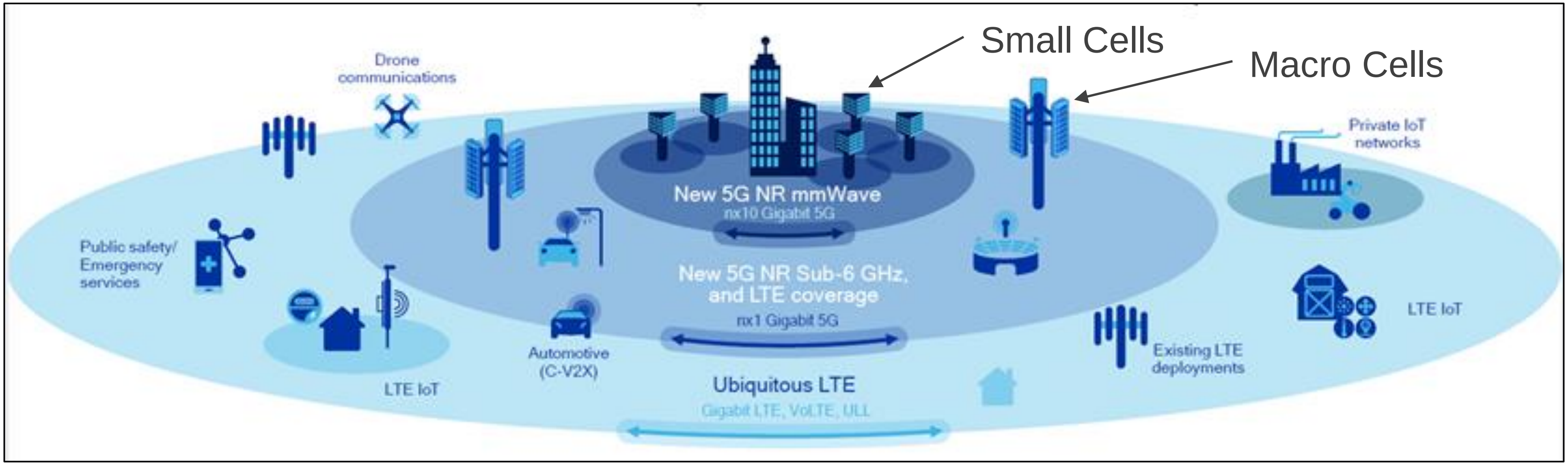
5G毫米波与Sub-6GHz特性与量产挑战

5G NR Overview

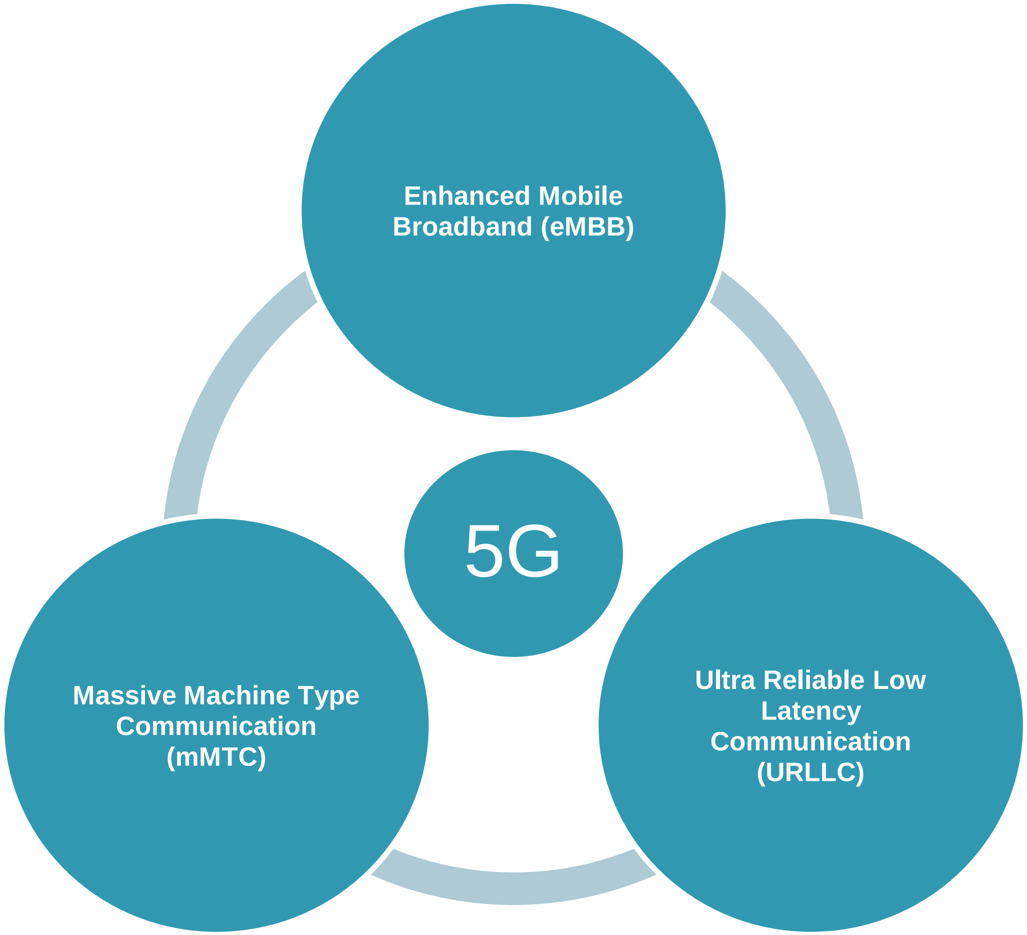
5G NR MIMO: Sub-6GHz vs mmWave



	< 6 GHz	mmWave
Deployment Scenario	Macro cells High user mobility	Small cells Low user mobility
MIMO Order	Up to 8x8	Less MIMO order (typically 2x2)
Number of Simultaneous Users	Tens of users Large coverage area	A few users Small coverage area
Main Benefit	Spatial multiplexing	Beamforming for single user
Channel Characteristics	Rich multipath propagation	A few propagation paths
Spectral Efficiency	High due to the spatial multiplexing	Low spectral efficiency (few users, high path loss)
Transceiver	Digital transceiver	Hybrid

5G Use Cases

> 10 Gbps
peak rates



> 100K
connections
per cell

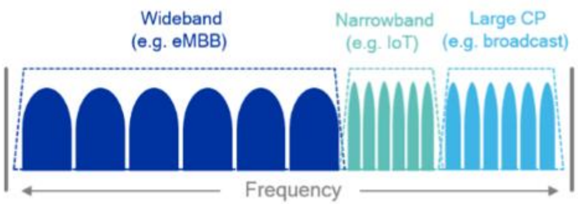
< 0.5 ms
latency

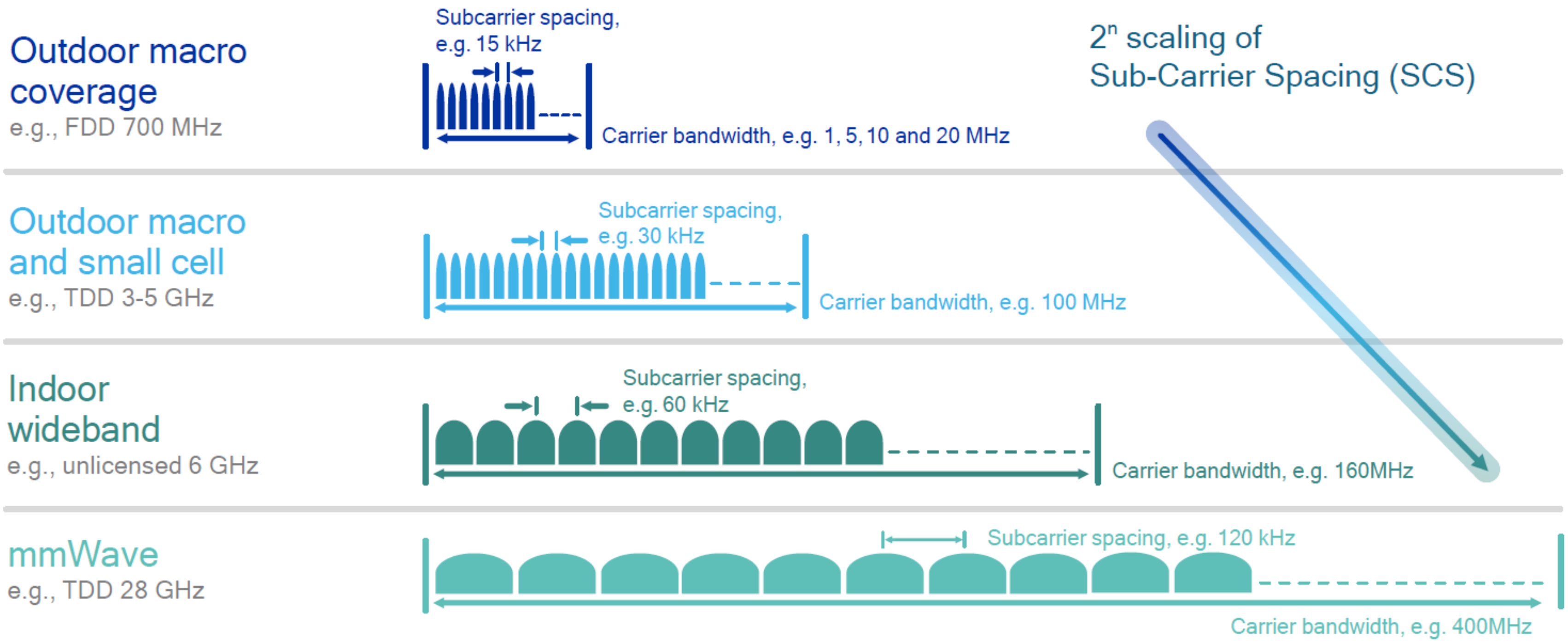
5GNR KPI (3GPP TR38.913 V15.0.0 2018-06)

Capability	Usage scenario	Target value
Peak data rate	eMBB	DL:20Gbps UL:10Gbps
Control plane latency	eMBB/URLLC	10ms
User plane latency	eMBB/URLLC	URLLC: 0.5ms eMBB: 4ms
Mobility	eMBB/URLLC	500km/h which defined QoS can be achieved
Reliability	URLLC	**URLLC:** 99.999% success for 32bytes with latency 1ms **eV2X:** 99.999% success for 300bytes with latency 3~10ms
Connection density	mMTC	1,000,000 devices/km^2
UE battery life	mMTC	>10 years

5G NR’s Biggest Contribution

- Multiple OFDM numerologies
  - A fancy way to say that scalable Sub-Carrier Spacing (SCS)
  - SCS is controlled by a parameter called μ
  - Why change SCS? What is the real life application?

