



5G NR Overview & mmW OTA Solution

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Agenda



5G

5G Overview & 3GPP Update



5G

5G New Radio (NR) Physical
Layer Review



5G

5G mmW OTA Solution

3GPP NR Use Cases

3GPP Rel. 15 covers eMBB and URLLC



eMBB

Enhanced Mobile Broadband (eMBB)

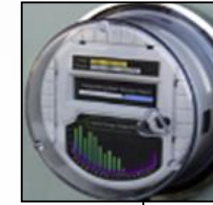
- 10-20 Gbps peak
- 100 Mbps whenever needed
- 10000x more traffic
- Macro and small cells
- Support for high mobility (500 km/h)
- Network energy saving by 100 times



URLLC

Ultra Reliable Low Latency Communication (URLLC)

- Ultra responsive
 - <1 ms air interface latency
 - 5 ms E2E latency
- Ultra reliable and available (99.9999%)
- Low to medium data rates (50 kbps - 10 Mbps)
- High speed mobility

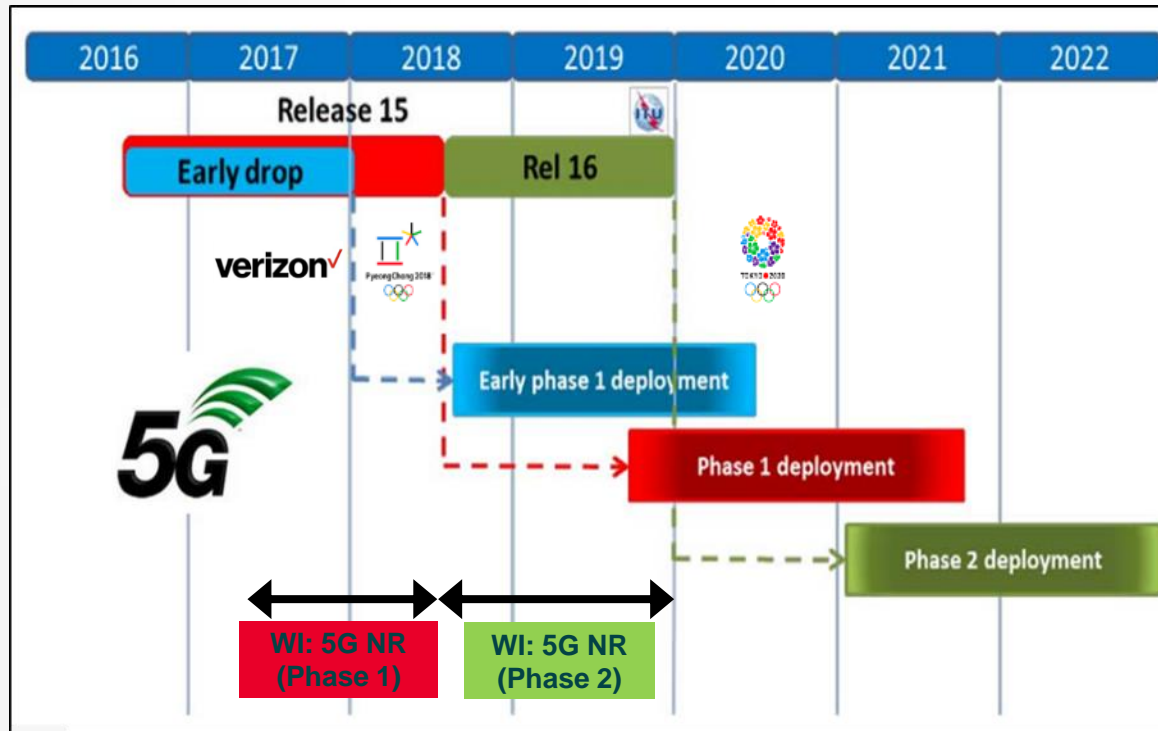


mMTC

Massive Machine Type Communication (mMTC)

- High density of devices (2×10^5 - $10^6/\text{km}^2$)
- Long range
- Low data rate (1 - 100 kbps)
- M2M ultra low cost
- 10 years battery
- Asynchronous access

3GPP NR Roadmap



Source: 3GPP activity towards IMT-2020 http://www.itu.int/en/ITU-R/study-groups/rsg5/rwp5d/imt-2020/Documents/S02-1_3GPP%20IMT-2020.pdf

- “Early drop” of Release 15 (Dec 2017) to support emerging market needs
 - NR Non Stand-Alone (NSA)
 - Uses 4G Core Network (EPC)
 - LTE eNB always acts as a master
 - NR gNB always acts as a slave
- Release 15 (aka Phase I, by June 2018)
 - First phase of expected deployments in 2020
 - 5G core network
 - NR Stand-Alone (SA), eLTE Stand Alone and NSA combinations
- Release 16 (aka Phase II, by Dec 2019)

3GPP 5G standards development

3GPP branding



3GPP has been branding some standards since LTE in Release 8

Release	Applicability	Branding	Logo
8, 9	LTE	LTE	The LTE logo, consisting of the lowercase letters "lte" in a bold, black font with a red signal wave above the "e".
10, 11, 12	LTE	LTE-Advanced	The LTE-Advanced logo, consisting of the lowercase letters "lte" in a bold, black font with a red signal wave above the "e" and the word "ADVANCED" in a smaller, black font to the right.
13, 14	LTE	LTE-Advanced Pro	The LTE-Advanced Pro logo, consisting of the lowercase letters "lte" in a bold, black font with a green signal wave above the "e" and the words "Advanced Pro" in a smaller, red font to the right.
15 and beyond	All 3GPP standards	5G	The 5G logo, featuring the text "5G" in a bold, black font with a stylized green signal wave above the "G".

New Frequency bands for NR

Table 5.1-1: Definition of frequency ranges

Frequency range designation	Corresponding frequency range
FR1	450 MHz – 6000 MHz
FR2	24250 MHz – 52600 MHz

Table 4.1-3: New NR bands in FR1.

Band number	UL	DL	Duplex mode
n1	1920 – 1980 MHz	2110 – 2170 MHz	FDD
n2	1850 – 1910 MHz	1930 – 1990 MHz	FDD
n3	1710 – 1785 MHz	1805 – 1880 MHz	FDD
n5	824 – 849 MHz	869 – 894MHz	FDD
n7	2500 – 2570 MHz	2620 – 2690 MHz	FDD
n8	880 – 915 MHz	925 – 960 MHz	FDD
n20	832 – 862 MHz	791– 821MHz	FDD
n28	703 – 748 MHz	758 – 803 MHz	FDD
n38	2570 – 2620 MHz	2570 – 2620 MHz	TDD
n41	2496 – 2690 MHz	2496 – 2690 MHz	TDD
n50	1432 – 1517 MHz	1432 – 1517 MHz	TDD
n51	1427 – 1432 MHz	1427 – 1432 MHz	TDD
n66	1710 – 1780 MHz	2110 – 2200 MHz	FDD
n70	1695 – 1710 MHz	1995– 2020 MHz	FDD
n71	663 – 698 MHz	617 – 652 MHz	FDD
n74	1427 – 1470 MHz	1475 – 1518 MHz	FDD
n75	N/A	1432 – 1517 MHz	SDL
n76	N/A	1427 – 1432 MHz	SDL
n77	3.3 – 4.2 GHz	3.3 – 4.2 GHz	TDD
n78	3.3 – 3.8 GHz	3.3 – 3.8 GHz	TDD
n79	4.4 – 5.0 GHz	4.4 – 5.0 GHz	TDD
n80	1710 – 1785 MHz	N/A	SUL
n81	880 – 915 MHz	N/A	SUL
n82	832 – 862 MHz	N/A	SUL
n83	703 – 748 MHz	N/A	SUL
n84	1920 – 1980 MHz	N/A	SUL
n85	2496 – 2690 MHz	N/A	SUL

FR1_TR 38.817 v0.3.0



Table 4.1-4: New NR bands in FR2.

Band number	UL	DL	Duplex mode
n257	26.5 – 29.5 GHz	26.5 – 29.5 GHz	TDD
n258	24.25 – 27.5 GHz	24.25 – 27.5 GHz	TDD
n259	N/A	N/A	TDD
n260	37 – 40 GHz	37 – 40 GHz	TDD

FR2_TR 38.817 v0.3.0

Channel bandwidth for FR1 and FR2

Table 4.2-1: NR channel bandwidth for FR1

NR Band	SCS kHz	NR band / SCS / Channel bandwidth													
		5 MHz	10 ^{1,3} MHz	15 ² MHz	20 ³ MHz	25 ⁵ MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz	
n1	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60		Yes	Yes	Yes										
n2	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60	Yes	Yes	Yes	Yes										
n3	15	Yes	Yes	Yes	Yes	Yes	Yes								
	30	Yes	Yes	Yes	Yes	Yes	Yes								
	60	Yes	Yes	Yes	Yes	Yes	Yes								
n5	15	Yes	Yes												
	30	Yes	Yes												
	60														
n7	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60	Yes	Yes	Yes	Yes										
n8	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60	Yes	Yes	Yes	Yes										
n20	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60														
n28	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60														
n38	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60	Yes	Yes	Yes	Yes										
n41	15		Yes	Yes	Yes		Yes	Yes							
	30		Yes	Yes	Yes		Yes	Yes	Yes		Yes		Yes		
	60		Yes	Yes	Yes		Yes	Yes	Yes		Yes		Yes		
n50	15	Yes	Yes	Yes	Yes		Yes	Yes	Yes		Yes				
	30	Yes	Yes	Yes	Yes		Yes	Yes	Yes		Yes				
	60	Yes	Yes	Yes	Yes										
n51	15	Yes													
	30														
	60														
n66	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes		Yes								
	60	Yes	Yes	Yes	Yes		Yes								
n70	15	Yes	Yes	Yes	Yes	Yes									
	30	Yes	Yes	Yes	Yes	Yes									
	60	Yes	Yes	Yes	Yes	Yes									
n71	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60														
n74	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60	Yes	Yes	Yes	Yes										
n75	15	Yes	Yes	Yes	Yes										
	30	Yes	Yes	Yes	Yes										
	60	Yes	Yes	Yes	Yes										
n76	15	Yes													
	30														
	60														
n77	15		Yes	Yes	Yes		Yes ¹	Yes	Yes		Yes ¹	Yes	Yes ¹	Yes	
	30		Yes	Yes	Yes		Yes ¹	Yes	Yes	Yes	Yes ¹	Yes	Yes ¹	Yes	
	60		Yes	Yes	Yes		Yes ¹	Yes	Yes	Yes	Yes ¹	Yes	Yes ¹	Yes	

CBW in FR1

FR1_TR 38.817 v0.3.0

n78	15		Yes	Yes	Yes		Yes ¹	Yes	Yes					
	30		Yes	Yes	Yes		Yes ¹	Yes	Yes	Yes	Yes ¹	Yes	Yes ¹	Yes
	60		Yes	Yes	Yes		Yes ¹	Yes	Yes	Yes	Yes ¹	Yes	Yes ¹	Yes
n79	15								Yes	Yes				
	30								Yes	Yes	Yes		Yes	Yes
	60								Yes	Yes	Yes		Yes	Yes
n80	15	Yes	Yes	Yes	Yes	Yes	Yes	Yes						
	30		Yes	Yes	Yes	Yes	Yes	Yes						
	60		Yes	Yes	Yes	Yes	Yes	Yes						
n81	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n82	15	Yes	Yes	Yes	Yes									
	30	Yes	Yes	Yes	Yes									
	60													
n83	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60													
n84	15	Yes	Yes	Yes	Yes									
	30		Yes	Yes	Yes									
	60		Yes	Yes	Yes									

NOTE 1: The channel bandwidth is defined only as a BS channel bandwidth in these bands.
 NOTE 2: 90% spectrum utilization may not be achieved for 30kHz SCS.
 NOTE 3: 90% spectrum utilization may not be achieved for 60kHz SCS.

