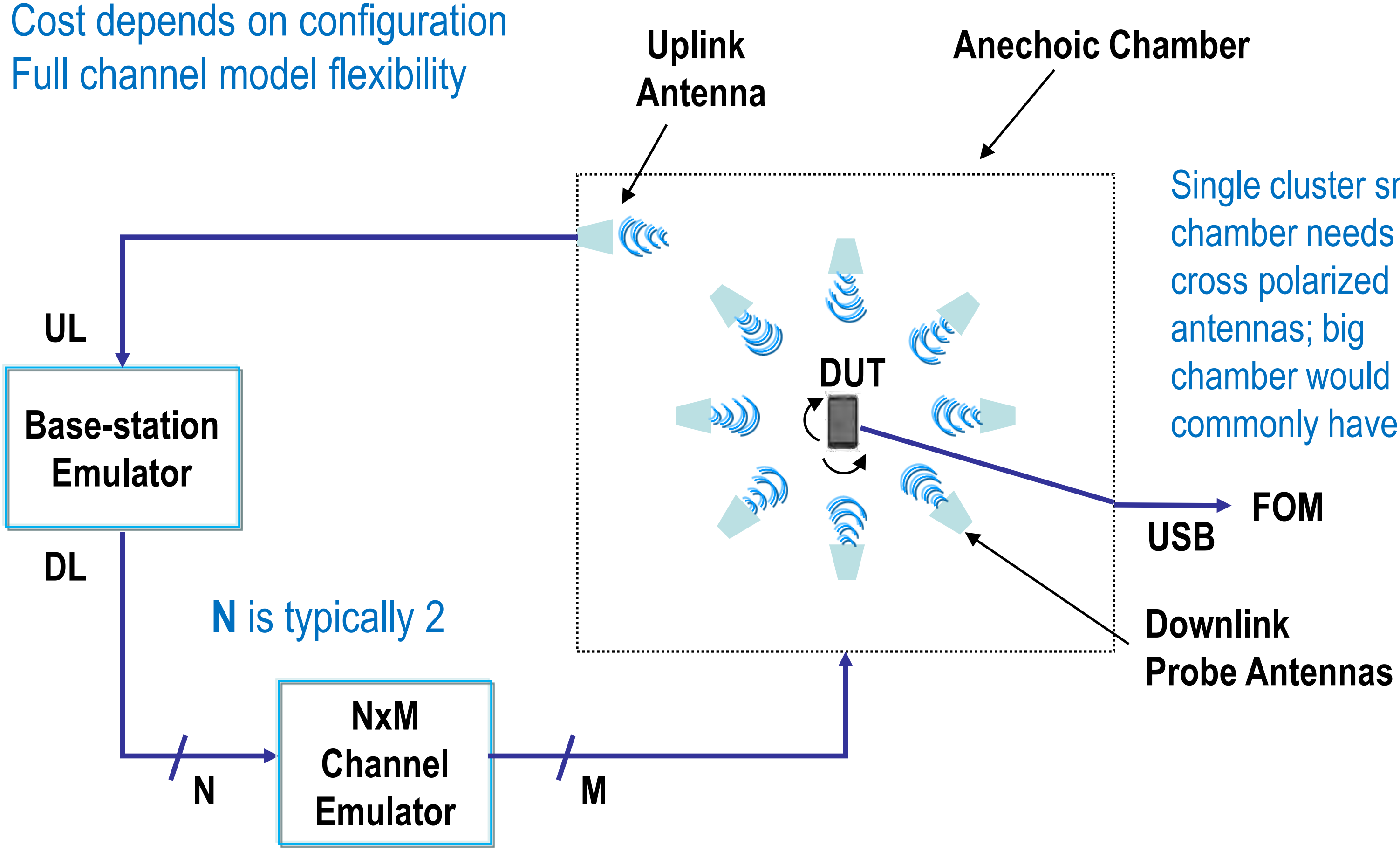


LTE channel models in the draft [1]: SCME Urban Macro (UMa), Urban Micro (UMi), WINNER II Outdoor-to-indoor and EPA.

SCME = spatial channel model enhanced
AS = angular spread
WINNER = Wireless World Initiative New Radio
EPA = extended pedestrian A

Anechoic Chamber Setup

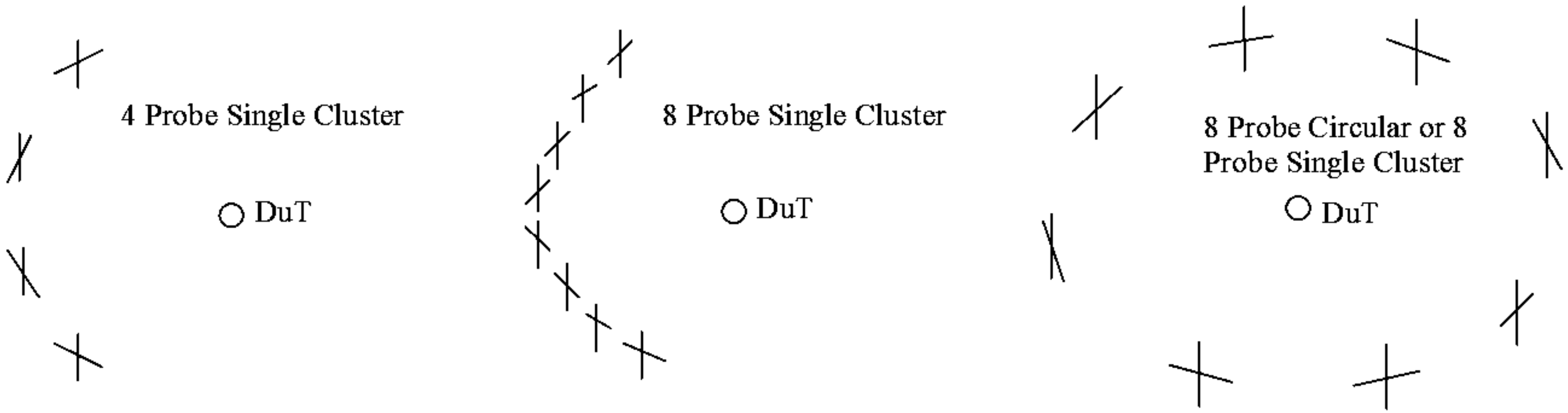
- Cost depends on configuration
- Full channel model flexibility



