6G SPECTRUM AND WAVEFORMS: ENABLING THE NEXT GENERATION OF WIRELESS

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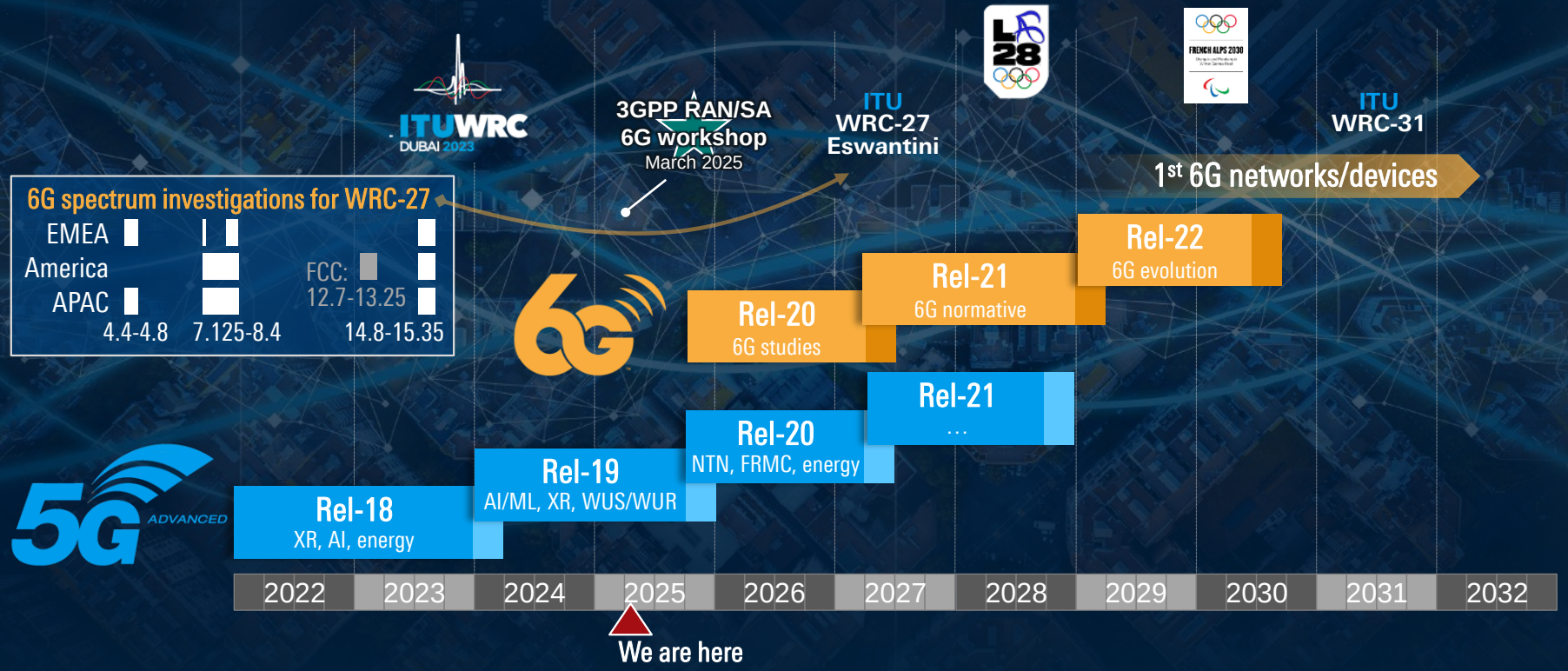
ROHDE&SCHWARZ
Make ideas real

Agenda

- Introduction
- 6G spectrum and waveforms including live demonstrations
- Conclusions

