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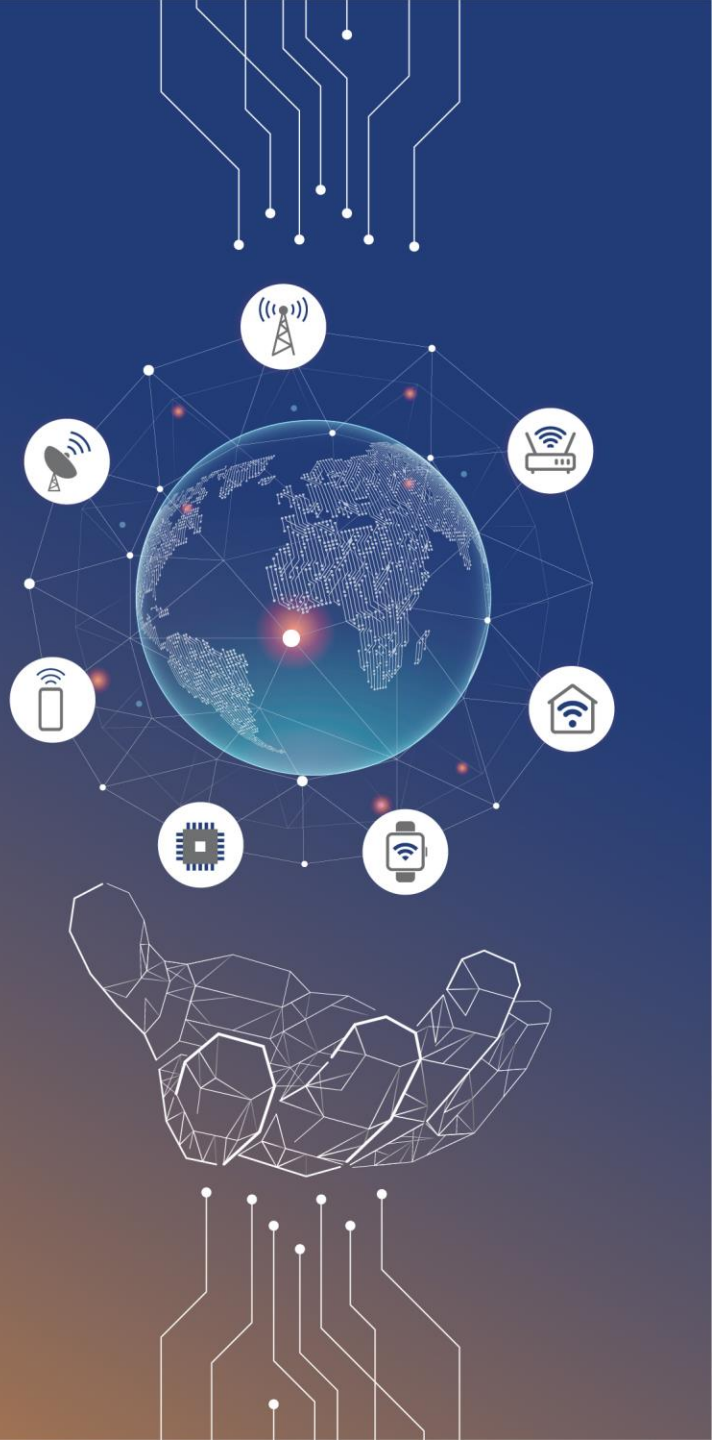
Workshop on