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

FOM = figure of merit

Anechoic Chamber - Cluster Modeling

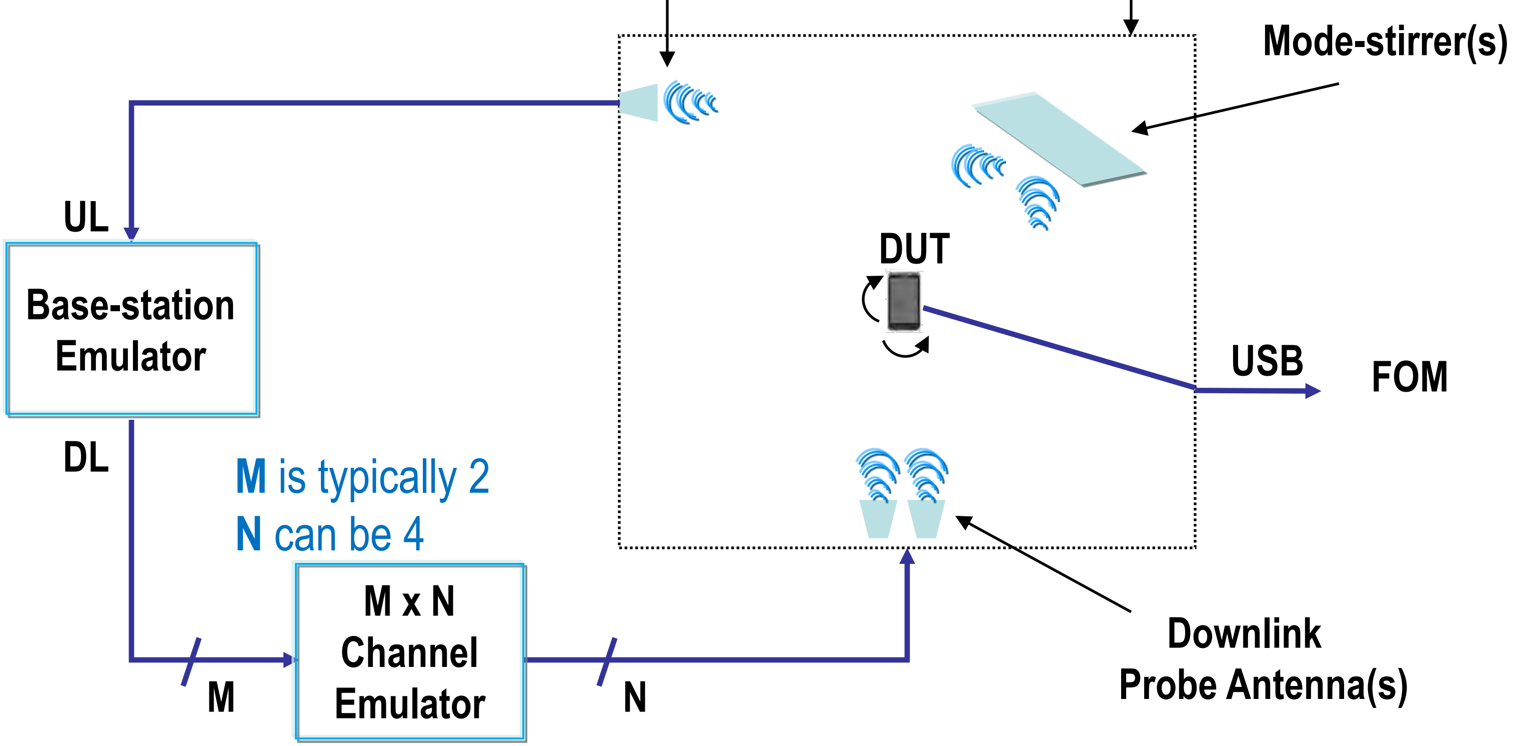


- MIMO/OTA modeling can be done in a large anechoic chamber with probes surrounding the DUT or in a small chamber modeling a single cluster
- 8 channel emulator DL RF ports are needed for 4 cross polarized probes modeling a cluster (configuration on left)

