Masterclass | The State of the Art in Electronics

COMPANY OVERVIEW AND T&M, KEY AREAS OF INNOVATION

Prof. Dr. Ulrich L. Rohde

ROHDE&SCHWARZ

Make ideas real

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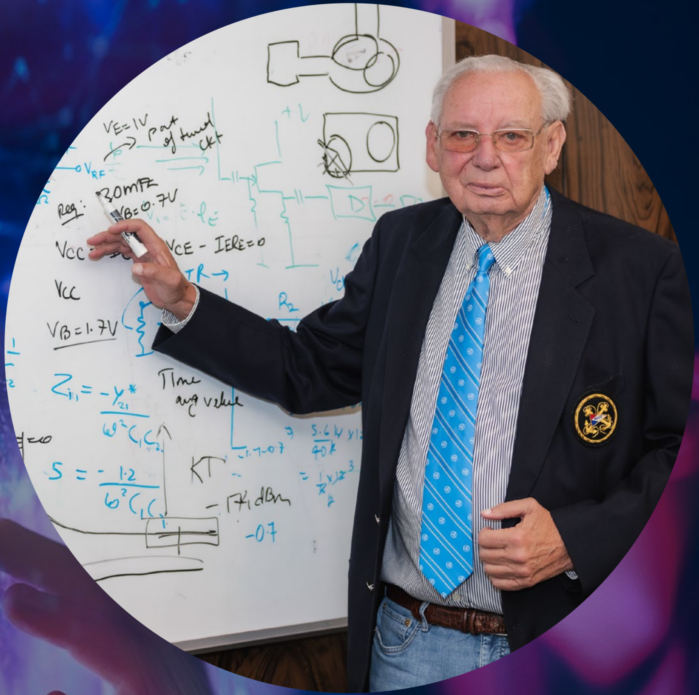
- Professor of Microwave and RF at the BTU Cottbus-Senftenberg University of Technology, Germany
- Full professor of Radio & Microwave Theory & Techniques at the University of Oradea, Romania
- Professor at the German Armed Forces University Munich, Germany (Microwave Systems, Technical computer science)
- Honorary professor at several other universities worldwide
- Honorary member of the Bavarian Academy of Sciences, Germany
- Partner of Rohde & Schwarz, Germany
- Chairman of Synergy Microwave Corp., Paterson, NJ
- IEEE Life Fellow, https://orcid.org/0009-0009-2271-4438



ROHDE&SCHWARZ
Make ideas real

Masterclass | The State of the Art in Electronics

STATE OF THE ART IN ELECTRONICS
HIGHER DENSITY, LOWER POWER, AND SOCS

KEY POINTS TO PONDER

Where do we come from?

Where are we today?

Where do we want to go?

An important principle: There are no free lunches!

Historical background:

- 1906: Lee de Forest invented the 'Audion' triode vacuum tube
- Enabled development of electronic oscillators and amplifiers
- Advantages of tubes: Thermal radiation, lax current limits, and robust power handling
- 1958: Jack Kilby (Texas Instruments) invented the Integrated Circuit (IC)

Evolution:

- Early systems used discrete components allowing circuit design flexibility
- 1958: Integrated Circuits (ICs) revolutionized electronics
- Modern ICs use nanometer-scale components with low voltages and ultra-low currents
- Today: Focus on System-on-Chip (SoC) for integrated digital and analog functions

State of the art technologies

- Gallium Nitride (GaN): High power density, overcoming frequency limitations
- Indium Phosphide (InP): Exceptional performance, sub-THz frequencies (>1 THz)
- Silicon Germanium (SiGe): High fT (up to 700 GHz), ideal for optical and RF modules

Key metrics and performance

- GaN HEMT: Low noise figure (1 dB at 1 GHz), increasing to ~5 dB at 150 GHz
- ScALN/GaN HFETs: Up to 24% Power-Added Efficiency (PAE)
- InP HBTs: Operating at frequencies up to 340 GHz, fmax > 1 THz
- SiGe BiCMOS: fT up to 700 GHz, essential for high-speed communications

Future directions & challenges

- Higher integration limits flexibility; relying on building blocks
- Foundry limitations and export controls impact new designs
- Cost-performance balance remains critical in advanced electronics
- Focus on scalable, energy-efficient designs for 5G/6G applications

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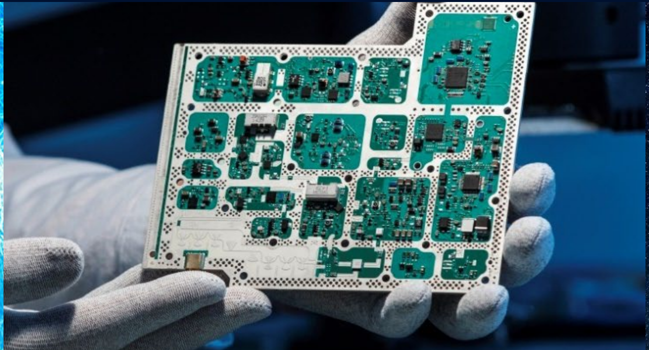
COMPANY OVERVIEW AND T&M

ROHDE & SCHWARZ
WHO WE ARE...

90 YEARS OF ENSURING A SAFER AND CONNECTED WORLD



We are technology.

\+ We innovate and connect.

\+ We thrive independently.

FROM A TWO-MAN LAB
TO A PRIVATELY OWNED GLOBAL COMPANY

90+ years
of success

EUR 2.93 billion
revenue in FY 23/24

> 14,400
employees

15% to 20%
of revenue
invested in R&D

WE LIVE INNOVATION AND MASTER OUR WHOLE VALUE CHAIN

One out of four employees in R&D

~20% of turnover is invested in R&D

Investments in leading-edge technologies from development to production

Collaboration w/ academic & industry

High-Degree of vertical integration

New center for cutting-edge technology

ONE COMPANY – THREE DIVISIONS

TEST & MEASUREMENT

Wireless I Industry, Components & Research I Aerospace & Defense Testing I Automotive

TECHNOLOGY SYSTEMS

Secure Communications I SIGINT/Electronic Warfare | Monitoring & Analytics | Infrastructure & Networks I IP Network Analytics

NETWORKS & CYBERSECURITY

Endpoint & Mobile Security | Secure Networks | Certified & High Grade Crypto Solutions

RELIABILITY FOR OUR CUSTOMERS, INDEPENDENCE THROUGH VERTICAL INTEGRATION AND RELEVANCE FOR SUPPLIERS

- Strong flexibility to handle a wide variety of products and changing batch sizes
- Flexible and fast deliveries to customers all over the world
- Complexity management through investments in digitalization, automatization and innovative technologies (e.g. AI and robotics)
- Relevant for our suppliers through close corporations in diverse market segments

SUSTAINABILITY
AT ROHDE & SCHWARZ

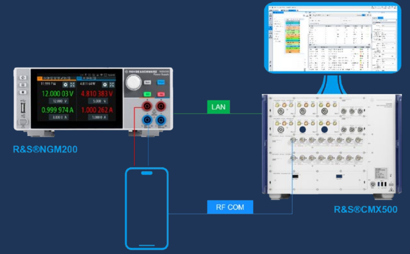
The pursuit of sustainability has always been part of our identity. We have a responsible and value based corporate culture that is committed to acting sustainably – toward our employees, customers and partners as well as society and the environment.