CBW in FR2

Table 4.2-2: NR channel bandwidth for FR2

NR Band	SCS kHz	NR band / SCS / Channel bandwidth			
		50 MHz	100 MHz	200 MHz	400 MHz
n257	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n258	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes
n260	60	Yes	Yes	Yes	
	120	Yes	Yes	Yes	Yes

TR 38.817 v0.3.0

UE characteristics (FR1)



Transmitter

5	UE Transmitter characteristics (frequency range 1).....
5.1	General
5.1.1	CA Bandwidth Class.....
5.2	Transmit power.....
5.2.1	Power Class.....
5.2.2	MPR /A-MPR
5.2.3	UE maximum output power for modulation / RB allocation.....
5.2.4	Inner RB allocation range for all 5MHz – 100MHz channel bandwidths and SCS.....
5.3	Output power dynamics.....
5.3.1	Minimum output power
5.3.1.1	Current LTE requirement.....
5.3.1.2	NR requirement.....
5.4	Transmit signal quality
5.4.1	IQ-Image and Carrier leakage.....
5.4.2	Error vector magnitude
5.4.3	In-band emissions
5.5	Output RF spectrum emissions.....
5.5.1	Occupied bandwidth
5.5.2	Spectrum emission mask
5.5.3	Adjacent Channel Leakage ratio
5.5.3.1	NR ACLR.....
5.5.3.2	E-UTRA ACLR
5.5.3.3	UTRA ACLR
5.5.4	Spurious emission
5.5.4.1	General requirements
5.5.4.2	Spurious emission band UE co-existence
5.6	Transmit intermodulation
5.7	ON/OFF time mask
5.7.1	UE transient time
5.8	Additional UE RF Tx requirements for SUL and LTE-NR co-existence
5.8.1	Transmit power
5.8.2	Output power dynamics
5.8.3	Transmit signal quality
5.8.4	Output RF spectrum emissions
5.8.5	Transmit intermodulation

Receiver

6	UE Receiver characteristics (frequency range 1)
6.1	General
6.2	Receiver Sensitivity.....
6.2.1	MSD (Maximum sensitivity reduction).....
6.3	Selectivity
6.4	Blocking performance
6.5	Spurious response.....
6.6	Intermodulation performance
6.7	Spurious emission.....
6.8	Additional UE RF Rx requirements for SUL and LTE-NR co-existence
6.8.1	REFSENS
6.8.2	Other receiver requirements.....

UE characteristics (FR2)

Transmitter

7	UE Transmitter characteristics (frequency range 2).....
7.1	General
7.1.1	CA Bandwidth Class.....
7.2	Transmit power.....
7.2.1	Power Class.....
7.2.1.1	UE Power class
7.2.1.2	Spherical coverage requirement.....
7.2.1	MPR /A-MPR
7.3	Output power dynamics.....
7.3.1	Minimum output power
7.4	Transmit signal quality
7.5	Output RF spectrum emissions.....
7.5.1	Occupied bandwidth
7.5.2	Spectrum emission mask
7.5.3	Adjacent Channel Leakage ratio
7.5.4	Spurious emission.....
7.6	Transmit intermodulation
7.7	ON/OFF time mask
7.7.1	UE transient time

Receiver

8	UE Receiver characteristics (frequency range 2)
8.1	General
8.2	Receiver Sensitivity.....
8.2.1	MSD (Maximum sensitivity reduction).....
8.3	Selectivity
8.4	Blocking performance
8.5	Spurious response.....
8.6	Intermodulation performance
8.7	Spurious emission.....

BS characteristics (Conducted)

Transmitter

- 6 Conducted transmitter characteristics
 - 6.1 General.....
 - 6.2 Base station output power.....
 - 6.2.1 General.....
 - 6.2.2 Minimum requirement for *BS type 1-C*.....
 - 6.2.3 Minimum requirement for *BS type 1-H*.....
 - 6.2.4 Additional requirements (regional).....
 - 6.3 Output power dynamics.....
 - 6.3.1 General.....
 - 6.3.2 RE power control dynamic range.....
 - 6.3.2.1 General.....
 - 6.3.2.2 Minimum requirement for *BS type 1-C* and *1-H*.....
 - 6.3.3 Total power dynamic range.....
 - 6.3.3.1 General.....
 - 6.3.3.2 Minimum requirement for *BS type 1-C* and *1-H*.....
 - 6.4 Transmit ON/OFF power.....
 - 6.4.1 Transmitter OFF power.....
 - 6.4.2 Transmitter transient period.....
 - 6.5 Transmitted signal quality.....
 - 6.5.1 Frequency error.....
 - 6.5.2 Modulation quality.....
 - 6.5.3 Time alignment error.....
 - 6.6 Unwanted emissions.....
 - 6.6.1 General.....
 - 6.6.2 Occupied bandwidth.....
 - 6.6.3 Adjacent Channel Leakage Power Ratio.....
 - 6.6.4 Operating band unwanted emissions.....
 - 6.6.5 Transmitter spurious emissions.....
 - 6.7 Transmitter intermodulation.....

There are 4 distinct types of NR BS each has a different architecture and requirements set corresponding to Table 5.3.2-1

Table 5.3.2-1: Supported requirement sets

BS type / Requirement set	BS Description	Additional information
1-C	A BS operating at FR1 with all requirements defined at individual antenna connectors.	Following the approach used in TS 36.104 and TS 37.104 [19]
1-H	A BS operating at FR1 with a requirement set holding requirements defined at the TAB and OTA requirements defined at RIB.	The requirement set is like the one defined for Hybrid AAS BS. Following the approach used in TS 37.105 [7]
1-0	A BS operating at FR1 with a requirement set consisting only OTA requirements defined at the RIB.	Following the approach developed in eAAS and documented in TR 37.843 [9].
2-0	A BS operating at FR2 with a requirement set consisting only of OTA requirements defined at the RIB.	This requirement set is relevant for AAS BS and does not require access to RF connectors.

Receiver

- 7 Conducted receiver characteristics
 - 7.1 General.....
 - 7.2 Reference sensitivity level.....
 - 7.2.1 General.....
 - 7.2.2 Minimum requirements for *BS type 1-C* and *BS type 1-H*.....
 - 7.3 Dynamic range.....
 - 7.4 In-band selectivity and blocking.....
 - 7.4.2 In-band blocking.....
 - 7.5 Out-of-band blocking.....
 - 7.6 Receiver spurious emissions.....
 - 7.7 Receiver intermodulation.....
 - 7.8 In-channel selectivity.....



BS characteristics (Radiated)

Transmitter

- 9 Radiated transmitter characteristics
- 9.1 General.....
- 9.2 Radiated transmit power
- 9.2.1 General
- 9.2.2 Minimum requirement for *BS type 1-H* and *BS type 1-O*
- 9.2.3 Minimum requirement for *BS type 2-O*
- 9.3 OTA base station output power
- 9.4 OTA output power dynamics.....
- 9.4.2 OTA RE power control dynamic range
- 9.4.3 OTA total power dynamic range.....
- 9.5 OTA transmit ON/OFF power.....
- 9.5.1 General
- 9.5.2 Transmitter OFF power.....
- 9.5.3 OTA transient period
- 9.6 OTA transmitted signal quality
- 9.6.1 OTA frequency error.....
- 9.6.2 OTA modulation quality
- 9.6.3 OTA time alignment error.....
- 9.7 OTA Unwanted emissions
- 9.7.1 General
- 9.7.2 OTA occupied bandwidth
- 9.7.3 OTA Adjacent Channel Leakage Power Ratio (ACLR).....
- 9.7.4 OTA out-of-band emissions.....
- 9.7.4.3.2 OTA spectrum emission mask.....
- 9.7.5 OTA transmitter spurious emissions.....
- 9.8 OTA transmitter intermodulation

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1-H	A BS operating at FR1 with a requirement set holding requirements defined at the TAB and OTA requirements defined at RIB.	The requirement set is like the one defined for Hybrid AAS BS. Following the approach used in TS 37.105 [7]
1-O	A BS operating at FR1 with a requirement set consisting only OTA requirements defined at the RIB.	Following the approach developed in eAAS and documented in TR 37.843 [9]
2-O	A BS operating at FR2 with a requirement set consisting only of OTA requirements defined at the RIB.	This requirement set is relevant for AAS BS and does not require access to RF connectors.

RIB: Radiated Interface Boundary

Receiver

- 10 Radiated receiver characteristics.....
- 10.1 General.....
- 10.2 OTA sensitivity.....
- 10.2.1 BS type 1-H and *BS type 1-O*.....
- 10.2.2 BS type 2-O.....
- 10.3 OTA reference sensitivity level
- 10.4 OTA Dynamic range.....
- 10.5 OTA in-band selectivity and blocking.....
- 10.5.1 OTA adjacent channel selectivity
- 10.5.2 OTA in-band blocking
- 10.5.2.3 OTA in-band blocking for *BS type 2-O*.....
- 10.6 OTA out-of-band blocking
- 10.7 OTA receiver spurious emissions.....
- 10.8 OTA receiver intermodulation.....
- 10.9 OTA in-channel selectivity.....

Agenda



5G

5G Overview & 3GPP Update



5G

5G New Radio (NR) Physical
Layer Review



5G

5G mmW OTA Solution

Waveform

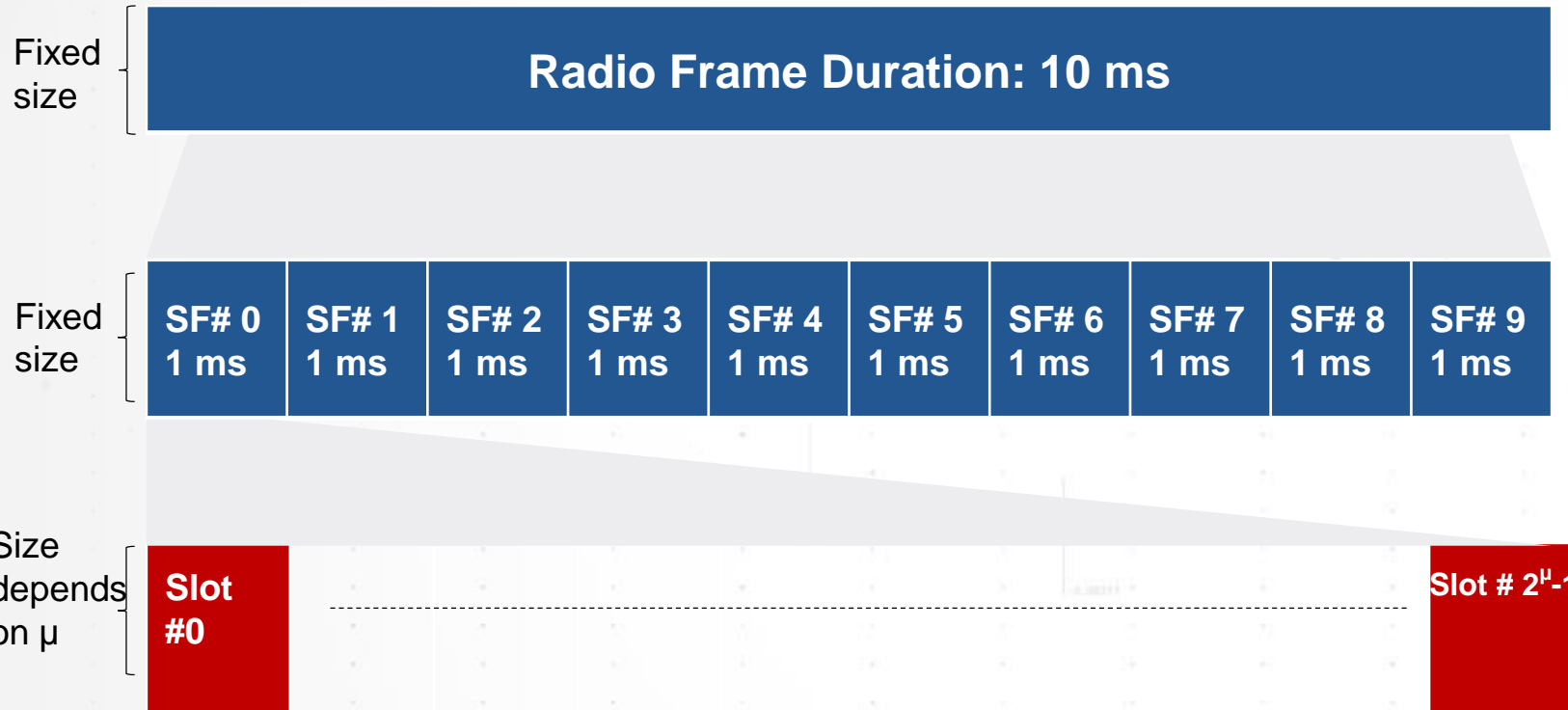
Waveform, Numerology and Frame Structure

- **Waveform** (for eMBB/URLLC and < 52.6 GHz)
 - DL Waveform: CP-OFDM
 - UL Waveform: CP-OFDM + DFT-s-OFDM
 - CP-OFDM targeted at high throughput scenarios
 - DFT-s-OFDM targeted at power limited scenarios
- **Multiple Access**
 - Orthogonal Multiple Access
 - Non-Orthogonal Multiple Access (NOMA) not supported in Rel-15
- **Bandwidth**
 - Maximum CC bandwidth is 400 MHz
 - Maximum number of subcarriers is 3300
 - 4096-FFT is needed
 - Maximum number of CCs is 16

This is from signaling point of view
Allowed combinations to be decided by RAN4

Frame Structure

Waveform, Numerology and Frame Structure



μ	N_{slot}^{symbol}	$N_{subframe, \mu}^{slot}$	$N_{slot}^{frame, \mu}$	Slot duration
0 15 kHz	14	1	10	1 ms
1 30 kHz	14	2	20	500 μ s
2 60 kHz (normal CP)	14	4	40	250 μ s
2 60 kHz (extended CP)	12	4	40	250 μ s
3 120 kHz	14	8	80	125 μ s
4 240 kHz	14	16	160	62.5 μ s

A slot is one possible scheduling unit.