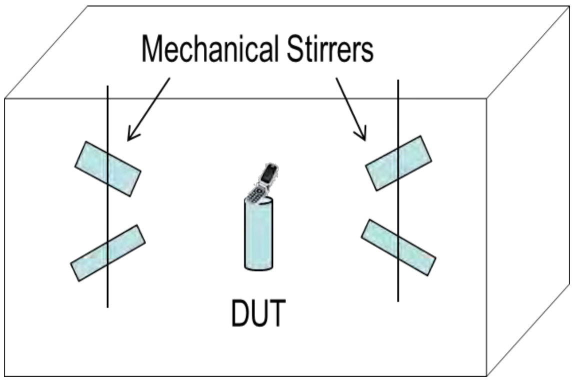
DL = downlink

Reverberation Chamber Setup

- Medium cost
- Limited channel model flexibility

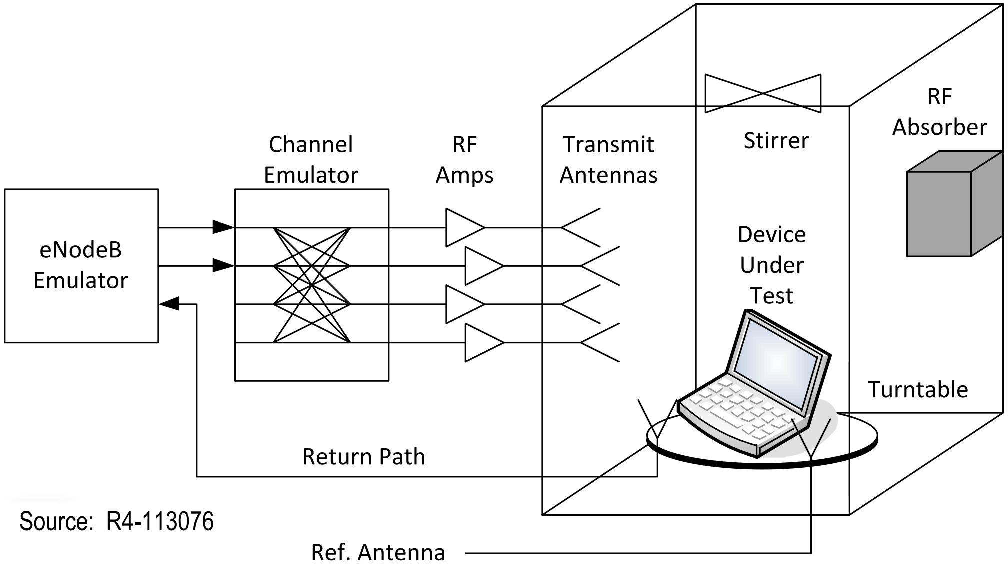


Reverberation Chamber Setup Example



Traditional reverb configuration
Doppler effects are modeled by stirrers

Uniform angular spread; difficult to reproduce a standards based model



Source: R4-113076

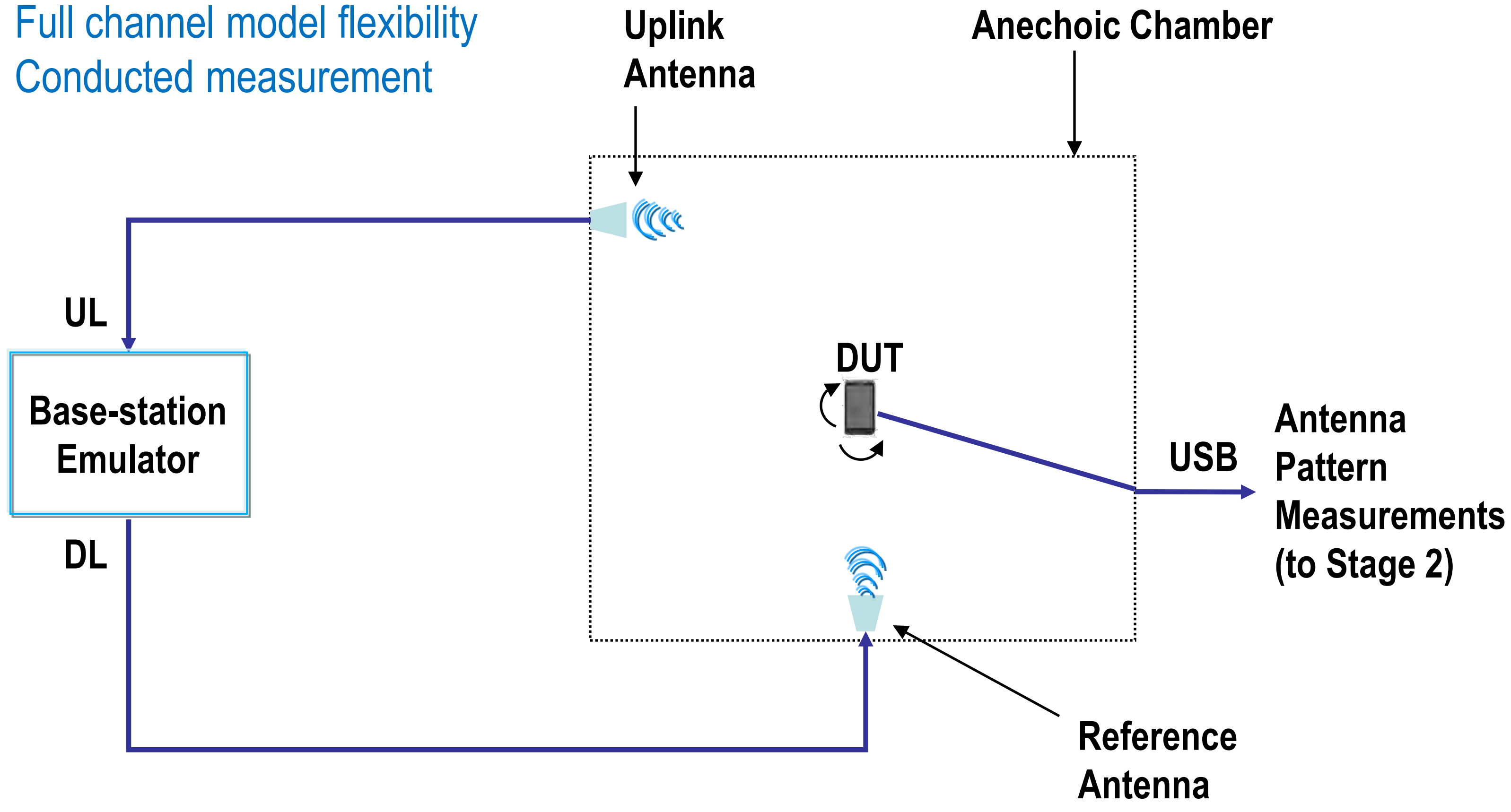
3GPP MIMO/OTA proposal
Doppler effects are modeled by stirrers; channel emulator provides more realistic Doppler

