



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



**MASTERCLASS**  
NOVEMBER CHAPTER

**THE STATE OF ART IN ELECTRONICS**  
**BY Dr. ULRICH L. ROHDE**  
PROFESSOR | AUTHOR | ENTREPRENEUR | ENGINEER

Join us for an insightful session on the State of Art in Electronics where innovation meets precision in the world of electronic design.

**DETAILS OF THE SESSION**

State of art in Electronics – higher density, lower power, SoCs



State of art in Communications – 5/6 G and LEO satellite communication

State of art in Testing & Measurement – R&S story


Systems engineering is critical for complex systems and role of software defined systems

Why and how you can be innovative?

The need and the process to be current in Technology – active participation in professional societies



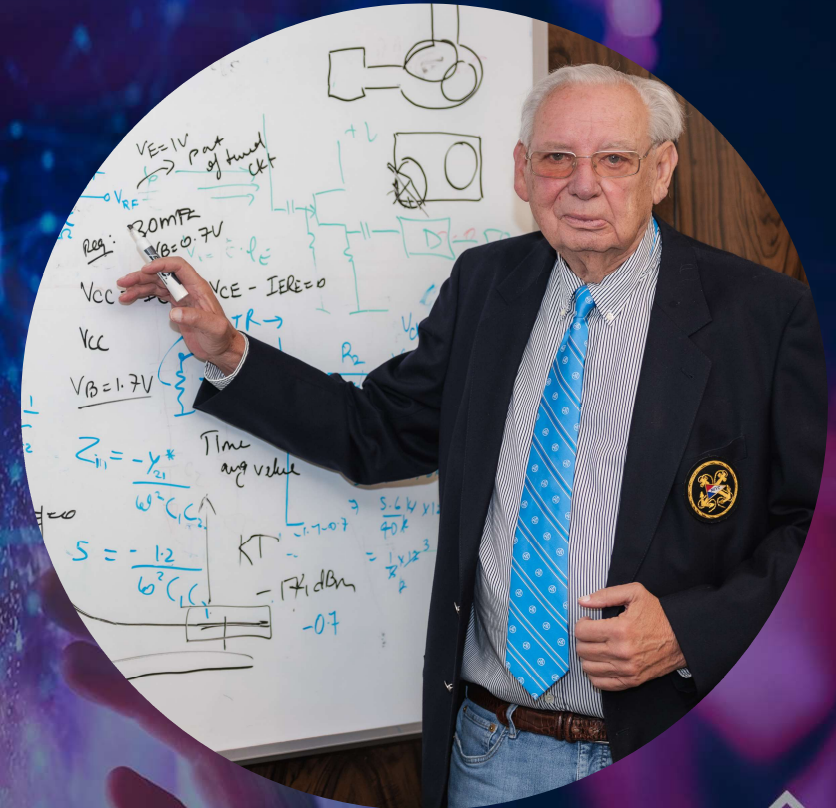
**Date : 18th November 2024**  
**Time : 4 to 5:15PM**  
**Teams invite will be shared separately**





Ulrich L. Rohde  
Prof. Dr.-Ing. habil.

- Chair Professor for Microwave Technology at IIT-Jammu
- Professor of Microwave Technology at IIT-Delhi
- 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
- Partner of Rohde & Schwarz, Germany
- Chairman of Synergy Microwave Corp., Paterson, NJ
- IEEE Life Fellow, <https://orcid.org/0009-0009-2271-4438>

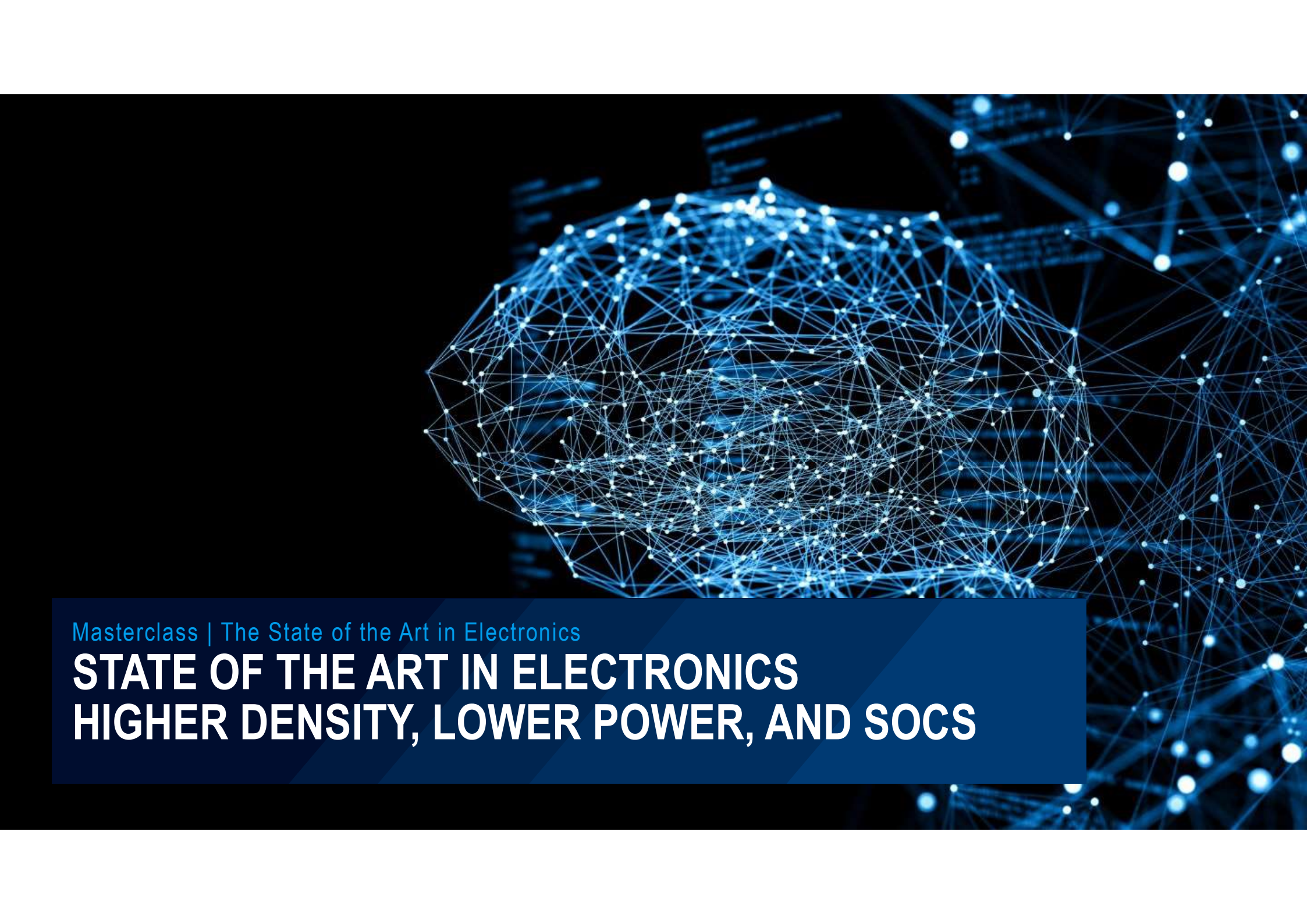


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# **STATE OF THE ART IN ELECTRONICS**

## **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  $f_T$  (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,  $f_{max} > 1$  THz
- ▶ SiGe BiCMOS:  $f_T$  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



A photograph of a modern office building complex with multiple stories, glass facades, and balconies. The building is surrounded by greenery and a clear blue sky. A dark blue banner is overlaid at the bottom of the image.