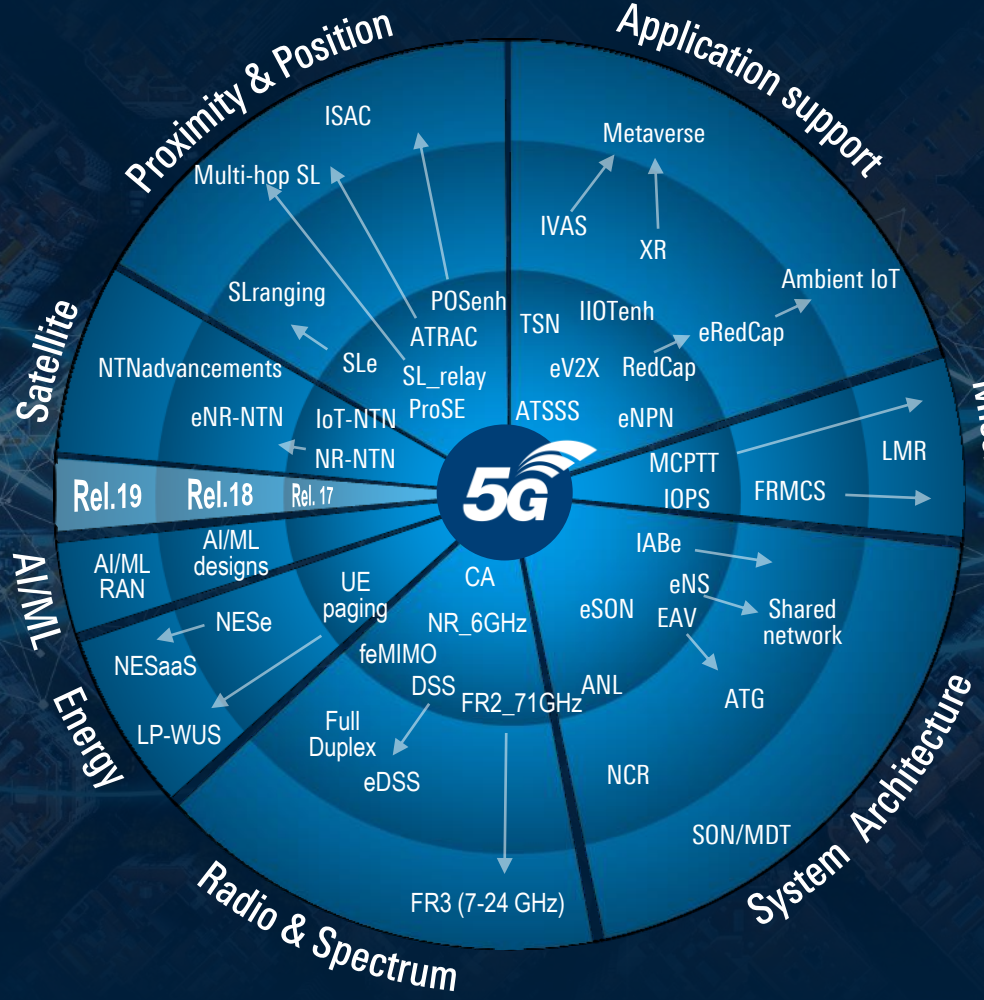
3GPP standardization and regulation

On the way towards planned 6G launch in 2030



5G ADVANCED → 6G

ATG	Air to ground network
ATRAC	Asset Tracking
ATSSS	Access Traffic Steering Switching-Splitting
ANL	Autonomous Network Level
CA	Carrier Aggregation
DSS	Dynamic spectrum sharing
EAV	enhanced UAV
FRMCS	Future Railway mission-critical
IAB	Integrated access /backhaul
IIOT	Industrial IoT
IOPS	Isolated operation f. Public safety
ISAC	Integrated Sensing and Communication
IVAS	Immersive Voice and Audio Services
LMR	Land mobile radio
MCX	Mission critical
MDT	Minimization of Drive Tests
NCR	Network controlled repeater
NES	Network Energy Saving
NESaaS	NES as a Service
NPN	non public network
NS	network slicing
NTN	non-terrestrial networks
POS	Positioning
ProSe	Proximity Services
RedCap	Reduced capability
SL	Side link
SON	Self-organized networks
TSN	Time sensitive networks
V2x	vehicle to everything
WUS	Wake up signal
XR	Extended reality