Standards-driven Research @ COMSNETS 2024

7th January 2024

08:45 to 17:30 IST

Chancery Pavilion Hotel,
Residency Road, Bengaluru



Workshop on Standards-driven Research @COMSNETS 2024

Decoding the 5G NR Radio specifications

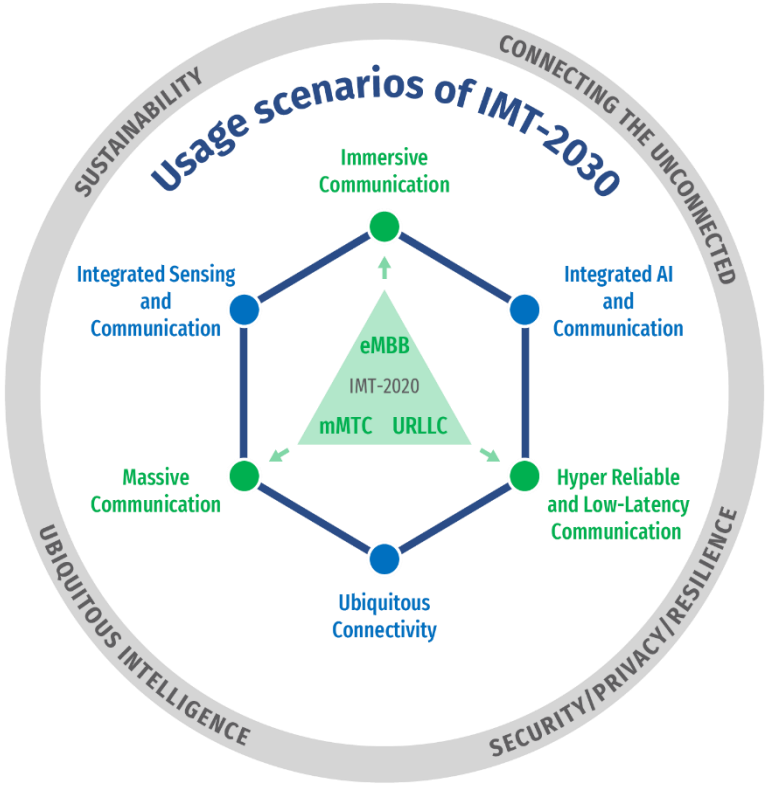
Subhas Mondal

HFCL Limited

The Inspiration

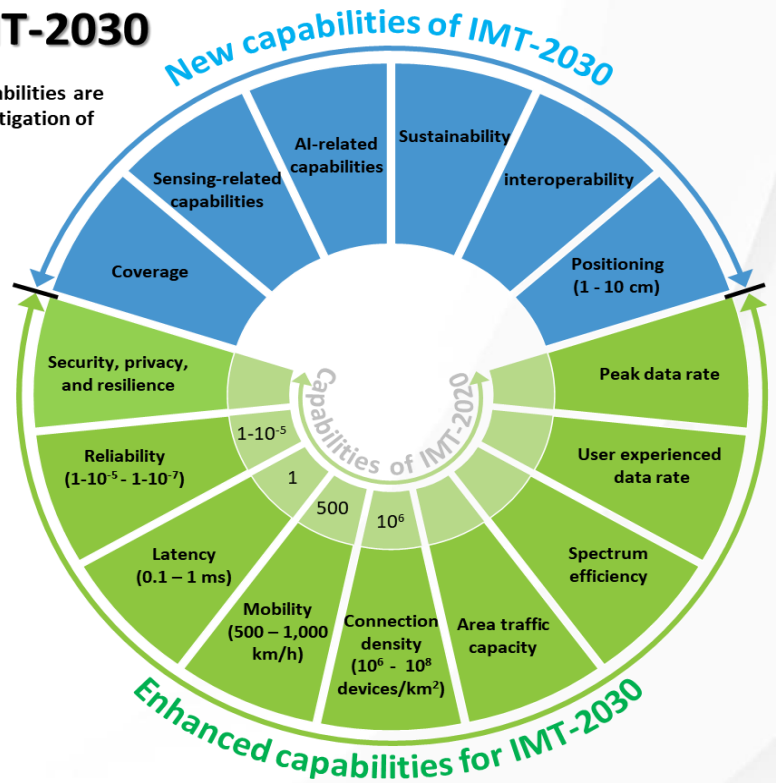
- The goal of building a 3GPP compliant radio product grounds up
- Aspiration to contribute to standards – 6G waveform design
- To find an answer to the question, where to start?

6G capabilities – the goalpost



Capabilities of IMT-2030

NOTE: The range of values given for capabilities are estimated targets for research and investigation of IMT-2030.



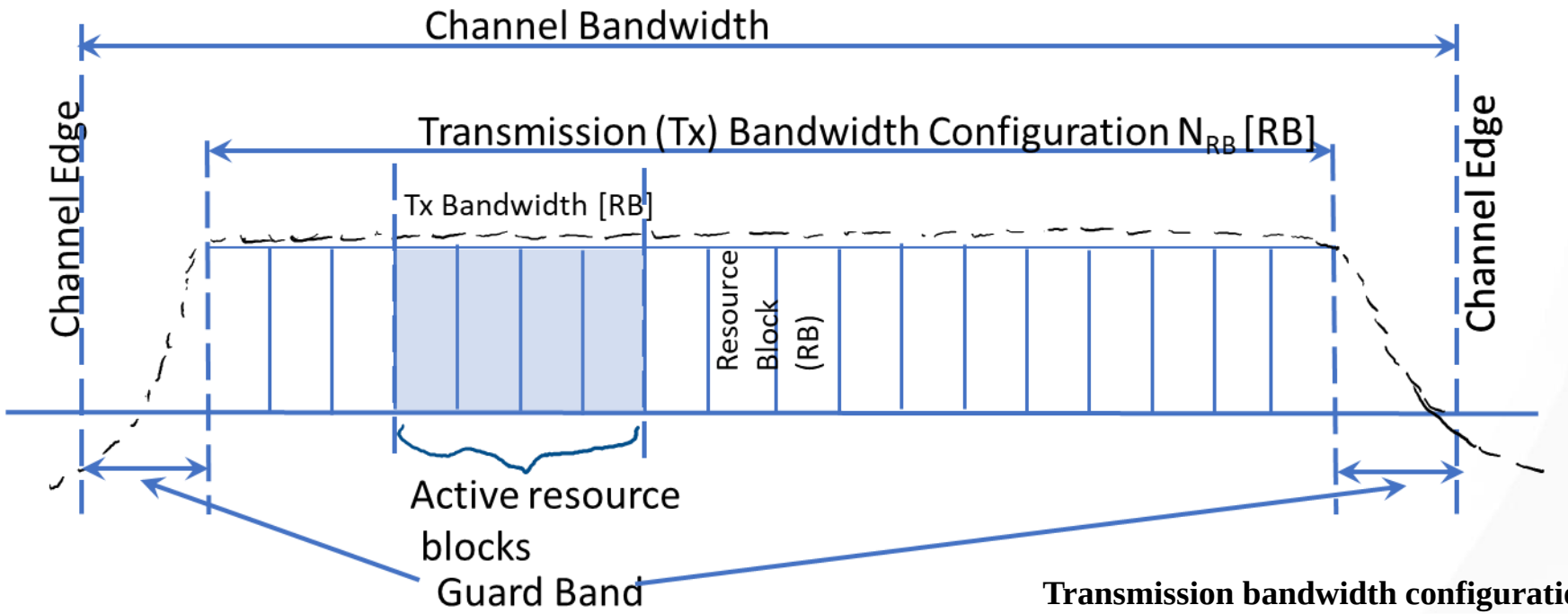
The Transmitter Requirements (38.104)

6.2	Base station output power	
6.3	Output power dynamics	
6.3.2		RE power control dynamic range
6.3.3		Total power dynamic range
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	
6.6.2		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	

The Receiver Requirements (38.104)

7.2	Reference sensitivity level	
7.3	Dynamic range	
7.4	In-band selectivity and blocking	
7.4.1		Adjacent Channel Selectivity (ACS)
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	

5G NR Channel



Example: 5G NR Sub-6 GHz 100 MHz channel

Numerology 1: 30 KHz Sub-carrier spacing; Number of RE per RB = 12,
RB Bandwidth = 12 x 30 = 360 Khz
Number of PRB in the Channel Bandwidth = 273
Transmission Bandwidth Configuration = 273 x 360 = 98.280 MHz
Total Guard band per sides = (100 -98.280)/2 = 1.72/2 = 0.86 MHz

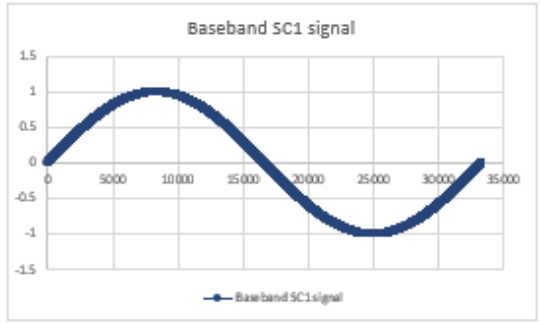
Transmission bandwidth configuration N_{RB} for FR1