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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.



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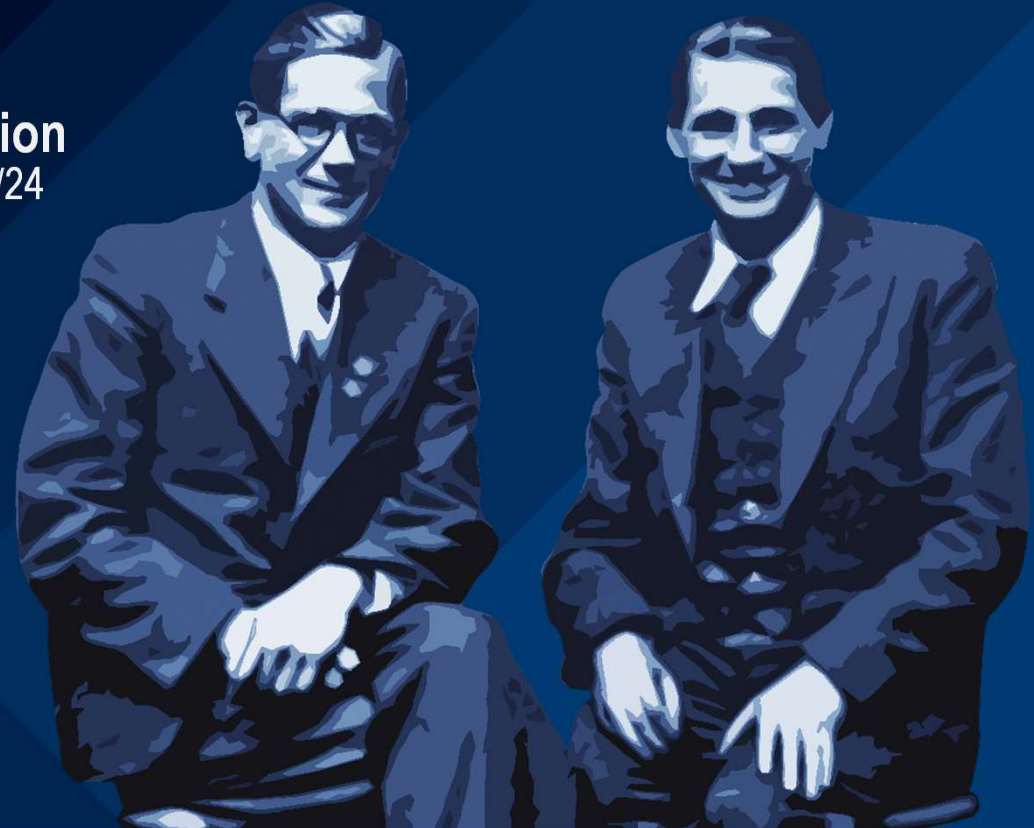
# FROM A TWO-MAN LAB TO A PRIVATELY OWNED GLOBAL COMPANY

**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



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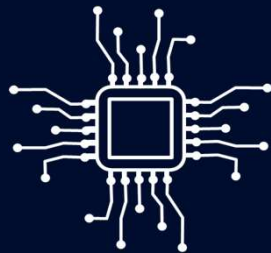
# WE LIVE INNOVATION AND MASTER OUR WHOLE VALUE CHAIN



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



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# ONE COMPANY – THREE DIVISIONS

## TEST & MEASUREMENT



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

## TECHNOLOGY SYSTEMS



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



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# 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.



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# R&S APPROACHES SUSTAINABILITY FROM VARIOUS ANGLES



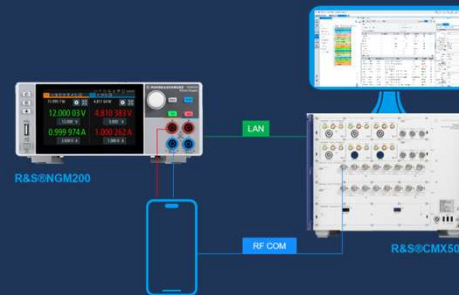
At our facilities



Analyse and improve, replace and optimize, avoid and reduce



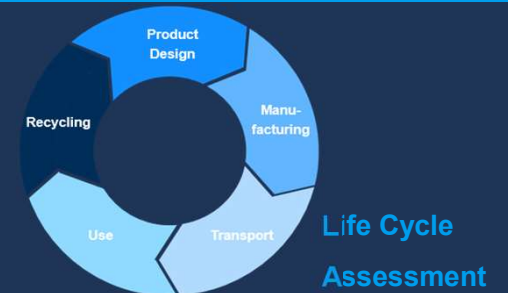
Part of our solutions



Test equipment to measure energy efficiency



Within our products



Approach over entire product lifecycle to improve environmental impact



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# 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



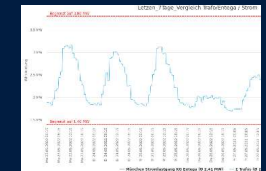
Energy efficient combined heat and power plants (CHP) in our plant in Teisnach, GER



Solar panels in our plant in Memmingen, GER



Energy Software to monitor energy use in our plants



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# 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



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# TEST & MEASUREMENT



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

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



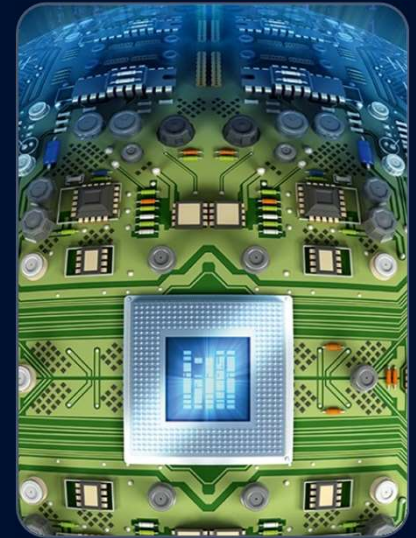
Wireless  
Communication (WIC)



Aerospace & Defense  
(ADT)



Automotive  
(AUT)



Industrial Electronics,  
Components,  
Research &  
Universities  
(ICR)



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# TEST & MEASUREMENT



Wireless | Industry, Components &  
Research | Aerospace & Defense Testing |  
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