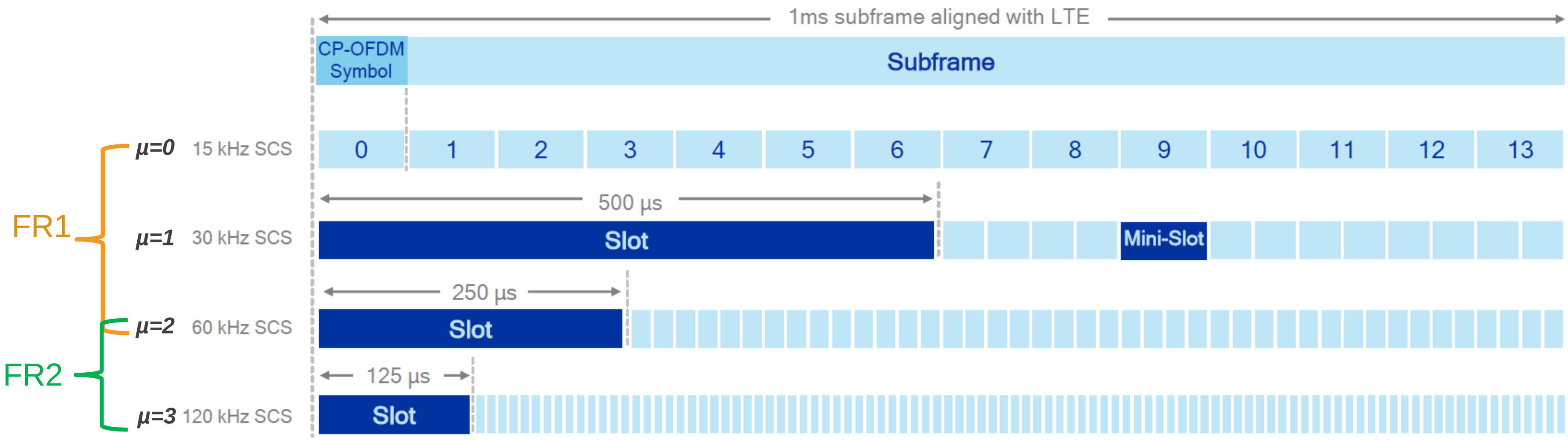




Source: Qualcomm

5G NR Frame Structure and Frequency Range

5G NR Frame Structure



5G NR Slot format

Format	Symbol number in a slot													
	0	1	2	3	4	5	6	7	8	9	10	11	12	13
0	D	D	D	D	D	D	D	D	D	D	D	D	D	D
1	U	U	U	U	U	U	U	U	U	U	U	U	U	U
2	X	X	X	X	X	X	X	X	X	X	X	X	X	X
3	D	D	D	D	D	D	D	D	D	D	D	D	D	X
4	D	D	D	D	D	D	D	D	D	D	D	D	X	X
5	D	D	D	D	D	D	D	D	D	D	D	X	X	X
6	D	D	D	D	D	D	D	D	D	D	X	X	X	X
7	D	D	D	D	D	D	D	D	D	X	X	X	X	X
8	X	X	X	X	X	X	X	X	X	X	X	X	X	U
9	X	X	X	X	X	X	X	X	X	X	X	X	U	U
10	X	U	U	U	U	U	U	U	U	U	U	U	U	U

LTE TDD UL/DL configuration

Uplink-downlink configuration	Downlink-to-Uplink Switch-point periodicity	Subframe number									
		0	1	2	3	4	5	6	7	8	9
0	5 ms	D	S	U	U	U	D	S	U	U	U
1	5 ms	D	S	U	U	D	D	S	U	U	D
2	5 ms	D	S	U	D	D	D	S	U	D	D
3	10 ms	D	S	U	U	U	D	D	D	D	D
4	10 ms	D	S	U	U	D	D	D	D	D	D
5	10ms	D	S	U	D	D	D	D	D	D	D
6	5 ms	D	S	U	U	U	D	S	U	U	D

Source: Qualcomm

5G-NR Key Parameters

Item	4G LTE	5G-NR Frequency Range1(FR1)	5G-NR Frequency Range2(FR2)
Known As	LTE	Sub6GHz	mmWave
Frequency Range	Upto 6GHz	450MHz - 6000 MHz	24250 MHz - 52600 MHz
Duplex Mode	FDD, TDD	FDD, TDD	TDD
Subcarrier Spacing	15KHz	15, 30, 60KHz	60, 120KHz
Bandwidth	1.5, 3, 5, 10, 20MHz	5, 10, 15, 20, 25, 30, 40, 50, 60, 80, 100 MHz	50, 100, 200, 400 MHz
MIMO	DL: 8x8 UL: 4x4		DL: 2x2 UL: 2x2
MIMO Method	Spatial Multiplexing for higher Throughput		Beamforming for better SNR
Radio Frame	10ms		
Subframe Duration	1ms		
Modulation	QPSK, 16QAM, 64QAM in both direction	pi/2-BPSK, BPSK, QPSK, 16QAM, 64QAM, 256QAM	
Access	DL: OFDMA UL: SC-FDMA	DL: CP-OFDM UL: CP-OFDM, DFT-s-OFDM	
Carrier Aggregation	5 Carriers (1PCC+4SCC)	16 Carriers maximum	

Source: LP

FR1: Frequency Range and Operating Bands

Frequency range designation	Corresponding frequency range
FR1	450MHz - 6000MHz

NR operating bands

NR operating band	Uplink (UL) operating band BS receive / UE transmit F_{UL_low} – F_{UL_high}	Downlink (DL) operating band BS transmit / UE receive F_{DL_low} – F_{DL_high}	Duplex Mode
n1	1920 MHz – 1980 MHz	2110 MHz – 2170 MHz	FDD
n2	1850 MHz – 1910 MHz	1930 MHz – 1990 MHz	FDD
n3	1710 MHz – 1785 MHz	1805 MHz – 1880 MHz	FDD
n5	824 MHz – 849 MHz	869 MHz – 894 MHz	FDD
n7	2500 MHz – 2570 MHz	2620 MHz – 2690 MHz	FDD
n8	880 MHz – 915 MHz	925 MHz – 960 MHz	FDD
n12	699 MHz – 716 MHz	729 MHz – 746 MHz	FDD
n20	832 MHz – 862 MHz	791 MHz – 821 MHz	FDD
n25	1850 MHz – 1915 MHz	1930 MHz – 1995 MHz	FDD
n28	703 MHz – 748 MHz	758 MHz – 803 MHz	FDD
n34	2010 MHz – 2025 MHz	2010 MHz – 2025 MHz	TDD
n38	2570 MHz – 2620 MHz	2570 MHz – 2620 MHz	TDD
n39	1880 MHz – 1920 MHz	1880 MHz – 1920 MHz	TDD
n40	2300 MHz – 2400 MHz	2300 MHz – 2400 MHz	TDD
n41	2496 MHz – 2690 MHz	2496 MHz – 2690 MHz	TDD
n50	1432 MHz – 1517 MHz	1432 MHz – 1517 MHz	TDD[1]
n51	1427 MHz – 1432 MHz	1427 MHz – 1432 MHz	TDD
n66	1710 MHz – 1780 MHz	2110 MHz – 2200 MHz	FDD
n70	1695 MHz – 1710 MHz	1995 MHz – 2020 MHz	FDD
n71	663 MHz – 698 MHz	617 MHz – 652 MHz	FDD
n74	1427 MHz – 1470 MHz	1475 MHz – 1518 MHz	FDD
n75	N/A	1432 MHz – 1517 MHz	SDL
n76	N/A	1427 MHz – 1432 MHz	SDL

LTE covered bands

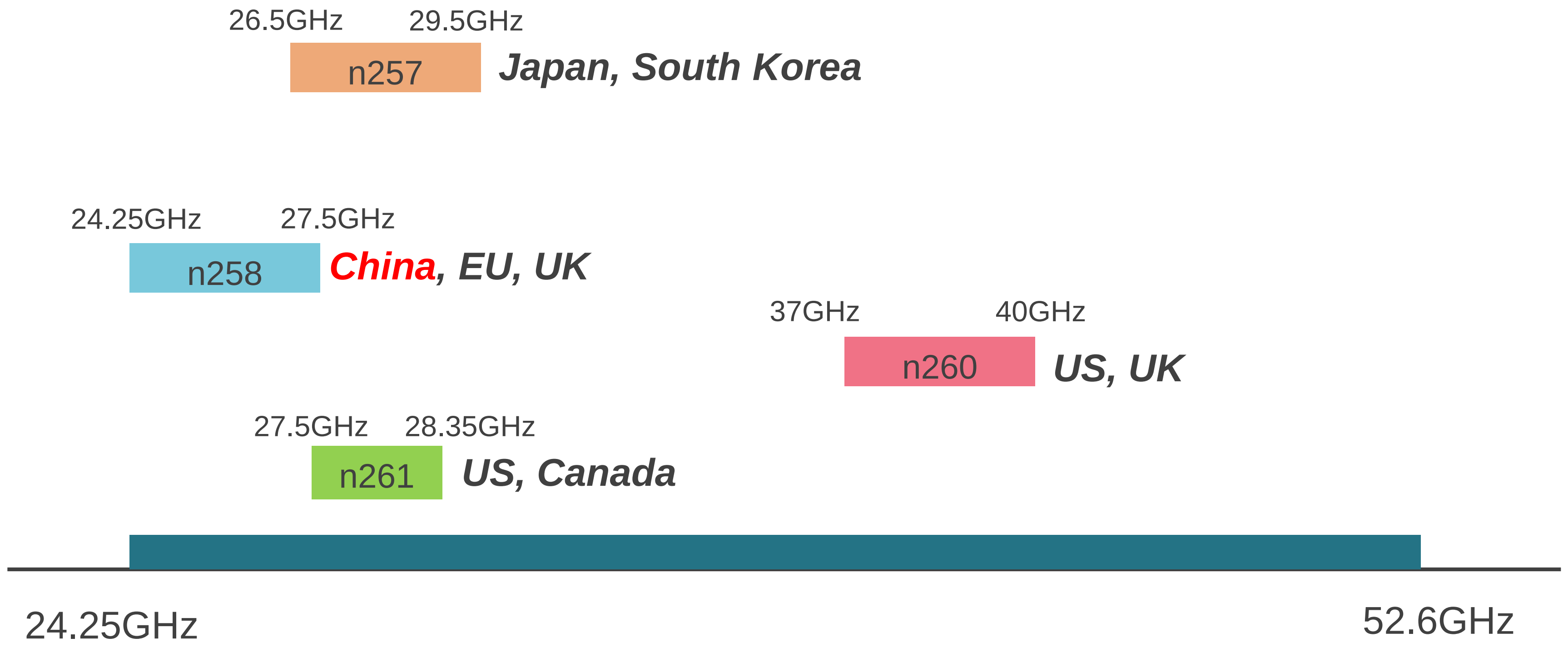
NR operating band	Uplink(MHz)	Downlink(MHz)	Duplex mode	Region/Country
n71	663-698	617-652	FDD	US, Canada
n77	3300-4200	3300-4200	TDD	US
n78	3300-3800	3300-3800	TDD	China, Japan, S.Korea, EU
n79	4400-5000	4400-5000	TDD	China, Japan

Source: 3GPP TS38.521-1 V15.2.0 (2019-03)

