WELCOME TO AUSTIN

20042758

NI CONNECT

2023 AUSTIN

Enabling the 6G vision through test, measurement and prototyping

Work NI is doing to ensure that our products and offerings are ahead of the evolving 6G needs!

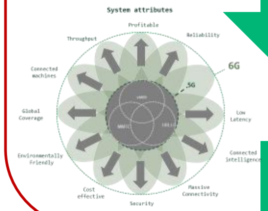
Marcus daSilva

NI Fellow

Enabling the 6G vision through test, measurement and prototyping

How NI's research products and offerings enable the evolution to 6G!

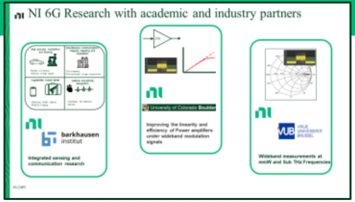
Wireless History



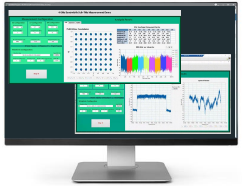
6G Vision

NI and the G's

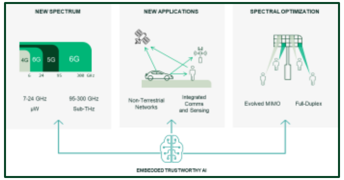
6G Research at NI



6G offerings and products from NI



6G Themes



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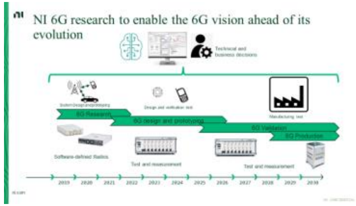
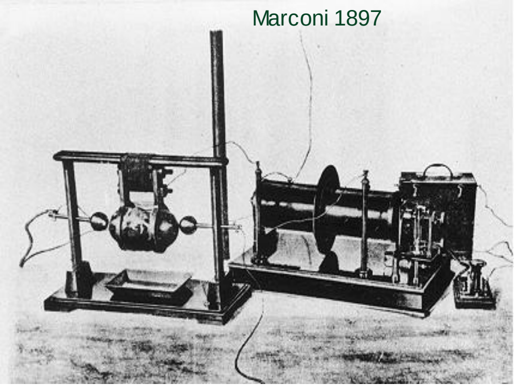


Zero G: Wireless communication is born in 1897

Telegraphy

Before1897: Telegraphy required a physical connection

Guglielmo Marconi



Telegraph becomes wireless

Telephony

1876: Alexander Graham Bell's telephone

Person-to-person voice connections remained wired for many decades!

The generations in **wireless** communications

1G
1980

2G
1990

3G
2000

4G
2010

5G
2020

6G
2030

- People to people voice
- Bits, text
- Internet access, email
- Internet access with high resolution video
- Connected machines
- XR, Ubiquity…

Evolution from human-centric to machine-centric communications

1G
Connecting
people

Human-Centric
Wireless Systems

Worldwide	2022		Notes
	Number	YoY Growth	
Population	8.0 B	0.9%	World Population growth is slowing Source: Data commons
Mobile subscriptions	8.3 B	2.0%	Nearing saturation Source : Ericsson Mobility report
Total IOT connections	13.2 B	13 %	**Continued Growth** Source : Ericsson Mobility report