One of the 3GPP RAN4 round-robin test DUTs

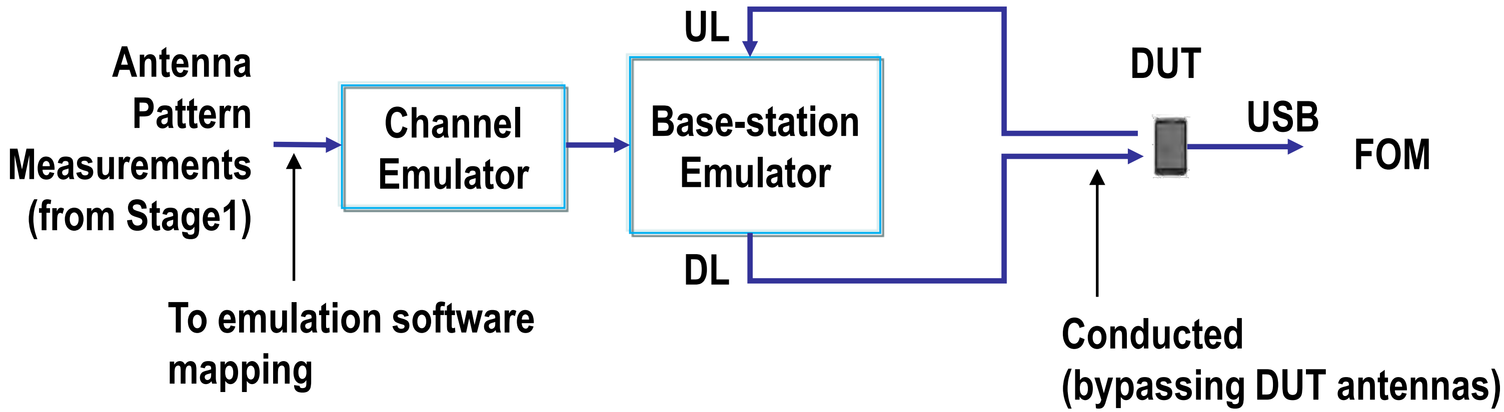
AS = angular spread

Two-Stage Method Setup (Stage 1)

- Lowest cost
- Full channel model flexibility
- Conducted measurement



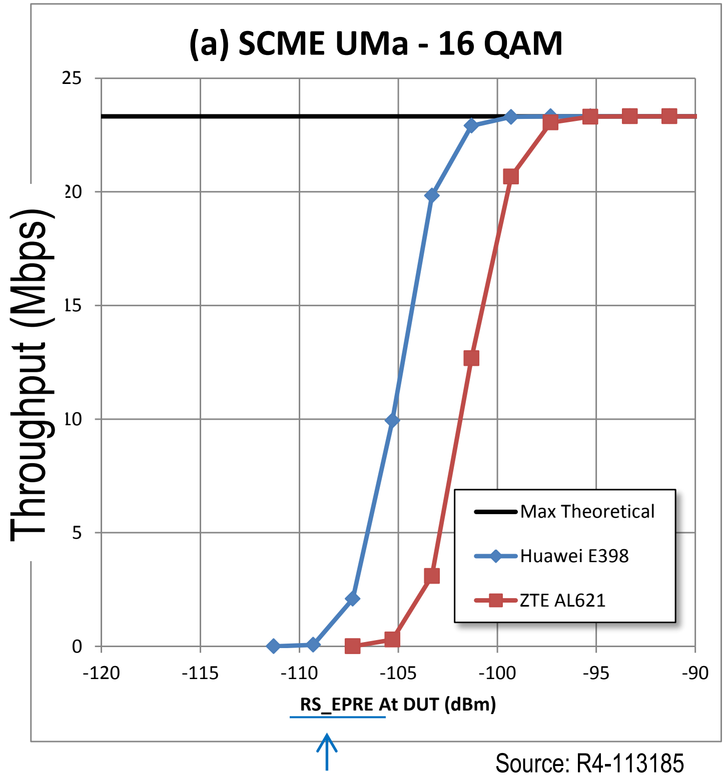
Two-Stage Method Setup (Stage 2)



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

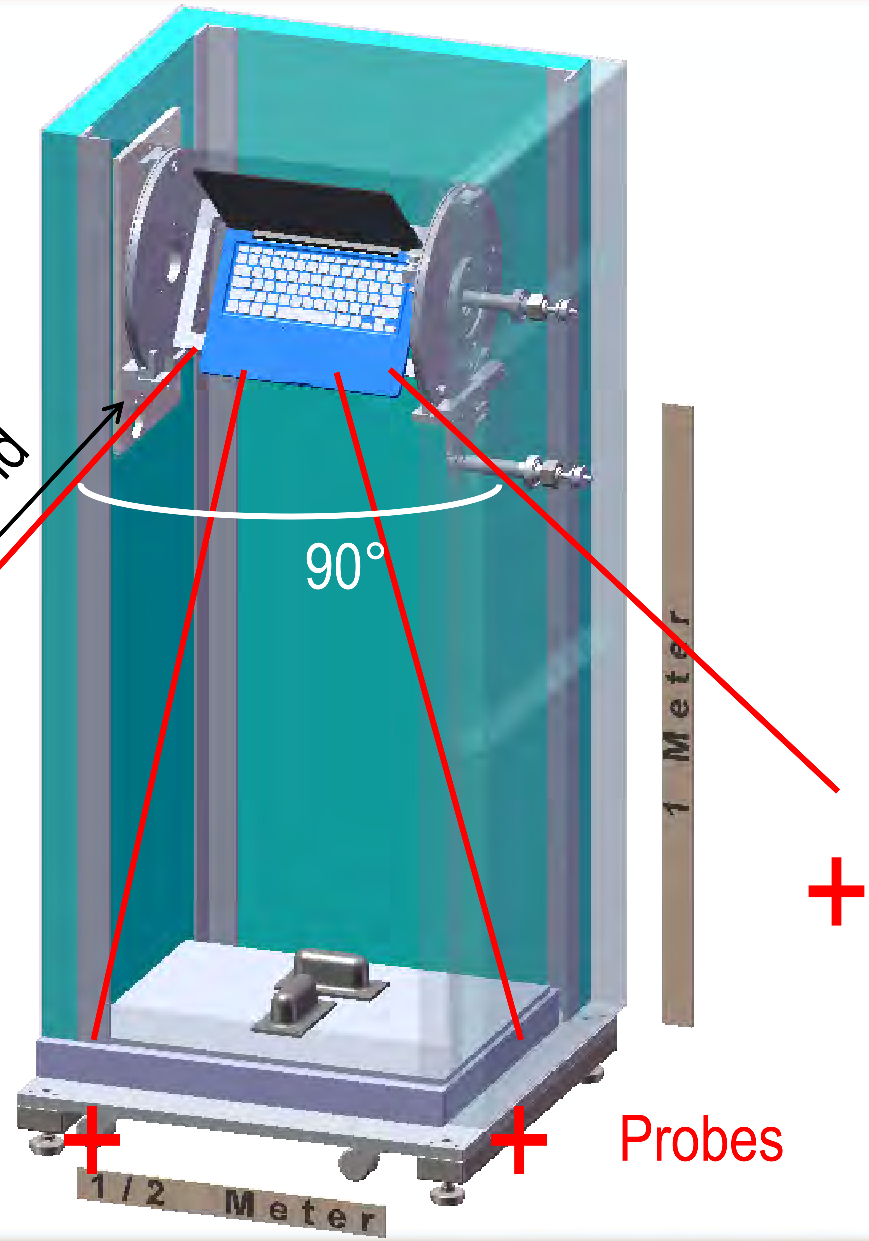
Energy at DUT per LTE subcarrier (i.e. per 15 kHz)