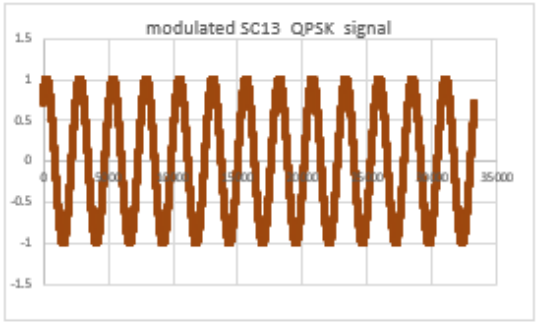
SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}	N_{RB}
15	25	52	79	106	133	160	216	270	N/A	N/A	N/A	N/A	N/A
30	11	24	38	51	65	78	106	133	162	189	217	245	273
60	N/A	11	18	24	31	38	51	65	79	93	107	121	135

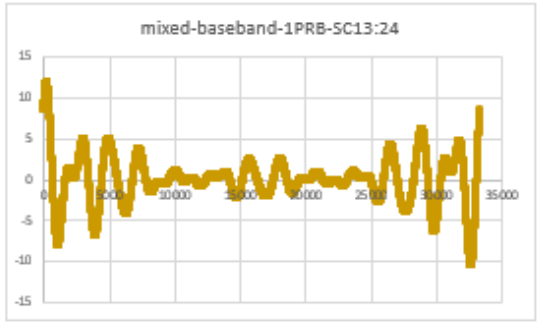
Minimum guardband (kHz) (FR1)

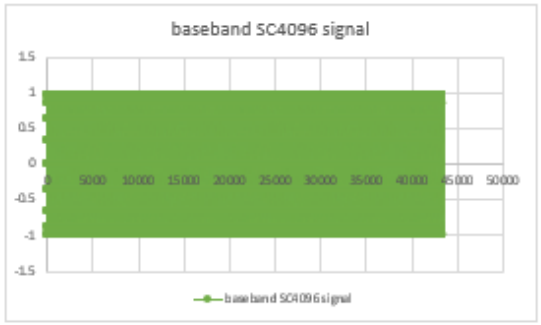
SCS (kHz)	5 MHz	10 MHz	15 MHz	20 MHz	25 MHz	30 MHz	40 MHz	50 MHz	60 MHz	70 MHz	80 MHz	90 MHz	100 MHz
15	242.5	312.5	382.5	452.5	522.5	592.5	552.5	692.5	N/A	N/A	N/A	N/A	N/A
30	505	665	645	805	785	945	905	1045	825	965	925	885	845
60	N/A	1010	990	1330	1310	1290	1610	1570	1530	1490	1450	1410	1370

What's a waveform









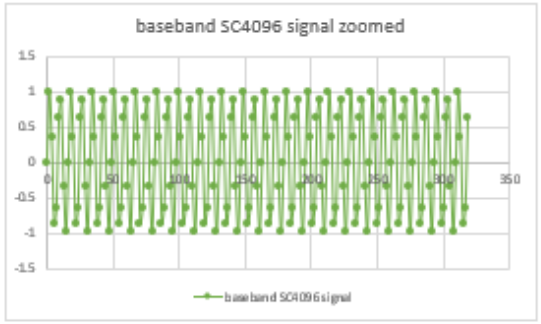
$$g(t) = \int_{-\infty}^{+\infty} G(f)\, e^{i2\pi ft}\, df$$

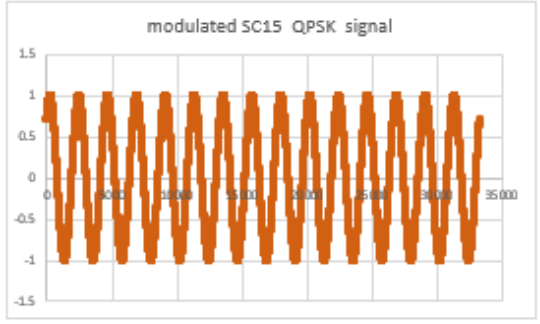
$$G(f) = \int_{-T_0/2}^{+T_0/2} g(t)\, e^{-i2\pi ft}\, dt$$

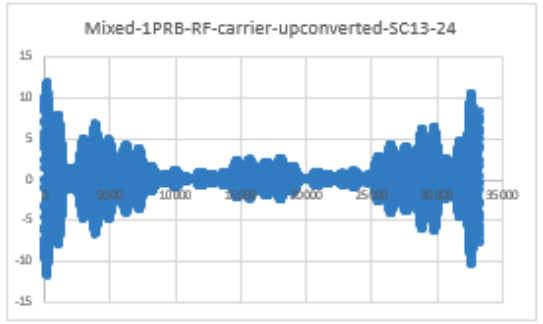
$$y_n(t) = \int_{-\pi}^{+\pi} \cos(m\omega t) * \cos(n\,\omega t)\, dt,\ \text{m,n} = 1, 2, 3\ldots N$$