Mini-Slot is a minimum scheduling unit with 7, 4 or 2 OFDM symbols

Numerology Definition

Waveform, Numerology and Frame Structure

- Scalable subcarrier spacing

$$\Delta f = 2^{\mu} \cdot 15 \text{ kHz}$$

- Parameters defining a numerology:
 - Subcarrier spacing (i.e. μ parameter)
 - Cyclic prefix (i.e. Normal/Extended)

	μ	$\Delta f = 2^{\mu} \cdot 15 \text{ kHz}$	Cyclic Prefix	
Sync < 6 GHz	0	15 kHz	Normal	Data < 6 GHz
	1	30 kHz	Normal	
	2	60 kHz	Normal, Extended	
Sync > 6 GHz	3	120 kHz	Normal	Data > 6 GHz
	4	240 kHz	Normal	
	5	480 kHz	Normal	

Specified but not supported in Rel- 15

Resource Grid

Waveform, Numerology and Frame Structure

- Resource elements are grouped into Physical Resource Blocks (**PRB**)
- Each PRB consists of **12 subcarriers**

μ	Δf	$N_{RB}^{min,\mu}$	$N_{RB}^{max,\mu}$
0	15 kHz	20	275
1	30 kHz	20	275
2	60 kHz	20	275
3	120 kHz	20	275
4	240 kHz	20	138
5	480 kHz	20	69

N7631C Signal Studio Pro for 5G NR

SIGNAL STUDIO SW FOR NR

The screenshot displays the Keysight Signal Studio Pro for 5G NR software interface. The window title is "Keysight Signal Studio Pro for 5G NR". The menu bar includes "File", "Control", "System", "Tools", and "Help". The interface is divided into several sections:

- Hardware:** A tree view showing "Instrument" > "Waveform Setup" > "Carrier 1 (DL)" > "Channel Setup".
- Carrier Configuration Table:** A table with columns: "Add Carrier", "Remove Carrier", "Copy Carrier", "Radio Format", "Carrier Type", "Frequency Offset", "Power", "Initial Phase", "Timing Off...", "Cell ID", and "Bandwidth".

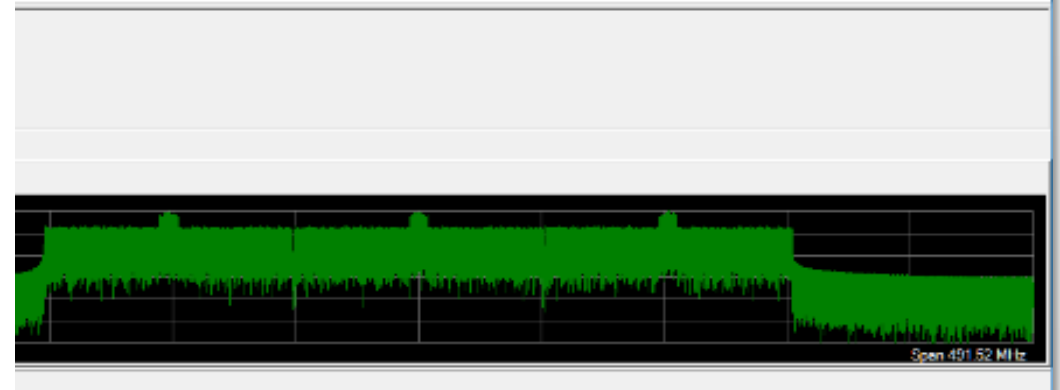
Radio Format	Carrier Type	Frequency Offset	Power	Initial Phase	Timing Off...	Cell ID	Bandwidth
NR Downlink	DL	-100.00 MHz	0.00 dB	0°	0	0	99.000 MHz
NR Uplink	DL	0.00 Hz	0.00 dB	0°	0	1	99.000 MHz
NR Pusch	DL	100.00 MHz	0.00 dB	0°	0	2	99.000 MHz
- 1. Basic:** A list of parameters including Sampling Rate Mode (Auto), Sampling Rate (491.52 MHz), OverSampling Ratio (1), Number of Radio Frames (1), Total Sample Points (4915200), Waveform Length (10.000000 ms), and Minor Spectrum (Off).
- 2. Marker:** A list of marker sources including Marker 1 Source (Waveform Start), Marker 2 Source (Frame Start), Marker 3 Source (RF Blanking Control), and Marker 4 Source (RF ALC Control).



5G NR Signal Creation and Playback

This bundle is part of **Signal Studio Software**

Installs on: Computer



Signal Studio N7631C for NR

CARRIER CONFIGURATION



The screenshot displays the main interface of the Keysight Signal Studio Pro for 5G NR. The top menu bar includes "File", "Control", "System", "Tools", and "Help". The left sidebar shows a tree view with "Hardware" expanded to "Waveform Setup" and "Carrier 1 (DL)". The main area contains a table for BWP configuration and a detailed view for "1. Carrier 1".

Name	Numerology	Subcarrier Spacing	CP Type	Location (RB)	Bandwidth (RB)	Bandwidth (Hz)	Number of CORESET
RWP1	1	30.00 kHz	Normal	0	275	99.00 MHz	1

Below the table, the "1. Carrier 1" section shows the following parameters:

- Enabled: On
- Frequency Offset: 0 Hz
- Timing Offset: 0 ms
- Power: 0.00 dB
- Initial Phase: 0°
- Cell ID: 0
- Carrier Type: Downlink
- Occupied Bandwidth: 99 MHz

The "2. To Be Defined Parameters" section shows:

- κ0: 0

At the bottom, a frequency spectrum plot shows the carrier configuration. The y-axis represents Frequency from -61.44 MHz to 61.44 MHz, and the x-axis represents Subcarriers from 0 to 9. Two green bars represent DL-SCH1 (μ = 1) centered around subcarrier 2. Yellow bars represent SS/PBCH (μ = 1) at subcarriers 0 and 5.

Numerology Setting

The screenshot shows the "BWPSetupForm" dialog box. The "Bandwidth part" section is expanded, and the "Subcarrier Spacing Config (μ)" field is highlighted with a red box. The "CORESET Settings" section is also visible.

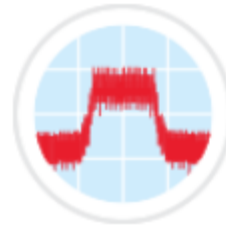
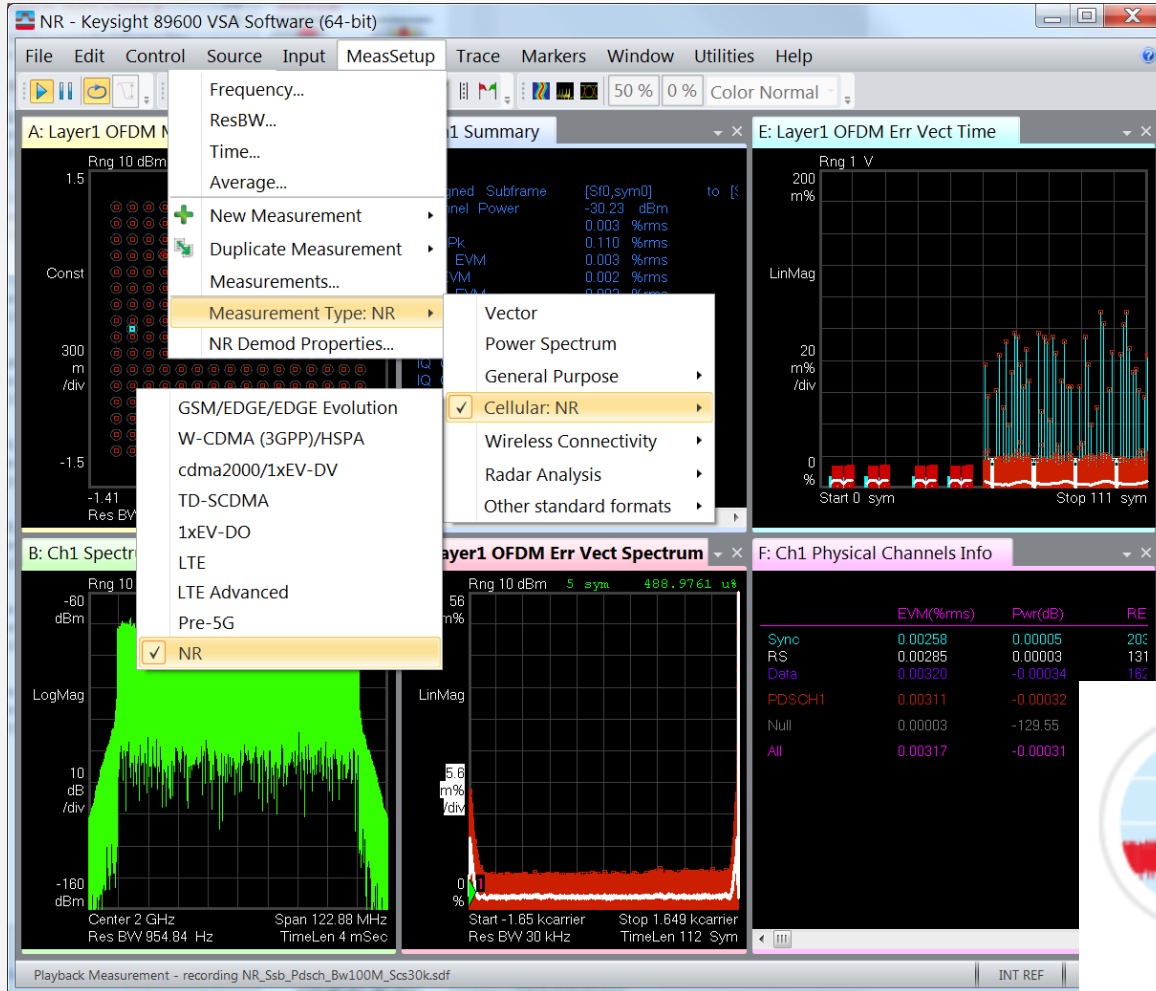
Bandwidth part	
Name	RWP1
Subcarrier Spacing Config (μ)	1
Cyclic Prefix Type	Normal
Bandwidth by RB	275
Location by RB	0
Number of CORESET	1

Below the "Bandwidth part" section, the "CORESET Settings" table is shown:

Frequency Domain Resources	Start Symbol	Time Duration	REG Bundle Size	Transmission Type
0	0	0	0	Interleaved

At the bottom of the dialog, there are "OK" and "Cancel" buttons.

89600 VSA Software 5G NR Modulation Analysis



5G NR/Pre-5G Modulation Analysis

This bundle is part of **89600 VSA Software**

Installs on: Computer or Instrument

N9085EM0E X-Series 5G NR Measurement Application



5G NR 1
Modulation Analysis

KEYSIGHT

Input: RF
Coupling: DC
Align: Off

Input Z: 50 Ω
Corrections: Off
Freq Ref: Ext (S)
NFE: Off

Atten: 0 dB (e0)
Preamp: Off
μW Path: Standard
#PNO: Best Wide

Trig: Free Run
#IF Gain: Low

Carrier Ref Freq: 1.000000000 GHz
CC Info: Downlink, 1 CC

Meas Setup

Component Carrier
CC0

1 CC0 IQ Meas Time

I-Q

Scale/Div 10.00 dB

Ref Value 10.00 dBm

Log

Start: 0.00 ns Stop: 21.00 ms

2 CC0 Raw Main Time

Scale/Div 10.00 dB

Ref Value 10.00 dBm

Log

Start: 0.00 ns Stop: 21.00 ms

3 CC0 Spectrum

Scale/Div 10.00 dB

Ref Value -80.00 dBm

Lin

Width: 70 MHz

Ctr: 1 GHz
Res BW: 447.6 Hz
Info BW: 49.15 MHz

4 CC0 Error Summary

P-SS Evm	0.76 %
S-SS Evm	0.79 %
PBCH Evm	0.97 %
PBCH DMRS Evm	0.71 %
Composite Evm	0.00 %
PDSCH Evm	1.07 %
PDSCH DMRS Evm	0.96 %

Control and User Channels

Settings

Component Carriers

Meas Time

Sync/Format

Channel Profile

Prototype
Limited Sale
Allowed

Nov 28, 2017 9:41:14 PM

RF Alignment Failure

Windows icons and navigation buttons

Agenda



5G

5G Overview & 3GPP Update



5G

5G New Radio (NR) Physical
Layer Review



5G

5G mmW OTA Solution

What is meant by Over-the-Air (OTA) Testing?

In general, OTA Testing is the characterization, evaluation and verification of device performance using radiated measurements instead of (or combined with) conducted/cabled measurements.