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

FOM = figure of merit
RS = reference signal
EPRE = energy per resource element

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

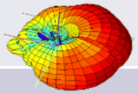


AS = angular spread

Small Anechoic Chamber for MIMO/OTA

- Depending on the angular spread requirements, small anechoic chamber for MIMO/OTA will be no bigger than about 1x3 meters inside, but likely narrower
- For smaller DUTs like handsets, a single section chamber may suffice
- The 2-stage method can also use a single section chamber

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

FOM = figure of merit

TIS = total isotropic sensitivity
TRP = total radiated power
BLER = block error rate
ECC = electronic communications committee

Thank you!

- For more information please visit www.octoscope.com
- Articles, white papers and test reports on a variety of wireless topics can be found at http://www.octoscope.com/English/Resources/Articles.html

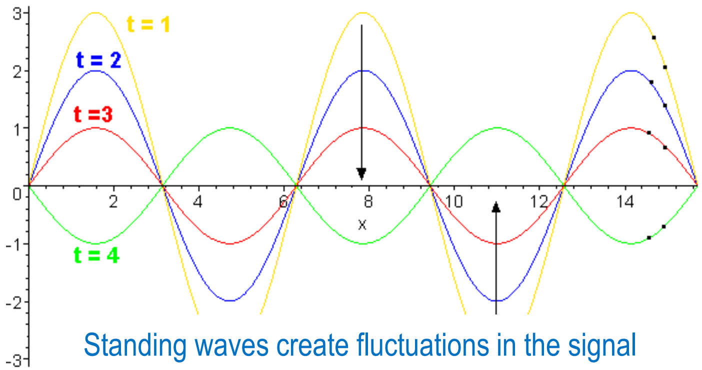
References

1) MIMO OTA technical report update: TR 37.976 Version 1.5.0
2) 3GPP TS 34.114: “User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) Antenna Performance Conformance Testing”
3) Charles Capps, “Near field or far field?”, EDN, Aug 16, 2001
4) 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

Back-up Material

Controlling Reflections and Nulls

- Reflections cause standing waves resulting in signal power fluctuation at the DUT or at the measurement antenna
- To make measurements repeatable, absorptive foam is used
- Absorptive foam
  - Controls reflections in the box; eliminates signal nulls due to standing waves
  - Requires layers with monotonically changing impedance (lowest towards the metal wall of the box; highest towards the air) to provide optimum impedance match and minimize inter-layer reflections

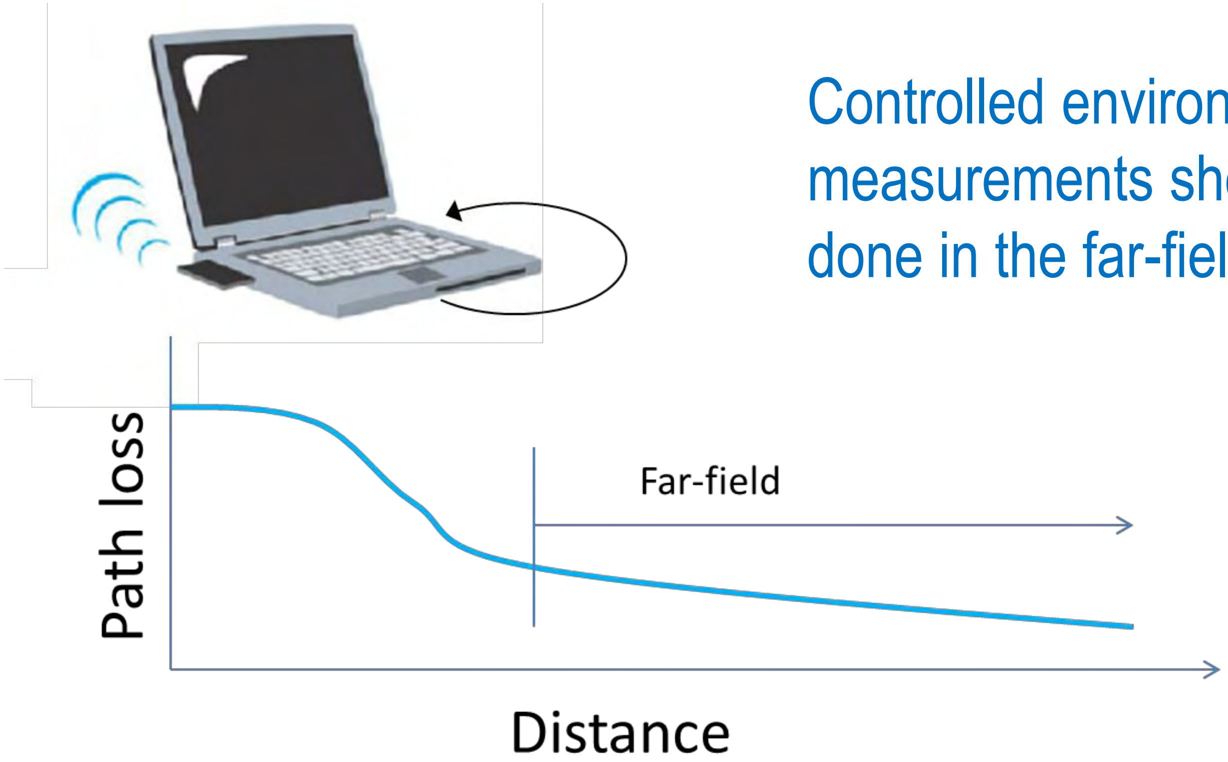


Standing waves create fluctuations in the signal


Absorptive foam with layers of graded impedance dampens signal fluctuations by attenuating standing waves

How is Far Field Defined?