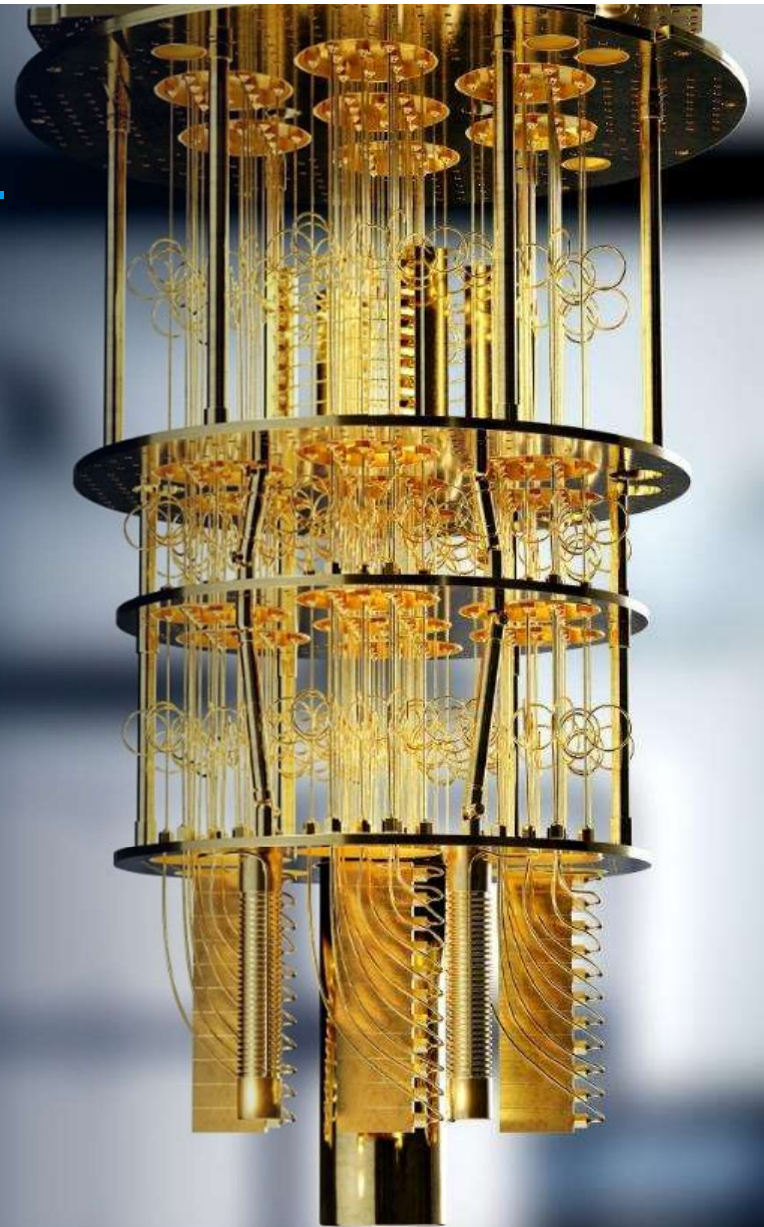
# Staying **RELEVANT** through Innovation

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

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



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 **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

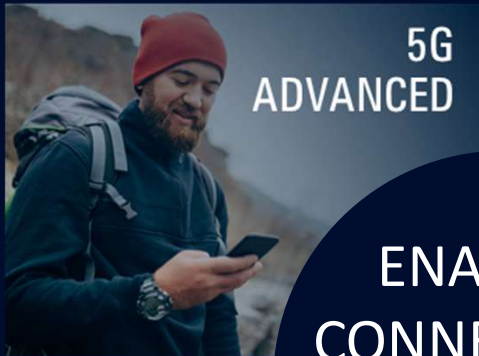


Standardize



Independent Reference





5G  
ADVANCED



MOBILE  
EXPERIENCE

ENABLING  
CONNECTIONS,  
EMPOWERING  
INNOVATION.



CONNECTING  
EVERYTHING



TOWARDS 6G

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



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# 5G FROM TERRESTRIAL TO SPACE

## 3GPP CALL IT NON TERRESTRIAL NETWORKS (NTN)

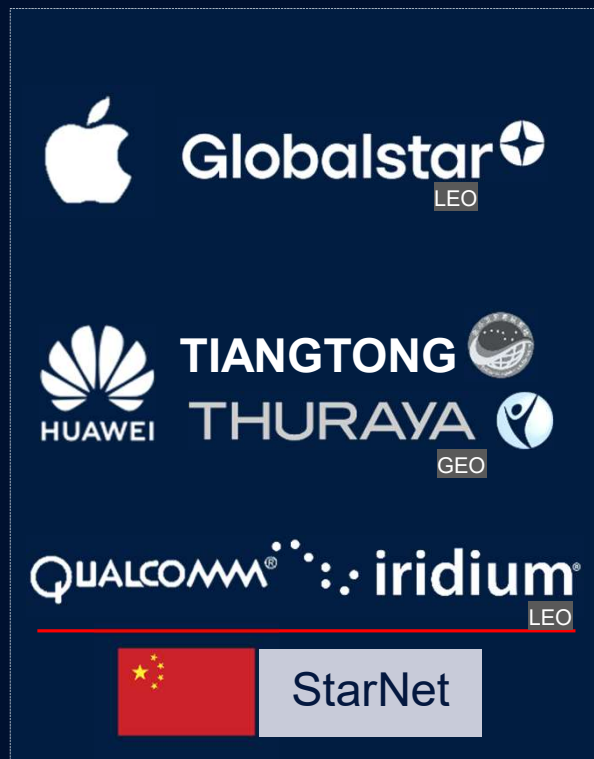


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# DIFFERENT IMPLEMENTATIONS OF NTN – DEVICE ASPECTS

## 3GPP VS. PROPRIETARY

### PROPRIETARY NTN



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



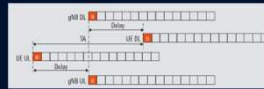
### 3GPP unmodified Direct to Device/Cell/Handset





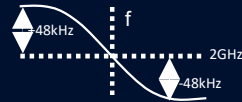
# NTN USER EQUIPMENT ESSENTIAL REQUIREMENTS AND CHALLENGES

## Time Synchronization



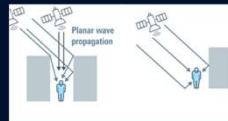
**Long delay and time variant delay:** Distance, UE to satellite causes long absolute delay (~40 ms for LEO and 544 ms for GEO). Orbital movement of satellite will cause a time variant delay during the connection time. Variable RTT due to Elevation angle and LEO, SIB31 K<sub>mac</sub> (RTT calc), K<sub>offset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

## Frequency Synchronization



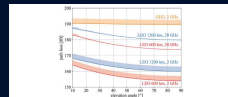
**Doppler shift:** Movements of LEO satellites causes a time and elevation angle variant Doppler shift.

## 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  $\geq -10$  dB, minimum RSRP  $\geq -137$  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

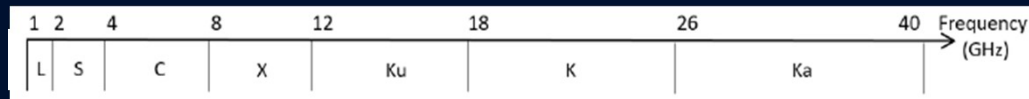


**Cell Acquisition**, mandatory GNSS, cell search, eDRX/PSM (start time of upcoming coverage info, repetitions in low CQI, UE to predict discontinuous coverage based on the satellite assistance information, SIB32).