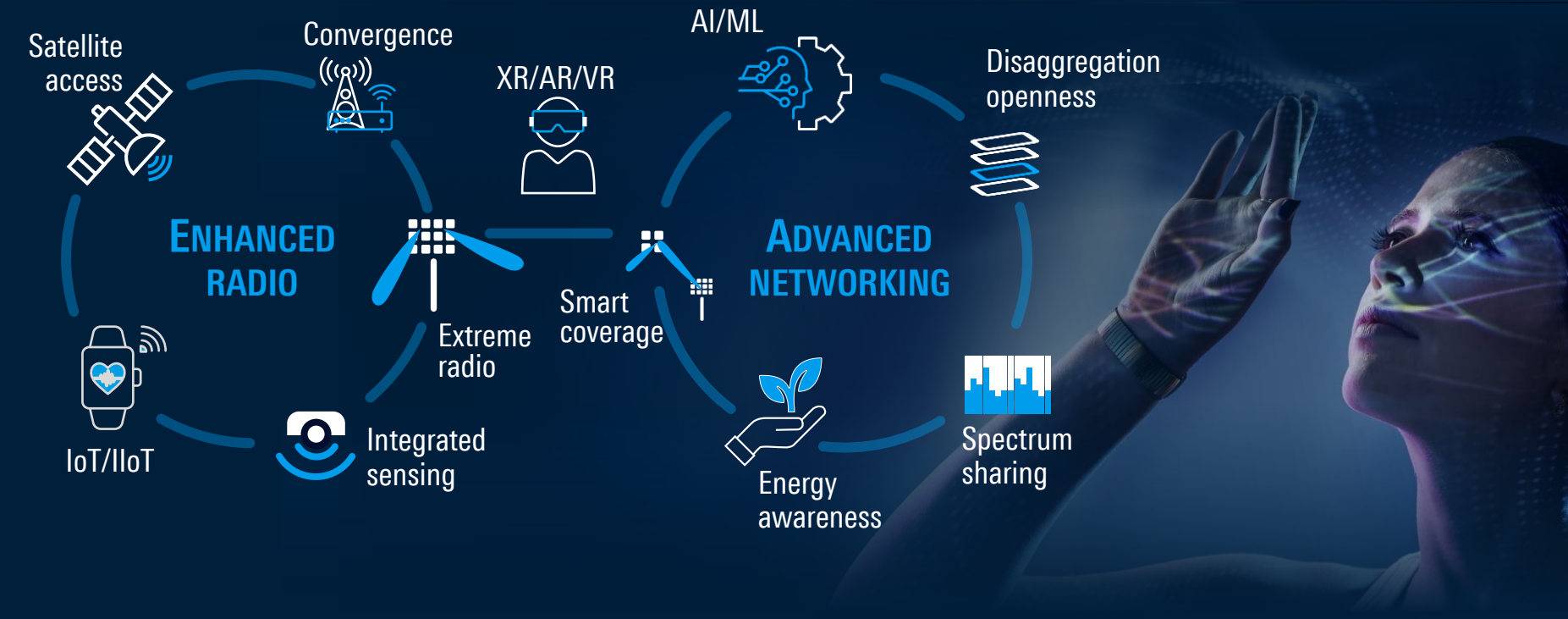


THE CONTINUOUS WORK OF 3GPP IS DRIVING THE EVOLUTION OF 5G NR TOWARDS 6G

Rohde & Schwarz

Heading towards the future of wireless communication

Technology cornerstones

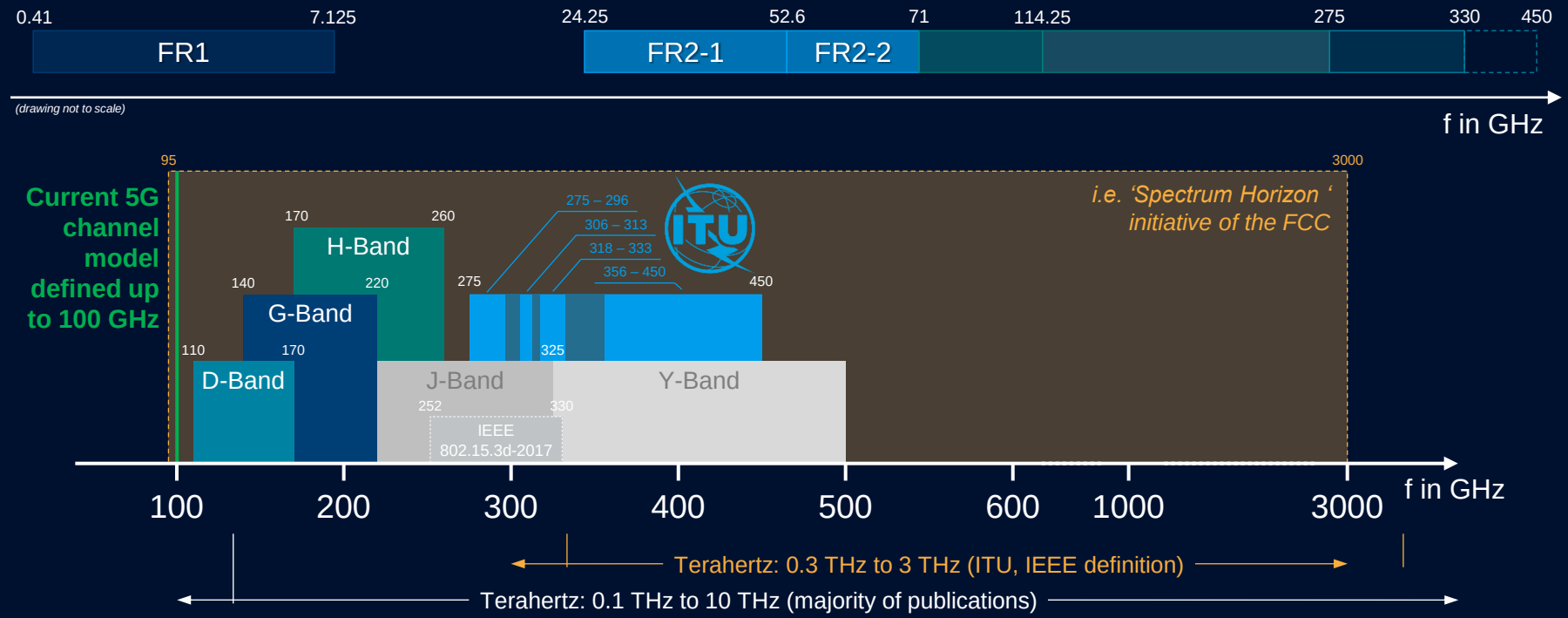


Technology components

A high-level overview of all these research areas is provided in one of our #THINKSIX videos

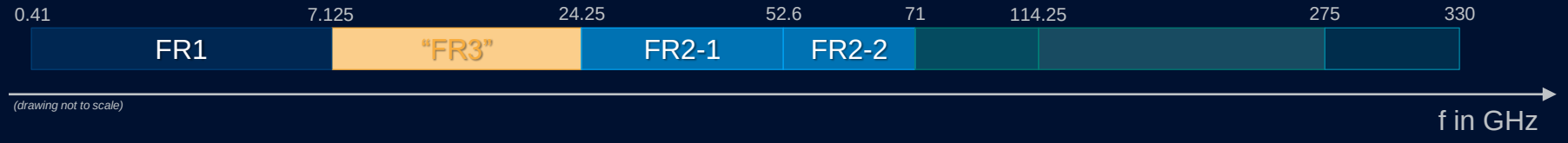
6G will deliver ultra-fast data connections

(sub)-THz was initially of interest and is still researched …



… but the commercial 6G spectrum interest is cm-wave

Focus is on upper mid-band ~ 6 GHz to 15 GHz



- 6.1.6 Potential Spectrum bands for study
  - 6.1.6.1 UHF Band
    - 6.1.6.1.1 1300-1350 MHz
    - 6.1.6.1.2 1780-1850 MHz
  - 6.1.6.2 Lower-cmW spectrum
    - 6.1.6.2.1 3100-3450 MHz
    - 6.1.6.2.2 3980-4180 MHz (TBD)
    - 6.1.6.2.3 4400-4940 MHz
    - 6.1.6.2.4 7125-8500 MHz
  - 6.1.6.3 Upper-cmW spectrum
    - 6.1.6.3.1 10-10.5 GHz
    - 6.1.6.3.2 10.7-12.2
    - 6.1.6.3.3 12.2 – 12.7 GHz
    - 6.1.6.3.4 12.7-13.75 GHz
    - 6.1.6.3.5 13.75-15 GHz
  - 6.1.6.4 EHF Band
    - 6.1.6.4.1 37.0-37.6 GHz
    - 6.1.6.4.2 42-43.5 (TBD)
    - 6.1.6.4.3 92-114.25 GHz (W-band) and 122.25-174.8 GHz (D-band):

Source: NEXT G ALLIANCE Spectrum Working Group

6G cmWave performance

ERICSSON

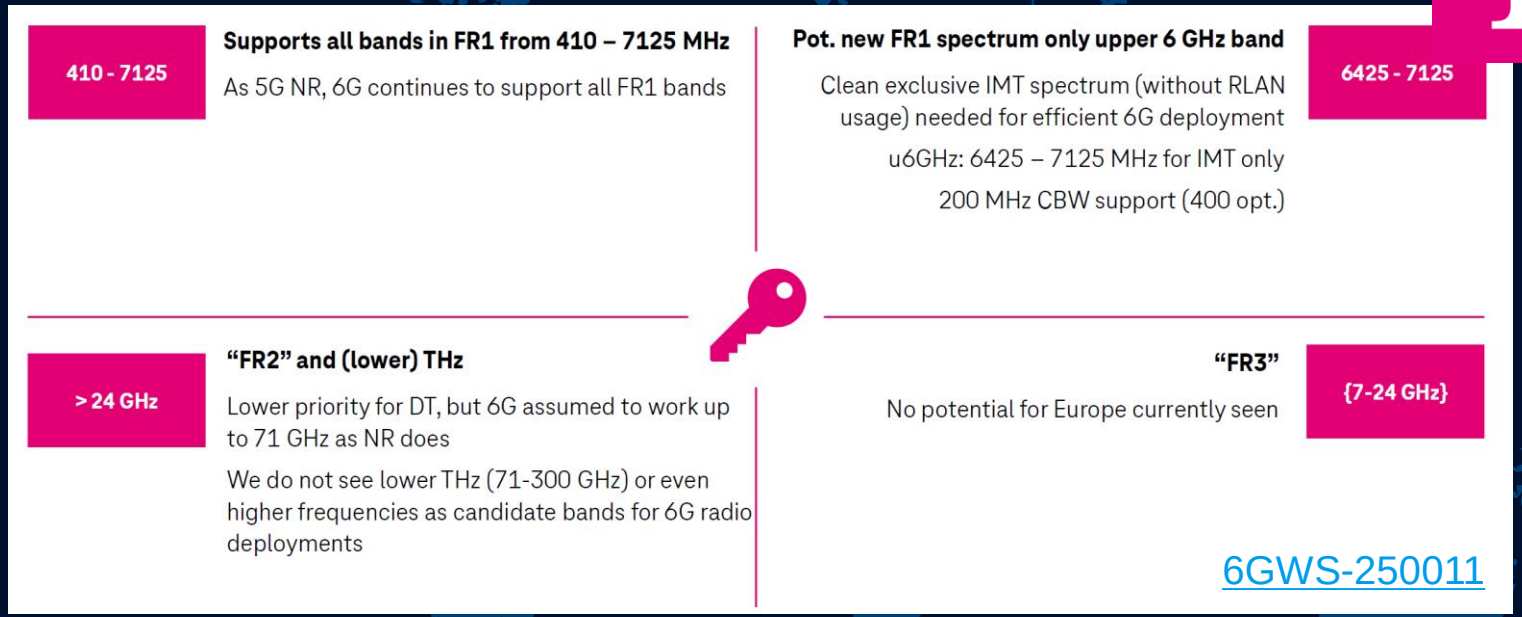
This MWC demo used a highly accurate digital model of Dubai, the location for the recent World Radiocommunication Conference (WRC-23), to show how the coverage compares between 3.5GHz, 7GHz, and 14GHz. The basic conclusion is that 7-8GHz is very interesting spectrum that can come quite close to matching the DL coverage of 3.5GHz. This means that re-use of the existing grid becomes a more likely possibility and this needs to be further explored.