OTA Testing may be required at every stage throughout the product development Lifecycle:

- Development (R&D)
- Device verification and test (DVT)
- Base Station Integration and verification (I&V)
- Conformance test
- Manufacturing test
- Installation and maintenance (I&M)

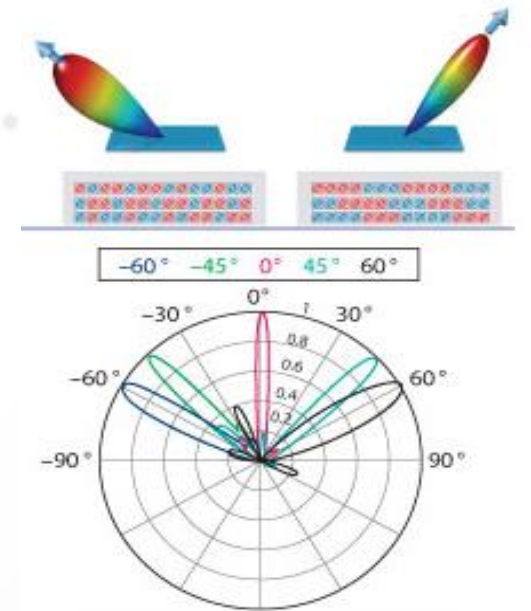


Key Aspects of mmW 5G

- Integrated RFIC Architecture
 - Improves overall system performance at high frequencies



- Beam forming and beam steering
 - Improves signal strength over isotropic radiator thus helping link budget

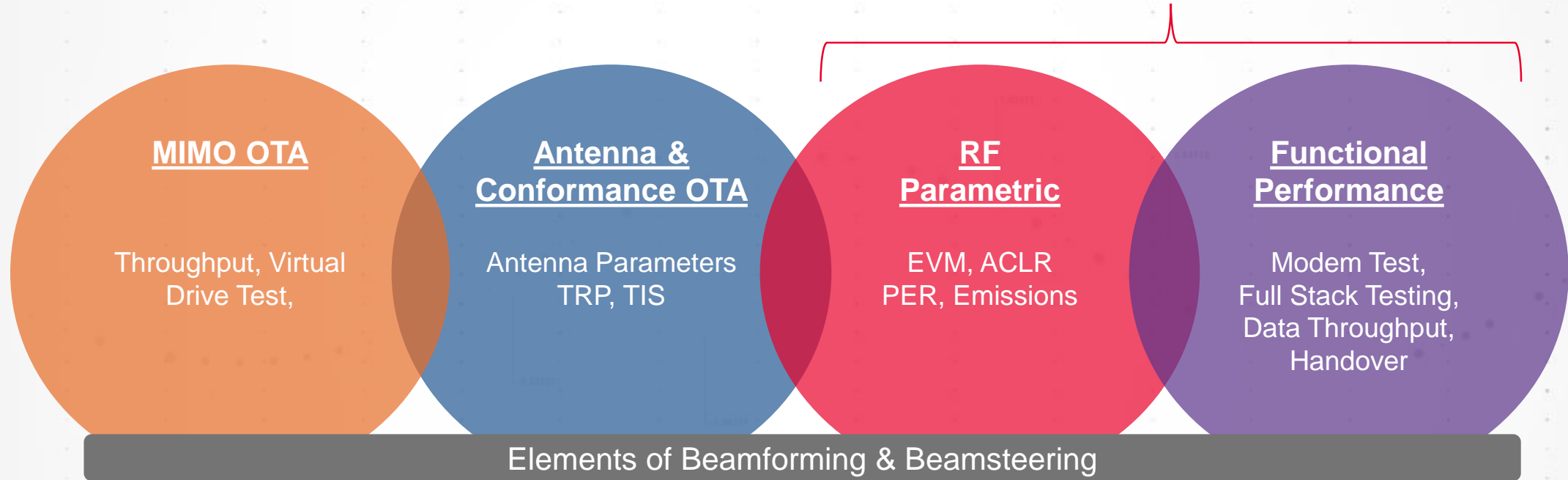


Testing OTA: The Cable is Gone

OTA = Over The Air

COMMERCIAL MMWAVE BRING CHANGING PARADIGM IN TEST

OTA Shift from 4G to mmWave 5G



Today: “Traditional” OTA Cellular & A/D business

- Antenna
- MIMO OTA

Tomorrow: “New” OTA in mmW 5G w/ Direction

- RF Parametric
- Functional Performance

Transmitting and Receiving Over the Air

The Friis Equation

Ignoring atmospheric effects, the received power for a transmitter and a receiver communicating via free space is calculated using the Friis transmission formula given as:

$$\frac{P_r}{P_t} = \left(\frac{c}{4\pi R f} \right)^2 G_t G_r$$

where P_r is the received power, P_t is the transmitted power, R is the distance between the transmitter and receiver, f is the frequency, G_t is the gain of the transmitter antenna, and G_r is the gain of the receiver antenna.

P_r is thus inversely proportional to the square of the frequency, f

Path loss increases with frequency

Free Space Path Loss

The loss associated with transmission over a distance D at a wavelength λ between two isotropic antennas (unity gain) can be expressed in dB

$$FSPL(dB) = 20 \log_{10} \left(\frac{4\pi R}{\lambda} \right)$$

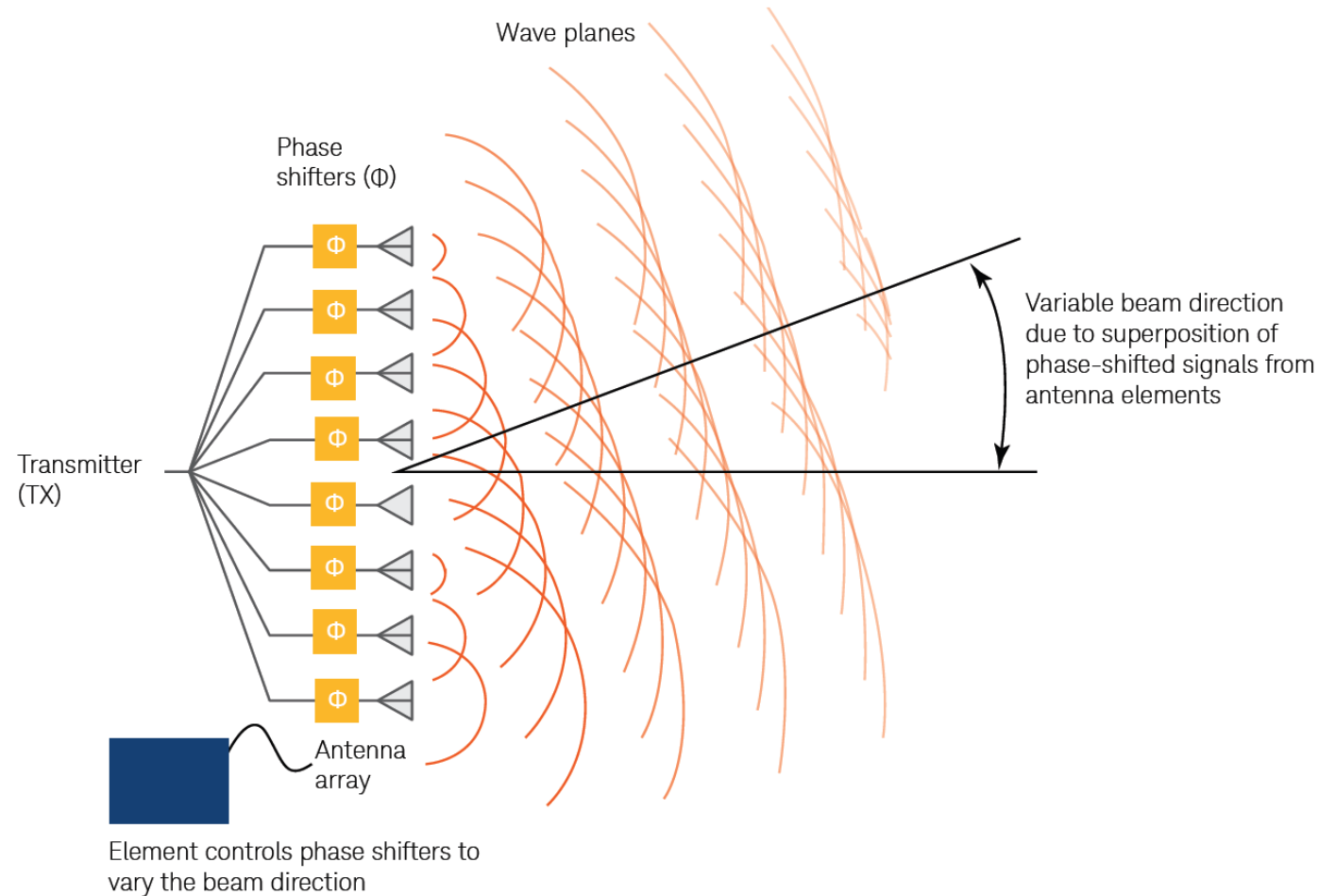
The RF power lost can also be thought of in terms of two effects inherited from the Friis transmission formula:

- Intensity (I), the reduction in power density caused by spreading of the electromagnetic energy over a sphere, proportional to the square of the distance.
- Antenna capture area (A_{eff}), the capability of the receiving antenna to capture electromagnetic energy, inversely proportional to the square of the frequency

Phased Arrays

Phased array antennas are a practical and low-cost means of creating narrow beams (beamforming) and **dynamically pointing them in the desired direction** (beamsteering).

A phased array antenna is **formed by an array of smaller antenna elements**, such as individual **patches or dipoles**. By varying the relative phases and amplitudes of the signals applied to the individual elements, the antenna array can steer and shape a beam in a chosen direction.



Phase shifters on the RF distribution lines allow for adjustment of the phase of the signal transmitted from each element, thereby enabling beamforming at a variable angle.

Determining D , the Antenna Dimension

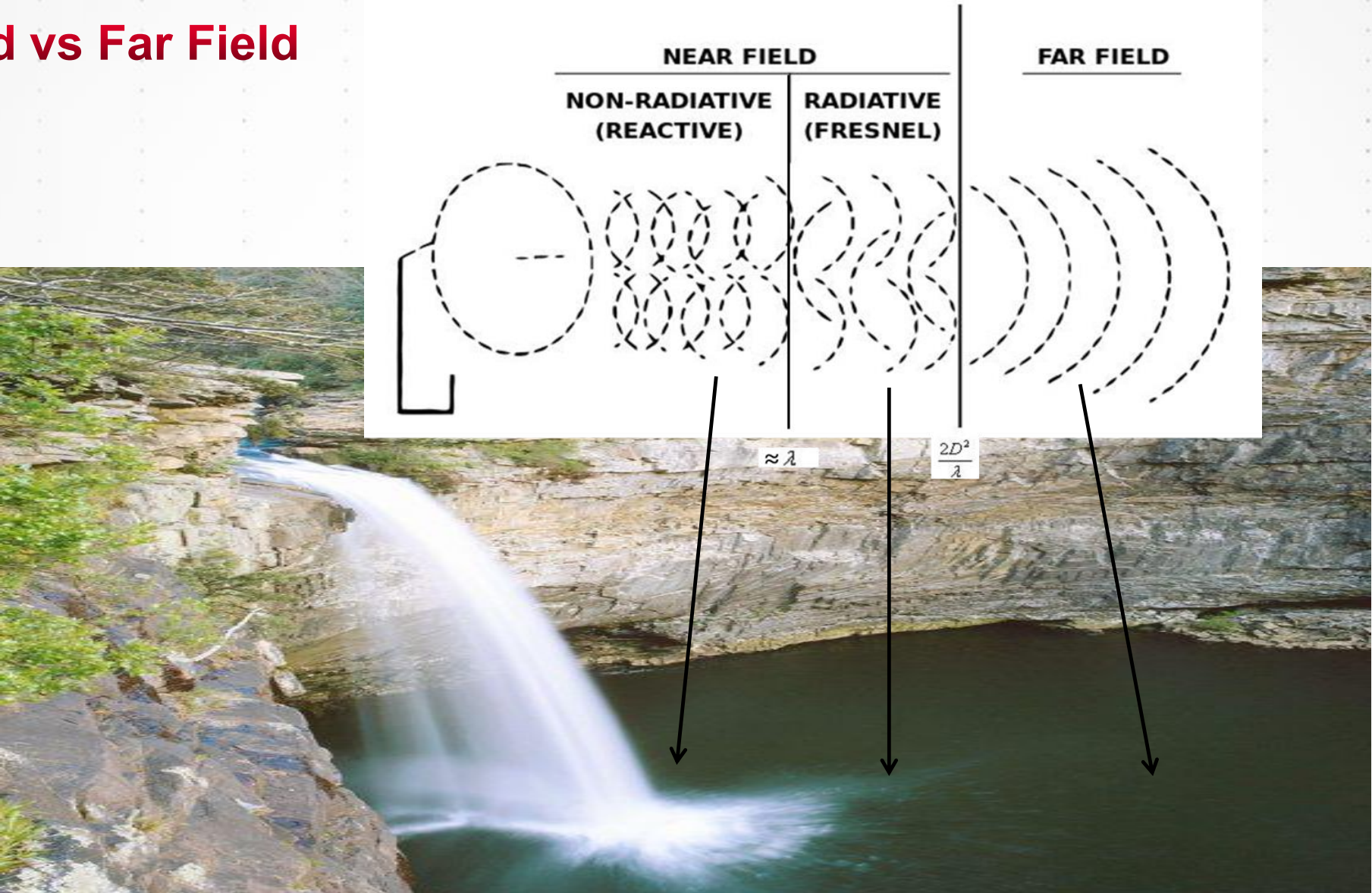
D depends on the mode of operation of the device



The Far Field distance can vary widely depending on a device's operating mode

- Not always straightforward to define the D to be used in the far-field equation.
- Array can couple to the ground plane behind it and to nearby conducting materials causing the effective radiating area to increase.
- Devices with multiple antenna arrays may exhibit an effective D larger than each individual array.
- 3GPP have selected “Black Box” testing of UEs for conformance testing—which means one cannot assume knowledge of the antenna locations. In that case, $D = \text{device size}$.