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# NTN BANDS AND FREQUENC



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

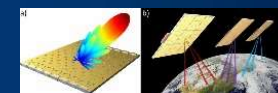
wideband

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



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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



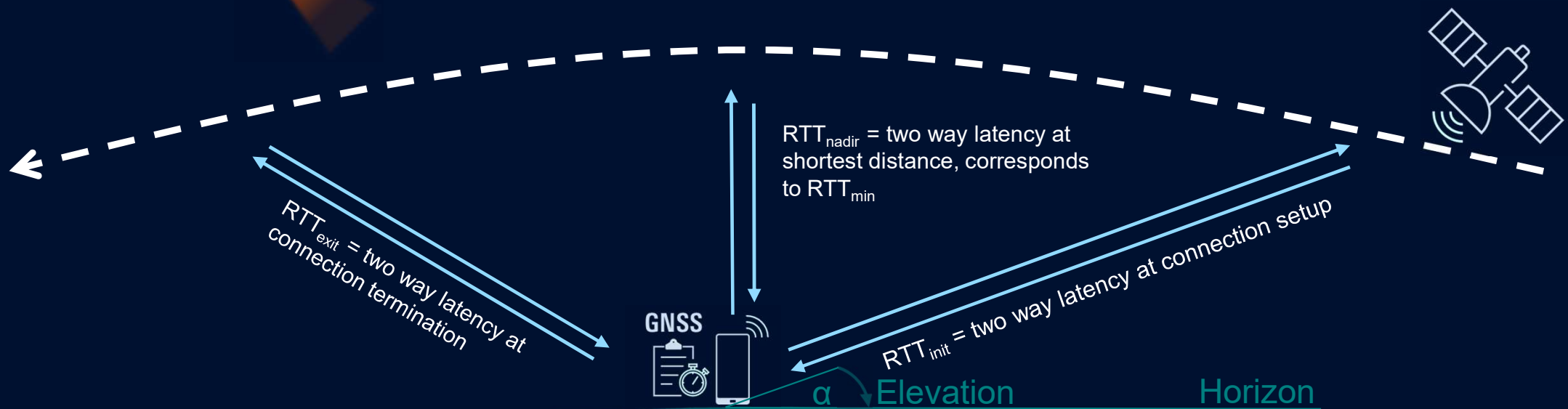
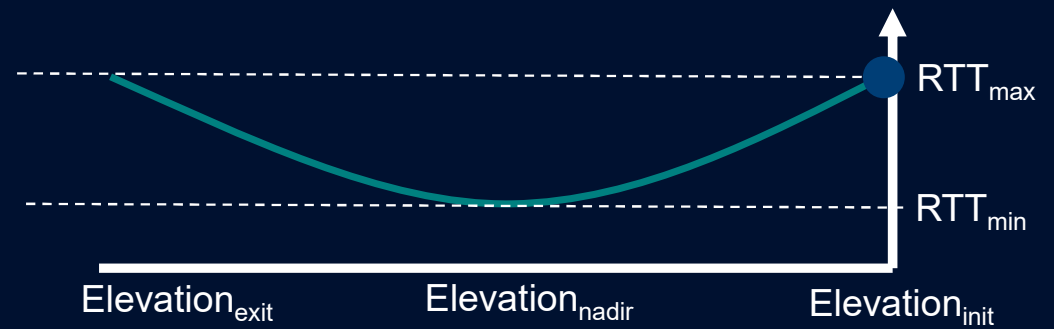
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NTN

# ROUND TRIP TIME



GNSS optionally used by  
LEO for orbit control



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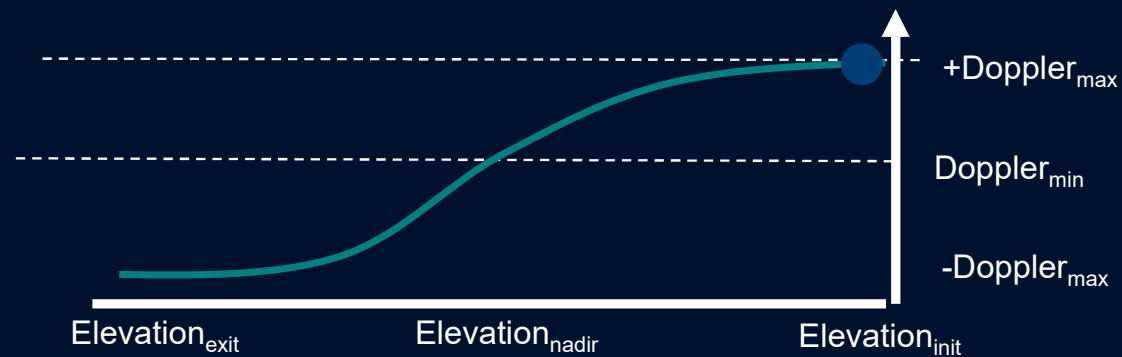