R&S APPROACHES SUSTAINABILITY FROM VARIOUS ANGLES

At our facilities

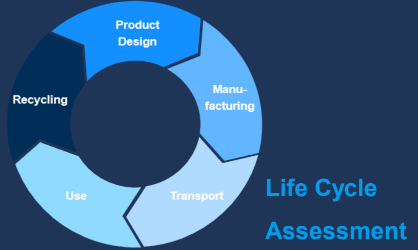
Analyse and improve, replace and optimize, avoid and reduce

Part of our solutions



Test equipment to measure energy efficiency

Within our products

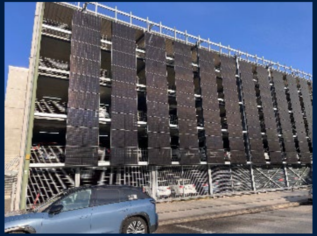


Approach over entire product lifecycle to improve environmental impact

OUR FACILITIES CONTRIBUTE TO OUR SUSTAINABILITY TARGETS

Usage of waste heat - Heat pumps for R&S data center (4 x 300 kW) in R&S Headquarters

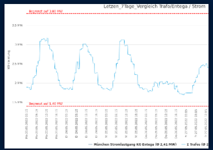


Energy efficient combined heat and power plants (CHP) in our plant in Teisnach, GER

Solar panels in our plant in Memmingen, GER

Energy Software to monitor energy use in our plants



CLOSE TO THE MARKET. CLOSE TO CUSTOMERS.

- Locations in around 70 countries
- More than 60 subsidiaries
- Worldwide development centers, sales and service offices
- Rohde & Schwarz develops solutions for a wide range of customers in a variety of markets

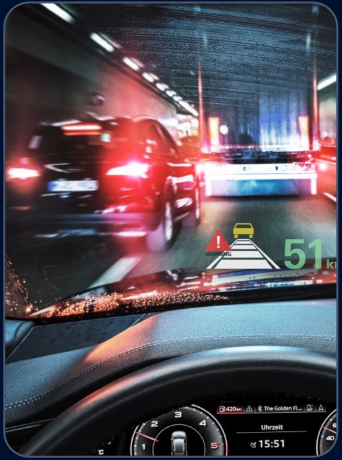
TEST & MEASUREMENT

Wireless I Industry, Components & Research I Aerospace & Defense Testing I Automotive

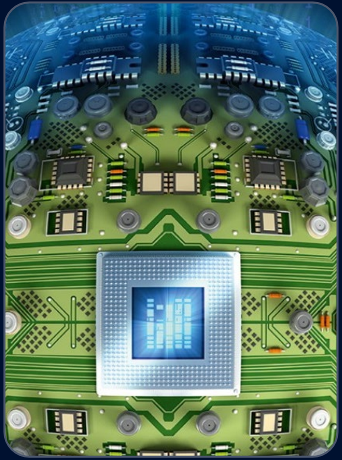
Focus on **customer needs** along the **value chain.**

Wireless Communication (WIC)

Aerospace & Defense (ADT)



Automotive (AUT)

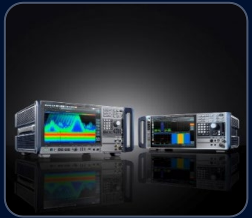


Industrial Electronics, Components, Research & Universities (ICR)

TEST & MEASUREMENT

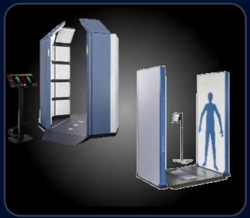
Wireless I Industry, Components & Research I Aerospace & Defense Testing I Automotive

Mobile Radio Testers



Spectrum & Network Analyzers, EMC & Antenna Test

Signal Generators, Power Supplies & Meters



Microwave Imaging

Oscilloscopes

Zurich Instruments

Service

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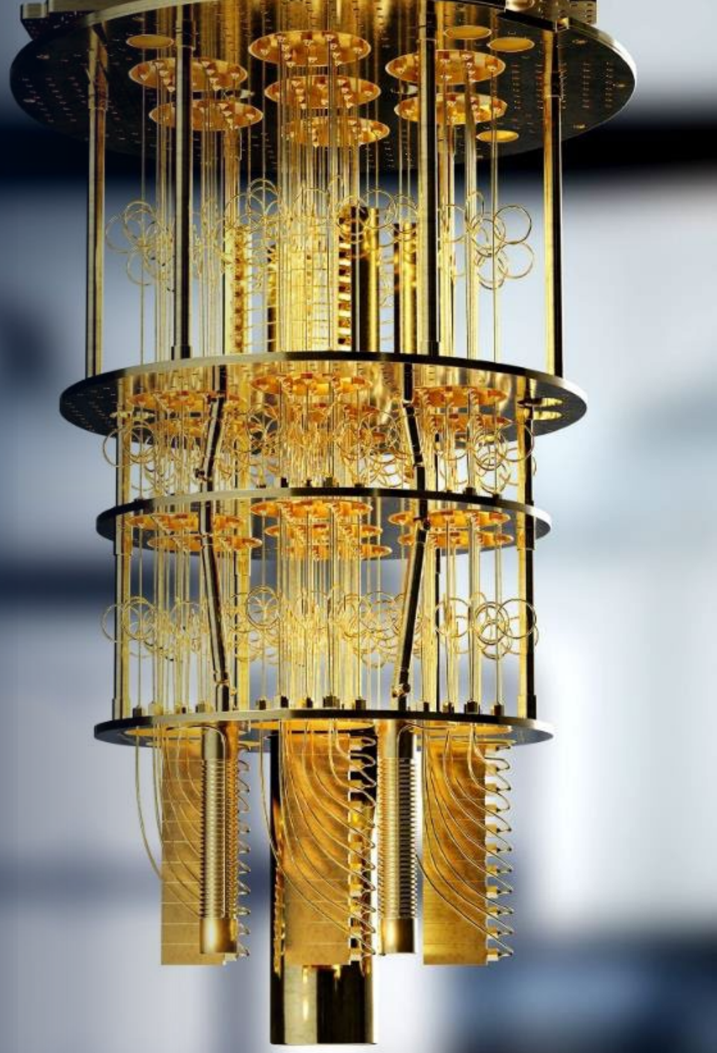
KEY AREAS OF INNOVATION

Staying RELEVANT through Innovation

Strong in-house expertise, partnerships and bolt-on technology acquisitions

Focus on today‘s and tomorrow‘s cutting-edge technologies



T&M Market Trends

6G **research** is emerging

Demand for **faster Wi-Fi** with low latency

High speed **Digital Design**

Higher **defense budgets** worldwide

Strong new space and **NTN** business

For autonomous driving more and more (radar) sensors

Electrification and high-voltage solutions getting more important

WE CONNECT THE WIRELESS ECOSYSTEM!
WITH OUR PEOPLE, EXPERTISE AND INNOVATIVE SOLUTIONS

Translate 〉 **Consolidate** 〉 **Standardize** 〉 **Independent Reference**

Test &measurement **solutions**

from the everyday

to the extraordinary

QualiPoc/Freerider Benchmarker PR200 FPH44 TSME6/TSMA6

SMW FSW PVT360 CMW500 CMX500 CMP200 CMP180 Flexx RTP Test System OTA Chamber

5G FROM TERRESTRIAL TO SPACE
3GPP CALL IT NON TERRESTRIAL NETWORKS (NTN)

DIFFERENT IMPLEMENTATIONS OF NTN – DEVICE ASPECTS
3GPP VS. PROPRIETARY

PROPRIETARY NTN

- Apple – Globalstar (LEO)
- HUAWEI – TIANGTONG, THURAYA (GEO)
- QUALCOMM – iridium (LEO)
- StarNet

3GPP >Rel.17 NB-NTN/NR-NTN

- skylo TECHNOLOGIES
- Viasat (GEO)
- ECHOSTAR (GEO)
- Globalstar (LEO)
- TIANGTONG (GEO)
- iridium (LEO)
- OQ TECHNOLOGY (LEO)
- Sateliot (LEO)
- INTELSAT (MEO)
- SES your satellite (MEO)
- IRIS² (LEO)
- LEO

QUALCOMM, MEDIATEK, Altair (A Sony Group Company), UNISOC, System LSI

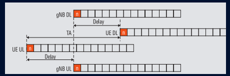
SAMSUNG, oppo, mi, vivo, QUECTEL, Fibocom, Telit Cinterion, COMPAL

3GPP unmodified
Direct to Device/Cell/Handset

- STARLINK (LEO) – T Mobile
- AST SpaceMobile (LEO) – AT&T, verizon
- amazon project kuiper (LEO)

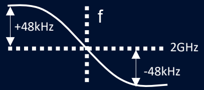
NTN USER EQUIPMENT ESSENTIAL REQUIREMENTS AND CHALLENGES

Time Synchronization



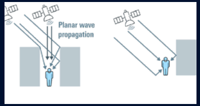
Long delay and time variant delay: Distance, UE to satellite causes long absolute delay (~40 ms for LEO and 544 ms for GEO). Orbital movement of satellite will cause a time variant delay during the connection time. Variable RTT due to Elevation angle and LEO, SIB31 K_mac (RTT calc), K_offset, SIB32, SIB19.