FR2: Frequency Range, Operating Bands

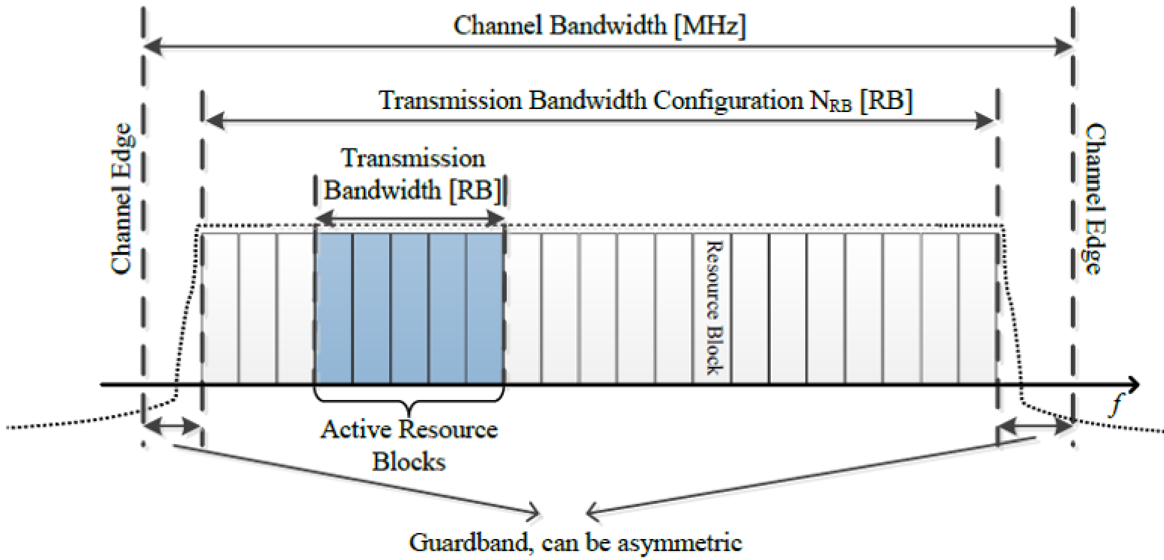
Definition of frequency ranges

Frequency range designation	Corresponding frequency range
FR2	24.25GHz – 52.6GHz



Source: 3GPP TS38.521-2 V15.2.0 (2019-03)

UE Channel Bandwidth



FR1

Table 5.3.2-1: Maximum transmission bandwidth configuration N_{RB}

SCS (kHz)	5MHz	10MHz	15MHz	20 MHz	25 MHz	30 MHz	40 MHz	50MHz	60 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	217	245	273
60	N/A	11	18	24	31	38	51	65	79	107	121	135

FR2

Table 5.3.2-1: Maximum transmission bandwidth configuration N_{RB}

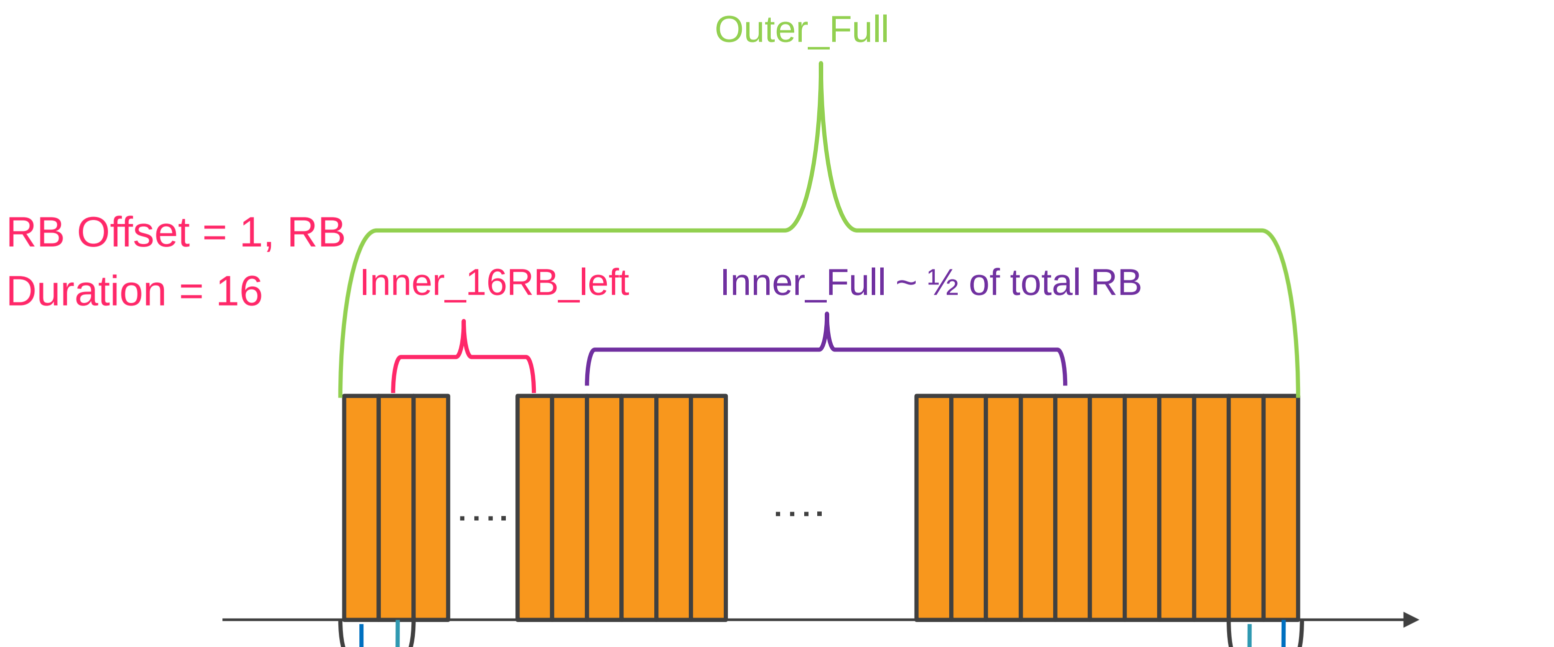
SCS (kHz)	50MHz	100MHz	200MHz	400 MHz
	NRB	NRB	NRB	NRB
60	66	132	264	N/A
120	32	66	132	264

Sub6GHz and mmWave Testing

Test Items in Sub6G and mmWave

Test Item	LTE (Conducted)	Sub-6GHz (Conducted)	mmWave (OTA)
UE Maximum Output Power	Yes	Yes	Yes
EVM	Yes	Yes	Yes
Carrier Leakage	Yes	Yes	Yes
In-band Emission	Yes	Yes	Yes
Spectrum Flatness	Yes	Yes	Yes
SEM	Yes	Yes	Yes
ACLR	Yes	Yes	Yes

Common UL configuration definitions



Channel Bandwidth	SCS(kHz)	OFDM	RB allocation							
			Edge_Full_Left	Edge_Full_Right	Edge_1RB_Left	Edge_1RB_Right	Outer_Full	Inner_Full	Inner_1RB_Left	Inner_1RB_Right
5MHz	15	DFT-s	2@0	2@23	1@0	1@24	25@0	12@6	1@1	1@23
		CP	2@0	2@23	1@0	1@24	25@0	13@6	1@1	1@23
	30	DFT-s	2@0	2@9	1@0	1@10	10@0	5@2	1@1	1@9
		CP	2@0	2@9	1@0	1@10	11@0	5@2	1@1	1@9
	60	DFT-s	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
		CP	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
10MHz	15	DFT-s	2@0	2@50	1@0	1@51	50@0	25@12	1@1	1@50
		CP	2@0	2@50	1@0	1@51	52@0	26@13	1@1	1@50
	30	DFT-s	2@0	2@22	1@0	1@23	24@0	12@6	1@1	1@22
		CP	2@0	2@22	1@0	1@23	24@0	12@6	1@1	1@22
	60	DFT-s	2@0	2@9	1@0	1@10	10@0	5@2	1@1	1@9
		CP	2@0	2@9	1@0	1@10	11@0	5@2	1@1	1@9
15MHz	15	DFT-s	2@0	2@77	1@0	1@78	75@0	36@18	1@1	1@77
		CP	2@0	2@77	1@0	1@78	79@0	39@19	1@1	1@77
	30	DFT-s	2@0	2@36	1@0	1@37	36@0	18@9	1@1	1@36
		CP	2@0	2@36	1@0	1@37	38@0	19@9	1@1	1@36
	60	DFT-s	2@0	2@16	1@0	1@17	18@0	9@4	1@1	1@16
		CP	2@0	2@16	1@0	1@17	18@0	9@4	1@1	1@16
20MHz	15	DFT-s	2@0	2@104	1@0	1@105	100@0	50@25	1@1	1@104
		CP	2@0	2@104	1@0	1@105	106@0	53@26	1@1	1@104
	30	DFT-s	2@0	2@49	1@0	1@50	50@0	25@12	1@1	1@49
		CP	2@0	2@49	1@0	1@50	51@0	25@12	1@1	1@49
	60	DFT-s	2@0	2@22	1@0	1@23	24@0	12@6	1@1	1@22
		CP	2@0	2@22	1@0	1@23	24@0	12@6	1@1	1@22
25MHz	15	DFT-s	2@0	2@131	1@0	1@132	128@0	64@32	1@1	1@131
		CP	2@0	2@131	1@0	1@132	133@0	67@33	1@1	1@131
	30	DFT-s	2@0	2@63	1@0	1@64	64@0	32@16	1@1	1@63
		CP	2@0	2@63	1@0	1@64	65@0	33@16	1@1	1@63
	60	DFT-s	2@0	2@29	1@0	1@30	30@0	15@7	1@1	1@29
		CP	2@0	2@29	1@0	1@30	31@0	15@7	1@1	1@29

UE Maximum Output Power

Assumption of UE Types

UE Power class	UE type
1	Fixed wireless access(FWA) UE
2	Vehicular UE
3	Handheld UE
4	High power non-handheld UE

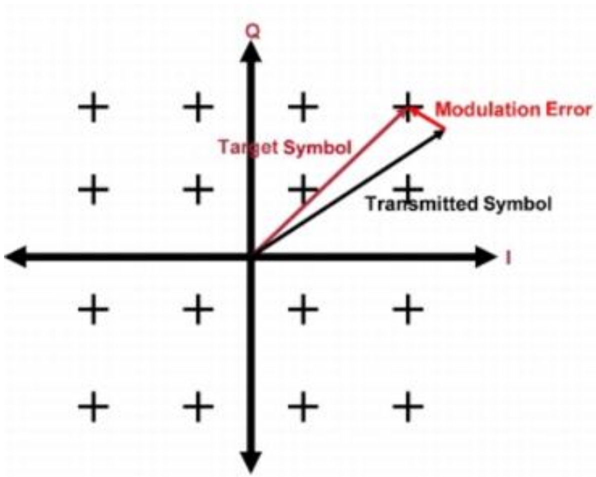
Max Power Limit	FR1 Power Class2 (dBm)	FR1 Power Class3 (dBm)	FR2 Power Class 1 (EIRP dBm)	FR2 Power Class 2 (EIRP dBm)	FR2 Power Class 3 (EIRP dBm)	FR2 Power Class 4 (EIRP dBm)
FR1 band	26	23				
FR2 n257			55 / 40-TT	43 / 29-TT	43 / 22.4-TT	43 / 34-TT
FR2 n258			55 / 40-TT	43 / 29-TT	43 / 22.4-TT	43 / 34-TT
FR2 n260			55 / 38-TT	-	43 / 20.6-TT	43 / 31-TT
FR2 n261			55 / 40-TT	43 / 29-TT	43 / 22.4-TT	43 / 34-TT