NTN

# DOPPLER



GNSS optionally used by  
LEO for orbit control



$\vec{v}_{\text{max\_leaving}}$

$\vec{v}_{\text{max\_approaching}}$

$\text{Doppler}_{\text{min}}$  = radial velocity with  
respect to DUT is 0

$-\text{Doppler}_{\text{max}}$  = max doppler shift  
at connection termination

$+\text{Doppler}_{\text{max}}$  = max doppler shift at connection setup

GNSS

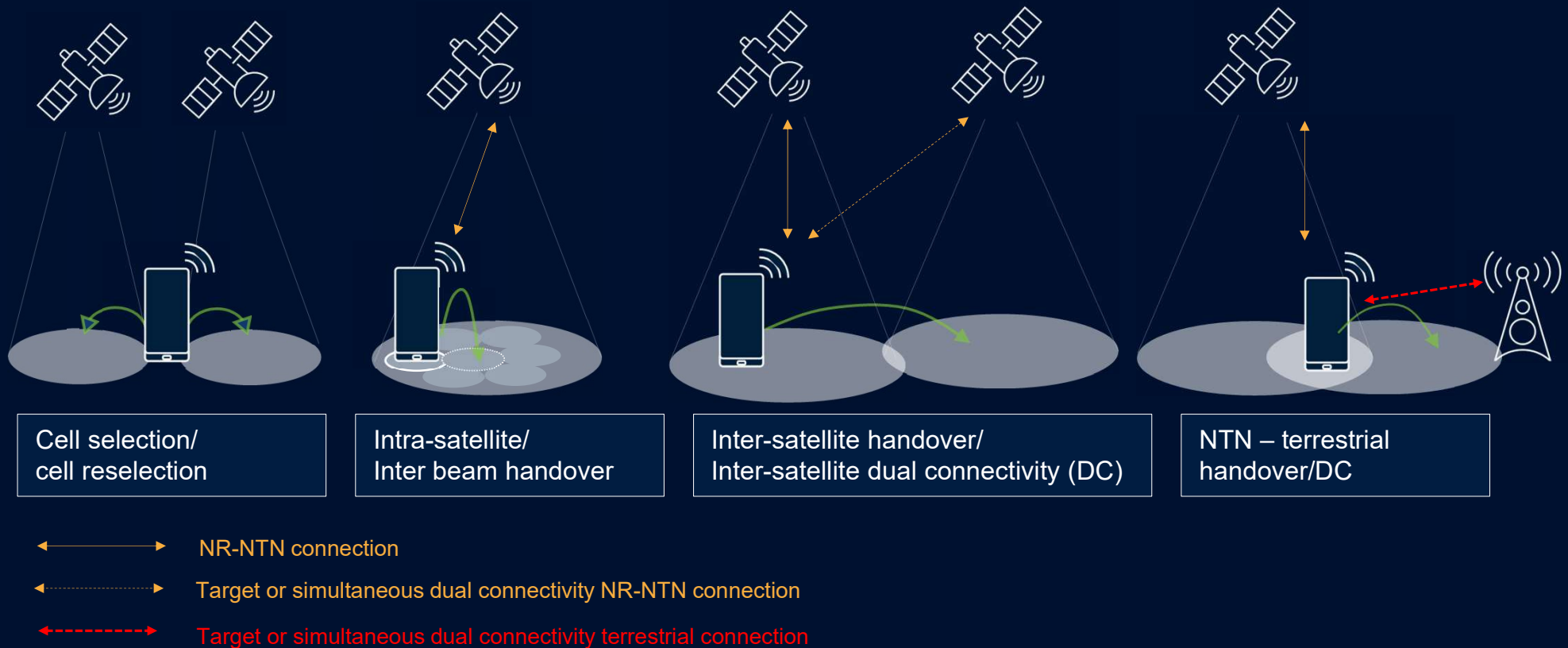
$\alpha$  Elevation

Horizon



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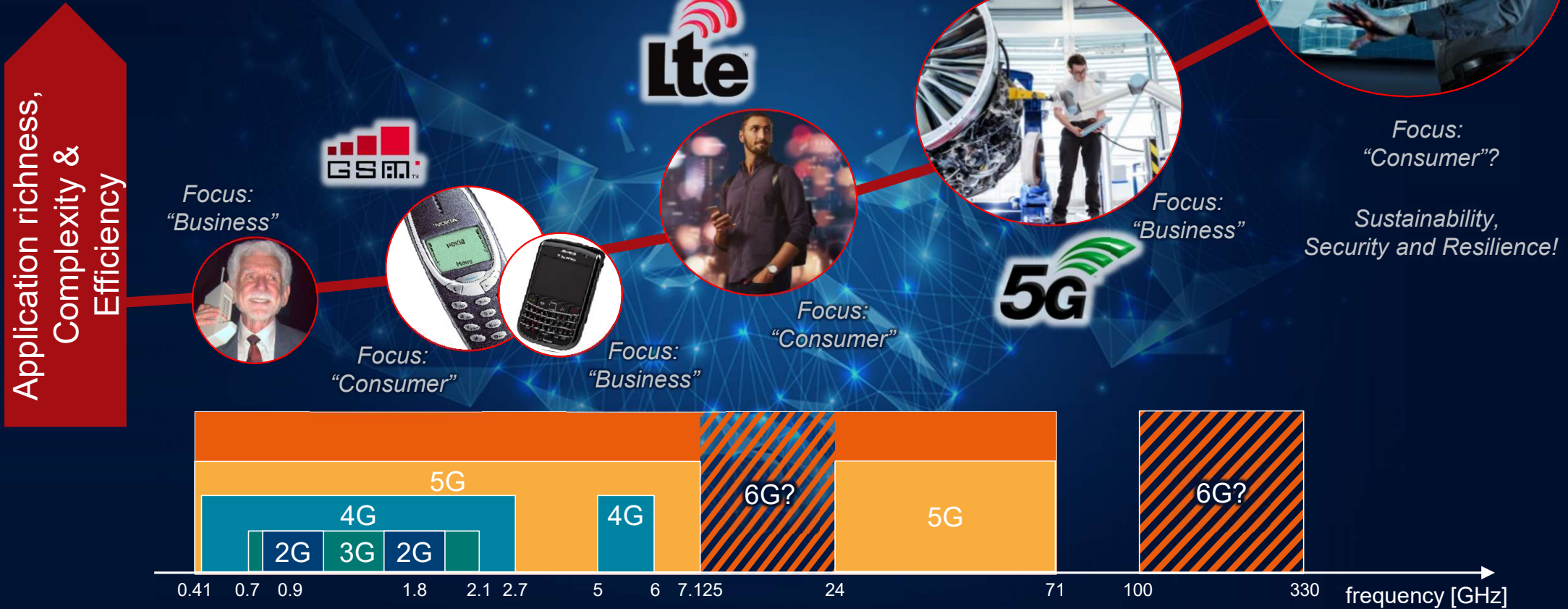
# MOBILITY SCENARIOS





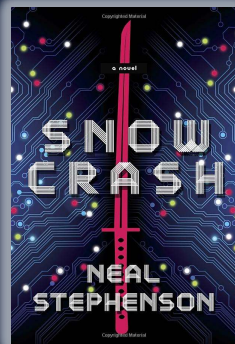
# From 5G to 6G

## 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



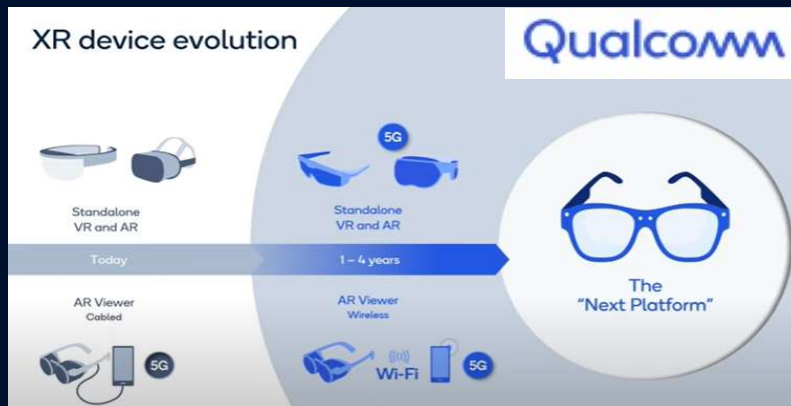
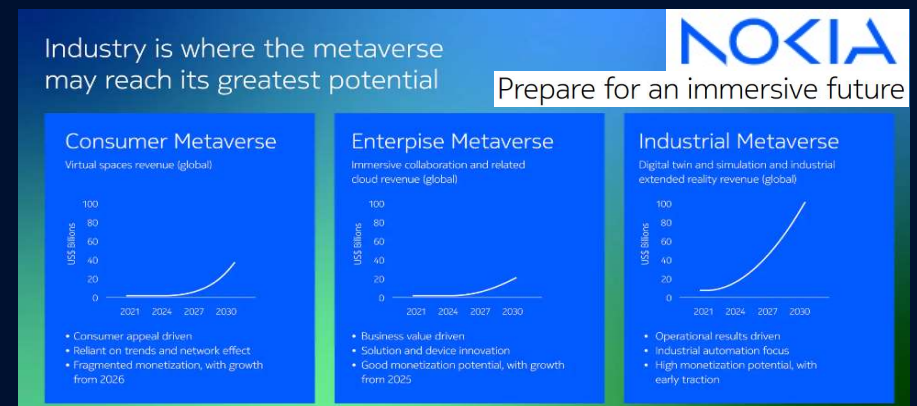
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A selection, there are many others...