Laying the groundwork for new spectrum

Qualcomm

Securing spectrum for 6G is a decade-long journey that is already underway. Frequencies between 6 GHz and 15 GHz — known as the upper mid-band — have been identified as prime candidates for 6G use. The International Telecommunication Union (ITU)'s World Radiocommunication Conference 2023 (WRC-23) have initiated studies to identify bands within this range for 5G Advanced and 6G. For instance, one of the most impactful agenda items for WRC-27 involves the identification of several frequency bands, including 4.4-4.8 GHz, 7.125-8.4 GHz and 14.8-15.35 GHz, for potential International Mobile Telecommunications (IMT) use. In addition, many countries throughout the world are planning to deploy IMT services in the upper 6 GHz band (6.425-7.125 GHz).

Operators view on 6G spectrum
Some examples



Operators view on 6G spectrum
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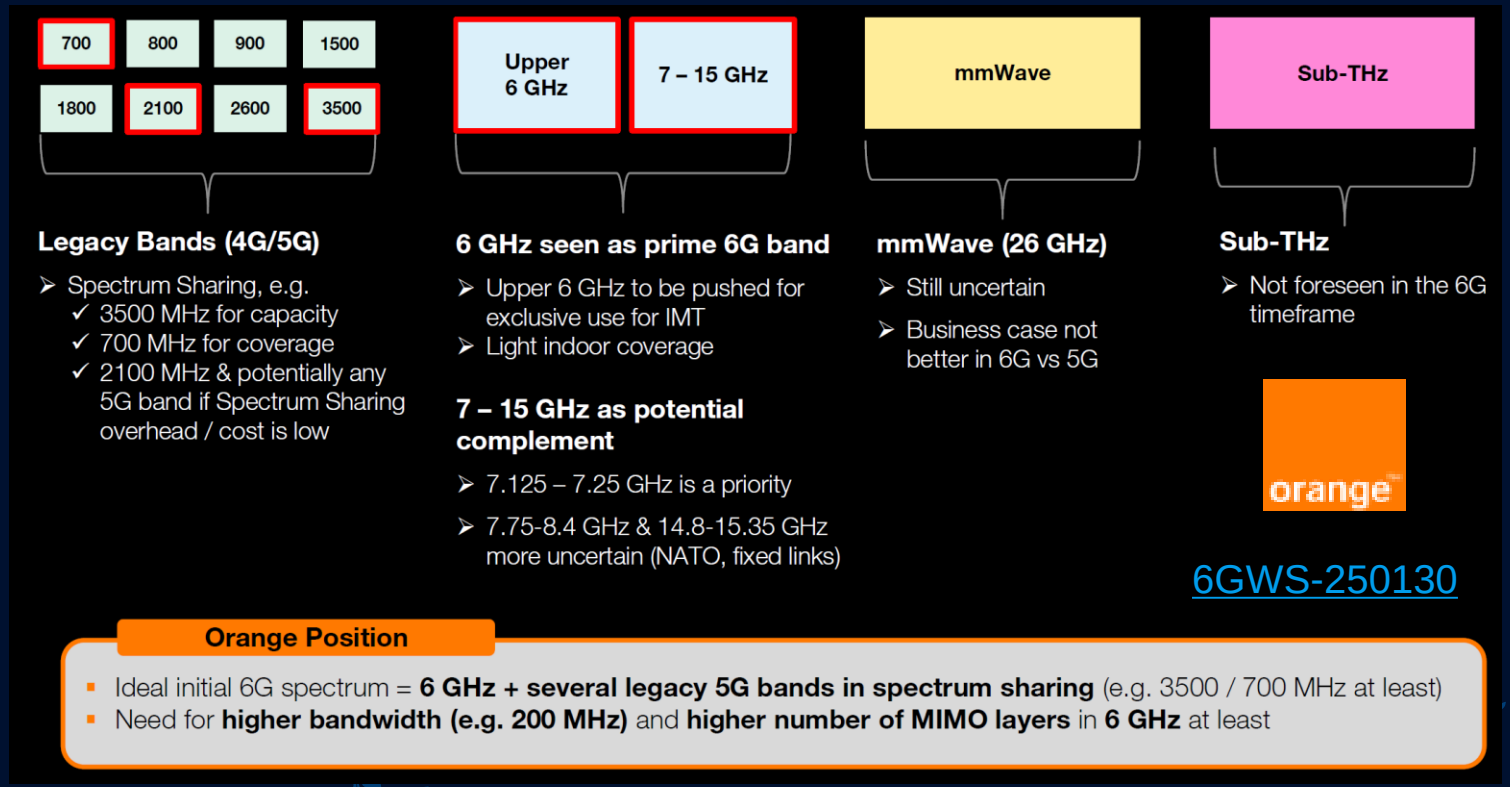
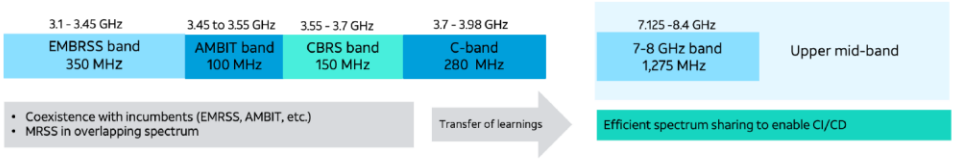


Operators view on 6G spectrum
Some examples

Agility of software on a stable, scalable, “generation-free” network that integrates new hardware driven by needs