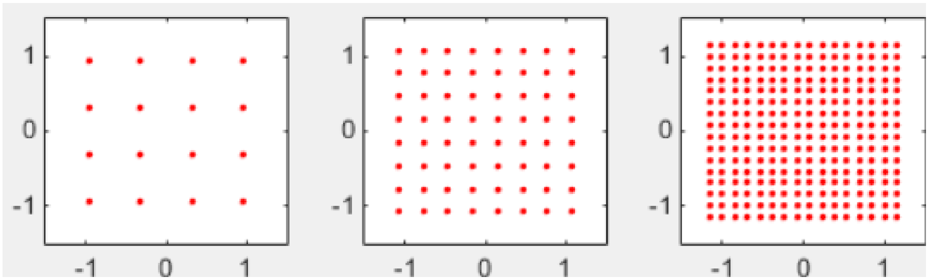
Test Tolerance

Test Metric	FR2a	FR2b
DUT ≤ 15 cm	3.18 dB	3.31 dB
DUT ≤ 30 cm	3.11 dB	3.24 dB

	FR1	FR2
RB allocation	Inner_Full Inner_1RB_Left Inner_1RB_Right	Outer_Full

EVM





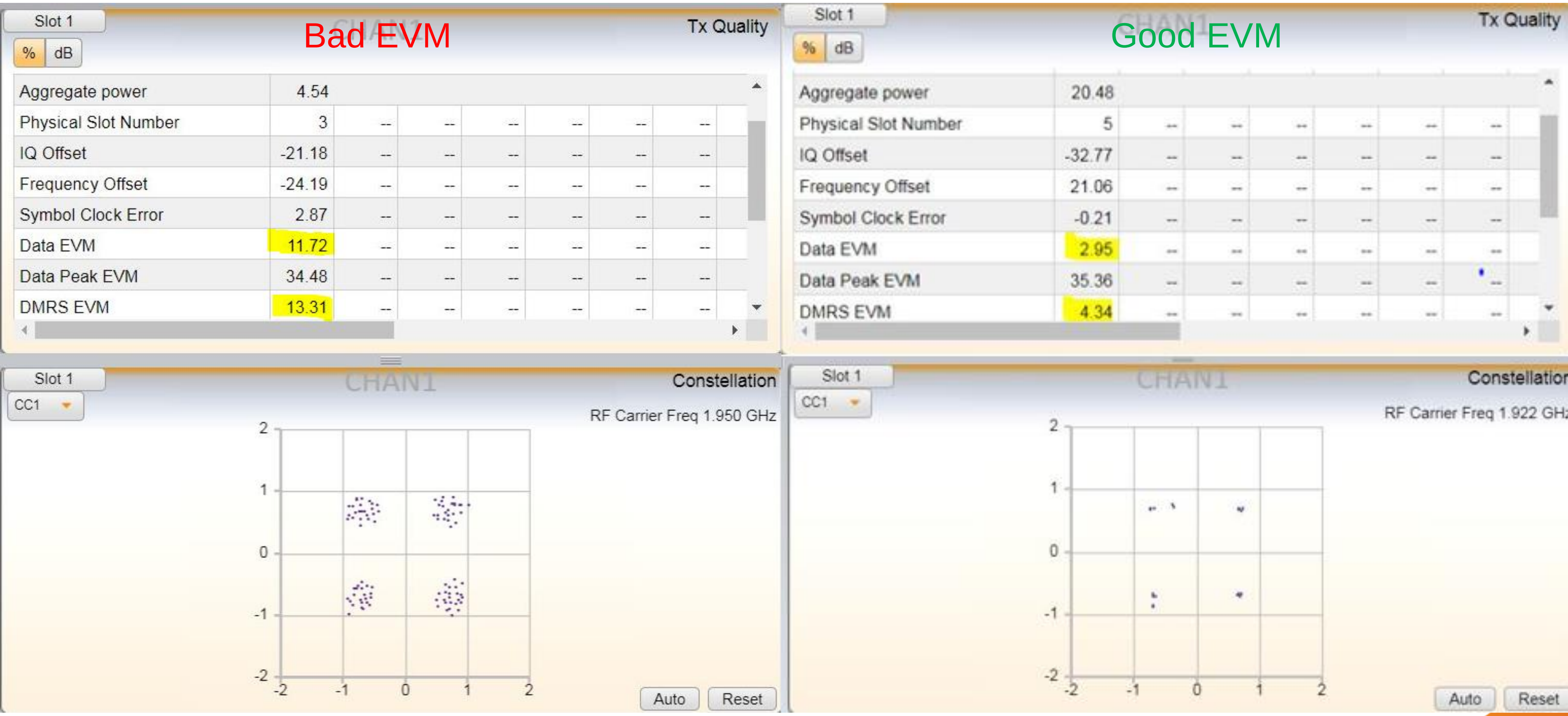
Modulation	Unit	Average EVM Level	RB allocation (FR1)	RB allocation (FR2)
Pi/2-BPSK	%	30	Inner_Full, Outer_Full	Inner_Full, Outer_Full
QPSK	%	17.5	Inner_Full, Outer_Full	Inner_Full, Outer_Full
16QAM	%	12.5	Inner_Full, Outer_Full	Inner_Full, Outer_Full
64QAM	%	8	Outer_Full	Inner_Full, Outer_Full
256QAM	%	3.5	Outer_Full	

FR2

FR1

EVM

- What different EVM results look like



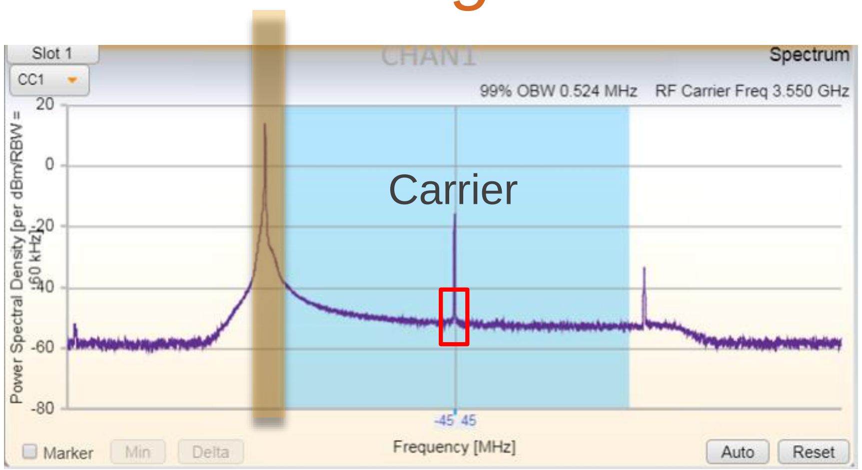
Bad EVM

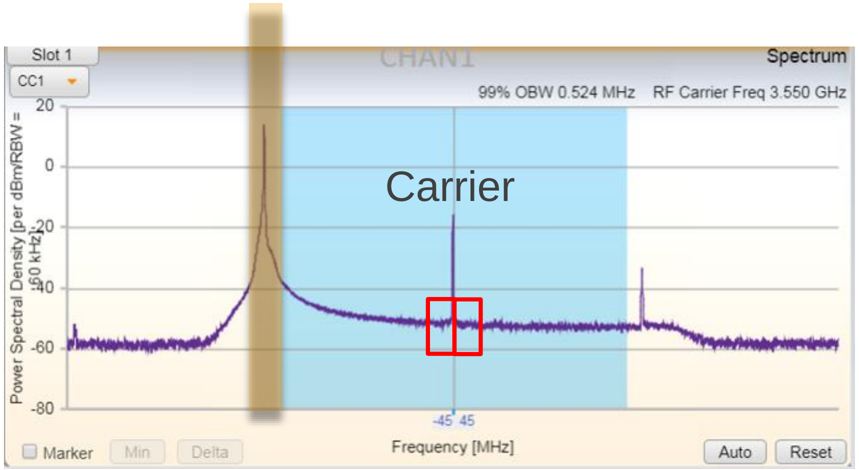
Aggregate power	4.54						
Physical Slot Number	3	--	--	--	--	--	--
IQ Offset	-21.18	--	--	--	--	--	--
Frequency Offset	-24.19	--	--	--	--	--	--
Symbol Clock Error	2.87	--	--	--	--	--	--
Data EVM	11.72	--	--	--	--	--	--
Data Peak EVM	34.48	--	--	--	--	--	--
DMRS EVM	13.31	--	--	--	--	--	--

Good EVM

Aggregate power	20.48						
Physical Slot Number	5	--	--	--	--	--	--
IQ Offset	-32.77	--	--	--	--	--	--
Frequency Offset	21.06	--	--	--	--	--	--
Symbol Clock Error	-0.21	--	--	--	--	--	--
Data EVM	2.95	--	--	--	--	--	--
Data Peak EVM	35.36	--	--	--	--	--	--
DMRS EVM	4.34	--	--	--	--	--	--