Frequency Synchronization



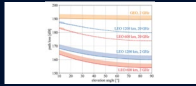
Doppler shift: Movements of LEO satellites causes a time and elevation angle variant Doppler shift.

Signal Fading



Fading profiles: Beside the legacy terrestrial fading profiles, satellite connectivity requires new fading profiles such as the combination of atmospheric and terrestrial fading as well as the emulation of weather specific effects (rain, cloud, sun storms causing electron flow).

Minimum SINR

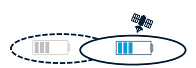


High attenuation and low SNR: The large distance causes a high free space path loss ending in a low SNR at the UE side. Minimum SINR ≥ -10 dB, minimum RSRP ≥ -137 dBm.

GNSS Measurements and Satellite Ephemerals

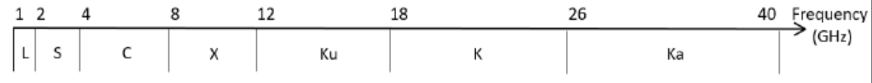
GNSS emulation and provisioning of ephemeris information in the first approach, NTN targets at outdoor connections, UE is capable of GNSS and determines its terrestrial position. The UE is pre-provisioned with the orbit information (ephemeris) via SIB broadcast.

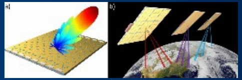
Power Saving Optimizations



Cell Acquisition, mandatory GNSS, cell search, eDRX/PSM (start time of upcoming coverage info, repetitions in low CQI, UE to predict discontinuous coverage based on the satellite assistance information, SIB32.

NTN BANDS AND FREQUENCIES

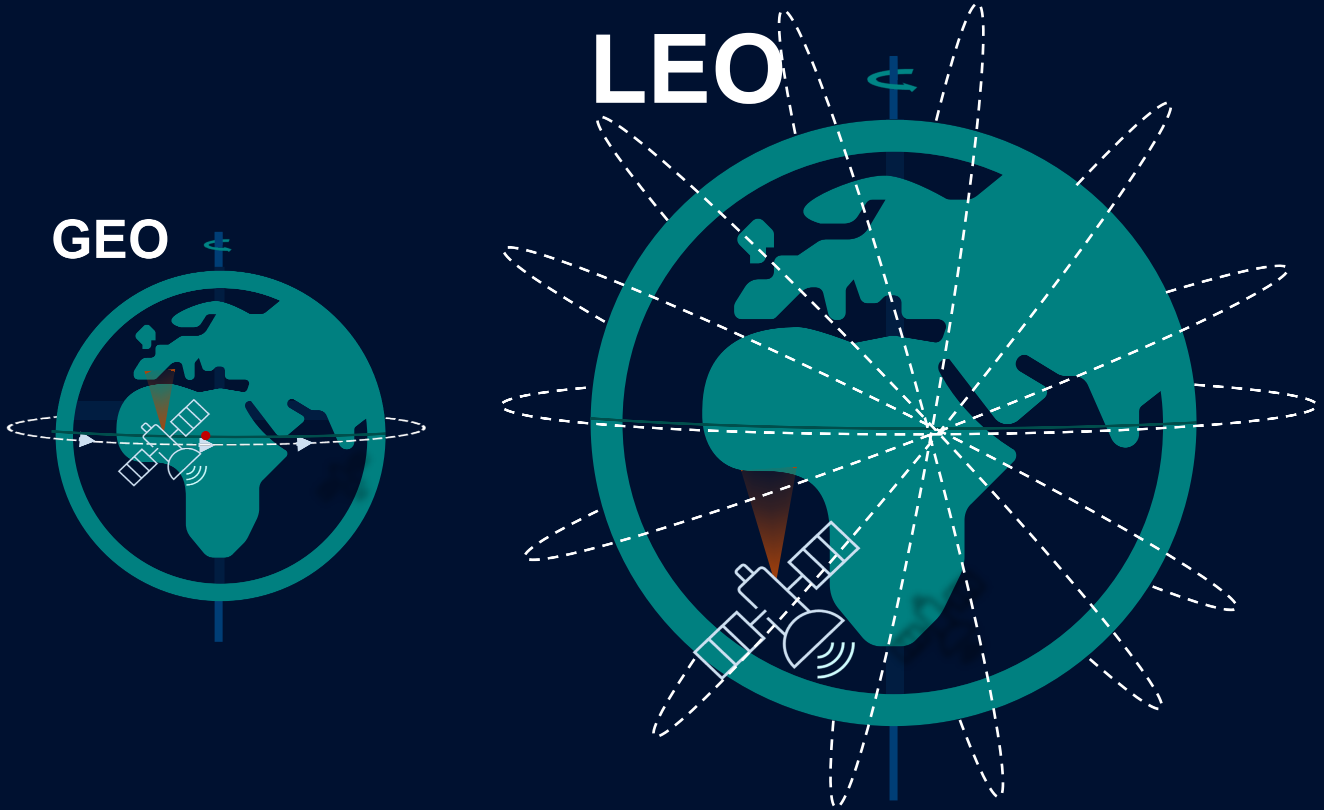


	2023 R17	2026/2027 R18	2029/2030 R19 prospect
	NTN-IoT@2GHz (S/L) → NTN-NR@2GHz (S/L)	NTN-NR@17-30GHz (K-Ka)	NTN-NR@12-16GHz (Ku)
	narrowband	wideband	broadband
Antenna profiles	• 23dBm • Linear polarization • Patch, FDD		• 33dBm  • 60cm circular polarization • Active Phased Array FDD/TDD
Device Types	Handheld, IoT, Wearable, AUT/TCU		CPE, TCU, VSAT
Speed	~200kbps (200KHz BW)	~1-2mbps (5MHz-30MHz BW)	~200mbps (~400MHz BW)
Service	Small data/one way voice?	Data/voice	Data broadband/voice
Usecases	SOS/messaging, Agriculture and farming, Asset tracking.	5G Connected Car, Ubiquitous continuity of 5G basic services, IoTs, Public Safety	5G fixed wireless access (FWA) enhancement by NTN, Maritime