6GWS-250078

4

AT&T

6GWS-250143

中国移动 China Mobile

1 Higher Frequency

2.6/3.5GHz → 6-7GHz

Upper mid-band (7.125-8.4GHz) to be prioritized for 6G RAN specification developments

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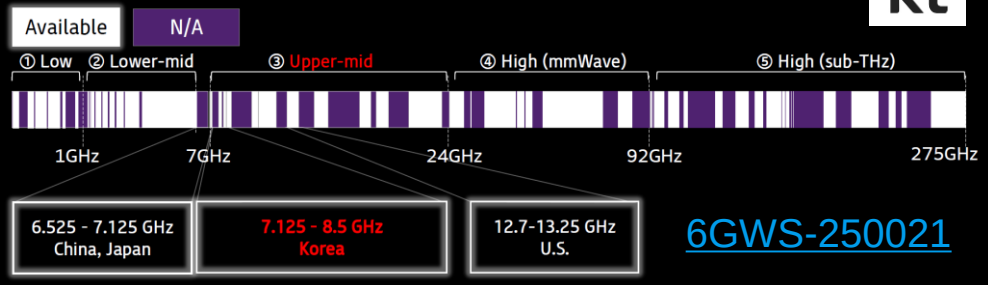
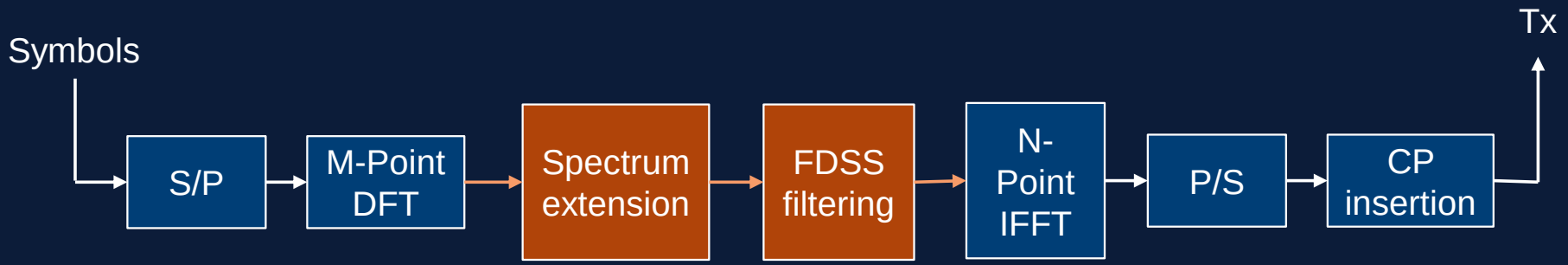
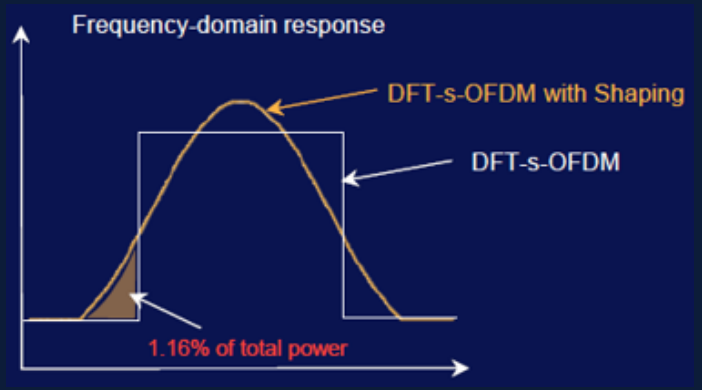
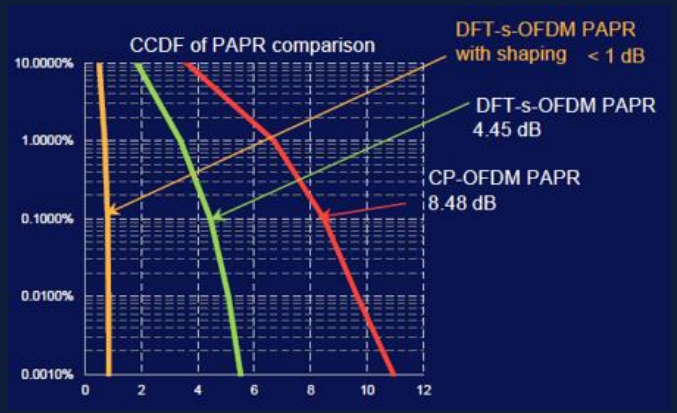


6GWS-250021

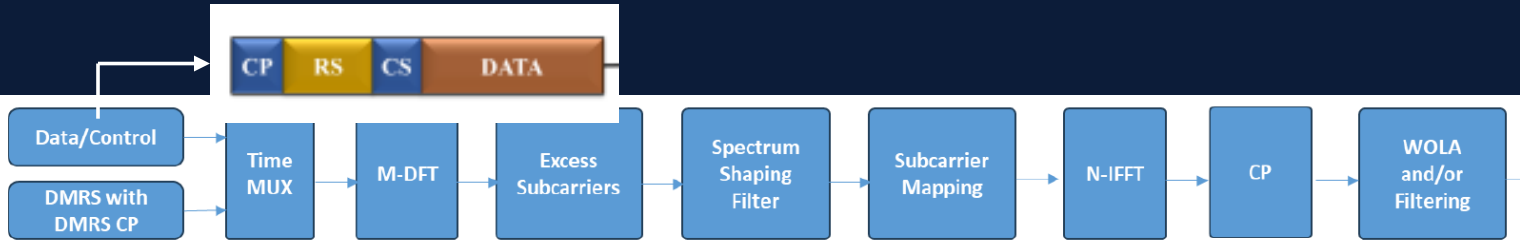
6G waveform proposals 6GWS-250036
Frequency-domain spectrum shaping (FDSS) in UL







6G waveform proposals: 6GWS-250026
Orthogonal Time Frequency Division Multiplexing (OTFDM)



Time Division Multiplexing in one Symbol

- Time multiplexing of Data and Control & DMRS with DMRS CP
- Instantaneous Channel Estimation with low DMRS overhead
- Information transfer in one shot with the Least Possible Latency

DFT Excess BW Spectrum Shaping Filter

- Nyquist Criterion for Zero ISI
- Excess BW signal shaping Controls the ISI caused by the pulse, reduces the tails of the ISI channel power to a below-noise floor, Reduces Effective ISI channel length, Enables DMRS-based estimation of the effective ISI channel
- Excess BW reduces PAPR further