= 0 for all m ≠ n

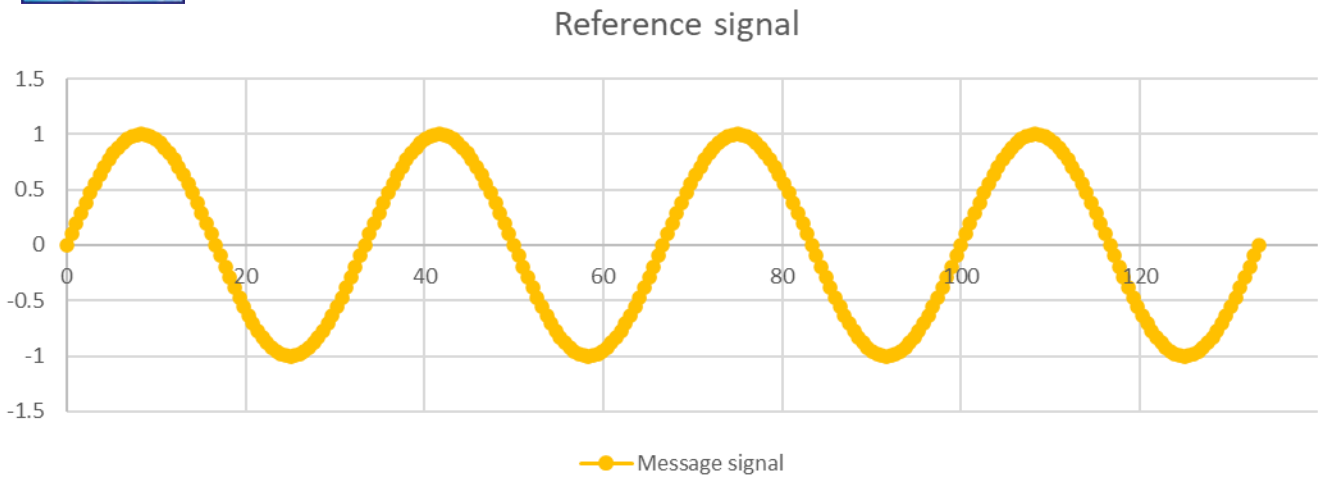
= 1 for all m = n



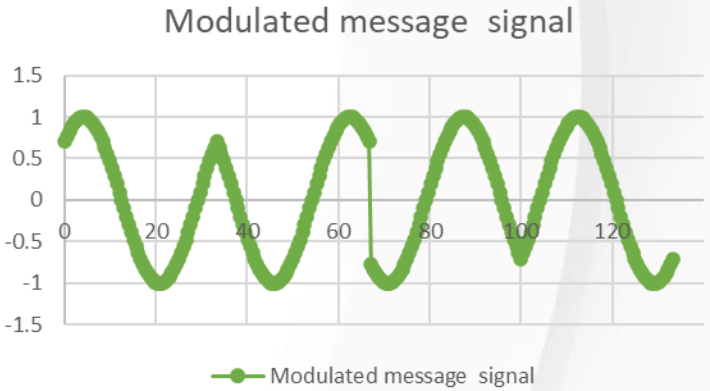


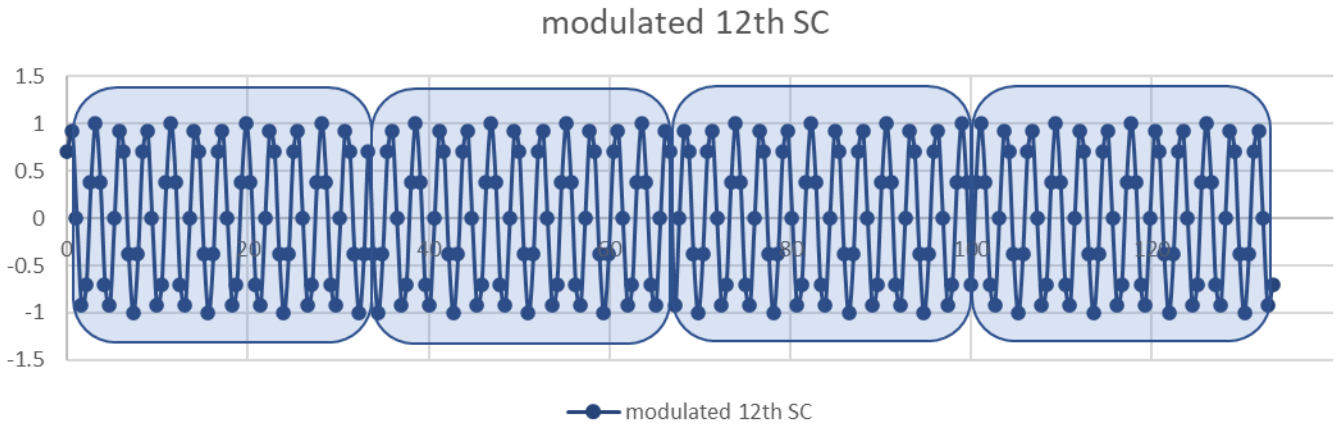


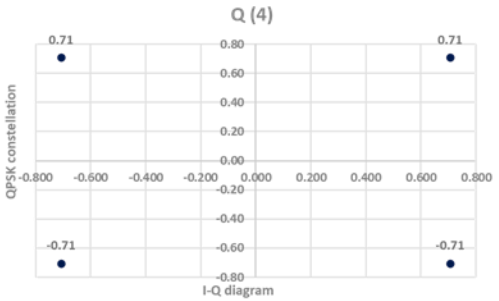
Modulated signal – basis of a NR waveform

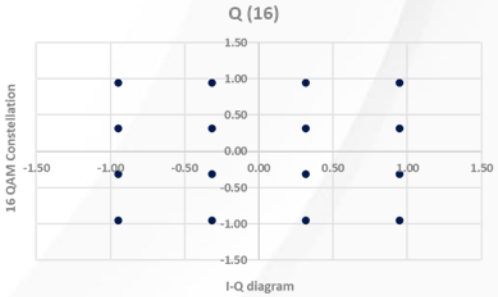


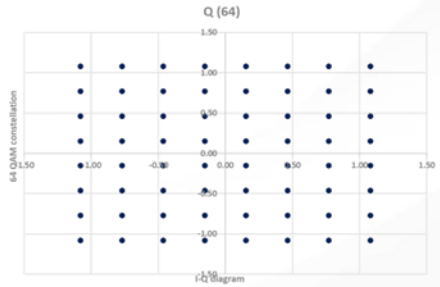
		QPSK		
LSB b(1)	MSB b(0)		I	Q (4)
0	0	0	0.707	0.71
1	0	1	0.71	-0.71
0	1	3	-0.71	0.71
1	1	2	-0.71	-0.71