NTN

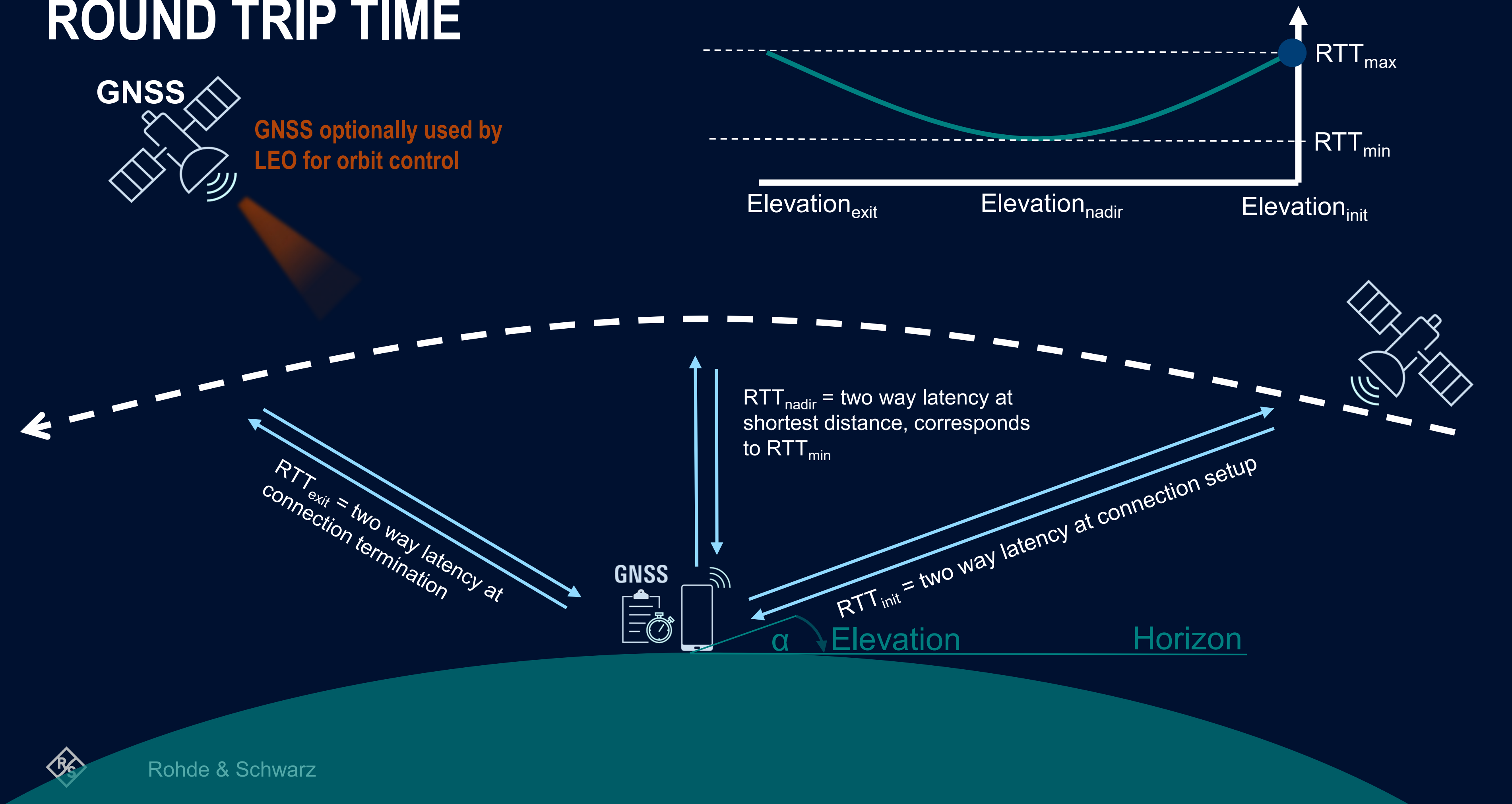
SATELLITE ORBIT: LEO

Altitude: 160-2000 km
Orbital time: 1.5 – 2 h
Total Latency: 2-27 ms
Sat. Velocity: 7.8 - 8.2 km/s



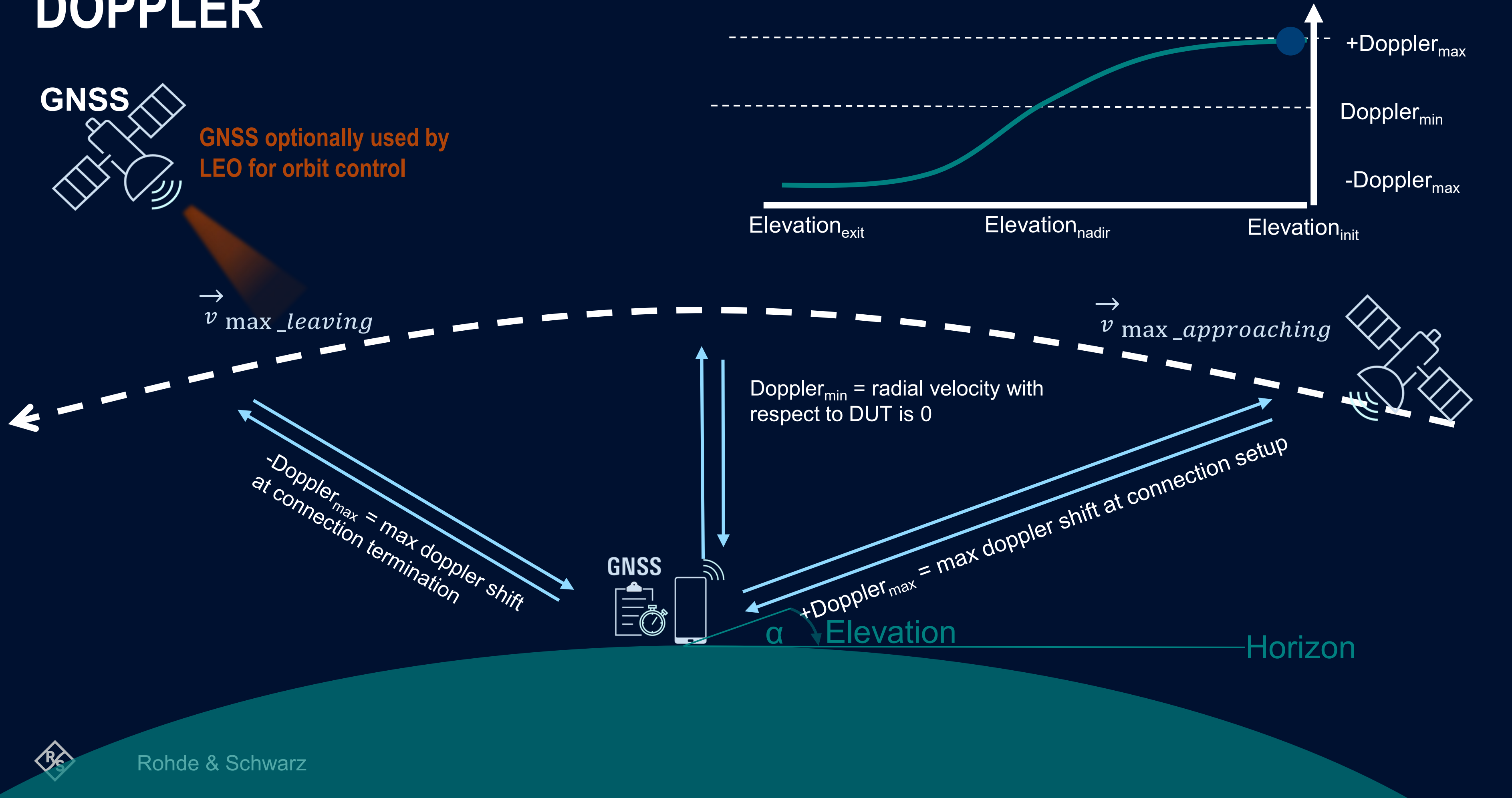
NTN

ROUND TRIP TIME



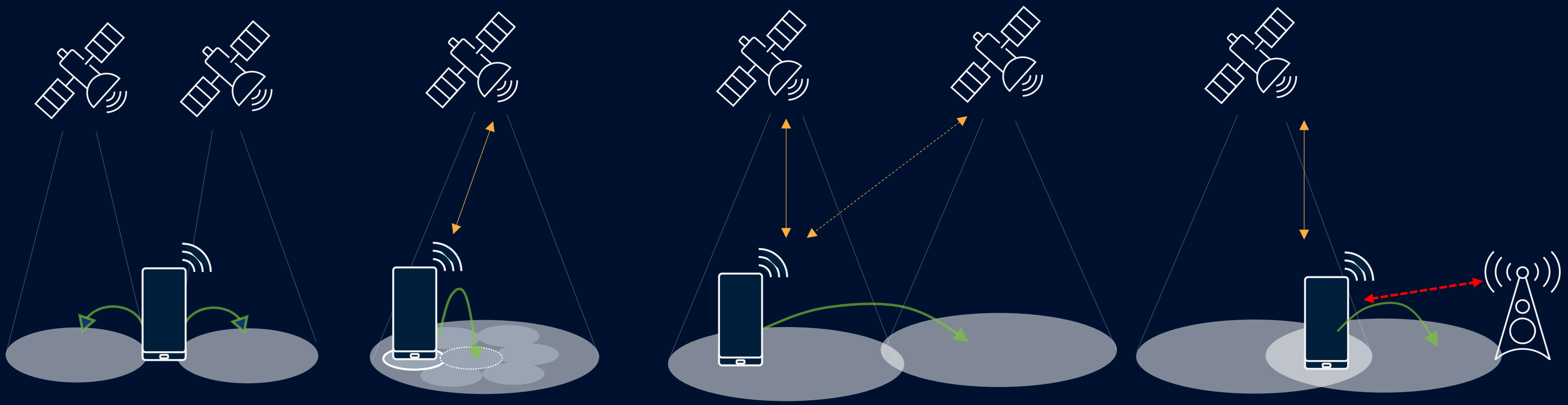
NTN

DOPPLER



GNSS
GNSS optionally used by LEO for orbit control
+Doppler$_{max}$
Doppler$_{min}$
-Doppler$_{max}$
Elevation$_{exit}$
Elevation$_{nadir}$
Elevation$_{init}$
$\vec{v}$ max _leaving
$\vec{v}$ max _approaching
Doppler$_{min}$ = radial velocity with respect to DUT is 0
-Doppler$_{max}$ = max doppler shift at connection termination
+Doppler$_{max}$ = max doppler shift at connection setup
GNSS
α
Elevation
Horizon