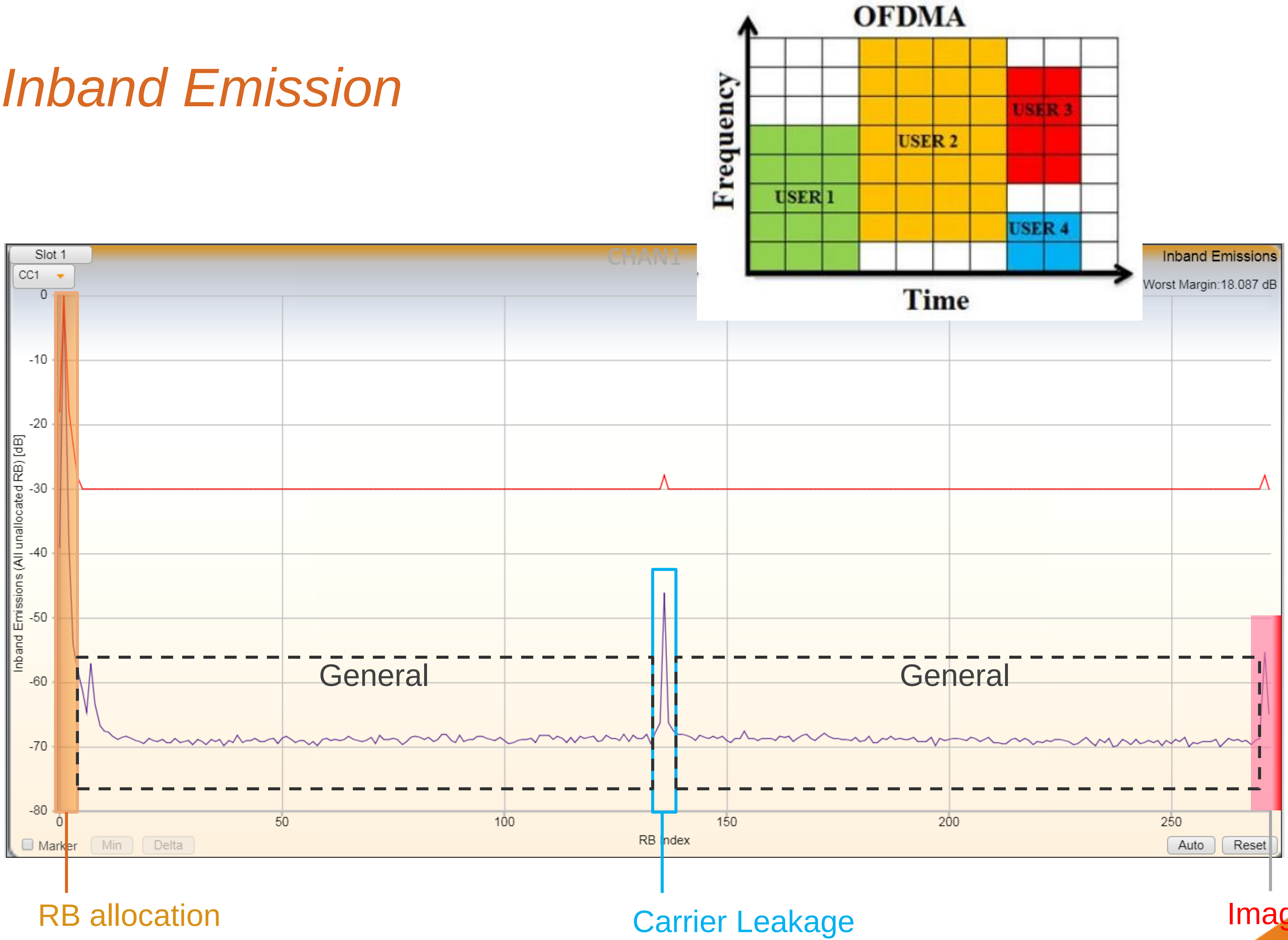
Carrier leakage





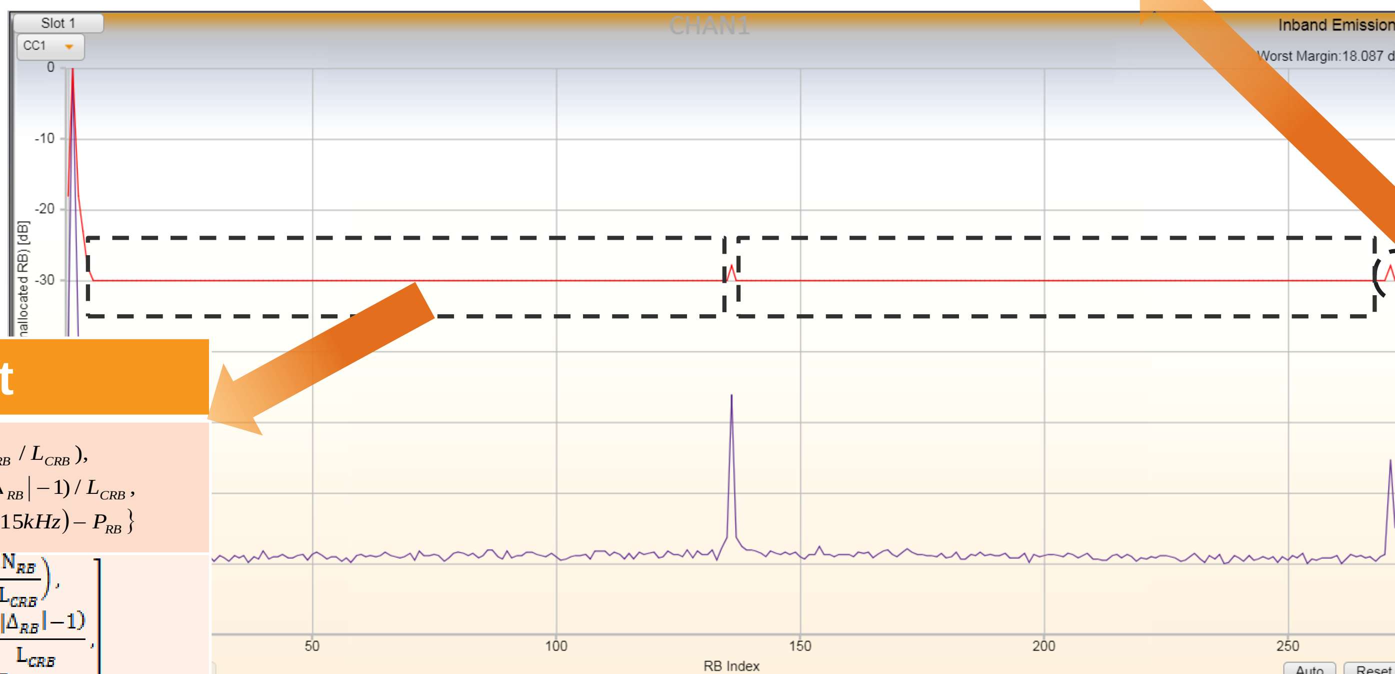
Frequency Range	Output power range	Relative limit (dBc)	RB allocation
FR1	> 10dBm	-28	Inner_1RB_Left
	0 ~ 10 dBm	-25	
	-30 ~ 0 dBm	-20	
	-40 ~ -30 dBm	-10	
FR2 power class 1	EIRP > 17 dBm	-25	Inner_16RB_Left
	4 dBm ≤ EIRP ≤ 17 dBm	-20	
FR2 power class 2	EIRP > 6 dBm	-25	
	-13 dBm ≤ EIRP ≤ 6 dBm	-20	
FR2 power class 3	EIRP > 0 dBm	-25	
	-13 dBm ≤ EIRP ≤ 0 dBm	-20	
FR2 power class 4	EIRP > 11 dBm	-25	
	-13 dBm ≤ EIRP ≤ 11 dBm	-20	

Inband Emission



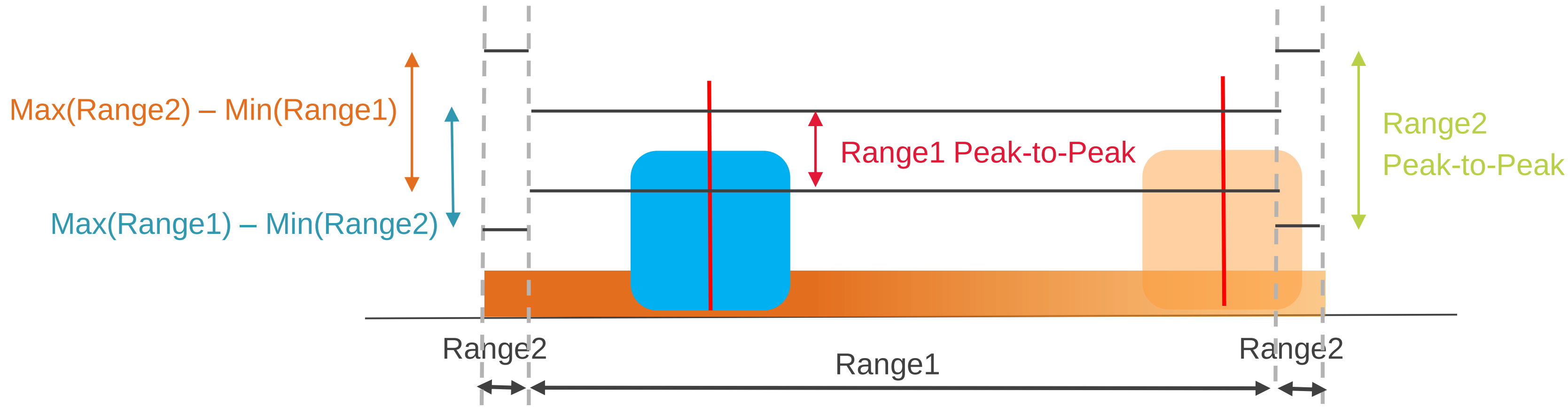
IQ Image Limit

Frequency Range	Output power range	Relative limit (dB)	RB allocation
FR1	> 10dBm	-28	Inner_1RB_Left Inner_1RB_Right
	0 ~ 10 dBm	-25	
FR2 power class 1 FR2 power class 2	EIRP > 27 dBm	-25	Inner_16RB_Left Inner_16RB_Right
	EIRP ≤ 27 dBm	-20	
FR2 power class 3	EIRP > 10 dBm	-25	
	EIRP ≤ 10 dBm	-20	
FR2 power class 4	EIRP > 21 dBm	-25	
	EIRP ≤ 21 dBm	-20	



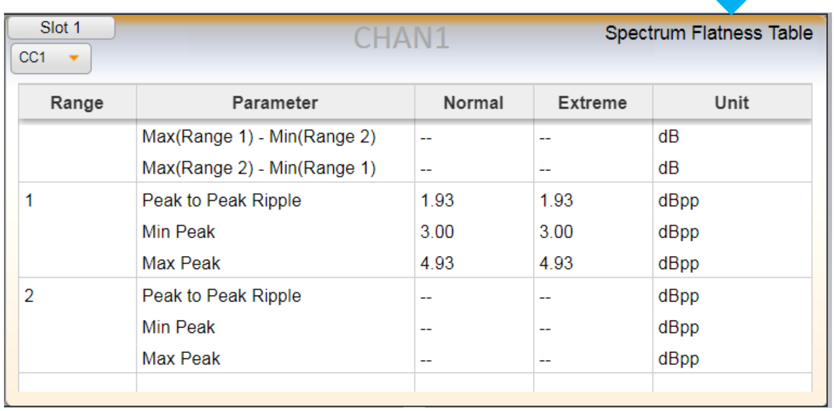
	General Limit
FR1	$\max\{-25-10\cdot\log_{10}(N_{RB}/L_{CRB}),\ 20\cdot\log_{10} EVM-3-5\cdot(\lvert\Delta_{RB}\rvert-1)/L_{CRB},\ -57\,dBm+10\log_{10}(SCS/15kHz)-P_{RB}\}$
FR2	$max\begin{bmatrix} -25\ -10.\log_{10}\left(\frac{N_{RB}}{L_{CRB}}\right), \\ 20.\log_{10}(\mathrm{EVM})-\ 5.\frac{(\lvert\Delta_{RB}\rvert-1)}{L_{CRB}}, \\ -55.1dBm-P_{RB} \end{bmatrix}$

EVM Equalizer Spectrum Flatness

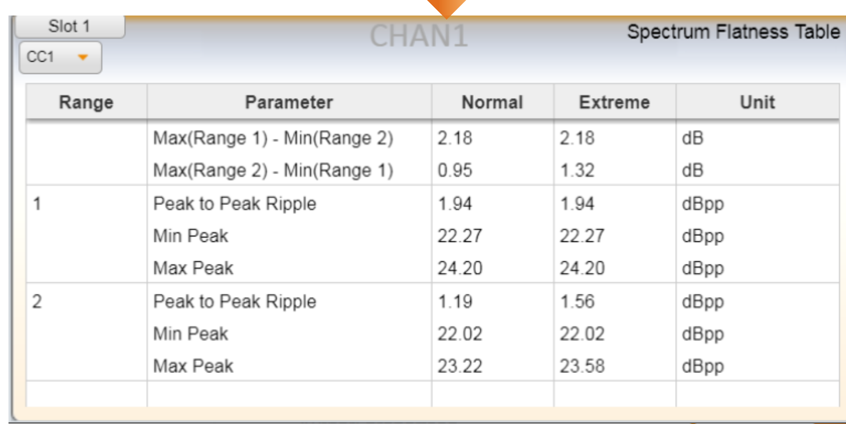


FR1	3300MHz	3300+3 MHz	4200-3MHz	4200MHz
FR2	37000MHz	37000+X MHz	40000-X MHz	40000MHz