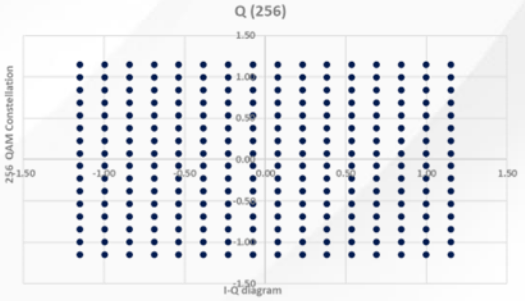




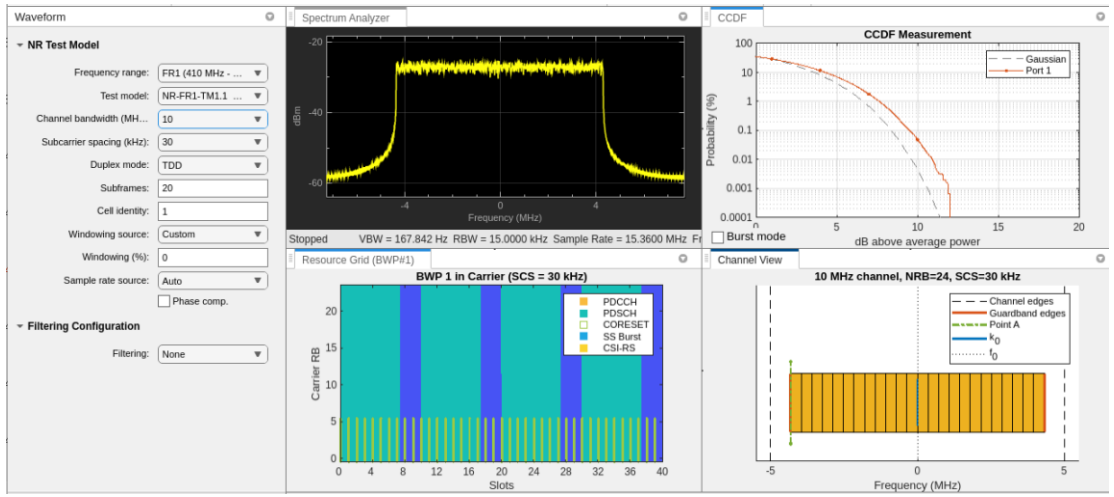


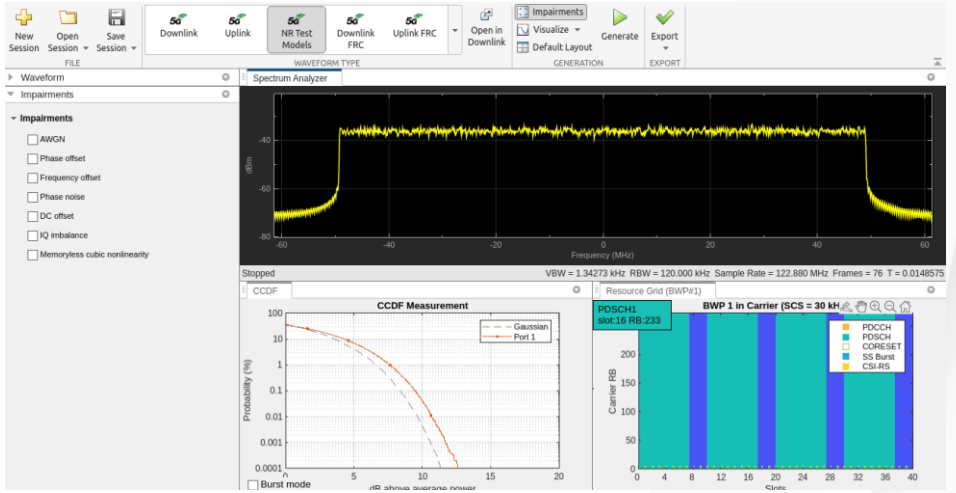


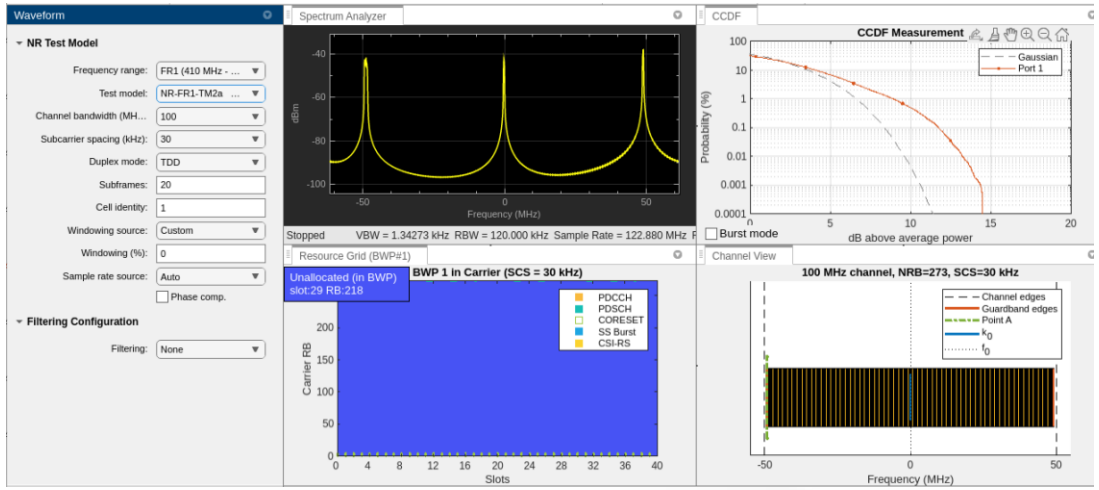


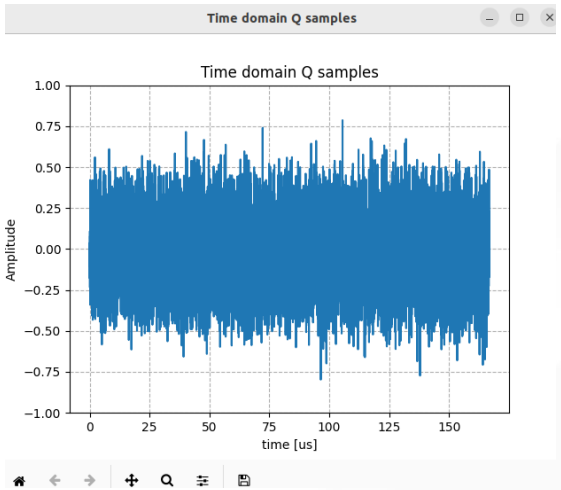


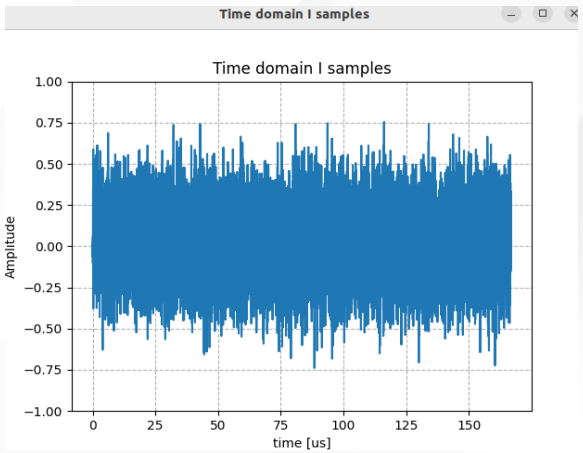
Reference test waveform



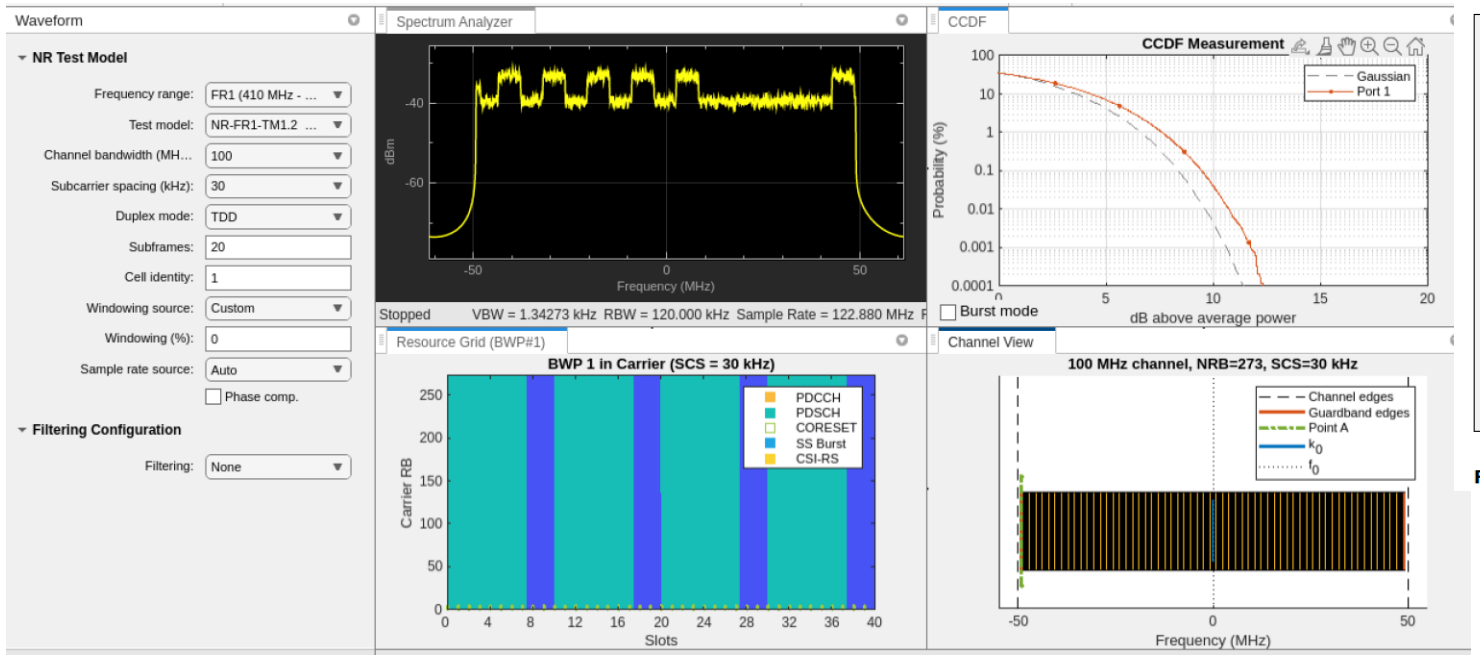








Energy of the waveform – power scaling



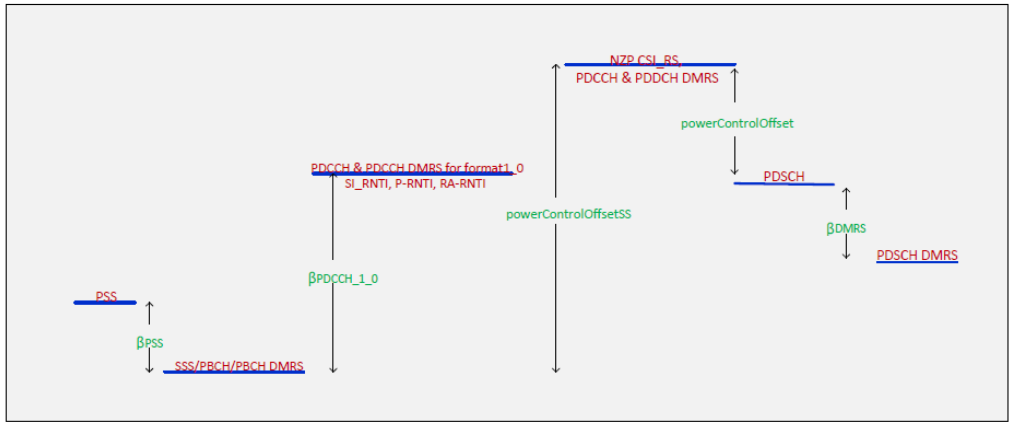


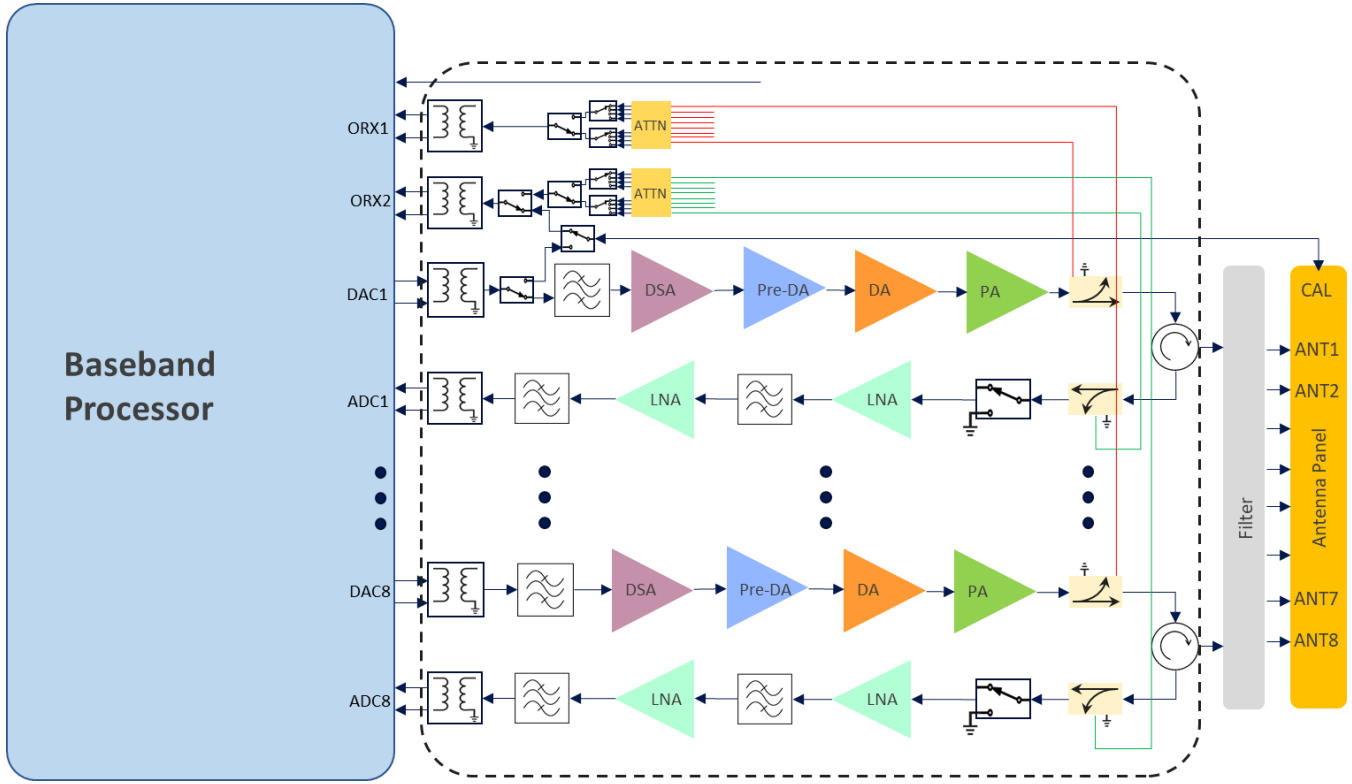
Figure 2-31 ProfileNR: Transmit power levels

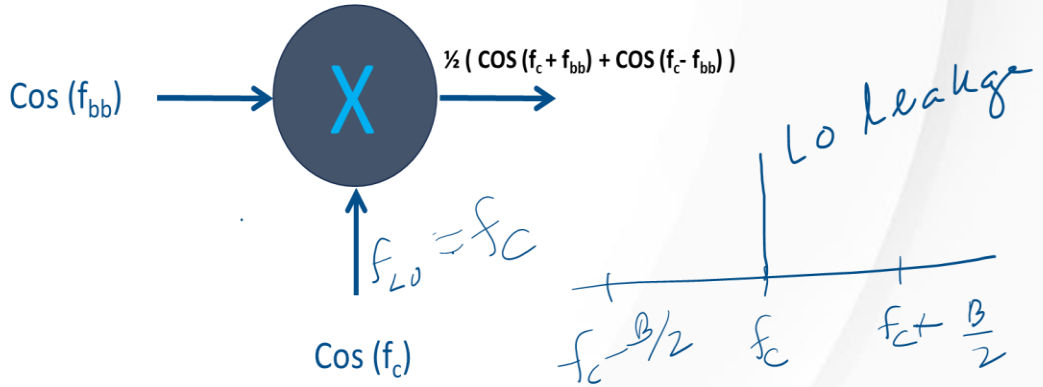
EPRE – Energy per resource element

Challenges with signal conversion

COS (A) * COS (B) = ½ (COS (A+B) + COS (A-B))

$LO = fc$ = carrier freq. Baseband BW = B, Baseband freq f_{bb} ranges from –B/2 to +B/2, in steps of Subcarrier Spacing





Challenges with signal quality assurance