Standard OFDM Operations

- Subcarrier mapping enables the multiplexing of multiple users/signals
- CP to offer frequency domain receiver processing
- Same spectral properties as OFDM - WOLA/filter for spectral confinement

OTFDM achieves the targets: low PAPR, Hyper low-latency
Enables multi-user multiplexing in time/frequency
Applicable in DL and DL

OTFDM publication pre-print

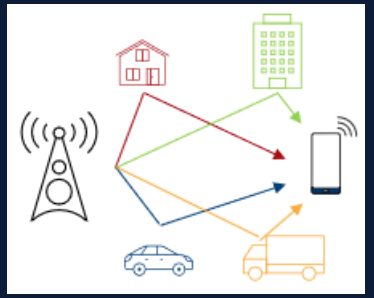
https://arxiv.org/abs/2409.01114

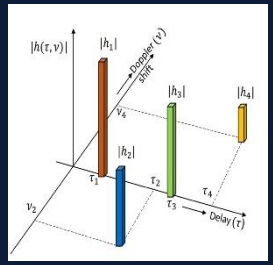
6G waveform proposals 6GWS-250233

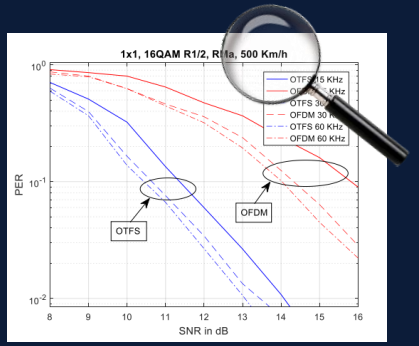
Zak-OTFS (Orthogonal Time Frequency Space) modulation

- For TDM and FDM the signal is localized in time or in frequency → time selective or frequency selective fading
- **Idea: Go to the Delay-Doppler (DD) domain**

- Doppler Delay Modulation (DDM)
  - Information is carried over DD domain pulse
  - Delay period τ_p ; Doppler period $\nu_p = \frac{1}{\tau_p}$
  - Zac transform z_t, used to transform the DD signal to a TD signal $x(t)$



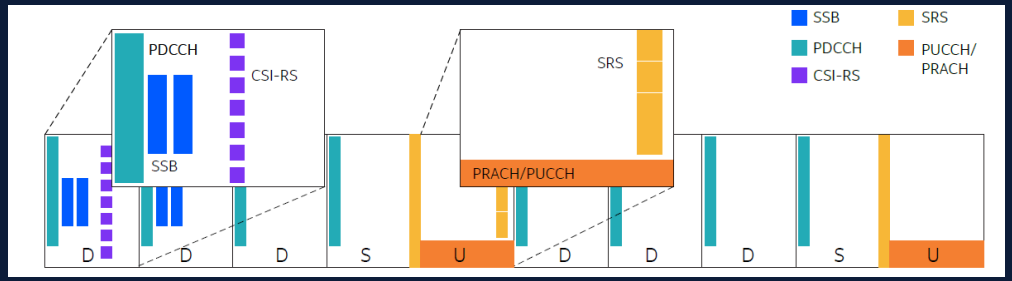




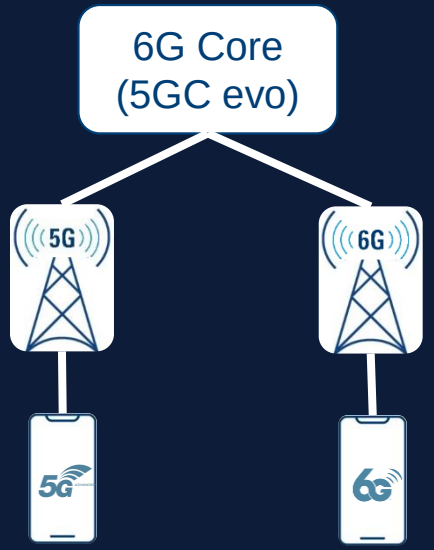
Ref: R1-1609825, 3GPP TSG RAN WG1 Meeting #86bis, 2016

6G waveform at cm-wave spectrum
MRSS motivates similarity with 5G NR

- Clear requirement to allow 6G SA operation in existing FR1 spectrum
- Potential solution: Multi-RAT Spectrum Sharing with focus on 5G/6G MRSS
- Based on similar principles than DSS in 5G/4G but leveraging 5G flexibility for always on signals