- X, in MHz, is equal to 20% of the CC bandwidth



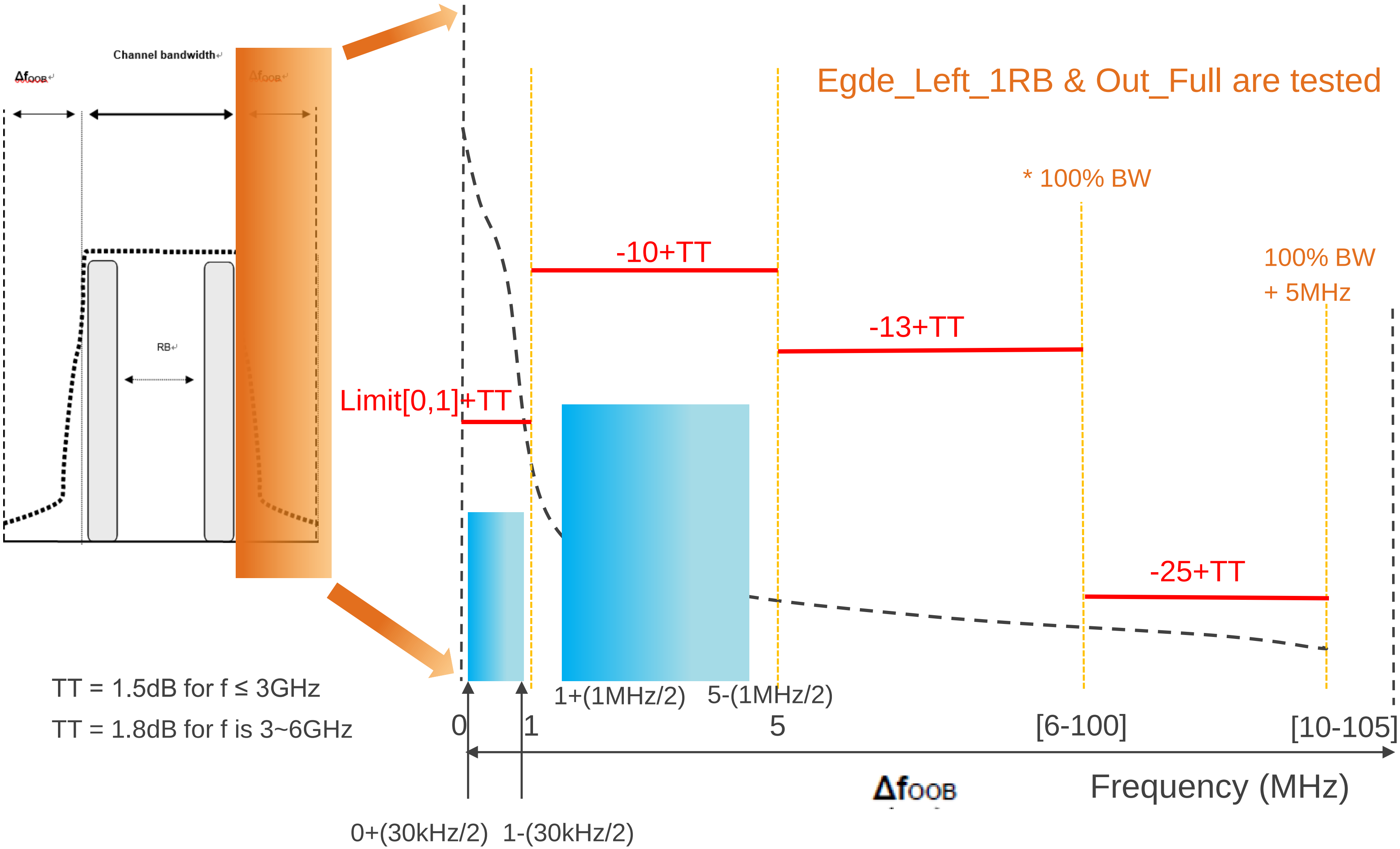
Range	Parameter	Normal	Extreme	Unit
	Max(Range 1) - Min(Range 2)	--	--	dB
	Max(Range 2) - Min(Range 1)	--	--	dB
1	Peak to Peak Ripple	1.93	1.93	dBpp
	Min Peak	3.00	3.00	dBpp
	Max Peak	4.93	4.93	dBpp
2	Peak to Peak Ripple	--	--	dBpp
	Min Peak	--	--	dBpp
	Max Peak	--	--	dBpp



Range	Parameter	Normal	Extreme	Unit
	Max(Range 1) - Min(Range 2)	2.18	2.18	dB
	Max(Range 2) - Min(Range 1)	0.95	1.32	dB
1	Peak to Peak Ripple	1.94	1.94	dBpp
	Min Peak	22.27	22.27	dBpp
	Max Peak	24.20	24.20	dBpp
2	Peak to Peak Ripple	1.19	1.56	dBpp
	Min Peak	22.02	22.02	dBpp
	Max Peak	23.22	23.58	dBpp

- Only check Range1 result if a channel doesn’t occupy Range2.

Spectrum Emission Mask (FR1)



TT = 1.5dB for f ≤ 3GHz

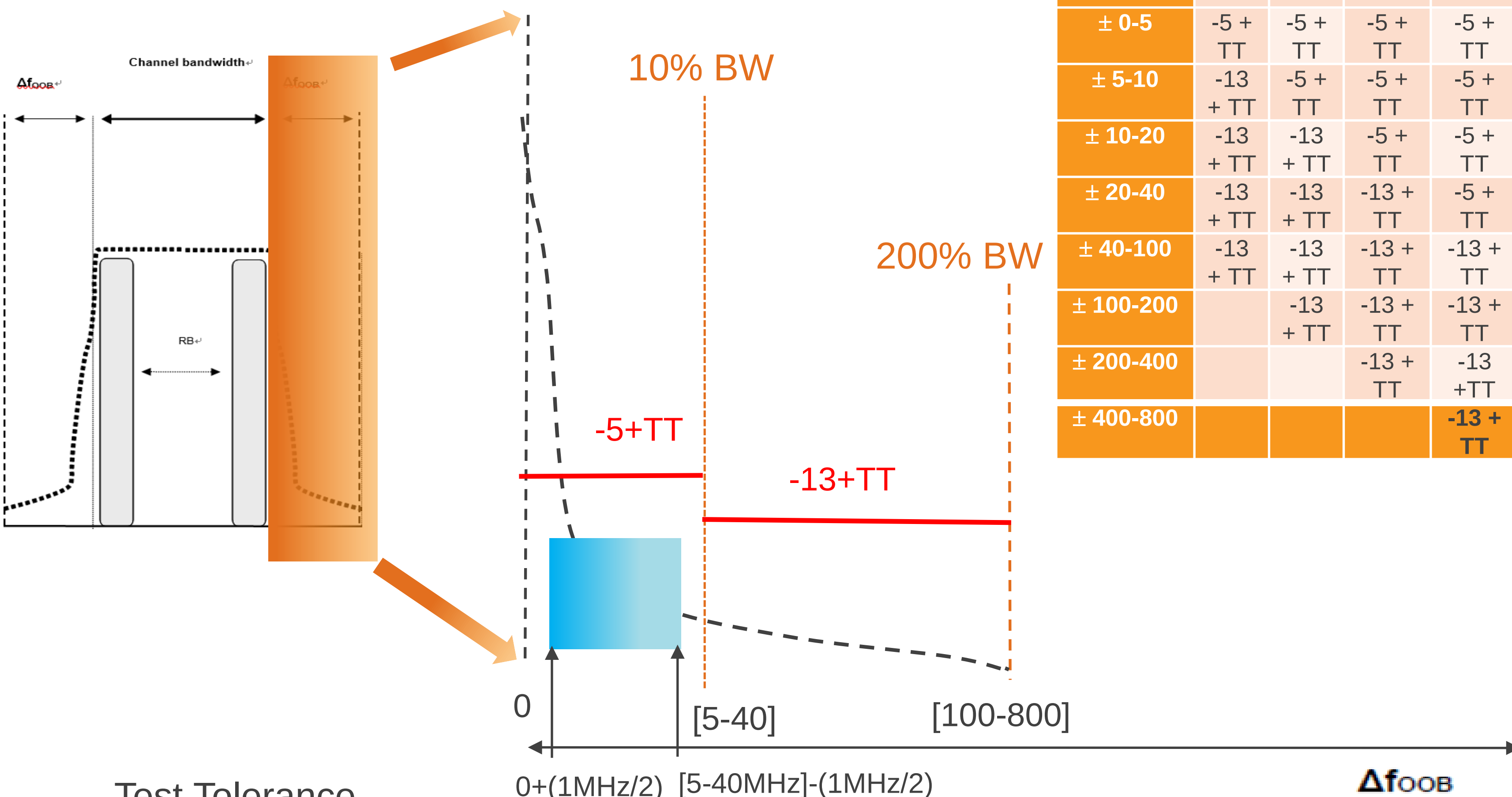
TT = 1.8dB for f is 3~6GHz

	5MHz	10MHz	15MHz	20MHz	25MHz	30MHz	40MHz	50MHz	60Mhz	80MHz	90MHz	100MHz
Limit[0,1]	-15	-18	-20	-21	-22	-23	-24	-24	-24	-24	-24	-24

* Exception when CBW is 5MHz, ΔfooB is 6MHz, not 100% BW

Spectrum Emission Mask (FR2)

Out_Full is tested



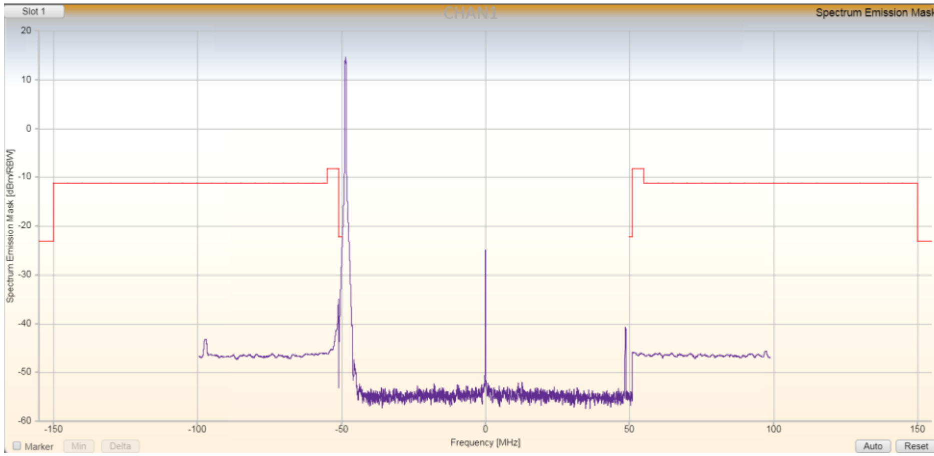
Spectrum emission limit (dBm)/ Channel bandwidth					
Δf_{OOB} (MHz)	50 MHz	100 MHz	200 MHz	400 MHz	**MBW**
± 0-5	-5 + TT	-5 + TT	-5 + TT	-5 + TT	**1 MHz**
± 5-10	-13 + TT	-5 + TT	-5 + TT	-5 + TT	**1 MHz**
± 10-20	-13 + TT	-13 + TT	-5 + TT	-5 + TT	**1 MHz**
± 20-40	-13 + TT	-13 + TT	-13 + TT	-5 + TT	**1 MHz**
± 40-100	-13 + TT	-13 + TT	-13 + TT	-13 + TT	**1 MHz**
± 100-200		-13 + TT	-13 + TT	-13 + TT	**1 MHz**
± 200-400			-13 + TT	-13 +TT	**1 MHz**
± 400-800				**-13 + TT**	**1 MHz**