- It is generally accepted that **far-field antenna radiation is characterized by path loss proportional to 1/r**, whereas near-field radiation is characterized by path loss proportional to $1/r^2$ or $1/r^3$ or a product thereof [3]



Controlled environment OTA measurements should be done in the far-field

Far Field Definition from 3GPP

- 3GPP TS 34.114: "User Equipment (UE) / Mobile Station (MS) Over The Air (OTA) Antenna Performance Conformance Testing" [2] defines far-field as follows:

D the maximum extension of the radiating structure

$$r > \max\left(\frac{2D^2}{\lambda}, 3D, 3\lambda\right)$$

Wavelength

Far-field Calculation – Laptop, Phone

Laptop formfactor (D = 0.33 m)

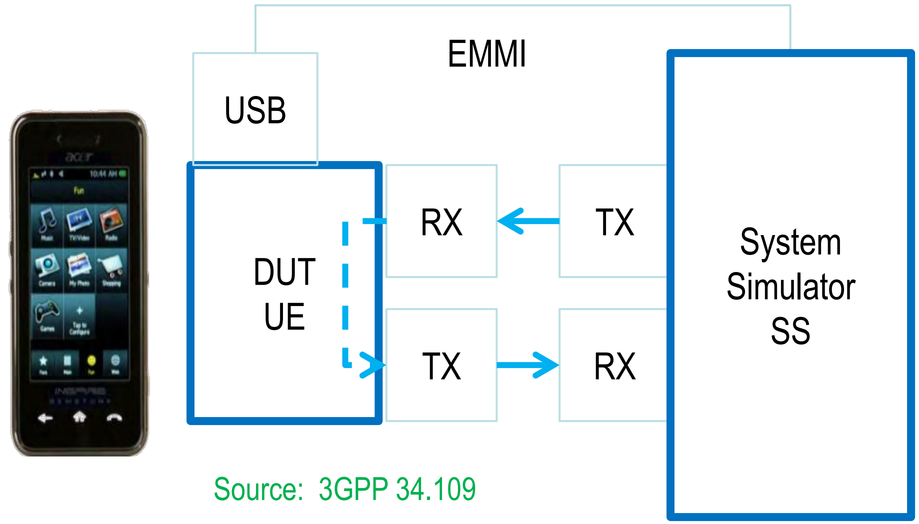
Laptop far-field distance, m	$2D^2/\lambda$, m	3D, m	3λ, m	f, MHz	λ, m
1.50	0.44	0.99	1.50	600	0.50
1.28	0.51	0.99	1.28	700	0.43
1.00	0.73	0.99	0.90	1000	0.30
1.45	1.45	0.99	0.45	2000	0.15
4.36	4.36	0.99	0.15	6000	0.05

↑ Suspect value

Handset formfactor (D = 0.1 m)

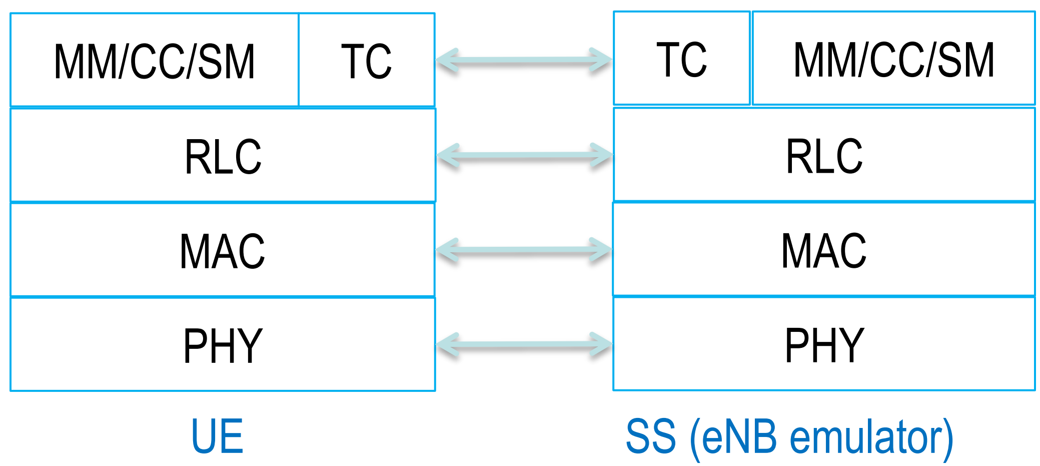
Handset far-field distance, m	$2D^2/\lambda$, m	3D, m	3λ, m	f, MHz	λ, m
1.50	0.04	0.3	1.50	600	0.50
1.28	0.05	0.3	1.28	700	0.43
0.75	0.08	0.3	0.75	1200	0.25
0.45	0.13	0.3	0.45	2000	0.15
0.40	0.40	0.3	0.15	6000	0.05

Typical UE Certification



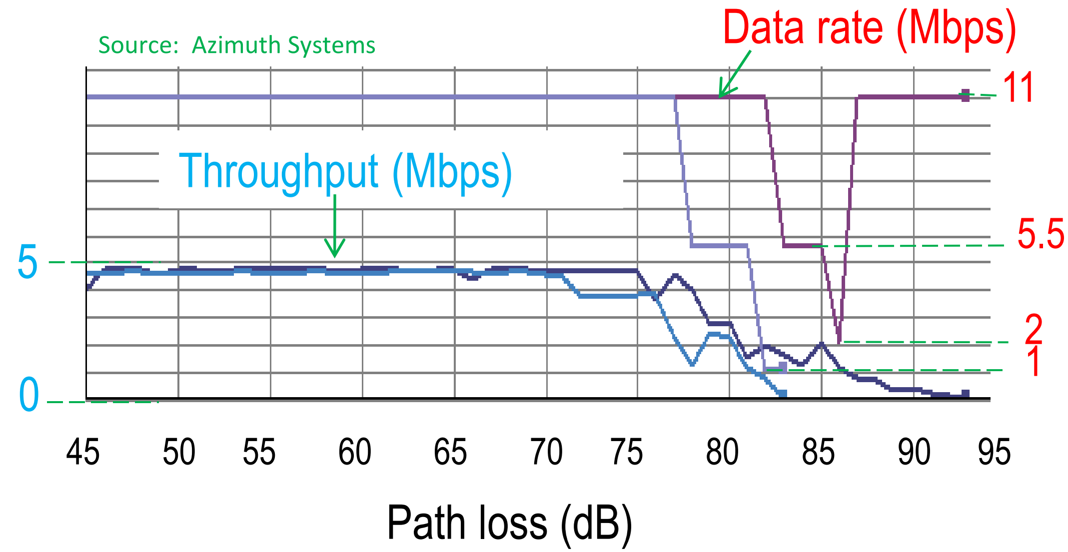
Source: 3GPP 34.109

MM = mobility management
CC = call control
SM = session management
TC = test control
RRC = radio resource control
RLC = radio link control
MAC = medium access control
PHY = physical layer
UE = user equipment (handset)
SS = system simulator (base station emulator)
EMMI = Electrical Man Machine Interface
eNB = enhanced Node B (LTE base station)