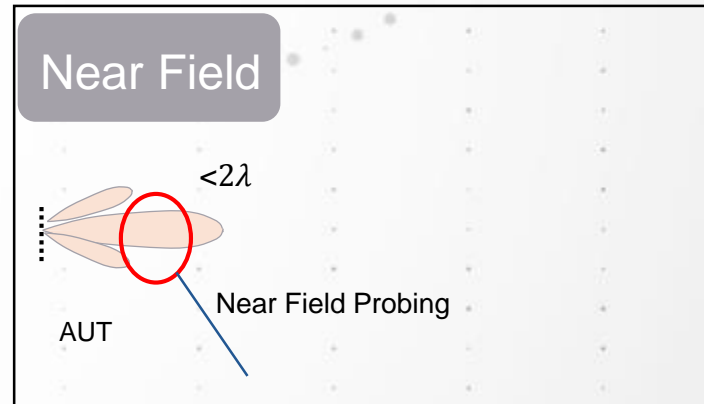
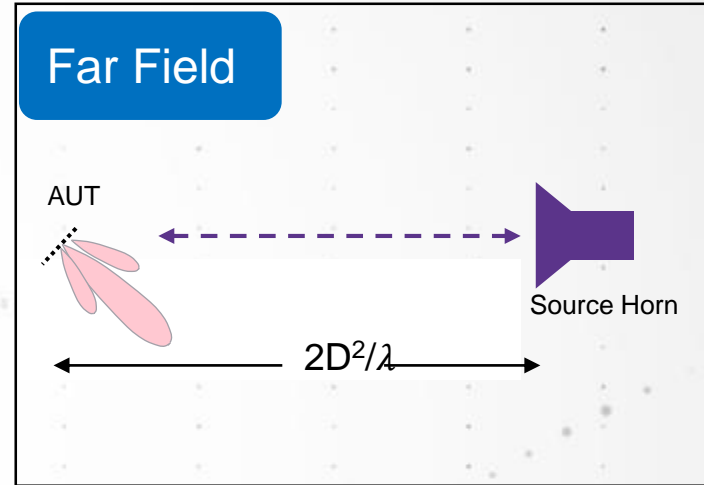
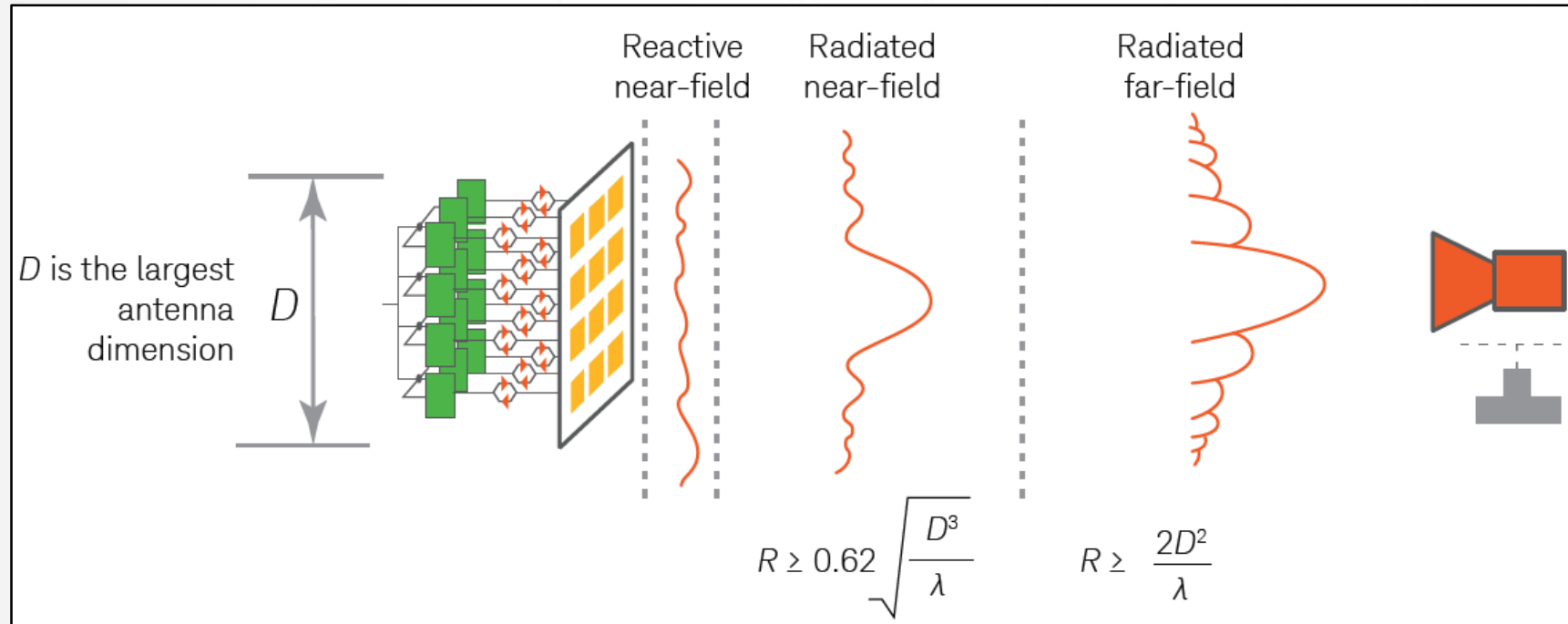
Near Field vs Far Field



Measurement of Radiated Fields

Far Field vs. Near Field

Beam evolution as a function of distance from an antenna



What is the range length for the far field?

The far field distance d - which is the reference for measurements - is based on the max dimension of the radiator D and the wavelength λ

$$d = \frac{2D^2}{\lambda}$$

D* (cm)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)	Freq. (GHz)	Far field (m)	Path Loss (dB)
3	2	0.01	0.05	28	0.17	45.90	100	0.60	68.01
10	2	0.13	20.97	28	1.87	66.81	100	6.67	88.93
15	2	0.30	28.01	28	4.20	73.86	100	15.00	95.97
30	2	1.20	40.05	28	16.80	85.90	100	60.00	108.01
100	2	13.33	60.97	28	186.67	106.81	100	666.67	128.93

* Note: If the device has more than one array, for some requirements D may be the much larger array separation

Some of these distances and path losses create serious practical and technical difficulties which is why CATR and near field methods are important to study for mmWave

Introduction to CATR(Compact Antenna Test Range)

True Far-field in a Compact footprint with Reflector

Reflector(or lens):

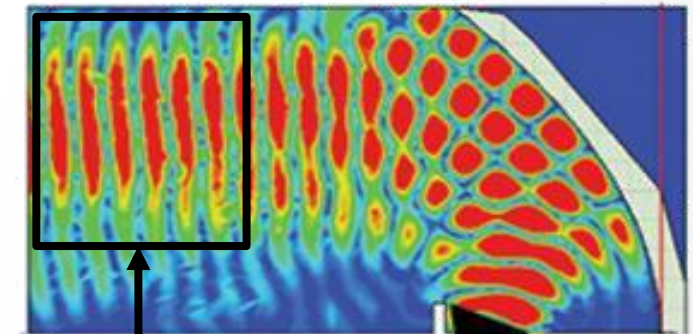
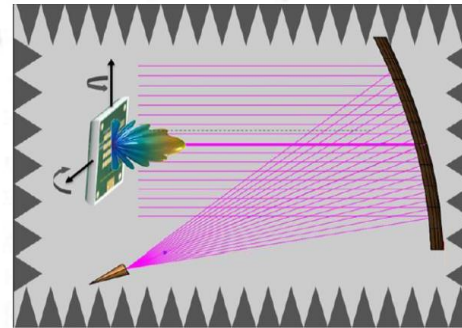
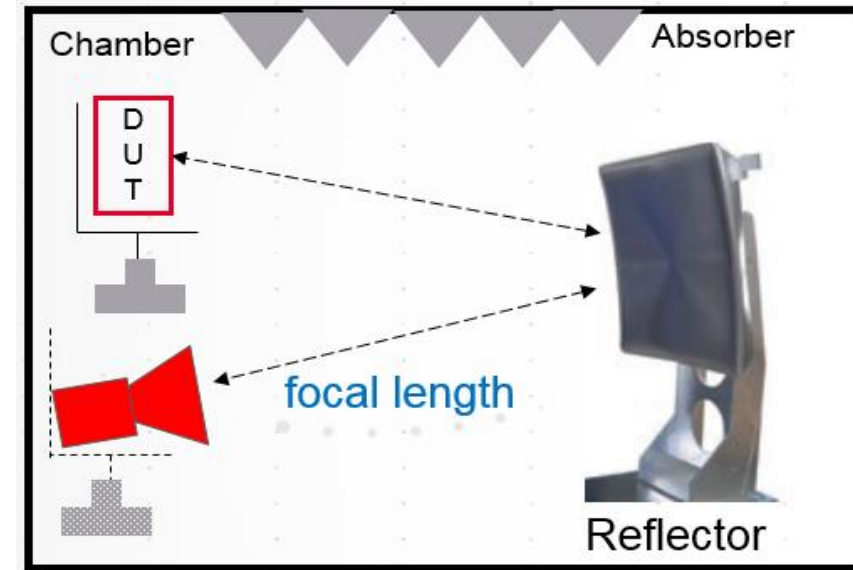
- Collimates radiated pattern into a plane wave
- Performs near field to far field conversion
- Reciprocal for both transmit and receive testing

Complete Characterization

- Antenna patterns/Gain/EIRP/TRP
- RF parametric (Ch. Power, EVM, Spurious)

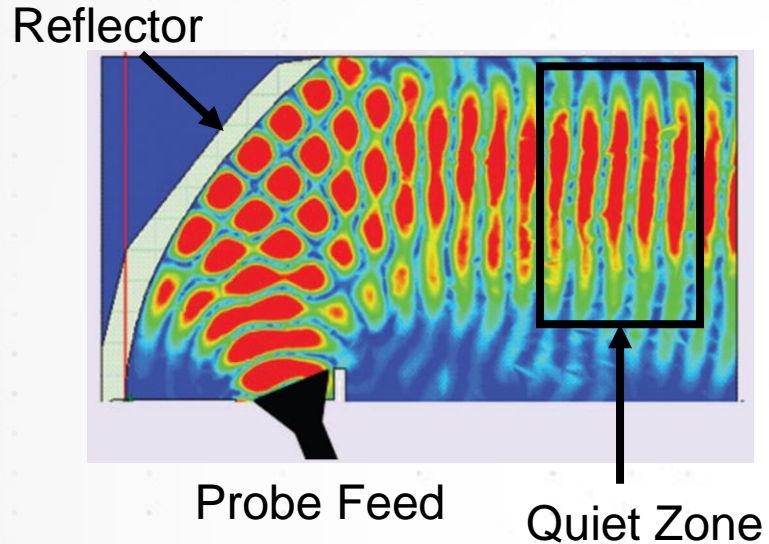
Solved Measurement Challenges

- Reduced path loss
- Smaller footprint than Far-field method
- Multi-antenna device test without repositioning
- Harmonic tests in same footprint



Quiet Zone

CATR Operation



Simulation of signal transmitted from Probe Feed, showing parallel phase fronts in Quiet Zone

- In a CATR system, a diverging beam from the probe antenna illuminates the parabolic reflector from the focal point.
- The reflector collimates the beam and directs it to the DUT.
- The collimated beam has a nearly uniform amplitude and phase across its extent; it provides a nominally ideal plane-wave illumination to the DUT.
- The reflector allows the DUT to be tested under far-field plane wave conditions at a shorter distance than $2D^2/\lambda$ (the far field distance), resulting in a system with potentially a much smaller footprint and lower path loss than the equivalent direct far-field method.

CATRs are reciprocal so that a beam transmitted from the DUT in the Quiet Zone is focused back to the probe feed.