MOBILITY SCENARIOS

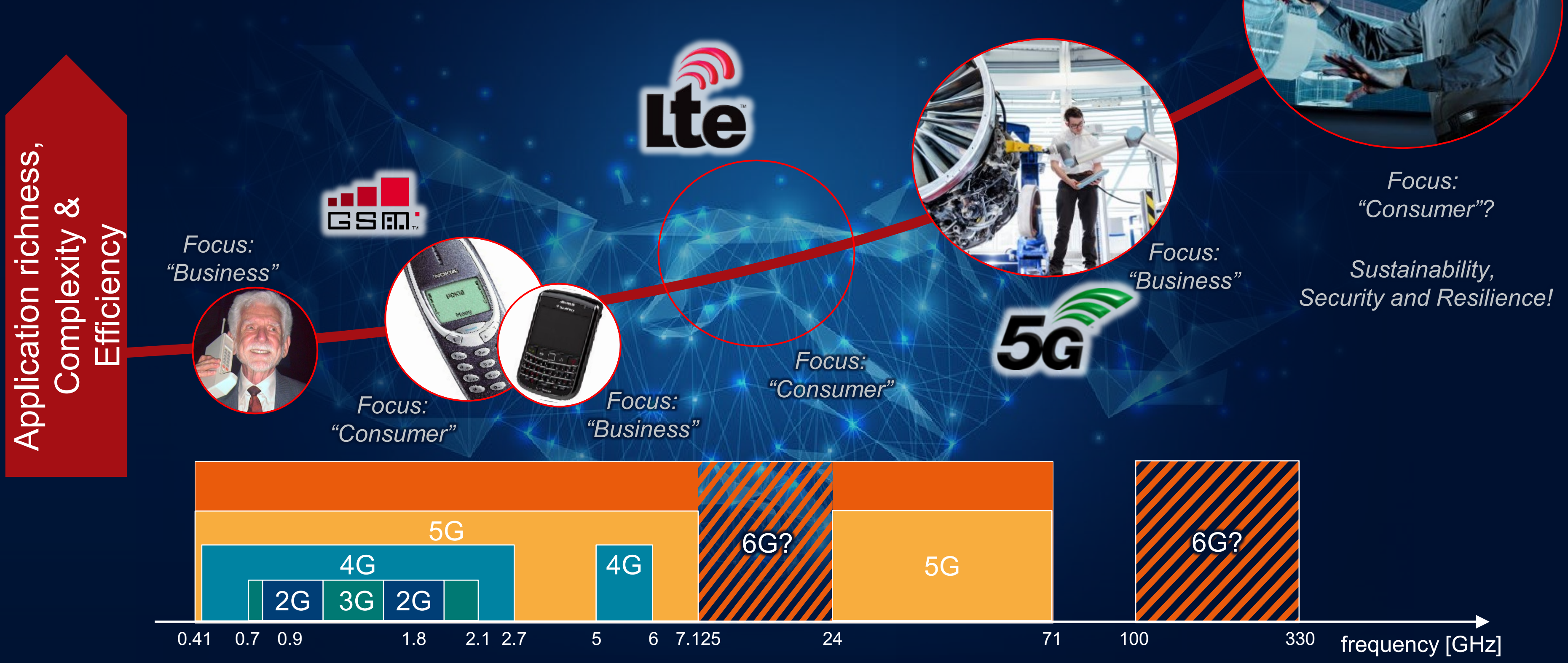


Cell selection/ cell reselection	Intra-satellite/ Inter beam handover	Inter-satellite handover/ Inter-satellite dual connectivity (DC)	NTN – terrestrial handover/DC

- NR-NTN connection
- Target or simultaneous dual connectivity NR-NTN connection
- Target or simultaneous dual connectivity terrestrial connection

From 5G to 6G

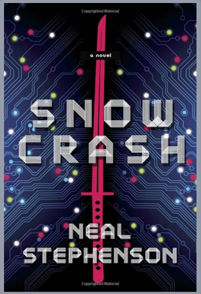
Evolution of the mobile wireless standards and frequencies



WHAT IS THE METAVERSE?
AND WHAT IS IT FOR?

An immersive, pervasive, interconnected virtual 3D world shaped by extended reality applications where many people can gather to work, shop, play, and socialize, facilitated by virtual reality (VR) and augmented reality (AR) headsets via cloud computing.

The origin of the term Metaverse is in Neal Stephenson's novel "Snow Crash"