Frequency error minimum requirement

BS class	Accuracy
Wide Area BS	±(0.05 ppm + 12 Hz)
Medium Range BS	±(0.1 ppm + 12 Hz)
Local Area BS	±(0.1 ppm + 12 Hz)

EVM requirements

Modulation scheme for PDSCH	Required EVM
QPSK	17.5 %
16QAM	12.5 %
64QAM	8 %
256QAM	3.5 %

TAE minimum requirement

For MIMO transmission, at each carrier frequency, TAE shall not exceed 65 ns.

For *intra-band contiguous carrier aggregation*, with or without MIMO, TAE shall not exceed 260ns.

For *intra-band non-contiguous carrier aggregation*, with or without MIMO, TAE shall not exceed 3µs.

For inter-band *carrier aggregation*, with or without MIMO, TAE shall not exceed 3µs.

Managing the unwanted emission

- The out-of-band emissions requirement for the BS transmitter is specified both in terms of Adjacent Channel Leakage power Ratio (ACLR) and *operating band* unwanted emissions (OBUE).

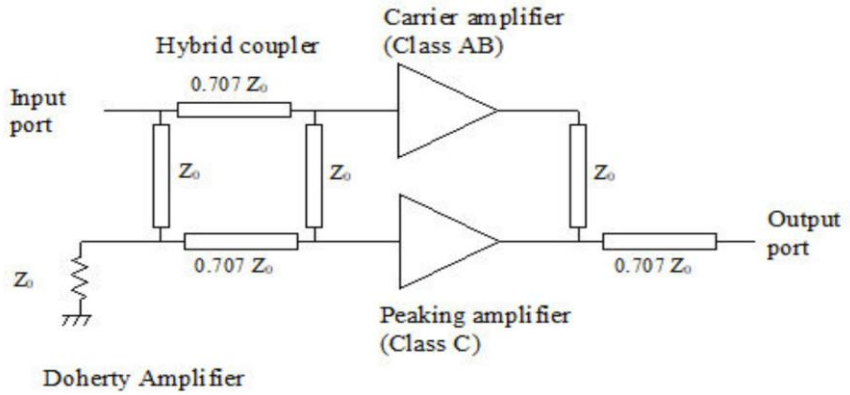
Base station ACLR limit

BS channel bandwidth of lowest/highest carrier transmitted $BW_{Channel}$ (MHz)	BS adjacent channel centre frequency offset below the lowest or above the highest carrier centre frequency transmitted	Assumed adjacent channel carrier (informative)	Filter on the adjacent channel frequency and corresponding filter bandwidth	ACLR limit
5, 10, 15, 20, 25, 30, 40, 50, 60, 70, 80, 90,100	$BW_{Channel}$	NR of same BW (Note 2)	Square (BW_{Config})	45 dB
	2 x $BW_{Channel}$	NR of same BW (Note 2)	Square (BW_{Config})	45 dB
	$BW_{Channel}$ /2 + 2.5 MHz	5 MHz E-UTRA	Square (4.5 MHz)	45 dB (Note 3)
	$BW_{Channel}$ /2 + 7.5 MHz	5 MHz E-UTRA	Square (4.5 MHz)	45 dB (Note 3)