# METaverse IS ON THE AGENDA OF ALL INDUSTRY PLAYERS

## INDUSTRIAL METAVERSE NOW, ENTERPRISE & CONSUMER FOLLOW



**6G - Connecting a cyber-physical world**

**EuCNC & 6G Summit**  
Wednesday June 7  
9:45-10:30  
Kongresshallen

**ERICSSON**



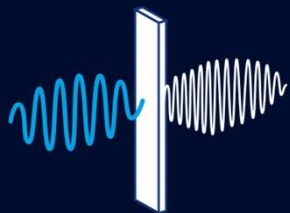
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# Research areas from an T&M perspective

## 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



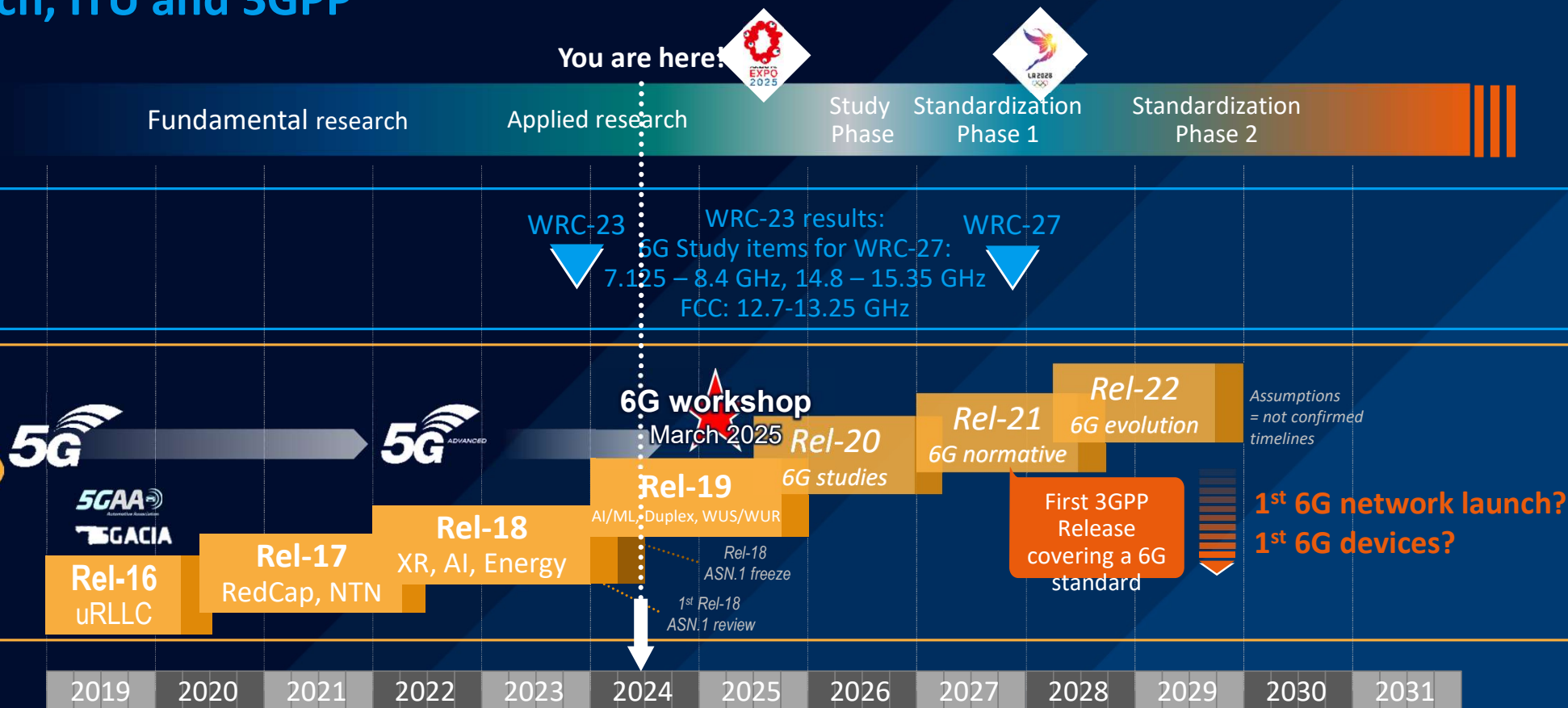
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A high-level overview of all these research areas is provided in one of our [#THINKSIX](#) videos



# 6G Phases and Timeline

## Research, ITU and 3GPP



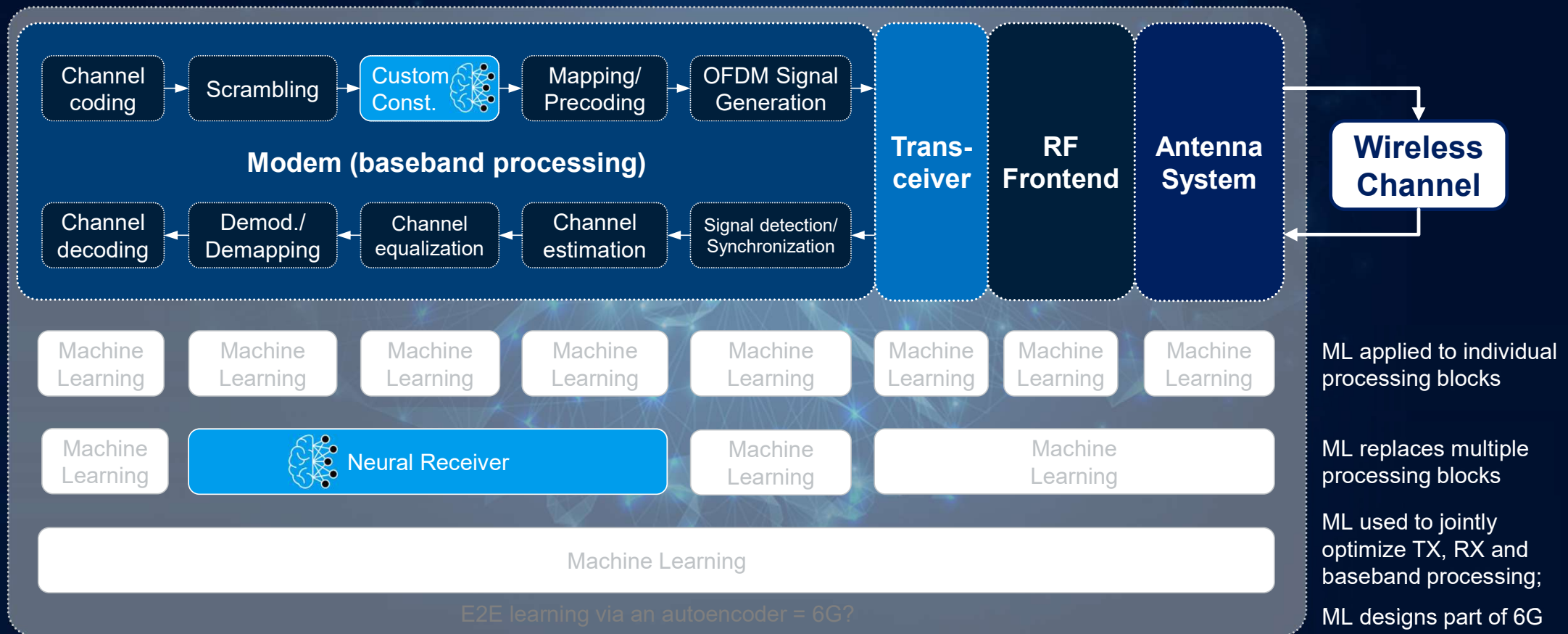
<sup>1)</sup> IMT-2020 systems are called 5G, The ITU has already started a new technology trend report to prepare the work on "IMT-2020 and beyond" that is likely to become 6G