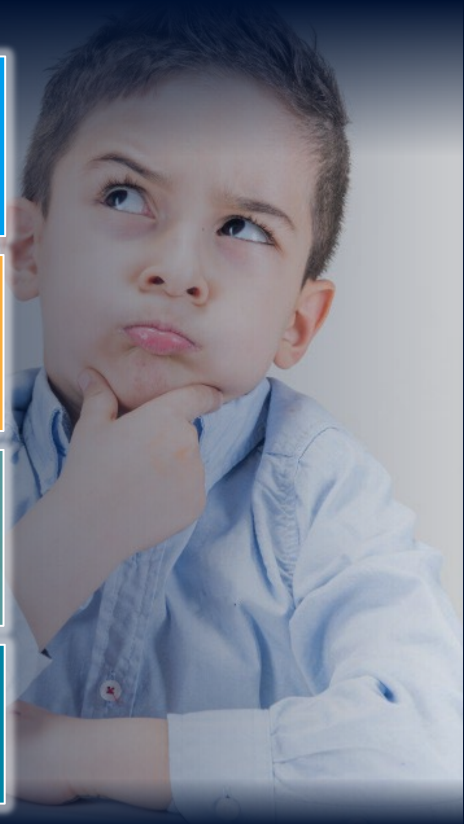


Collaboration

Digital Twins

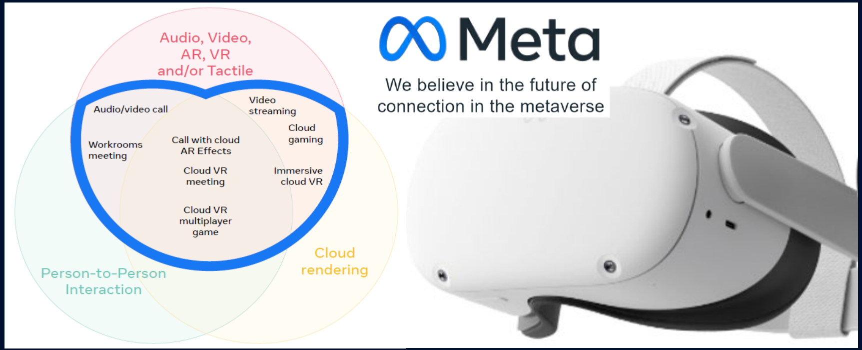
Training Education Healthcare

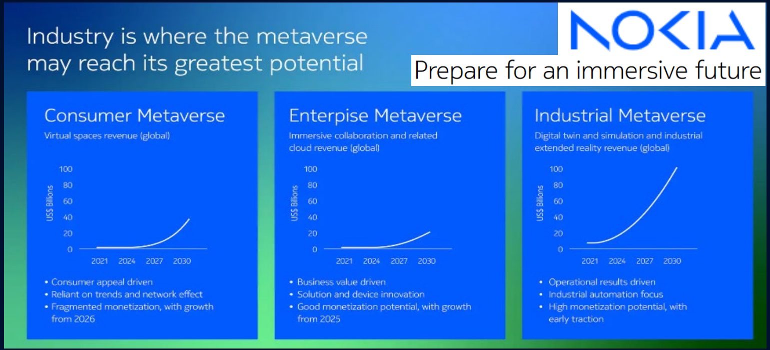
Gaming Social

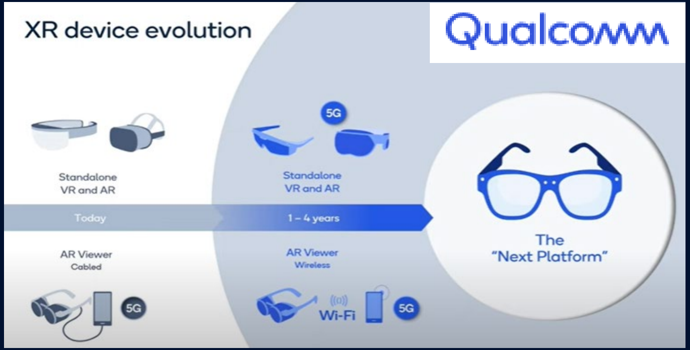


A selection, there are many others...

METAVERSE IS ON THE AGENDA OF ALL INDUSTRY PLAYERS
INDUSTRIAL METAVERSE NOW, ENTERPRISE & CONSUMER FOLLOW







6G Research areas from an T&M perspective

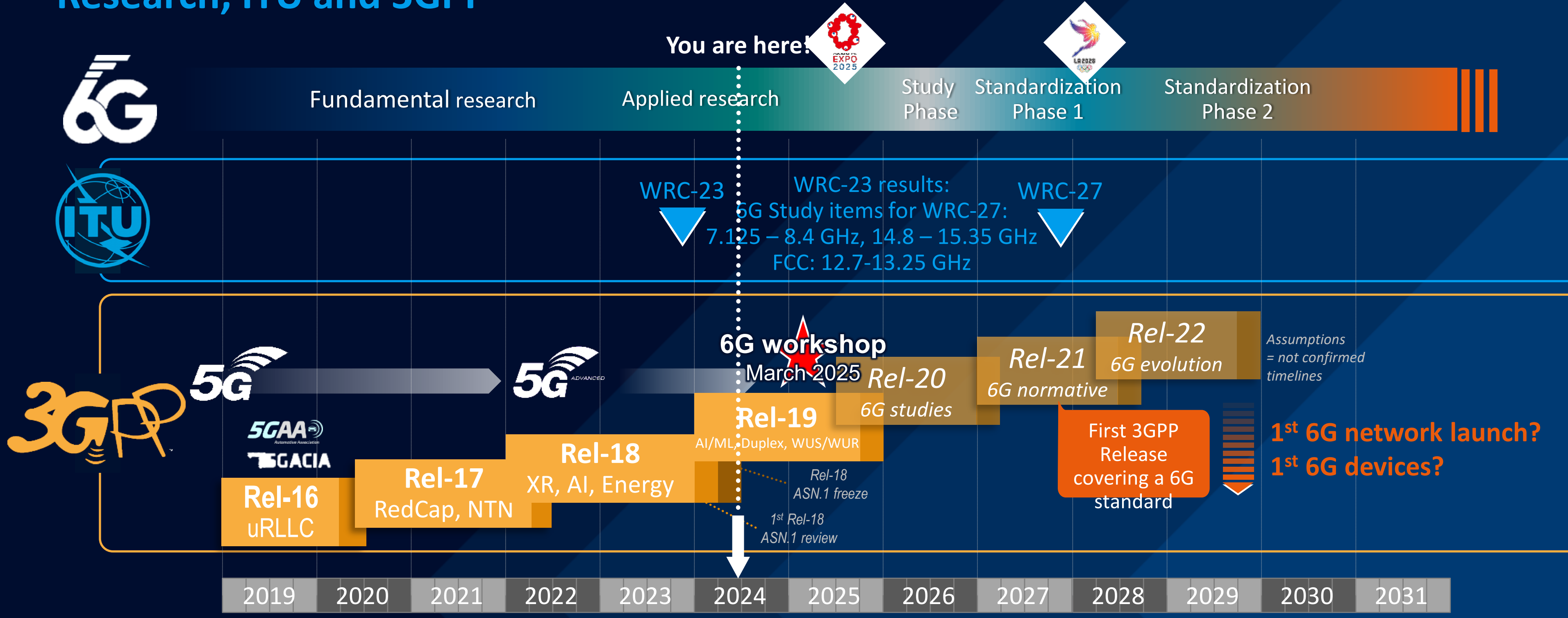
6G introduces many new technology components

- Spectrum for 6G: “FR3” and THz
- Integrated sensing & communication
- Artificial Intelligence and Machine Learning
- Reconfigurable Intelligent Surfaces
- Photonics, Visible Light Communication
- New network topologies, distributed computing
- Multiple access, new waveforms, channel coding
- Ultra-massive MIMO
- The Metaverse and eXtended Reality (XR)
- Full-duplex communication
- Security & Trustworthiness