Example: Controlled Environment Test

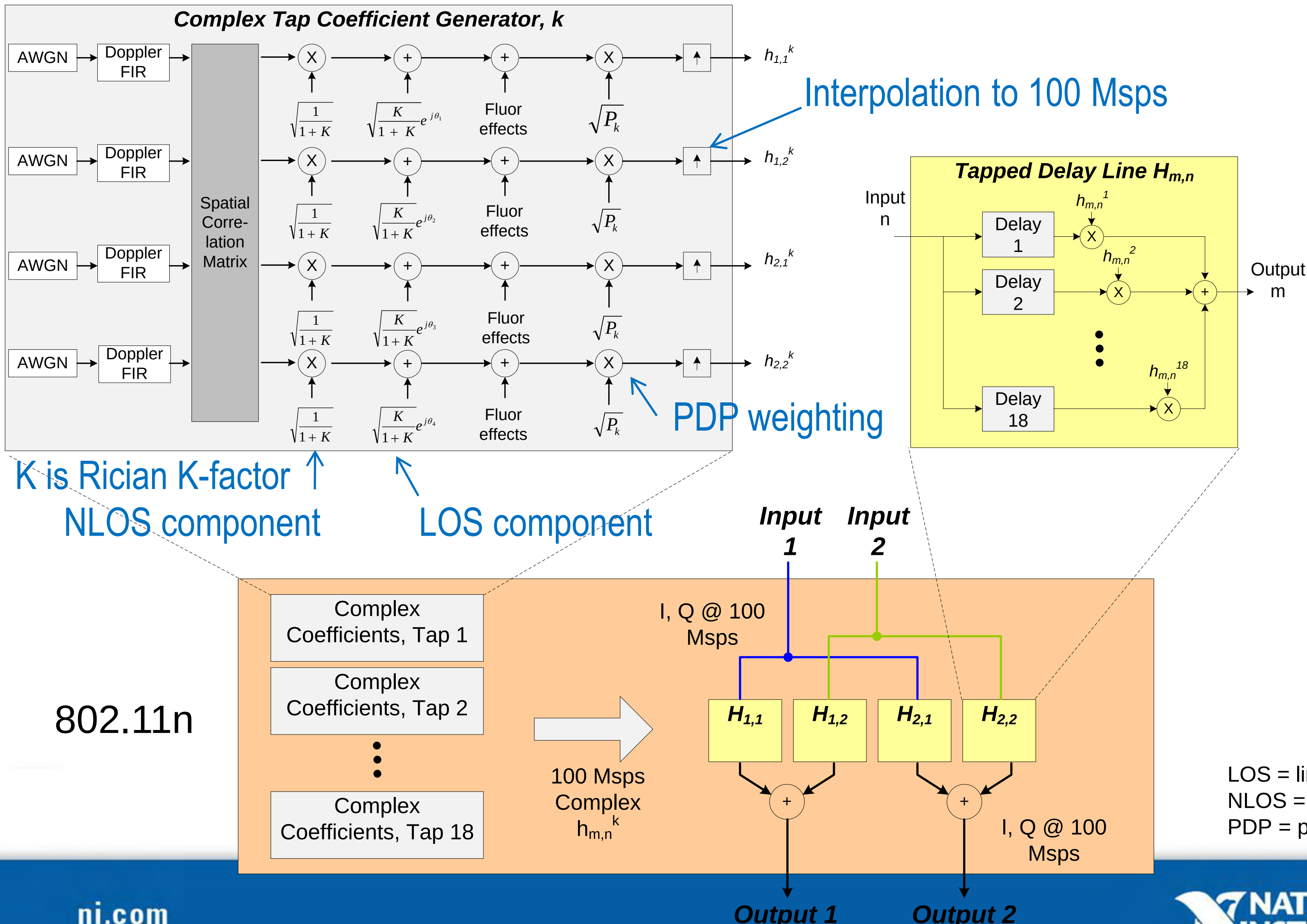
- Measurement of throughput and data rate adaptation vs. path loss
- 802.11 data rates
  - 11b (DSSS-CCK) – 1, 2, 5.5, 11 Mbps in 2.4 GHz band
  - 11a (OFDM) – 6, 9, 12, 18, 24, 36, 48, 54 Mbps in 5 GHz band
  - 11g – both 11b and 11a rates in 2.4 GHz band
  - 802.11n – 6 to 600 Mbps in 2.4 and 5 GHz bands
    - MIMO introduces the concept of MCS (modulation, coding rate, # spatial streams, # FEC encoders)



Above plot shows automatic adaptation of data rate as path loss increases.