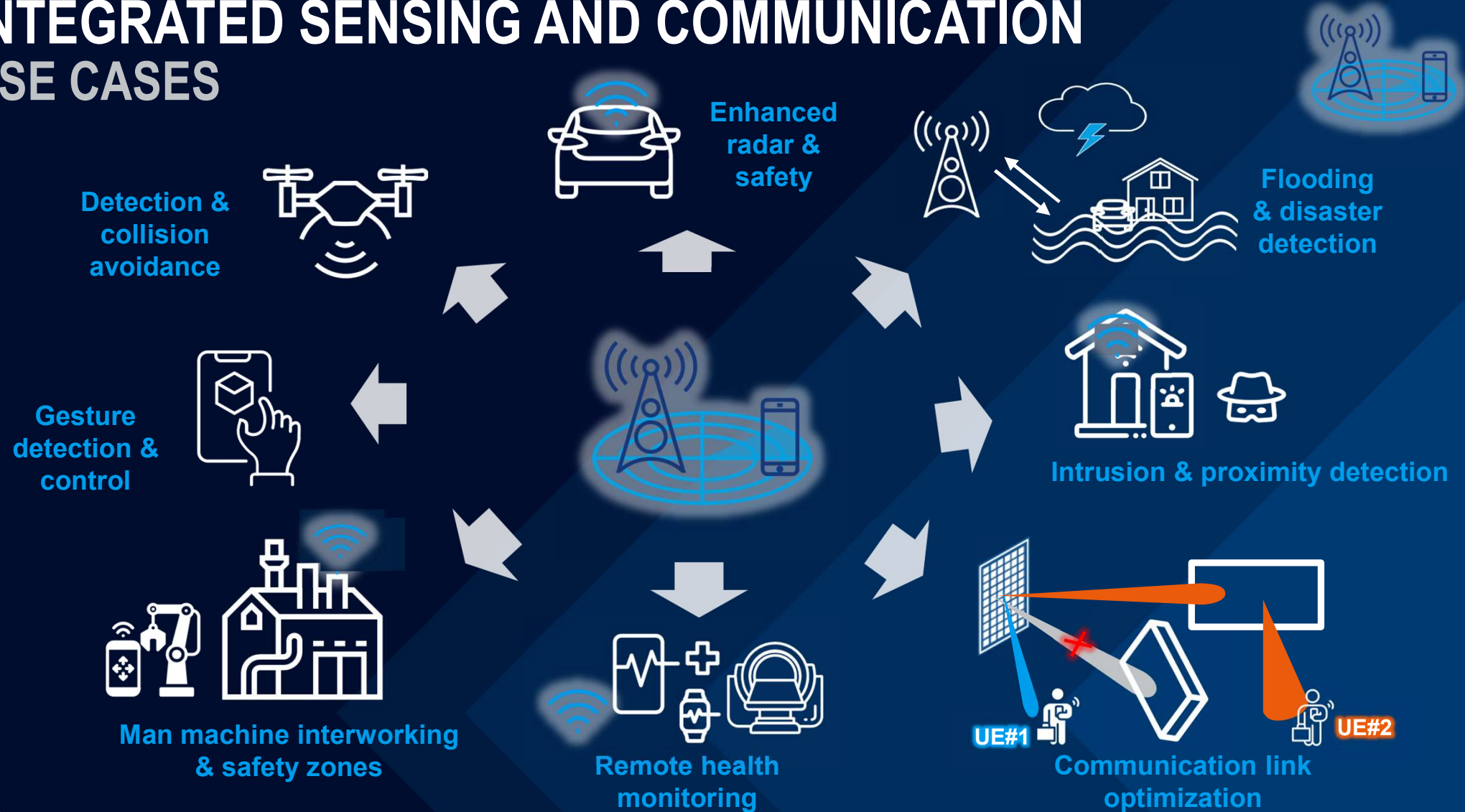
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# TOWARDS AN AI-NATIVE AIR INTERFACE FOR 6G

## ENHANCING THE NEURAL RECEIVER WITH CUSTOM CONSTELLATION



# INTEGRATED SENSING AND COMMUNICATION USE CASES

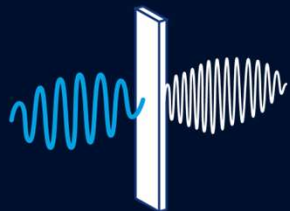






# RESEARCH AREAS FROM A T&M PERSPECTIVE

THz communication,  
and “FR3”



Integrated sensing  
& communication



Artificial Intelligence  
and Machine Learning



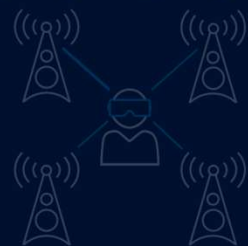
Reconfigurable  
Intelligent Surfaces



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



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Spectrum for 6G – What frequencies are we talking about?