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

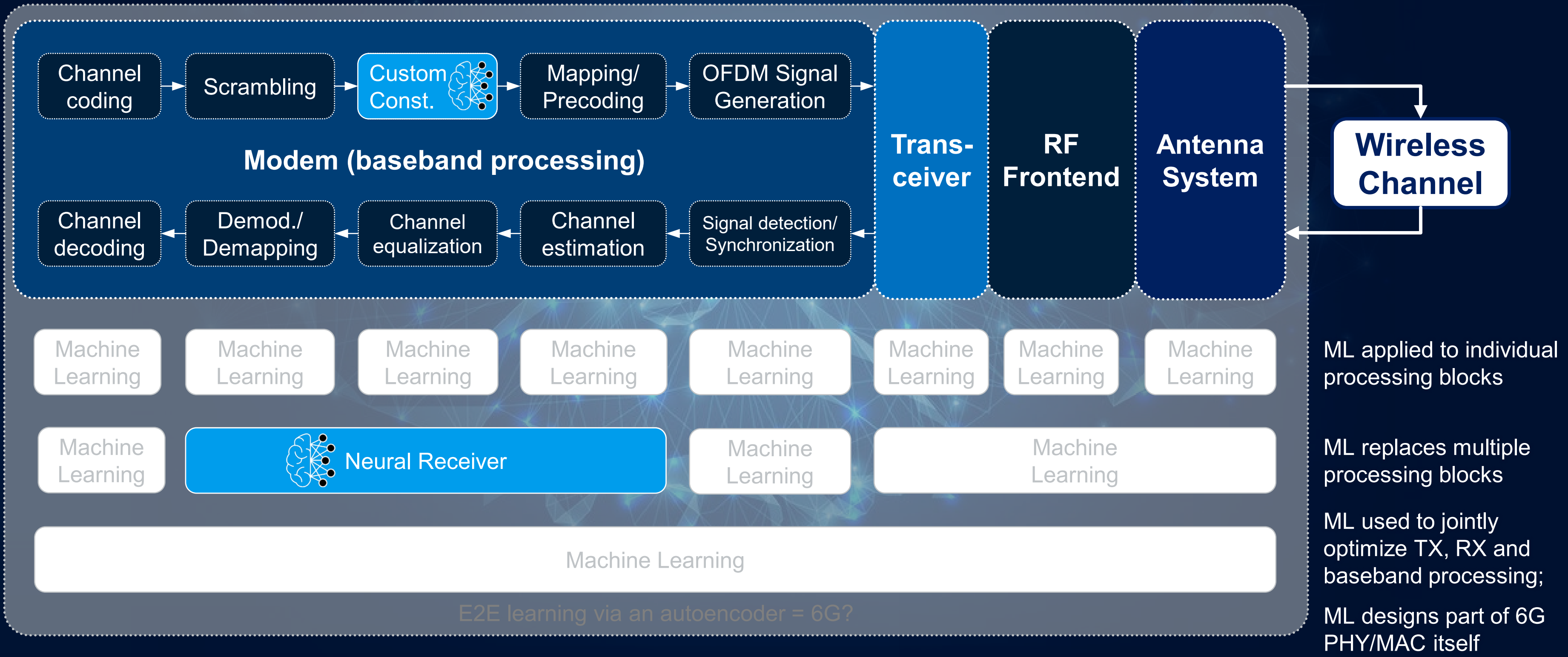
6G Phases and Timeline

Research, ITU and 3GPP

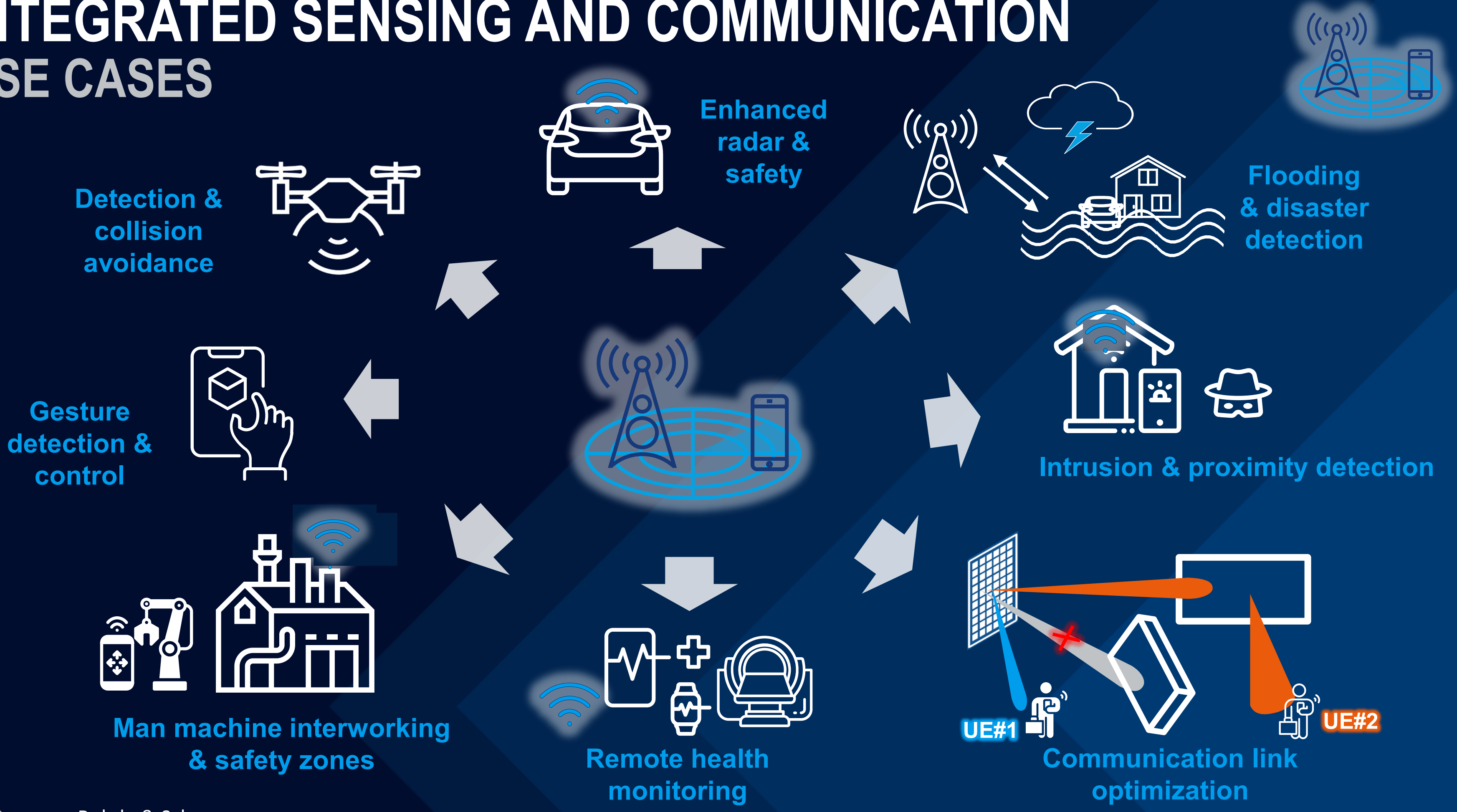


[1)] *IMT-2020 systems are called 5G, The ITU has already started a new technology trend report to prepare the work on "IMT-2020 and beyond" that is likely to become 6G*

TOWARDS AN AI-NATIVE AIR INTERFACE FOR 6G
ENHANCING THE NEURAL RECEIVER WITH CUSTOM CONSTELLATION



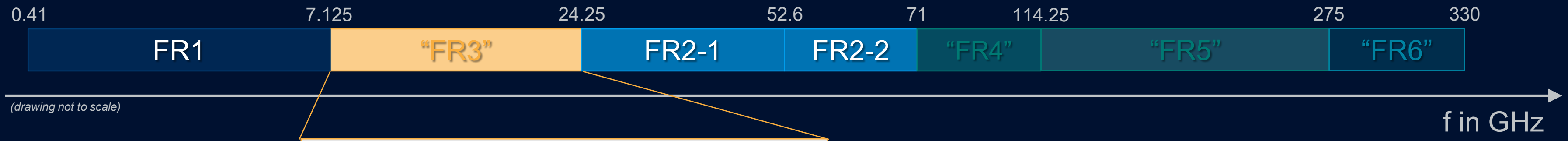
INTEGRATED SENSING AND COMMUNICATION
USE CASES

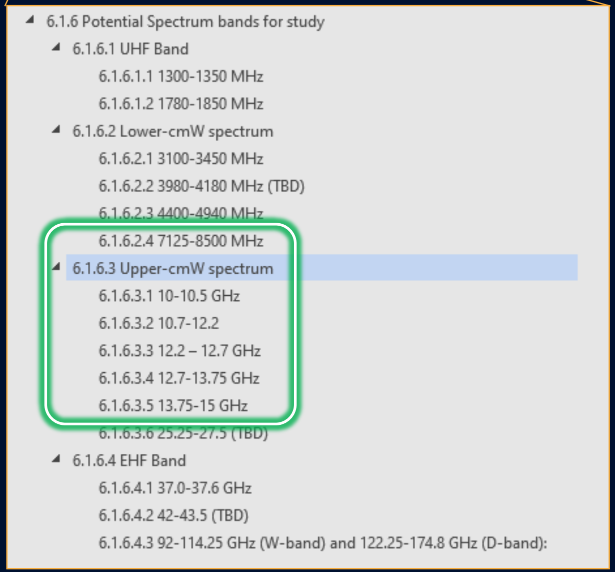


6G RESEARCH AREAS FROM A T&M PERSPECTIVE

- THz communication, and “FR3”
- Integrated sensing & communication
- Artificial Intelligence and Machine Learning
- Reconfigurable Intelligent Surfaces
- Photonics, Visible Light Communication
- The Metaverse and eXtended Reality (XR)
- Multiple access, new waveforms, channel coding
- Ultra-massive MIMO
- New network topologies, distributed computing
- Full-duplex communication
- Security & Trustworthiness

SPECTRUM CONSIDERATIONS FOR 6G
IS FR3 SPECTRUM FOR 5G-ADVANCED OR 6G OR BOTH?