MIMO = multiple input multiple output
MCS = modulation coding scheme

2 x 2 Channel Emulator Example



LOS = line of sight
NLOS = non-line of sight
PDP = power delay profile

802.11n Channel Models A through F

Model		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

Outdoor Channel Models from 3GPP/3GPP2

Source: 3GPP TR 25.996 V9.0.0 (2009-12)

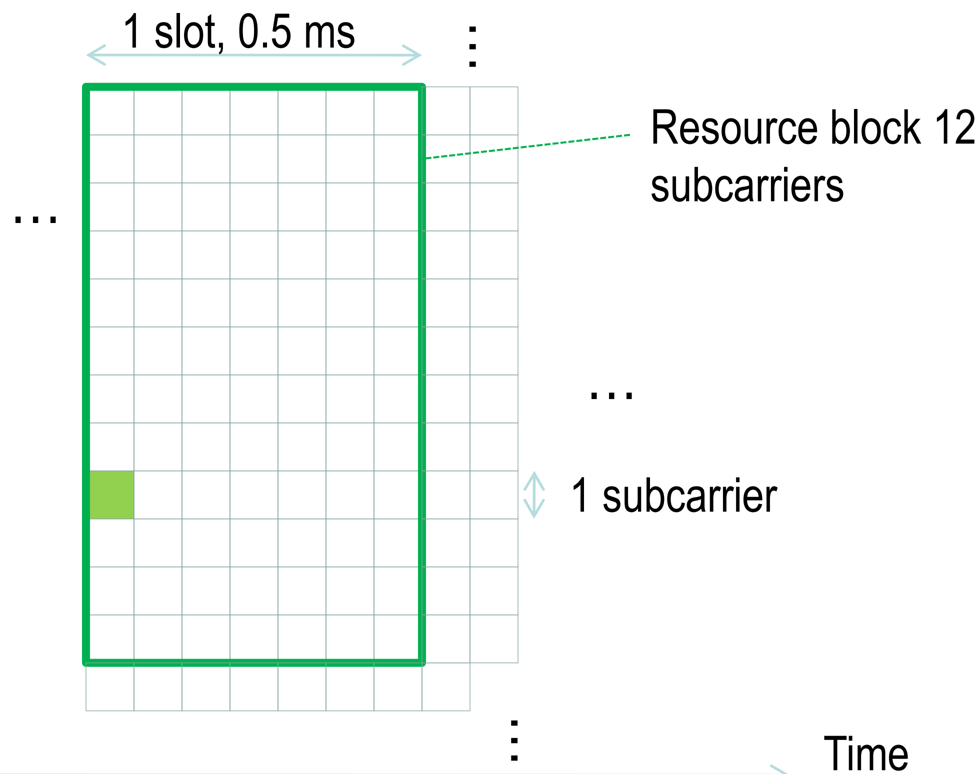
Model	Case I	Case II	Case III	Case IV
Corresponding 3GPP Designator*	Case B	Case C	Case D	Case A
Corresponding 3GPP2 Designator*	Model A, D, E	Model C	Model B	Model F
PDP	Modified Pedestrian A	Vehicular A	Pedestrian B	Single Path
# of Paths	1) 4+1 (LOS on, K = 6dB) 2) 4 (LOS off)	6	6	1

⋮

- Spatial Channel Models (SCM)
- Fewer taps (paths), but faster Doppler speeds to model high speed trains and other transport

LTE Resource Block

A resource block (RB) is a basic unit of access allocation.
RB bandwidth per slot (0.5 ms) is12 subcarriers times 15 kHz/subcarrier equal to 180 kHz.

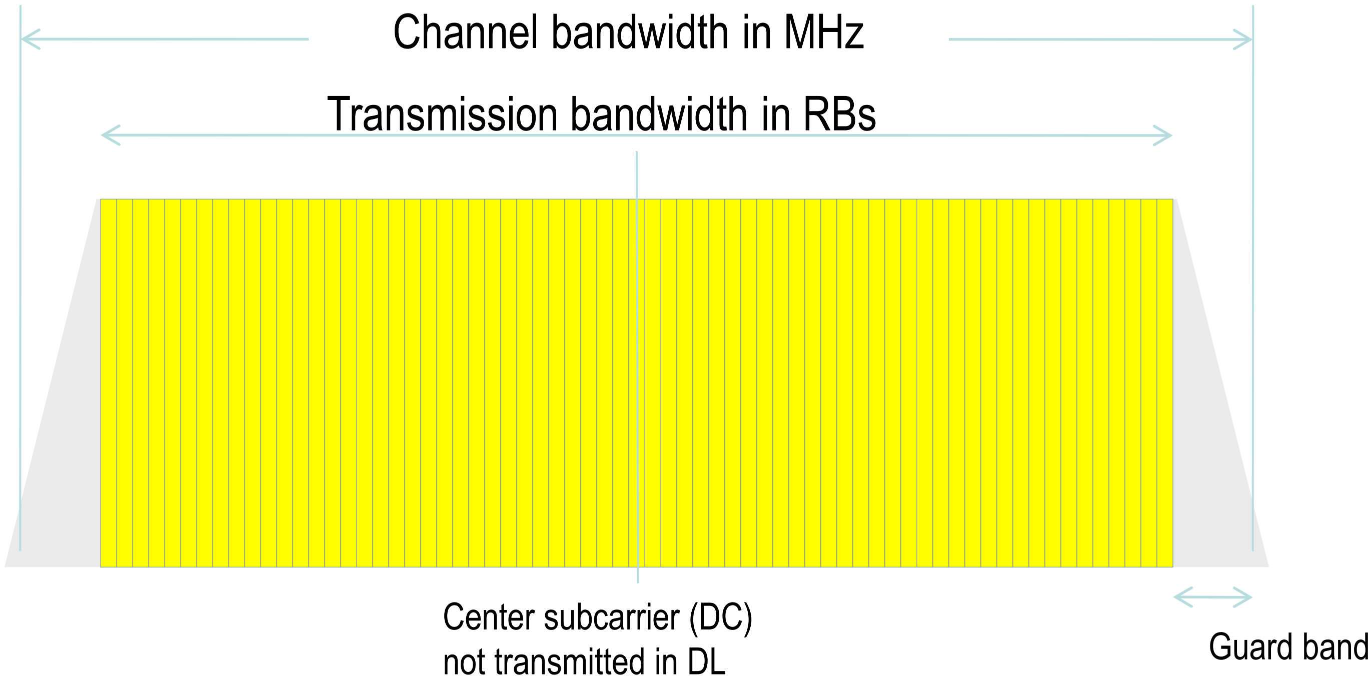


Resource Element
1 subcarrier
QPSK: 2 bits
16 QAM: 4 bits
64 QAM: 6 bits

Subcarrier (frequency)

Time

LTE Scalable Channel Bandwidth



Channel bw	1.4	3	5	10	15	20	MHz
Transmission bw	1.08	2.7	4.5	9	13.5	18	
# RBs per slot	6	15	25	50	75	100	

Thank you!

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