CATR Specifications

- CATR specifications begin with determining Quiet Zone size, frequency range and performance parameters (e.g. Quiet Zone specification)
- The Quiet Zone normally encloses the entire active array of the DUT
- Typical Quiet Zone specifications are shown below – these are a contributing component in determining the accuracy of measurements

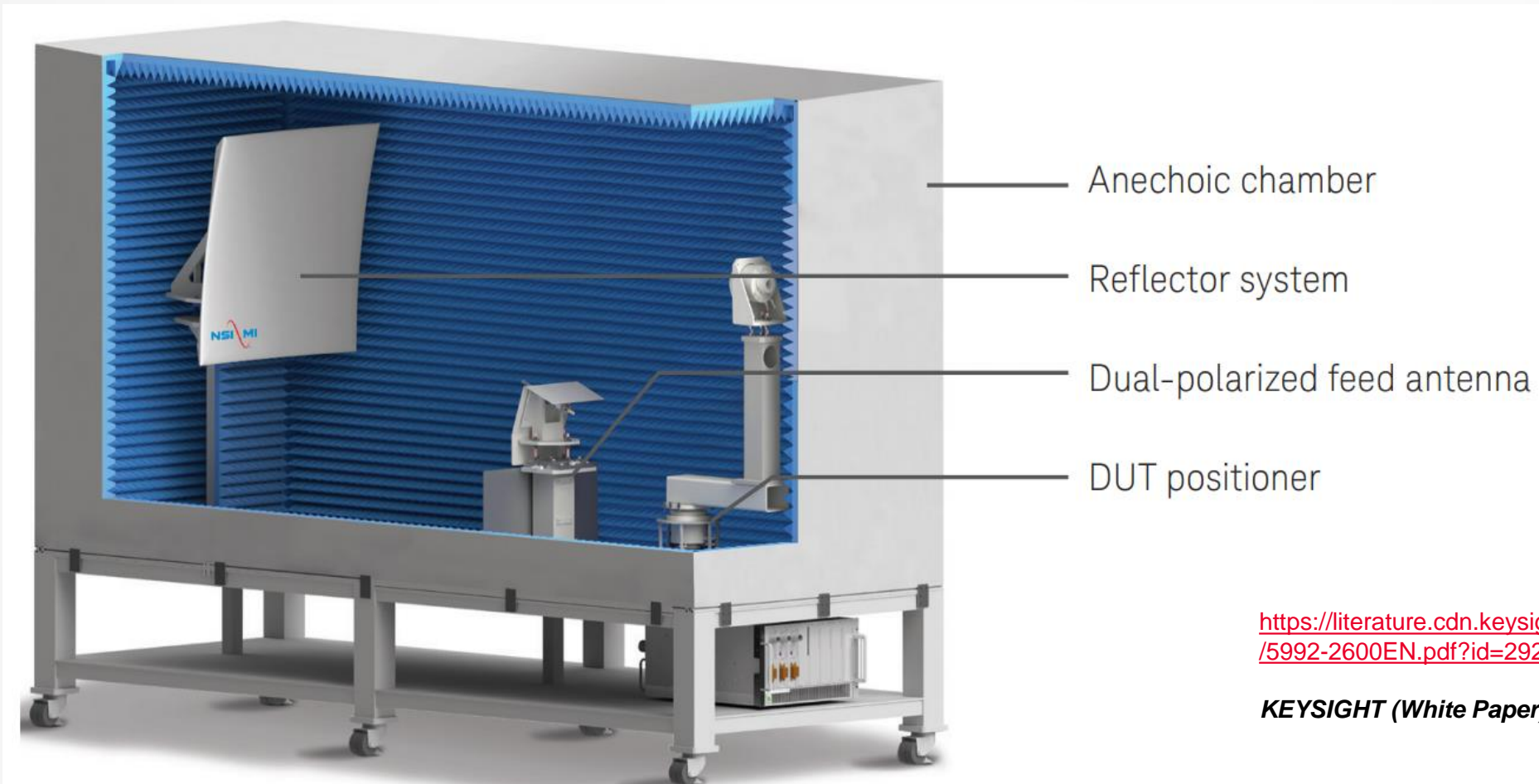
Example

Quiet Zone Size	80cm x 80cm
Quiet Zone Shape	Circular Cylindrical
Amplitude Taper (dB)	≤ 1
Amplitude Ripple (dB)	$\leq \pm 0.5$
Total Phase Variation (°)	± 10
Cross Polarization (dB)	30



Minimum diameter Quiet Zone enclosing all of the active array, or multiple subarrays.

Compact Antenna Test Range (CATR) $d=30\text{cm}$



<https://literature.cdn.keysight.com/litweb/pdf/5992-2600EN.pdf?id=2920272>

KEYSIGHT (White Paper)

Image courtesy of NSI-MI.

Figure 8. A compact antenna test range.

CATR vs Far Field Measurements

- Equivalence of CATR measurements to far field measurements has been dealt with in literature

1668

PROCEEDINGS OF THE IEEE, VOL. 61, NO. 12, DECEMBER 1973

Determination of Far-Field Antenna Patterns from Near-Field Measurements

RICHARD C. JOHNSON, H. ALLEN ECKER, AND J. SEARCY HOLLIS

Invited Paper

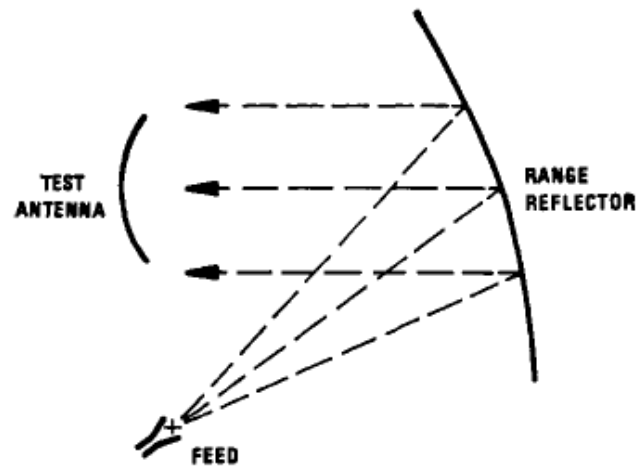


Fig. 16. Schematic representation of a compact range employing a reflector and feed.

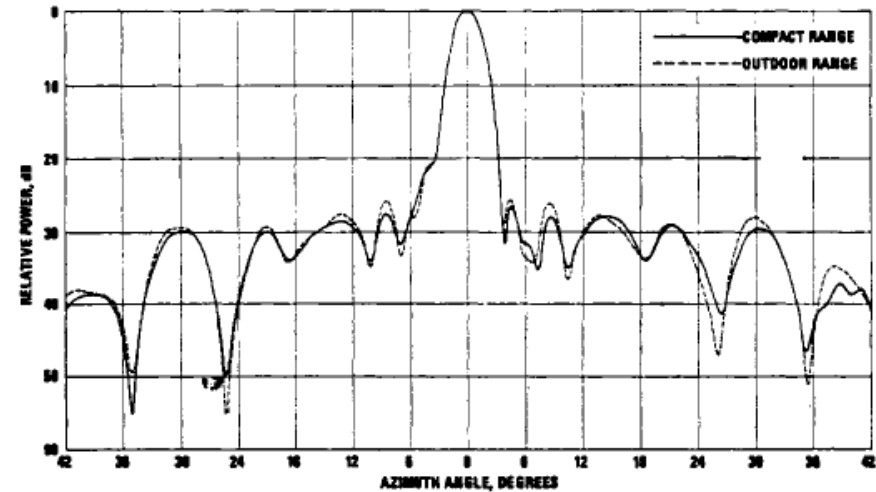
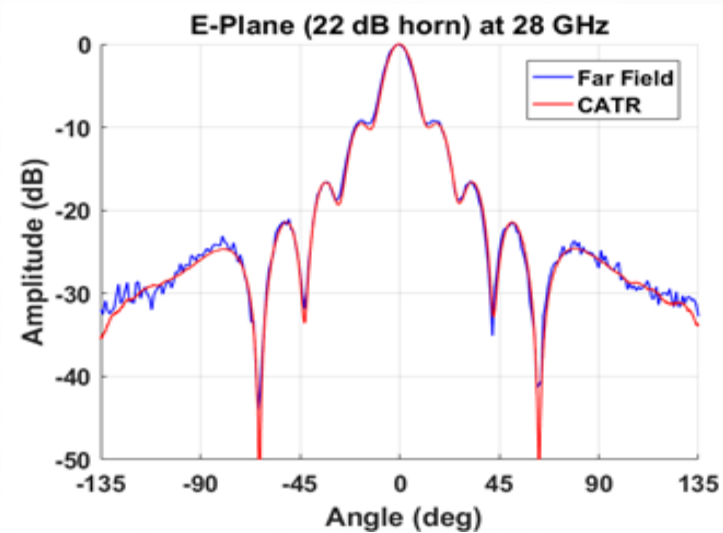
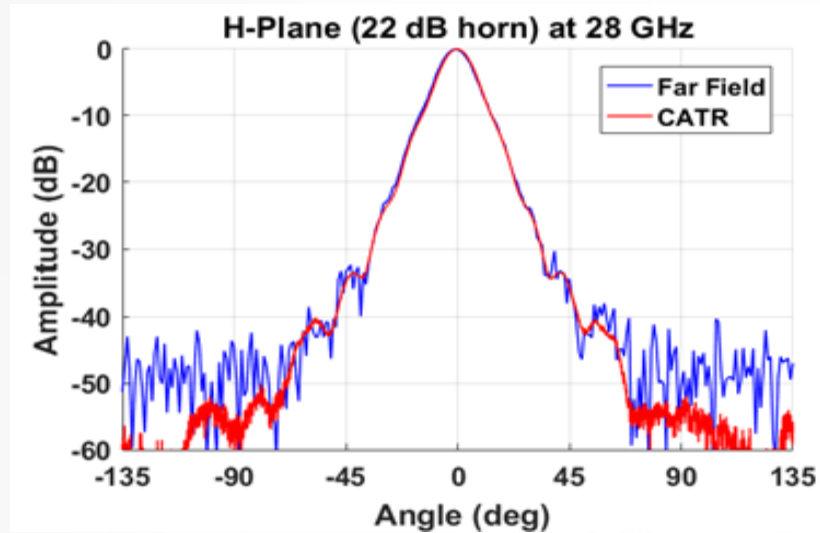


Fig. 18. Comparison of azimuth patterns (H plane) measured on a point-source compact range and on a far-field outdoor range. The antenna was a 76-cm paraboloidal reflector with a horn feed operating at 10 GHz.

CATR vs Far-Field Antenna Measurements

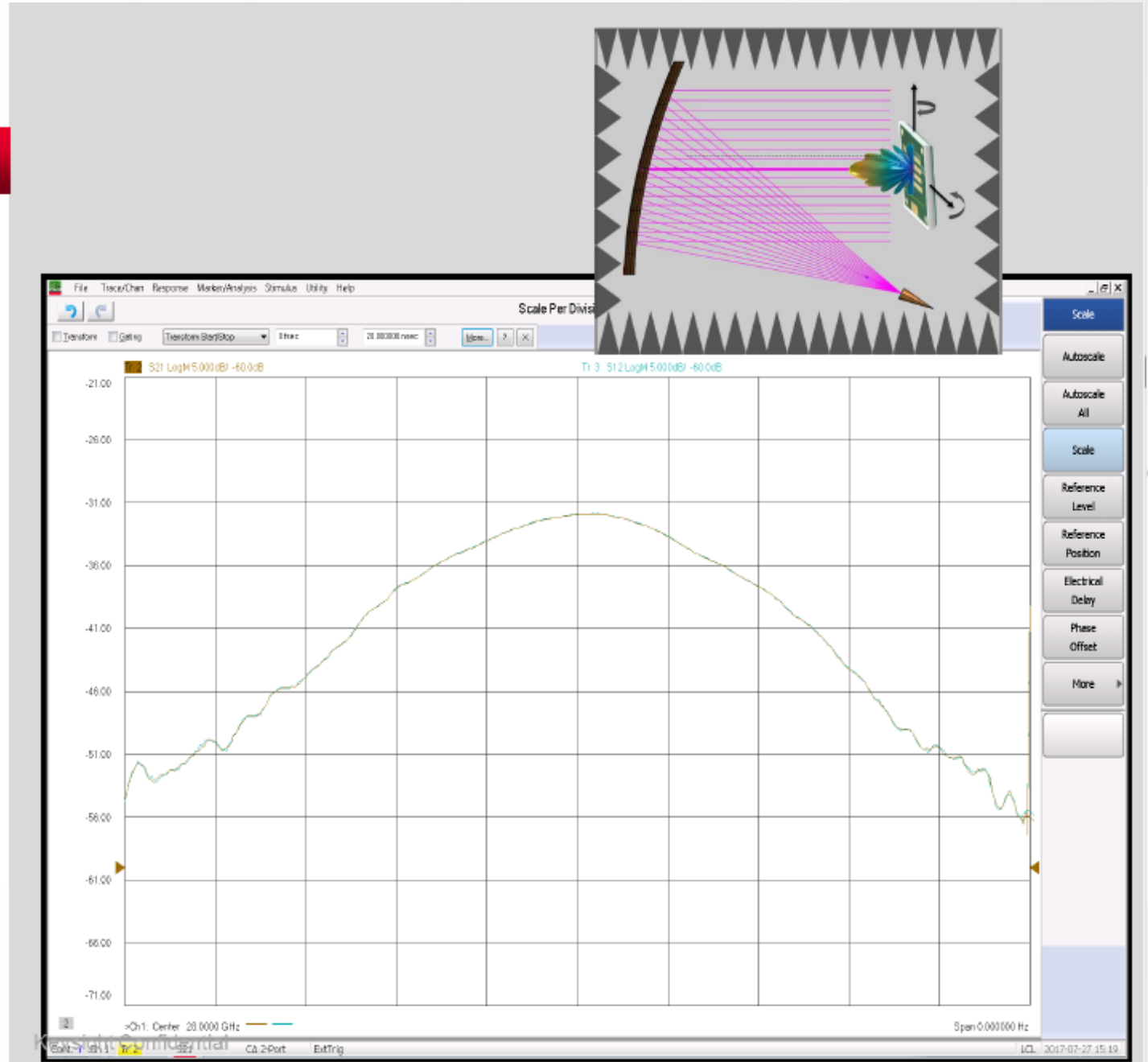


- Both far-field and CATR methods can provide comparable far-field measurements.
- These plots show 28 GHz antenna pattern measurements of a standard gain horn performed in two different chambers. The blue far-field measurements were performed in a >3 m direct far-field chamber.
- The red CATR measurements were obtained using a small CATR chamber. The results are in excellent agreement, where the direct far-field results have sufficient dynamic range for comparison.