Test Tolerance

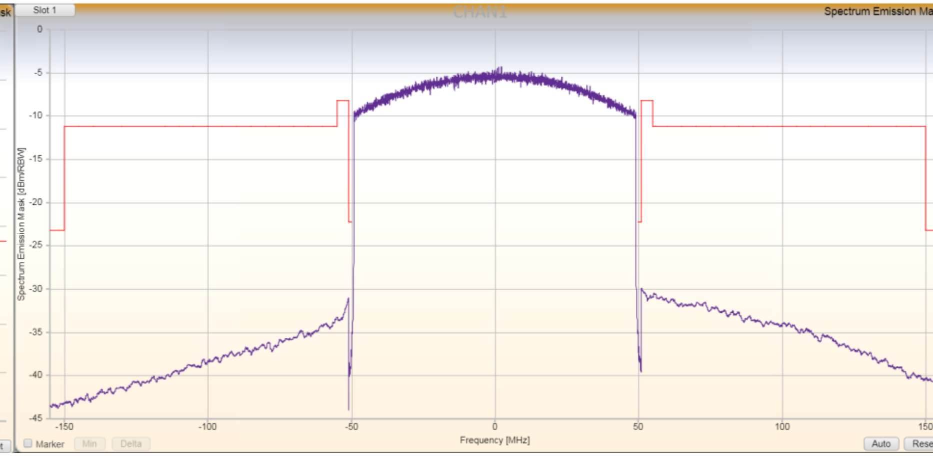
Test Metric	23.45~30.3GHz	30.3~40.8GHz
IFF(DUT ≤ 15cm)	TBD	TBD
IFF(DUT ≤ 30cm)	4.6dB	5.6dB

Spectrum Emission Mask

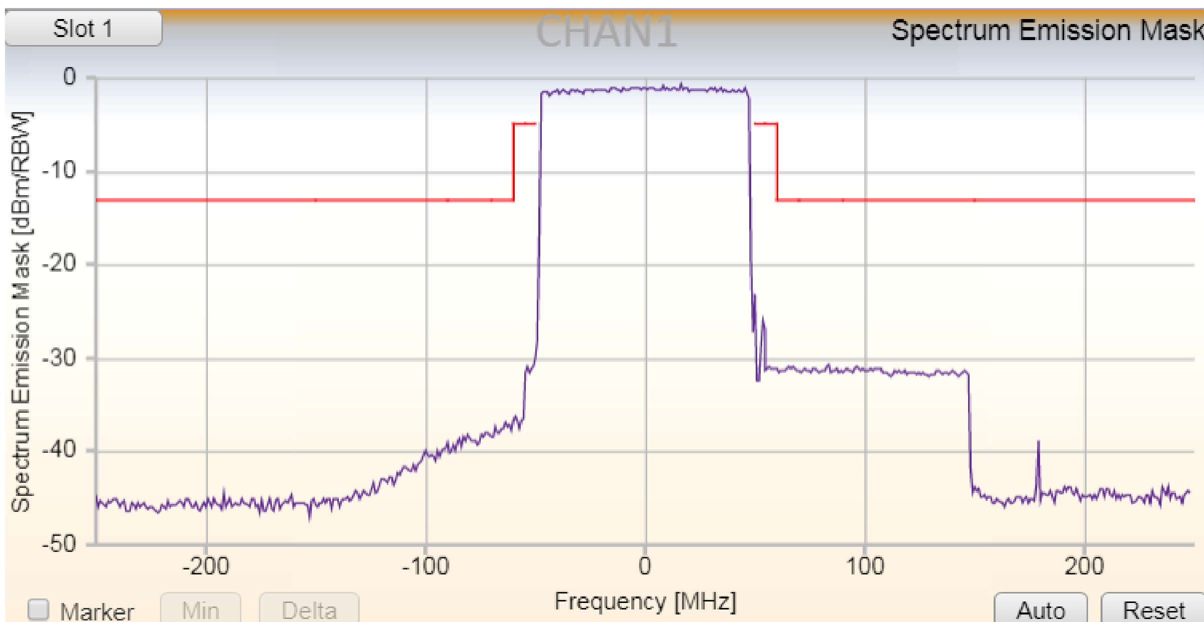
FR1 Edge_1RB_Left



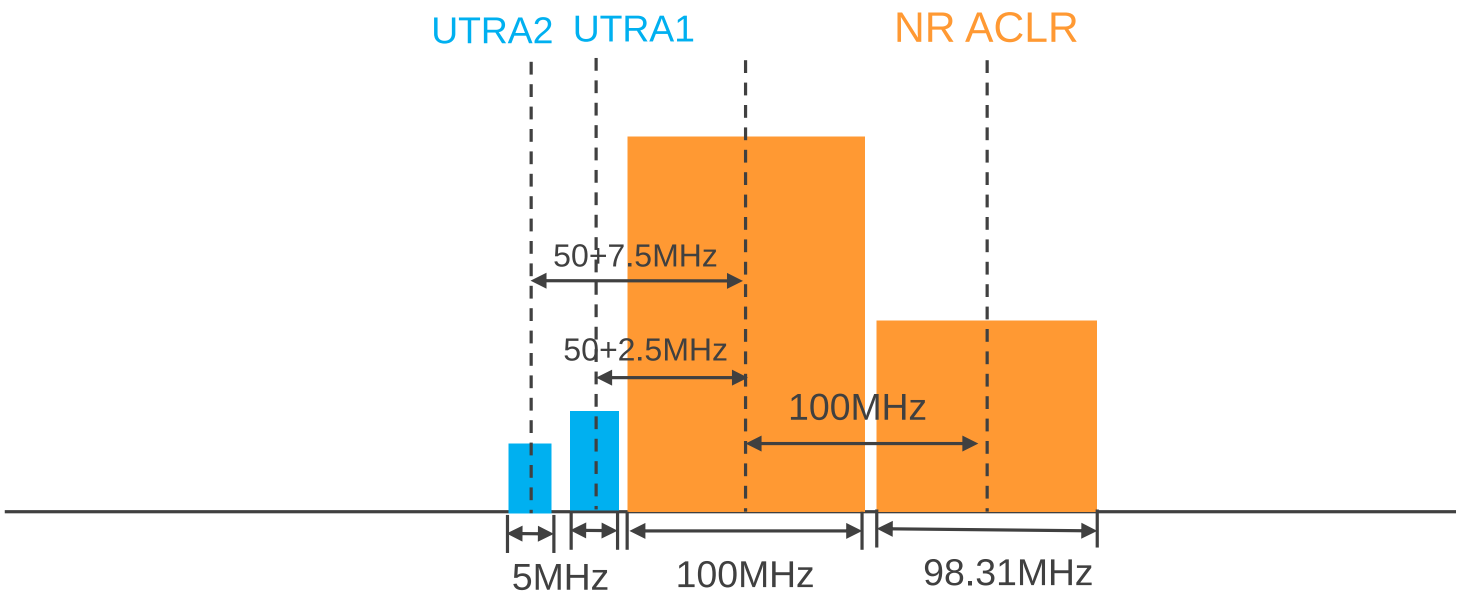
RF1 Outer_Full



FR2 Outer Full



ACLR (Adjacent Channel Leakage Ratio)

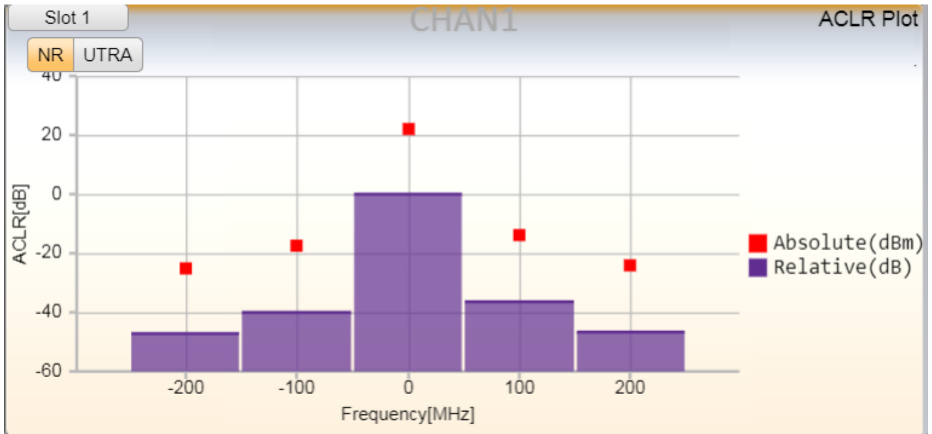


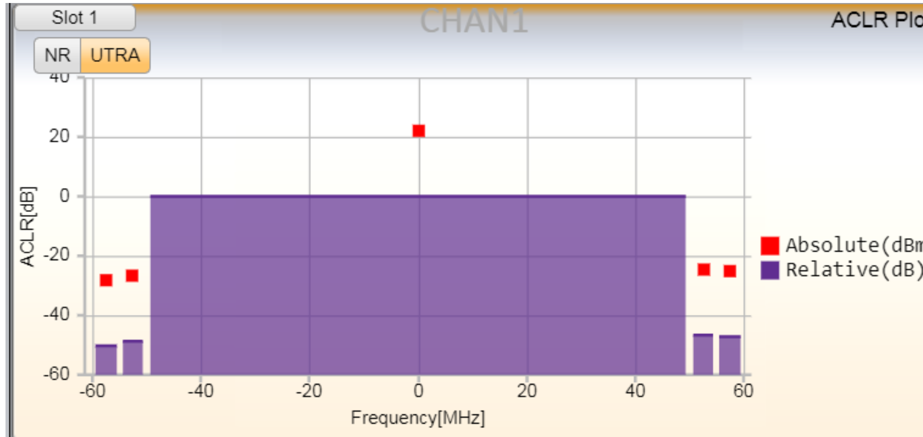
NR ACLR measurement bandwidth

5MHz	10MHz	15MHz	20MHz	25MHz	30MHz	40MHz	50MHz	60Mhz	80MHz	90MHz	100MHz
4.515	9.375	14.235	19.095	23.955	28.815	38.895	48.615	58.35	78.15	88.23	98.31

	Power Class 2	Power Class 3
NR ACLR limit	31+TT dB	30+TT dB
TT=0.8dB for f ≤ 4.0GHz, TT=1.0dB for 4.0GHz < f ≤ 6.0GHz		

ACLR (FR1)





Slot 1 NR UTRA

NR ACLR

ACLR Table

Frequency(MHz)	Relative(dB)	Absolute(dBm)
-200.00	-47.39	-25.26
-100.00	-39.77	-17.63
0.00	0.00	22.14
100.00	-36.17	-14.03
200.00	-46.49	-24.35