Source: Nokia white paper on „Simplifying spectrum migration from 5G to 6G “

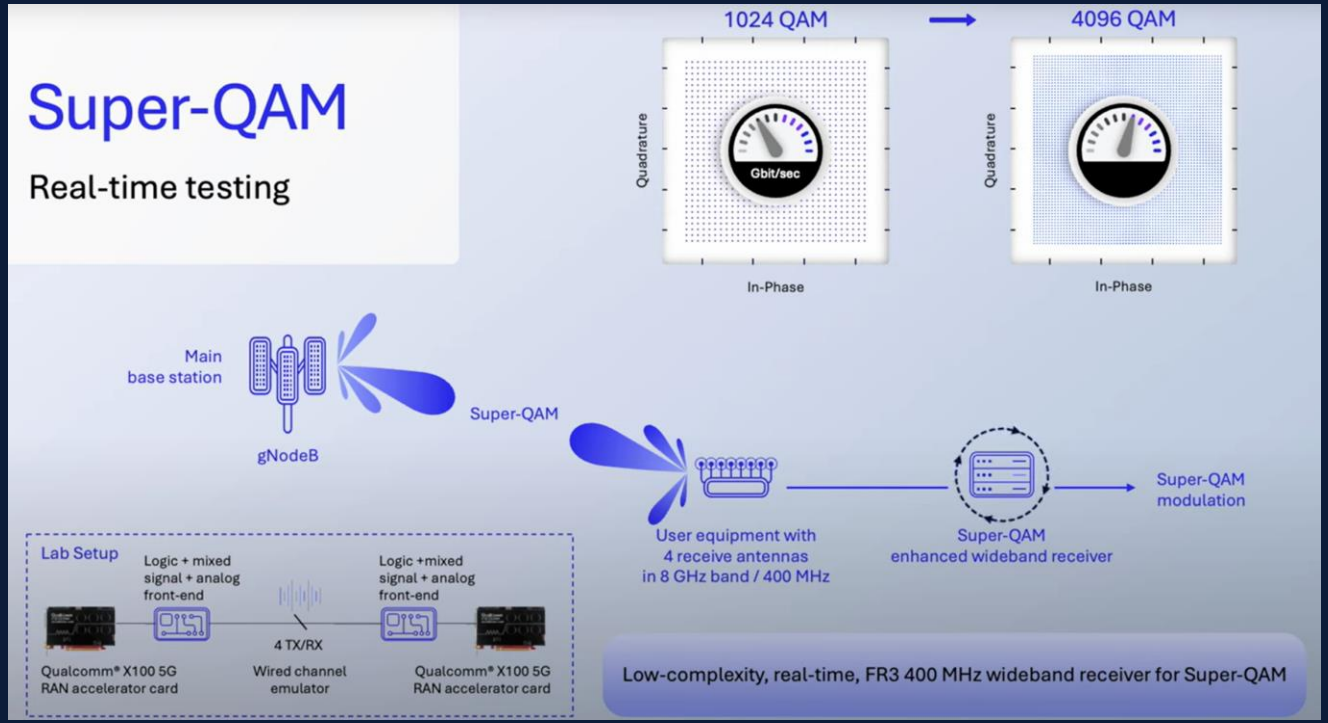


Chair’s summary of the 3GPP WS on 6G radio interface (6GWS-250243):

“Non-backwards compatible (from a UE perspective) to exploit full potential, with certain characteristics (e.g. waveform, modulation and channel coding) based on 5G NR with possible enhancements.”

6G waveform at cm-wave spectrum
Evolution of modulation: Super-QAM

- Qualcomm video on „Super-QAM“ to „enable significant increase in speed and spectral efficiency“



DEMO SETUP

R&S®SMW200A Vector Signal Generator

5G

Signal Generation and Analysis

R&S®FSVA3000 Signal and Spectrum Analyzer

RF

Non-standard settings of 5G parameters

Non-standard Channel BW

e.g. 500 MHz, 4 GHz, 8 GHz

Non-standard modulation format

e.g. 4kQAM, Custom, …

Non-standard cyclic prefix

And more…

Hexa-X project

Use cases for upper & lower mmWave frequencies

6G mmWave technology

Lower (30 to 100 GHz) and upper (100 to 300 GHz) mmWave frequencies

Short-range wireless links

Small cell & access points (< 100 m)

- **Wireless access** (Device-to-Infrastructure)
- **Wireless access** (Device-to-Device)

Long-range wireless links

Front-, mid- and backhaul

- **Fixed wireless links**
- **Mobile wireless links**

Sensing w/ radio waves

- **Locali-zation**
- **Mapping, tracking**
- **Spectros-copy**

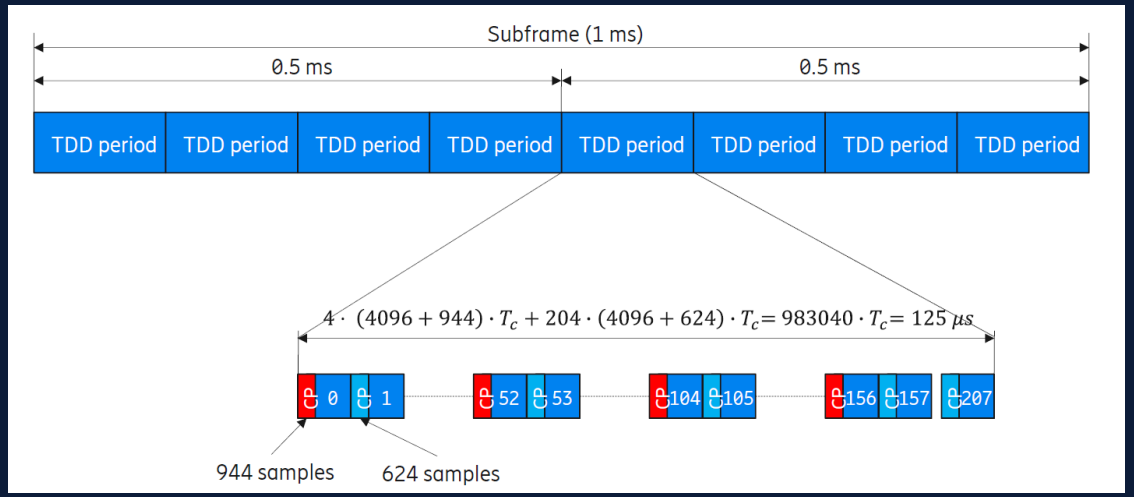
Source: https://hexa-x.eu/wp-content/uploads/2021/08/D2.1-summary-slides-short.pdf

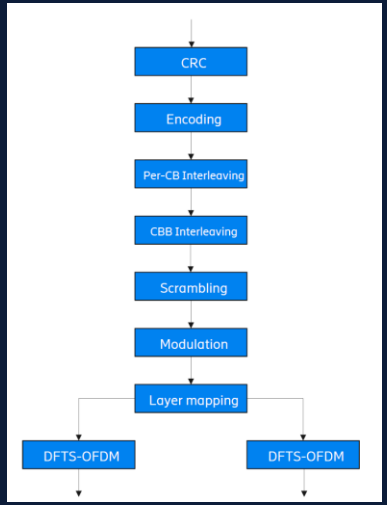
One sub-THz waveform example

”A concept for evaluating sub-THz communication for future 6G”

- TDD / DFTs-OFDM low latency approach without real frame structure, rather TDD period based.
- High SCS (1920 kHz) to support large bandwidth and to handle phase noise.

Subcarrier spacing	Useful symbol time, T_u	Cyclic prefix, T_{CP}
1920 kHz	$4096T_{\bar{c}} \approx 521$ ns	$624T_{\bar{c}} \approx 79$ ns[1]





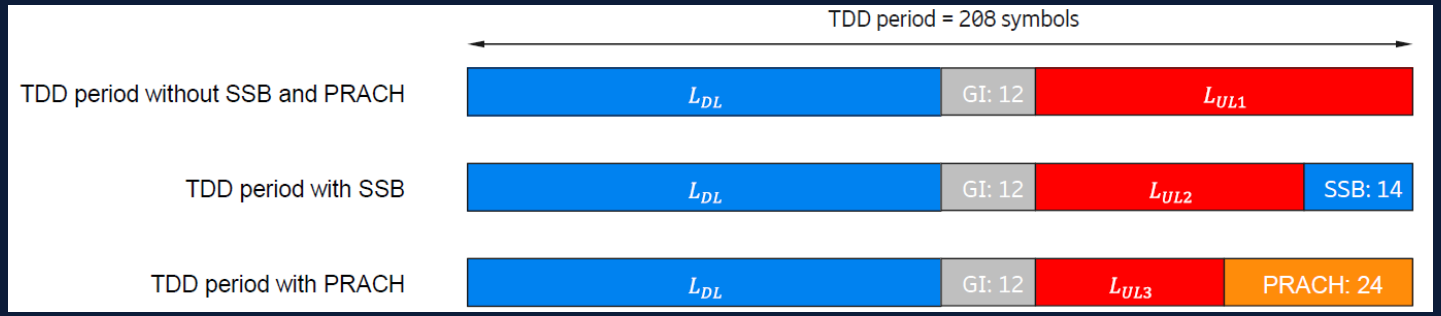
Transport-channel processing

One sub-THz waveform example

”A concept for evaluating sub-THz communication for future 6G”

- Three example configurations are described reflecting DL heavy, balanced and UL heavy traffic patterns.