Reciprocity

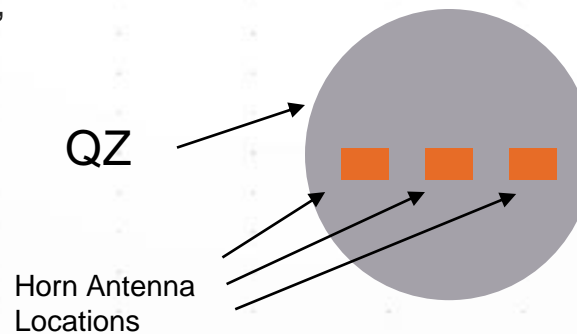
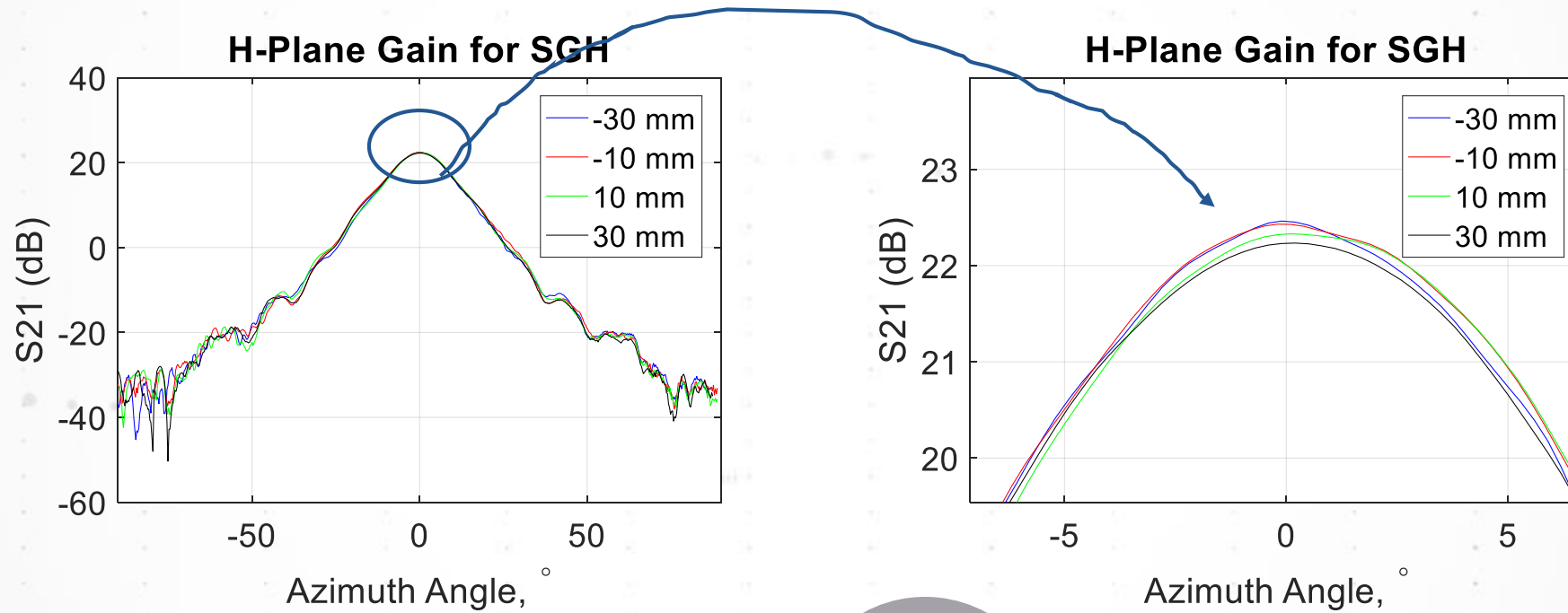
EXPERIMENTAL DEMONSTRATION

- Low-gain (10-dBi) SGH was measured in H-plane
- Screen shot of overlaid S12 and S21 traces directly from VNA
- There is no difference.

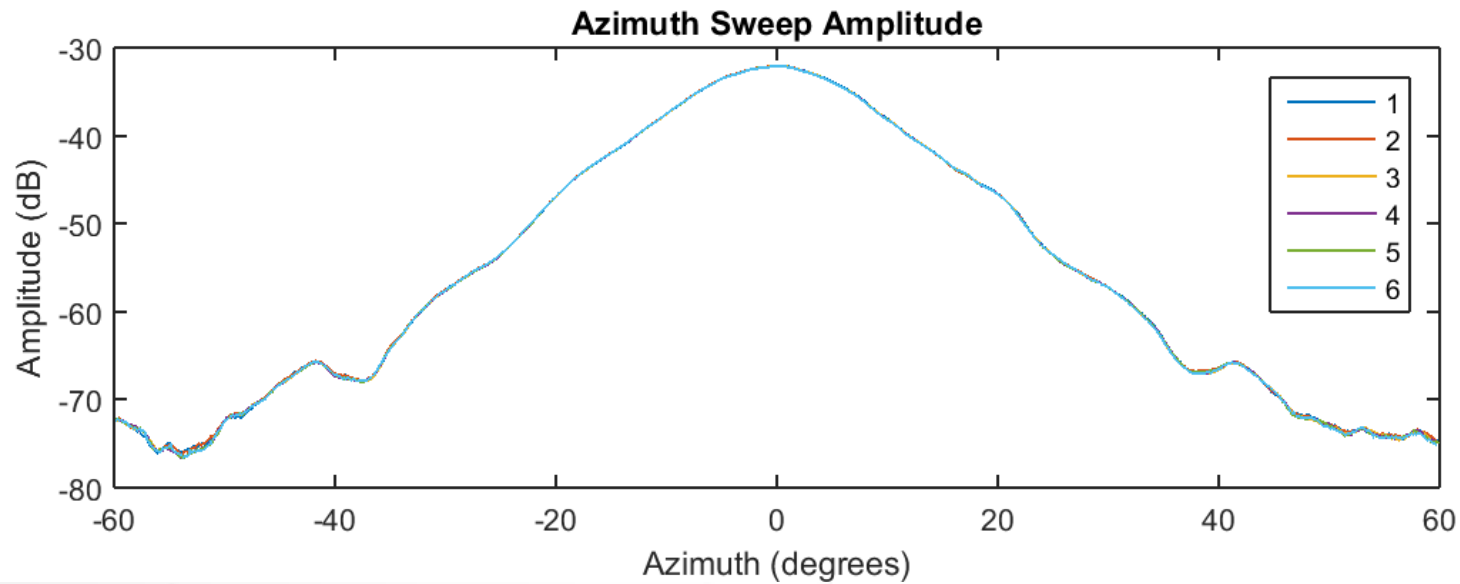


DUT as across QZ

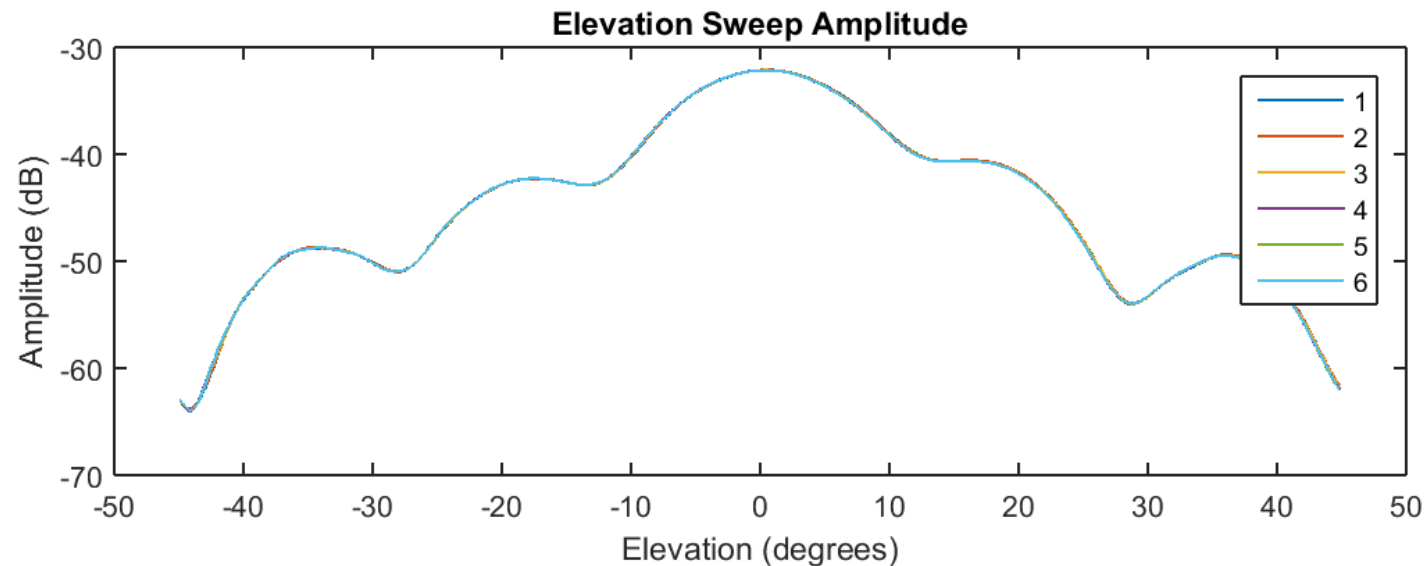
AMPLITUDE SENSITIVITY OF DUT AT DIFFERENT POSITIONS



CATR Repeatability



- SGH Sage SAR-2013-34-S2 was measured in the CATR chamber to check measurement repeatability
- Between each of the measurement the antenna was taken out of the chamber, disconnected and mounted back



Impact of range length reduction for Direct FF system

Impact of D (R4-1714541)

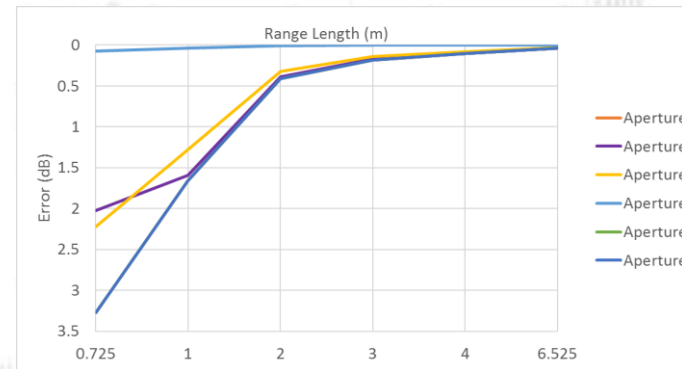
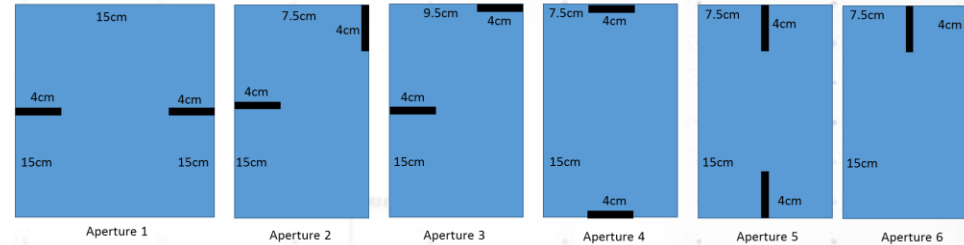
43 GHz	Far field baseline		CATR	
	D = 5 cm	D = 15 cm	D = 5 cm	D = 15 cm
EIRP MU @ 23 dBm	6.71 dB	11.87 dB	6.64 dB	6.64 dB
Range length	0.7 m	6.3 m	0.7 m	0.7 m
Total pathloss (inc. 17 dBi probe gain)	45 dB	64 dB	45 dB	45 dB
Notes	Assumes whitebox	Assumes blackbox	Assumes blackbox	Assumes blackbox
MU	[6.7dB]	Cannot be measured	[6.7dB]	[6.7dB]