Slot 1 NR UTRA

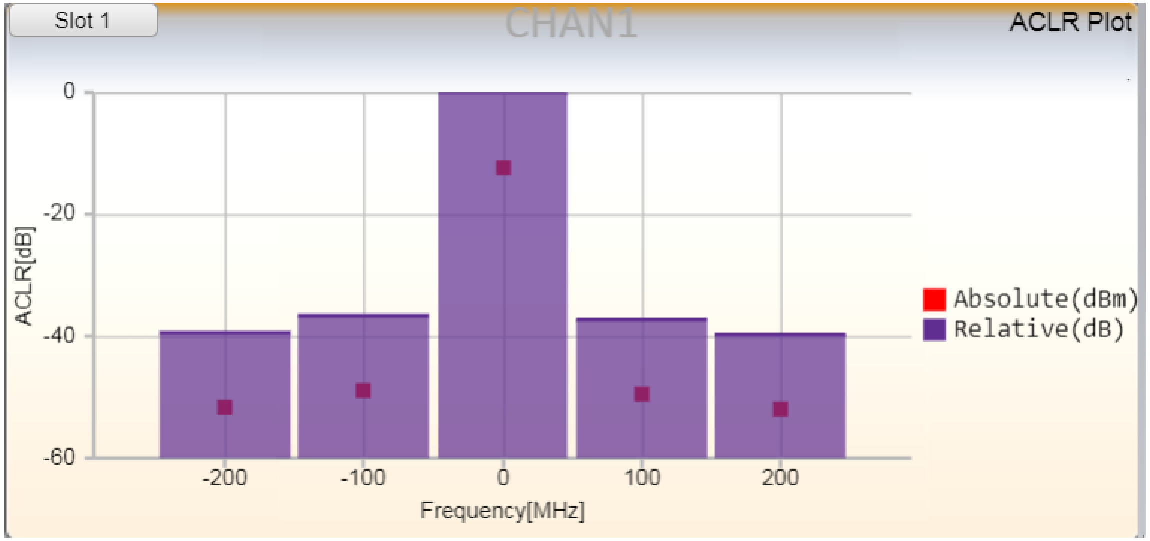
UTRA ACLR

ACLR Table

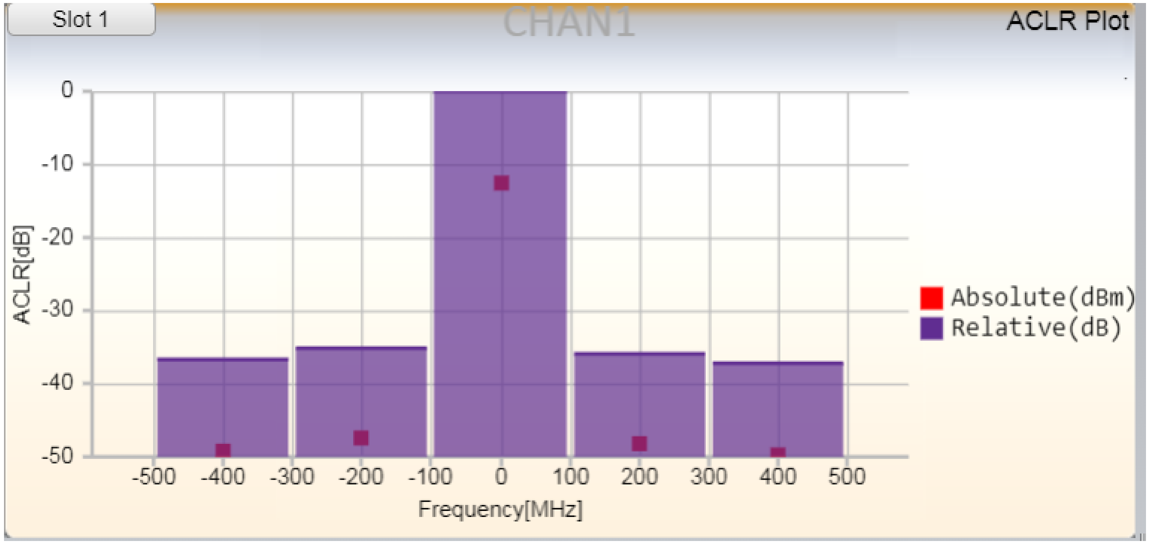
Frequency(MHz)	Relative(dB)	Absolute(dBm)
-57.50	-50.26	-28.12
-52.50	-48.57	-26.43
0.00	0.00	22.14
52.50	-46.71	-24.57
57.50	-47.08	-24.94

ACLR (FR2)

100MHz BW



200MHz BW

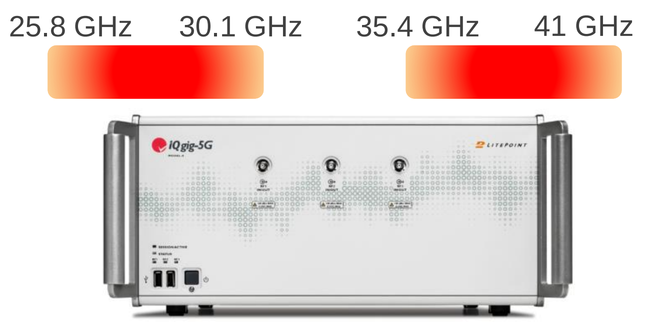


LitePoint 5G Solutions

LitePoint 5G Product Offerings

mmWave RF: IQgig-5G

- Fully-integrated solution for 28 GHz & 39 GHz bands
- Supports Verizon 5G Technical Forum pre-5G and 3GPP NR specification evolution
- Supports 8x100 MHz component carrier channels
- Instrument Bandwidth of 1 GHz



mmWave IF: IQgig-IF

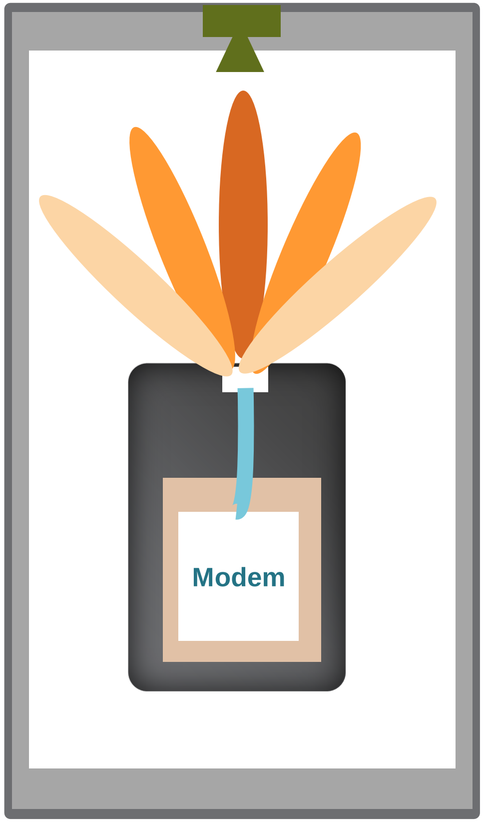
- Supports Verizon 5G pre-5G and 3GPP NR specification evolution
- Supports 8x100 MHz channels
- Instrument Bandwidth of 1.7 GHz

IQxstream-5G: Sub6GHz-5G

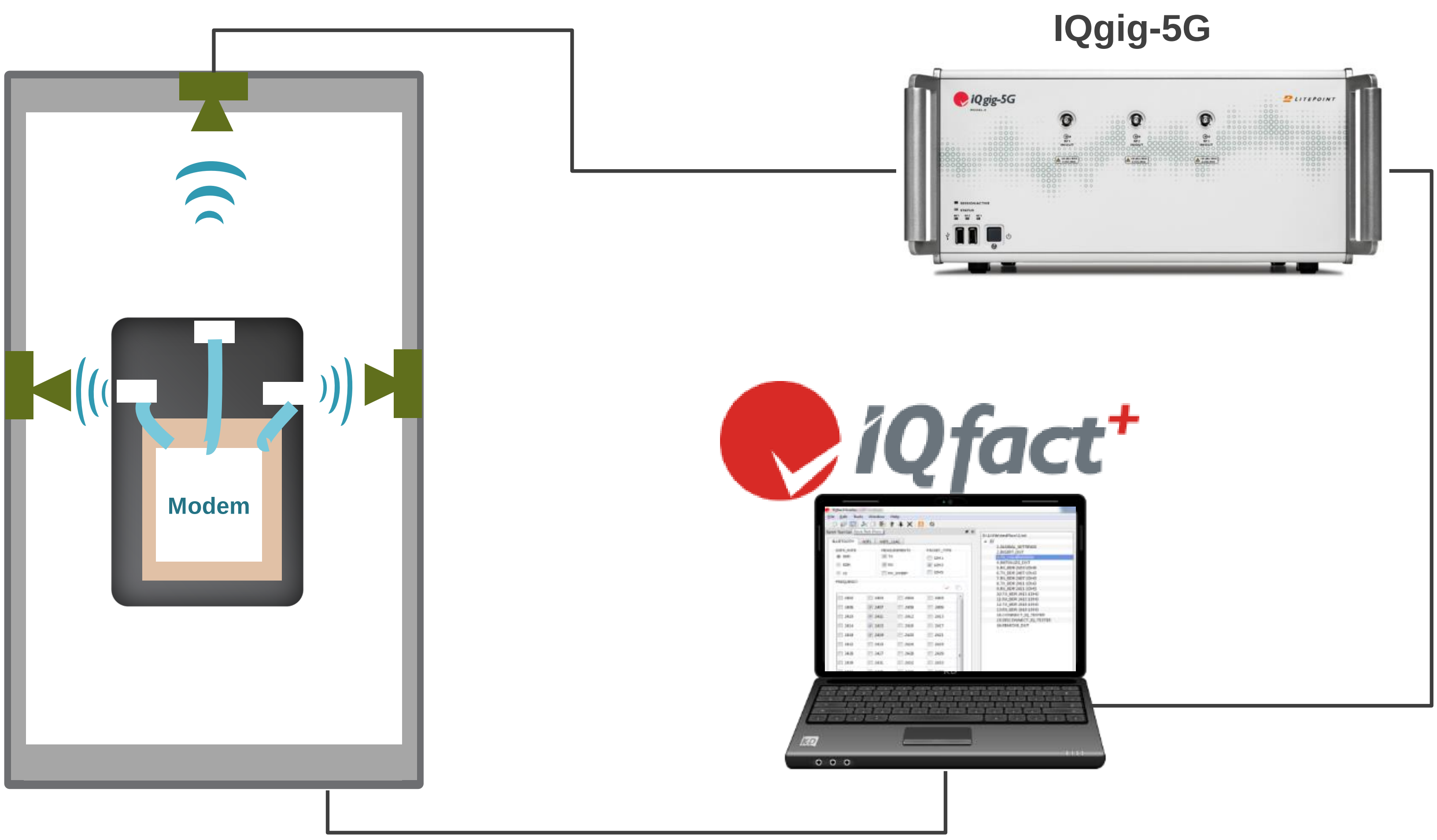
- **200 MHz** Bandwidth
- Supports 5G sub-6GHz spectrum bands: 3.3 – 4.9 GHz
- Supports existing 2G/3G/4G cellular bands
- Supports WiFi 802.11n/ac/ax

mmWave Production Setup

- Step1. Find the specific angle with largest EIRP
- Step2. Use the same angle for mass production
- Step3. Measure the signal for both H and V polarization in each antenna module
- Step4. Check measurement result



Production testing solution (mmWave)



For more information:

- Visit www.litepoint.com
- Read LitePoint's mmWave OTA Test Article Series:
  1. The Road Towards Faster, Simpler, and Smarter Test Equipment for mmWave Products. IEEE Standards e-Magazine, March 21, 2018.
  2. Link-budget calculations: Needed for 5G OTA testing. EDN Magazine, January 22, 2019,
  3. Over-the-Air Testing for 5G mmWave Devices: DFF or CATR? Microwaves and RF Magazine, February 13, 2019
  4. Understanding 5G millimeter wave beamforming test, RF Global Net, Date: April 15, 2019

Thanks!