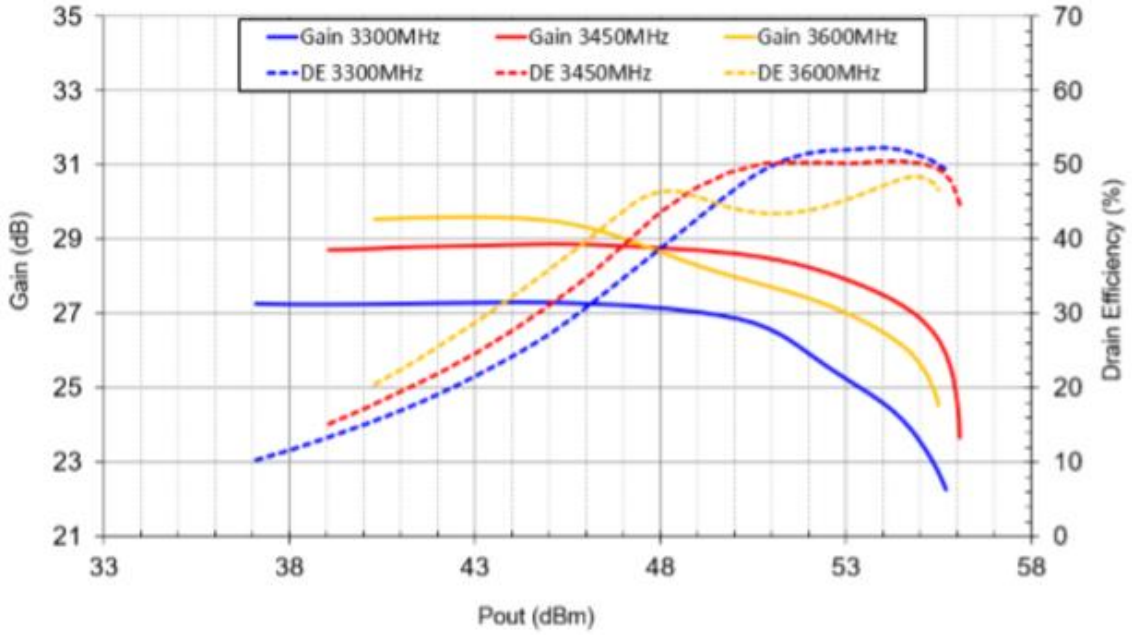
Base station ACLR absolute *basic limit*

BS category / BS class	ACLR absolute basic limit
Category A Wide Area BS	-13 dBm/MHz
Category B Wide Area BS	-15 dBm/MHz
Medium Range BS	-25 dBm/MHz
Local Area BS	-32 dBm/MHz

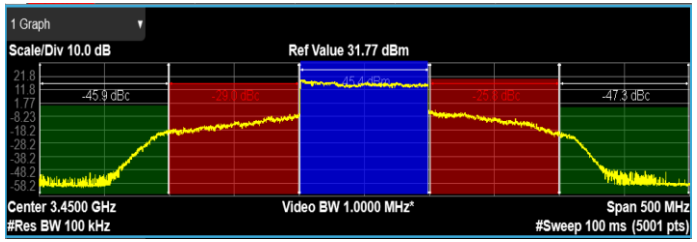
Managing the unwanted emission



Doherty Amplifier

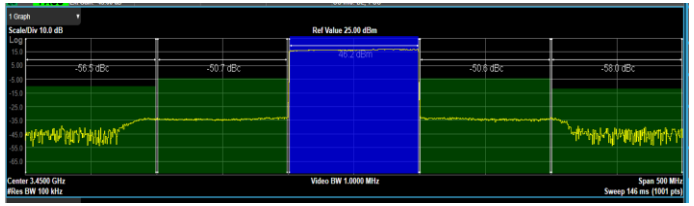


Uncorrected ACLR



- CFR : Set PAPR = 8 dB
- DPD: Reduce ACLR to better than 45 dB

Corrected ACLR



- Average output power = 46 dBm = 40 Watts
- Loss after PA = 2 dB
- PAPR = 8 dB
- Peak power = 56 dBm = 398 watts
- PA efficiency is higher at higher output powers

Summary

- Development of a waveform involves multi-dimensional aspects like spectral efficiency, spectrum mask, signal quality, emission cleanliness, energy efficiency, synchronization, coverage, capacity, latency, reliability, implement-ability etc.
- Consensus building mechanism in 3GPP standardization process ensures a robust technology evaluation process supported by global technology research work undertaken by diverse organizations.
- Decoding the existing 5G technology standards paves a way for deeper understanding, leading to new ideas beyond existing generation of technology.

References

TS 38.104	NR; Base Station (BS) radio transmission and reception
TS 38.141-1	NR; Base Station (BS) conformance testing Part 1: Conducted conformance testing
TS 38.141-2	NR; Base Station (BS) conformance testing Part 2: Radiated conformance testing
TS 38.101-1	NR; User Equipment (UE) radio transmission and reception; Part 1: Range 1 Standalone
TS 38.101-2	NR; User Equipment (UE) radio transmission and reception; Part 2: Range 2 Standalone
TS 38.306	NR; User Equipment (UE) radio access capabilities
TS 38.211	NR; Physical channels and modulation
TS 38.212	NR; Multiplexing and channel coding
TS 38.213	NR; Physical layer procedures for control
TS 38.214	NR; Physical layer procedures for data
TS 38.215	NR; Physical layer measurements

Thank You

Subhas.mondal@hfcl.com
https://www.linkedin.com/in/subhas-mondal-19027a1/