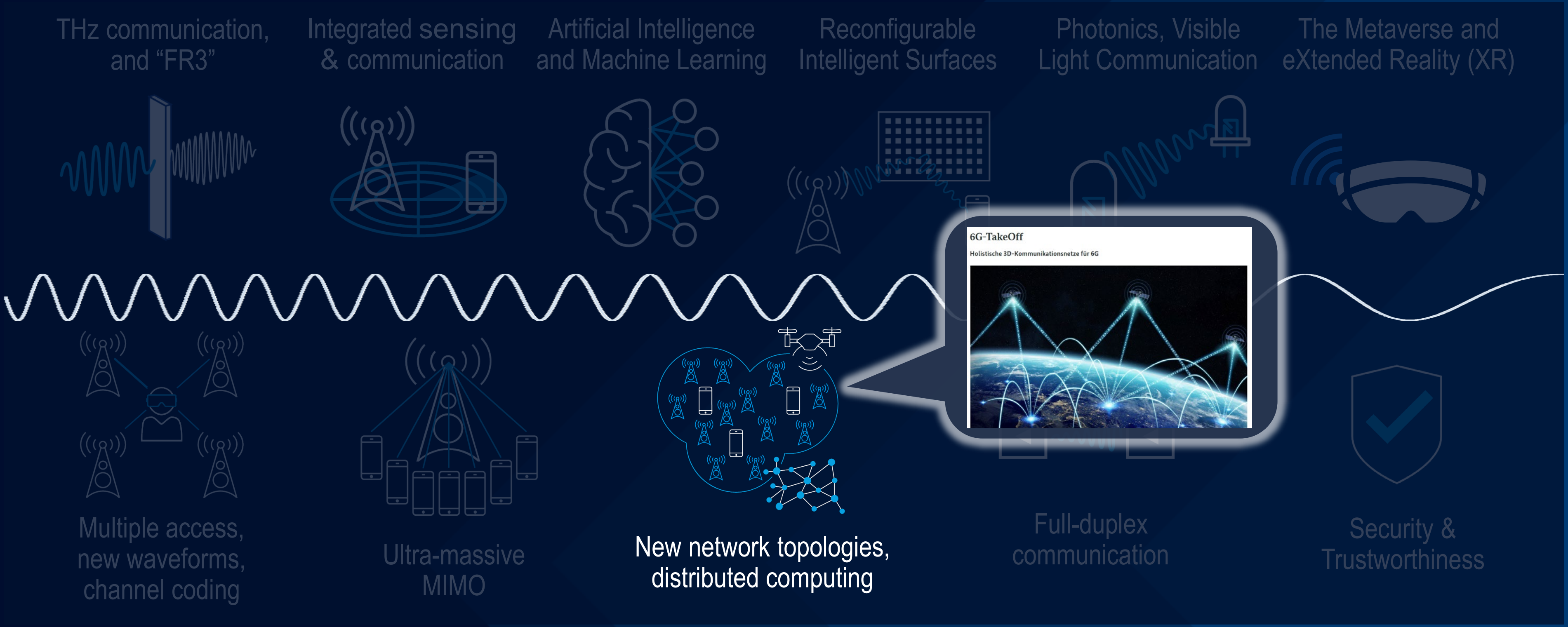



6.1.6 Potential Spectrum bands for study
- 6.1.6.1 UHF Band
  - 6.1.6.1.1 1300-1350 MHz
  - 6.1.6.1.2 1780-1850 MHz
- 6.1.6.2 Lower-cmW spectrum
  - 6.1.6.2.1 3100-3450 MHz
  - 6.1.6.2.2 3980-4180 MHz (TBD)
  - 6.1.6.2.3 4400-4940 MHz
  - 6.1.6.2.4 7125-8500 MHz
- 6.1.6.3 Upper-cmW spectrum
  - 6.1.6.3.1 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
  - 6.1.6.3.6 25.25-27.5 (TBD)
- 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):

NEXT G ALLIANCE

- Status after WRC-23 –
  New study items for input for WRC-27:
  - 4400 to 4800 MHz (in EMEA and APAC)
  - 7125 to 8400 MHz (excluding 7250 to 7750 MHz in Europe due to use by NATO)
  - 14.8 to 15.35 GHz
- Notable regional activities
  - FCC studies 12.7 to 13.25 GHz,

RESEARCH AREAS FROM A T&M PERSPECTIVE



SUMMARY

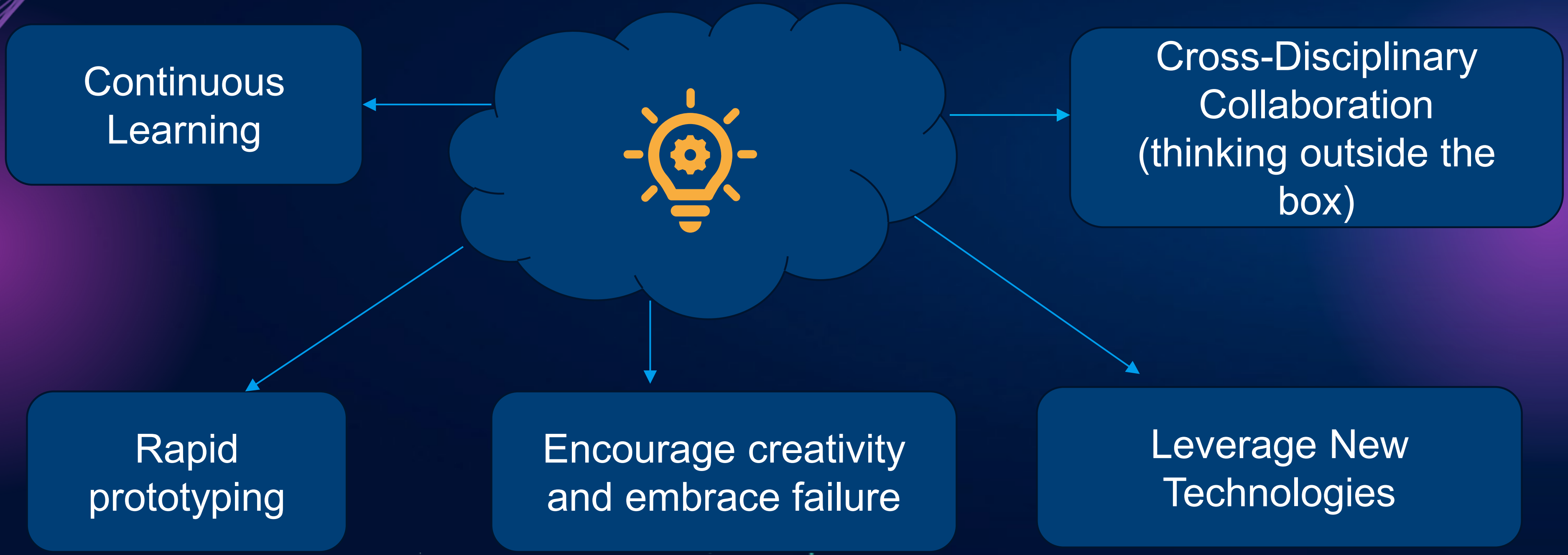
- Deployment of 5G networks is in full swing, although it is still a long way to go to reach its full capabilities and deliver on its promises.
- Meanwhile, researchers in academia and industry are exploring new technology components to make 6G networks and devices **more efficient, intelligent, sustainable, and secure**
- These new, challenging technology components will enable the next step towards an **immersive, pervasive, digital experience** in a hyper-connected world

WHY SHOULD YOU BE INNOVATIVE?

Reasons for being innovative

- Sustainability and impact
- Competitive advantage
- Adaption to changes (market demands)
- Problem solving
- Cost efficiency

HOW COULD YOU BE INNOVATIVE?



THE NEED AND THE PROCESS TO BE CURRENT IN TECHNOLOGY

Rapid technological advancements

Competitive edge

Career growth
(employers value engineers who are proactive)

Problem solving skills

ACTIVE PARTICIPATION IN PROFESSIONAL SOCIETIES

Please read:
https://builtin.com/hardware/moores-law

Important references:

- IEEE microwave Magazine for the Microwave & Wireless Engineer Volume 25 - Number 10 October 2024 ISSN 1527-3342 features.
- Walker, J. Fundamentals of Physics, 8th ed., John Wiley and Sons, 2008, p. 891. ISBN 9780471758013 (Wien's displacement law).

Thank you for your attention!