# 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):



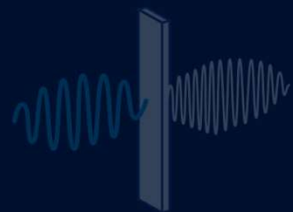
- Status after WRC-23 –  
New study items for input for WRC-27:
  - 4400 to 4800 MHz (in EMEA and APAC)
  - 7125 to 8400 MHz (excluding 7250 to 7750 MHz in Europe due to use by NATO)
  - 14.8 to 15.35 GHz
- Notable regional activities
  - FCC studies 12.7 to 13.25 GHz,





# RESEARCH AREAS FROM A T&M PERSPECTIVE

THz communication,  
and "FR3"



Integrated sensing  
& communication



Artificial Intelligence  
and Machine Learning



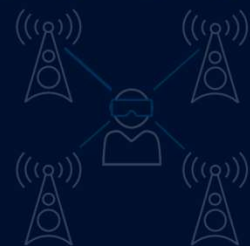
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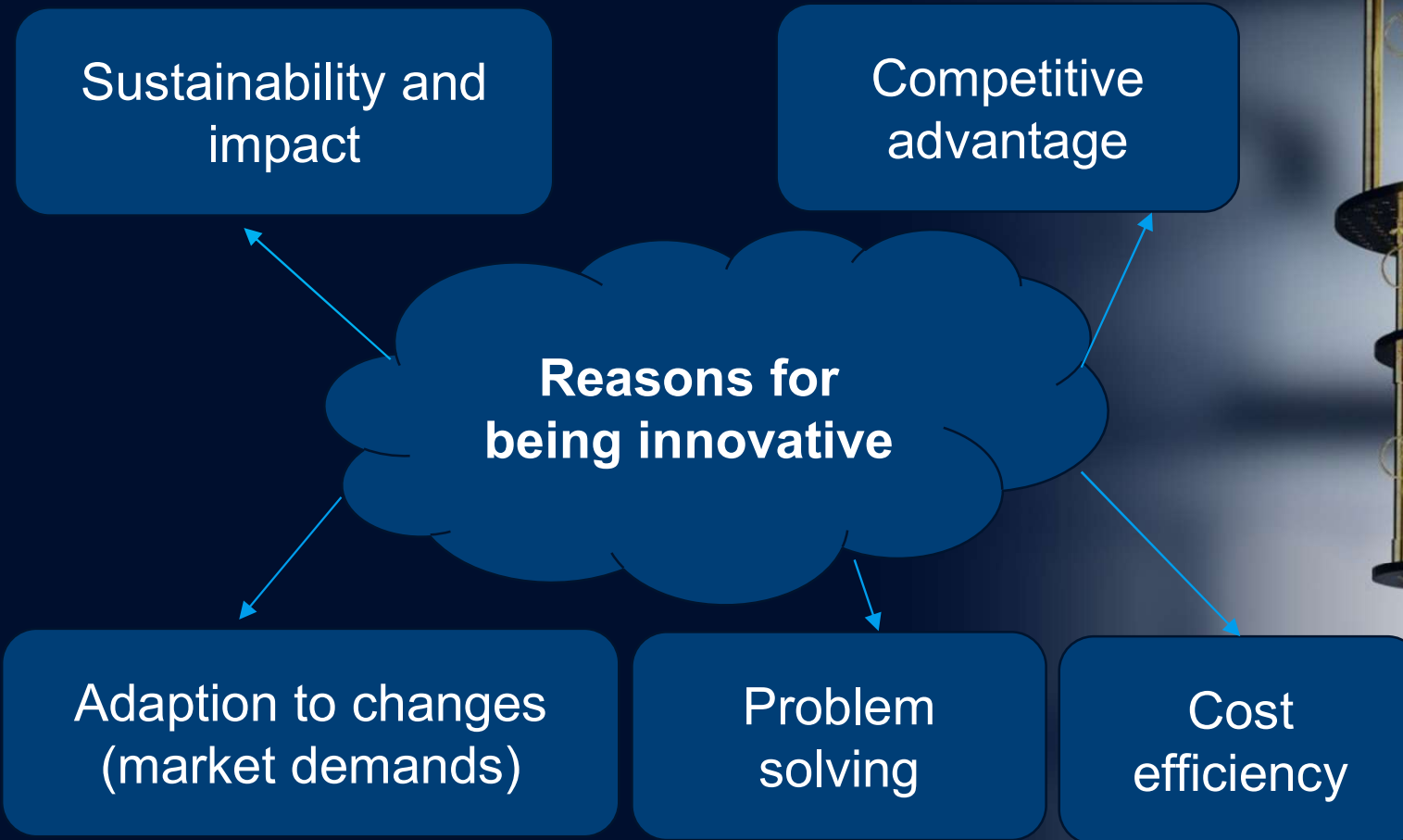
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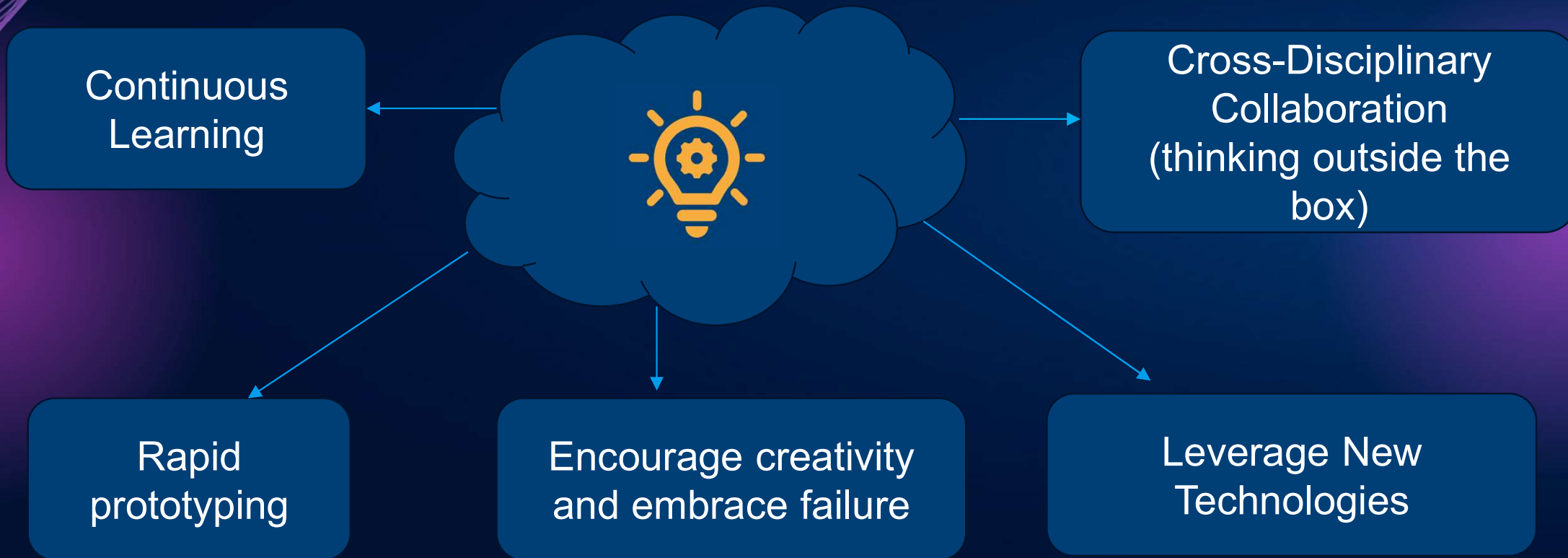
# SUMMARY

- ▶ 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?



# 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).

**ROHDE & SCHWARZ**

Make ideas real

Thank you for your attention!