Only applicable when DUT is at center of QZ.
Offset DUT will increase the MU

No dependence on the size of D or type of array

CATR DOES NOT SUFFER FROM SUCH LIMITATIONS

Impact of range length reduction of Direct FF system



The simulation results do not take into account:

- impact of improper spherical coverage
- simultaneous excitation of the panels
- sparse array designs
- more than 2 array panels
- the impact of surface currents and coupling effects to surrounding components in a real device
 - the impact of improper grounding, which cause current leakage
- the directivity error caused due to the amplitude taper of the probe antenna

The error due to the unaccounted factors will increase further the deviation from FF results

Error is dependent on the DUT configuration and scales with DUT dimension for Direct FF system

QZ validation results for EIRP and TRP in CATR>

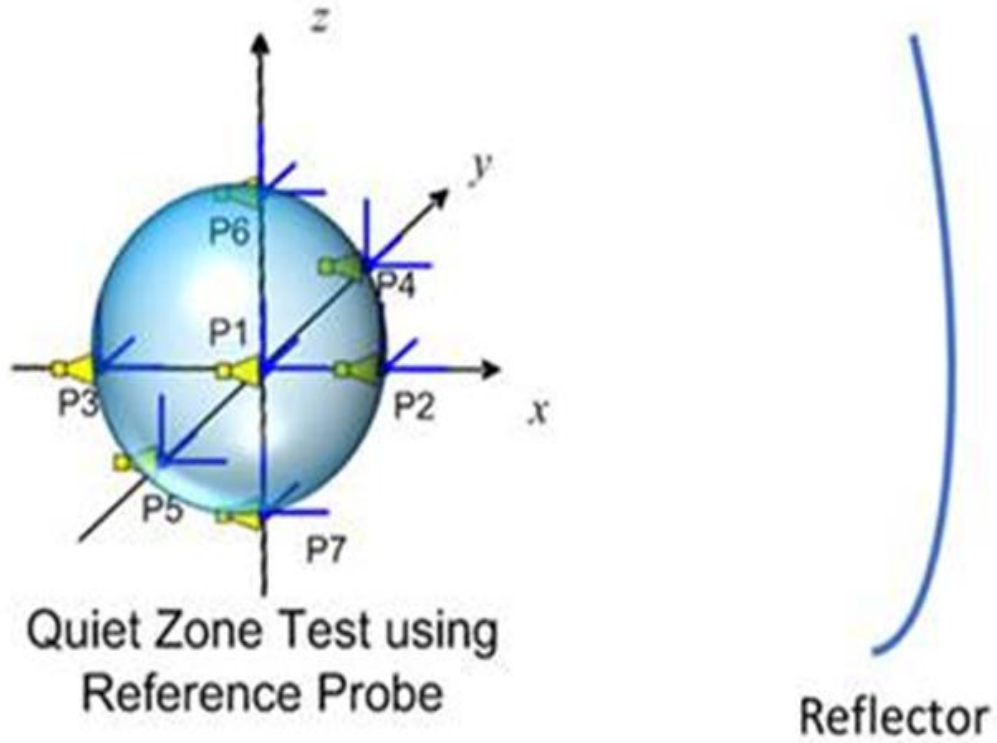


Fig 1. Representation of a typical CATR system

	EIRP	TRP
P1	15	-1.55
P2	15.39	-0.94
P3	13.91	-2.33
P4	15.02	-1.34
P5	14.78	-1.31
P6	15.13	-0.94
P7	15.13	-1.05
Standard Deviation	0.47	0.49

Table 1.

Comparison of measurement methods

Far Field Setup	CATR Setup	Near Field Setup
Very large dimensions due to black box approach	Measurements in farfield conditions in a compact footprint	Most compact setup
Both Antenna & RF parametric measurements can be done	Both Antenna & RF parametric measurements can be done	Suitable only for antenna measurements. <u>Not suitable for RF parametric measurements</u>
Large path loss -> low measurement dynamic range	Path loss only dependent on focal length. -> Good dynamic range	Very low path loss -> Best dynamic range
3GPP compliant	3GPP compliant	No proposals in 3GPP
High measurement uncertainty in case of making measurements of “offset DUT placement from phase center of Quiet Zone”	Low measurement uncertainty if the device can be placed within the Quiet Zone. Search algorithm can help identify the location of the radiating region to reposition the DUT	High measurement uncertainty in case of making measurements of “offset DUT placement from phase center of Quiet Zone”

3GPP TR 38.810

- 5 UE RF testing methodology
- 5.1 General
- 5.2 Permitted test methods
- 5.2.1 Direct far field (DFF)
- 5.2.1.1 Description
- 5.2.1.2 Parameter mapping to RF requirements
- 5.2.1.3 Far-field criteria
- 5.2.1.4 Testing and calibration aspects
- 5.2.1.4.1 Calibration Measurement Procedure
- 5.2.1.4.2 EIRP Measurement Procedure
- 5.2.1.4.3 TRP Measurement Procedure
- 5.2.1.4.4 EIS Measurement Procedure
- 5.2.2 Direct far field (DFF) setup simplification for centre of beam measurements ...
- 5.2.2.1 Description
- 5.2.2.2 Parameter mapping to RF requirements
- 5.2.2.3 Far-field criteria
- 5.2.2.4 Testing and calibration aspects
- 5.2.3 Indirect far field (IFF) method 1
- 5.2.3.1 Description
- 5.2.3.2 Parameter mapping to RF requirements
- 5.2.3.3 Far-field criteria
- 5.2.3.4 Testing and calibration aspects
- 5.2.3.4.1 Calibration Measurement Procedure
- 5.2.3.4.2 EIRP Measurement Procedure
- 5.2.3.4.2 TRP Measurement Procedure
- 5.2.3.4.2 EIS Measurement Procedure
- 5.3 Test method applicability
- 5.4 Summary of initial uncertainty assessment

5.2.3 Indirect far field (IFF) method 1

The IFF method 1 creates the far field environment using a transformation with a parabolic reflector. This is also known as the compact antenna test range (CATR). Refer to Annex E for additional information.

5.2.3.1 Description

The IFF measurement setup of UE RF characteristics for $f > 6$ GHz is capable of centre and off centre of beam measurements and is shown in Figure 5.2.3.1-1 below.

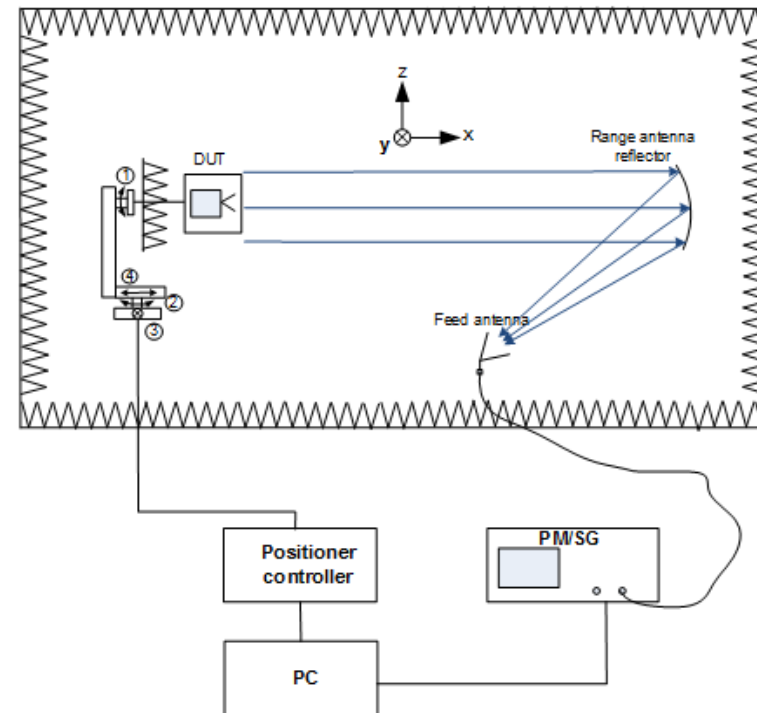


Figure 5.2.3.1-1: IFF method 1 (CATR) measurement setup of UE RF characteristic

Visit 3Gpp portal : <https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=3218>

Compact Antenna Test Range (CATR) in VERIZON'S 5G Test LAB

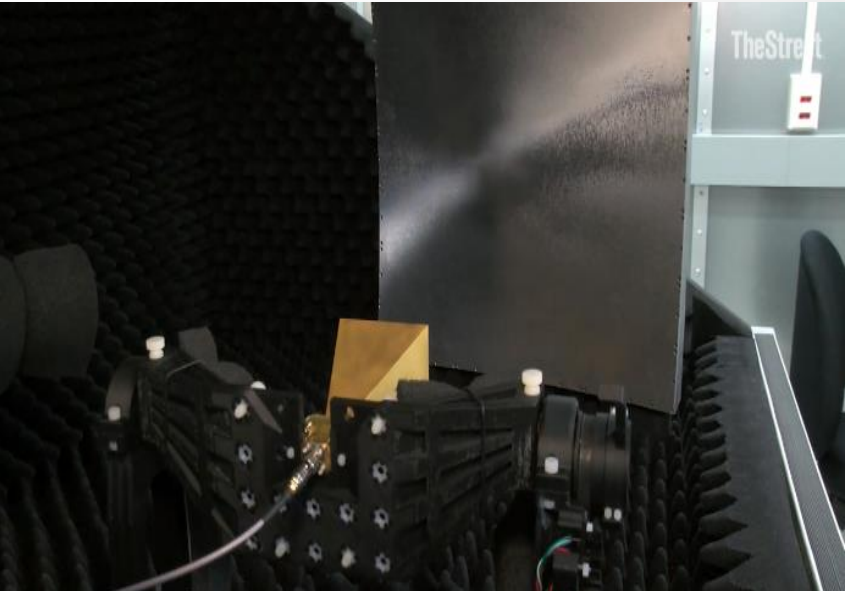
TheStreet.

Our EXCLUSIVE Look at Verizon's New 5G Network

Tracy Byrnes

Shawn Elias

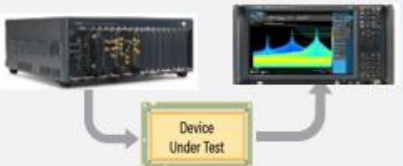



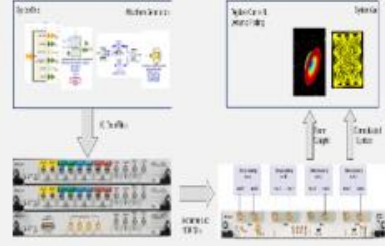

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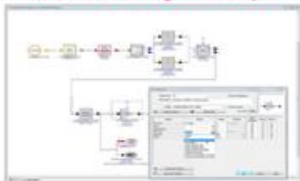
<https://www.thestreet.com.cdn.ampproject.org/c/s/www.thestreet.com/amp/video/14346395/our-exclusive-look-at-verizon-s-new-5g-network.html>

Keysight Test Solutions for 5G mmWave

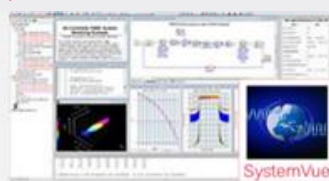
PAVE YOUR WAY FROM EARLY RESEARCH TO COMMERCIALIZATION

Wideband RF/ μ W/mmWave Generation & Analysis	Wideband mmWave Analysis	NES – Protocol, RF and Functional	Massive MIMO	OTA solution
<p>5G Waveform Generation & Analysis Testbed Reference Solution</p> <p>40GHz Signal Generation M9383A</p> <p>Up to 110 GHz Signal Analysis UXA N9041B</p> 	<p>E-Band Signal Analysis Reference Solution</p> <p>MSOS804A + M1971E</p> 	<p>Network Emulation, Protocol, Analysis, Automation RF Tool</p>  <p>UXM 5G E7515B</p> <p>Propsim Fading</p> 	<p>Real-time Beamforming Signal Generation & Analysis</p> 	<p>CATR (Compact Antenna Test Range)</p>  <ul style="list-style-type: none"> Anechoic chamber Reflector system Dual-polarized feed antenna DUT positioner <p>Figure 8. A compact antenna test range.</p>

ADS 5G Design Library



5G NR SystemVue W1906 Simulation Software



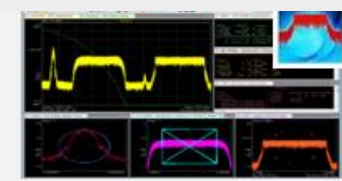
5G Channel Emulation



5G NR N7631C Signal Studio



5G NR 89601B-BHN VSA Software



Q and A Session



Thank you!