Ratio	Downlink L_{DL}	Guard L_{GI}	Uplink $L_{UL,1}$ (no PRACH, no SSB)	Uplink $L_{UL,2}$ (SSB)	Uplink $L_{UL,3}$ (PRACH)
3:1	140	12	56	42	32
1:1	90	12	106	92	82
1:3	48	12	148	134	124



Support of wider RF signal bandwidth & precise power measurements at D-Band

R&S®SFI100A Wideband IF Generator
For modulation bandwidths up to 10 GHz

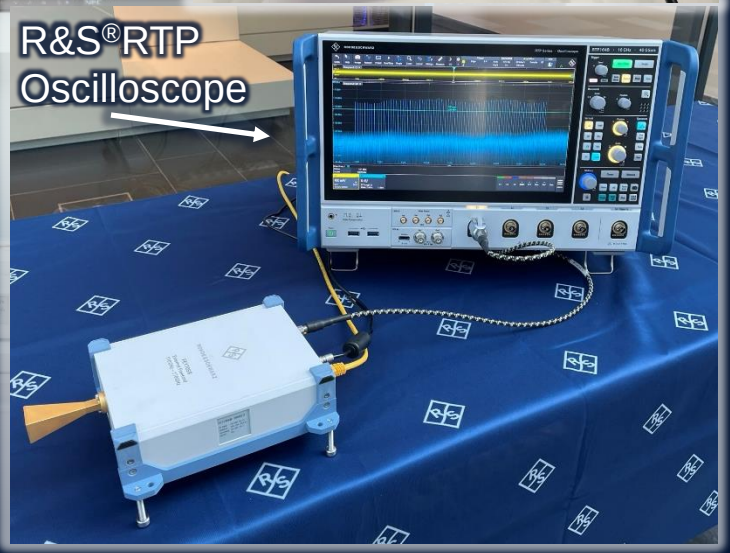
R&S®FE170ST/R
RF Frontend

Support of wider RF signal bandwidth & precise power measurements at D-Band

R&S®SFI100A Wideband IF Generator
For modulation bandwidths up to 10 GHz

R&S®FE170ST/R
RF Frontend

R&S®NRP170TWG
Power Sensor

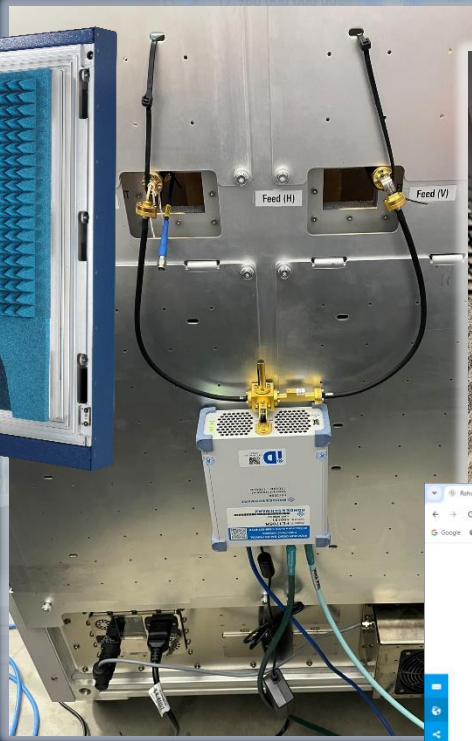


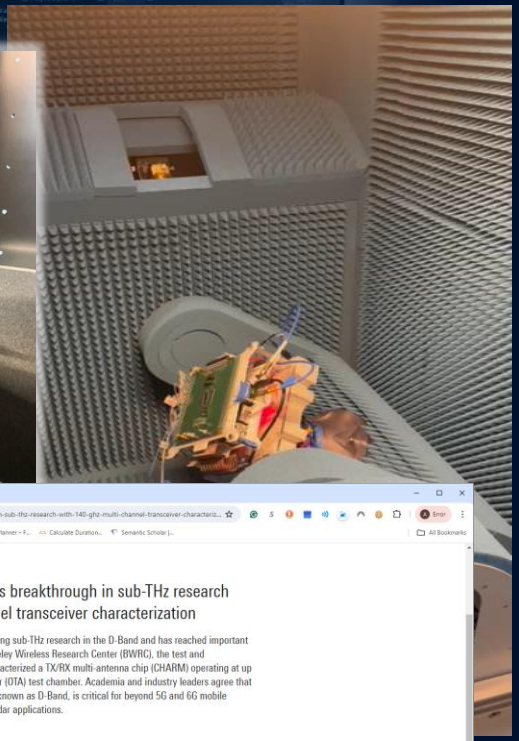
R&S®RTP
Oscilloscope

Over-The-Air (OTA) Testing in D-Band

R&S®FE110/170 frontends integrated into our chambers

R&S®ATS1800C
Compact 3GPP-compliant OTA chamber
for 5G NR mmWave signals





DEMO SETUP

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OFDM

Signal Generation and Analysis

R&S®FSW Signal and Spectrum Analyzer

IF

R&S®FE110ST Frontends R&S®FE110SR

IF

RF

Other Frontends and Converters

R&S®FE170ST/FE170SR R&S®FC330ST/FC330SR

CONCLUSIONS

- Although 3GPP has laid out the schedule for specifying the next generation of cellular technology, namely 6G, details will only become available over years to come.
- Early testing of components and RF modules with new physical layer parameters requires flexible software options already today.
- Rohde & Schwarz is committed to support our customers 6G product development to make their ideas real.

THANK YOU!

“No one can whistle a symphony. It takes a whole orchestra to play it.”

Halford E. Luccock (1885-1960)

www.rohde-schwarz.com/6G