6G
Connecting
people and
machines

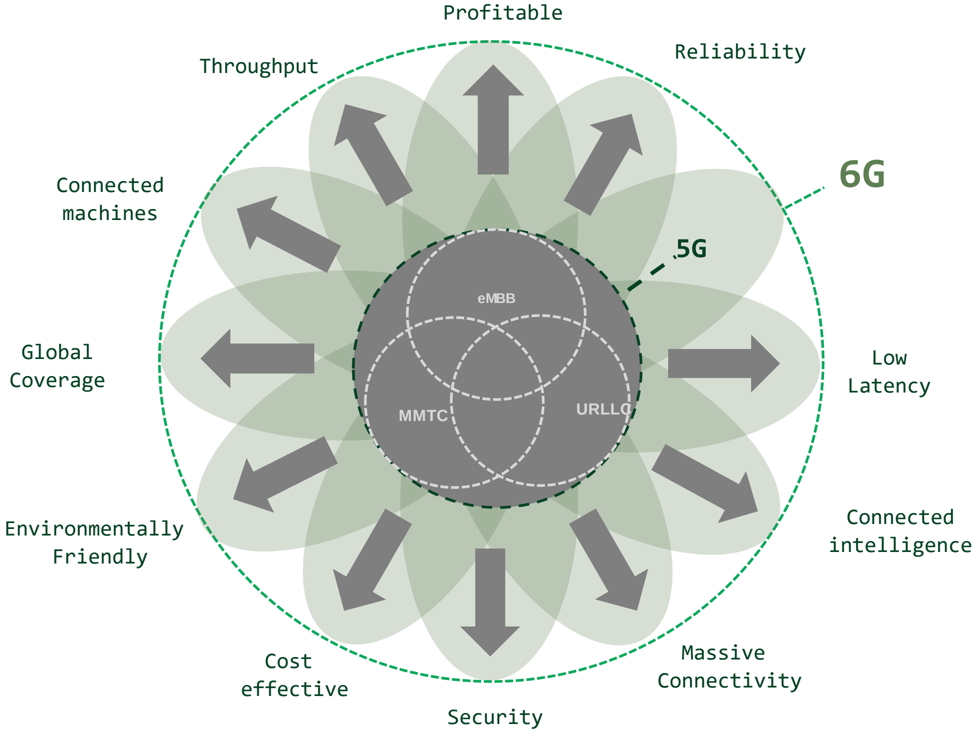
Machine-Centric
Wireless Systems

- **Inputs & outputs** are human-centric (audio, video, tactile)
- **Algorithmic** software and signal processing
- *Human-centric* **latency** requirements (100's of ms)
- H*uman population* density drives **Network throughput** needs
- **Systems** designed for *human-to-human* and *human-to-internet* connections
- **Infrastructure** built to cover people (cities, roads, etc.)

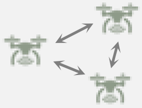
- **Inputs & outputs are machine-centric** (cameras, radar, motors, etc.)
- **AI/ML-based** intelligent machines and…networks
- *Machine-centric* **Latency** requirements (µs or better)
- *Density of connected machines* (>> population) drives **Network throughput requirements**
- Systems designed for **machines to collaboratively perform tasks**
- **Infrastructure** will include a **non-terrestrial layer** to cover the entire world.

The 6G Vision: An intelligent network interconnecting intelligent people and intelligent machines, anytime, anywhere.

System attributes



Applications


Wireless Cognition

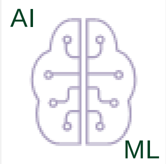

Wireless Sensing


Immersive XR


Device Location


Imaging & Radar


Mobile Hologram




Available anywhere, anytime

Enabling the 6G vision through test, measurement and prototyping: How NI's research enables the evolution to 6G!

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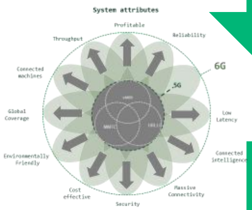

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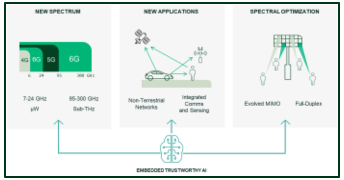
6G Themes



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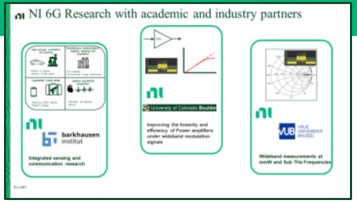
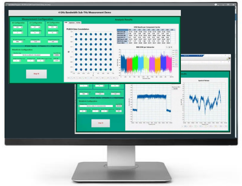


6G offerings and products from NI



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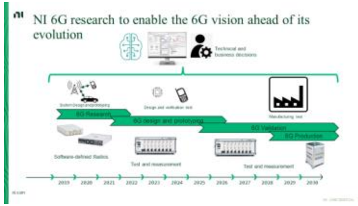
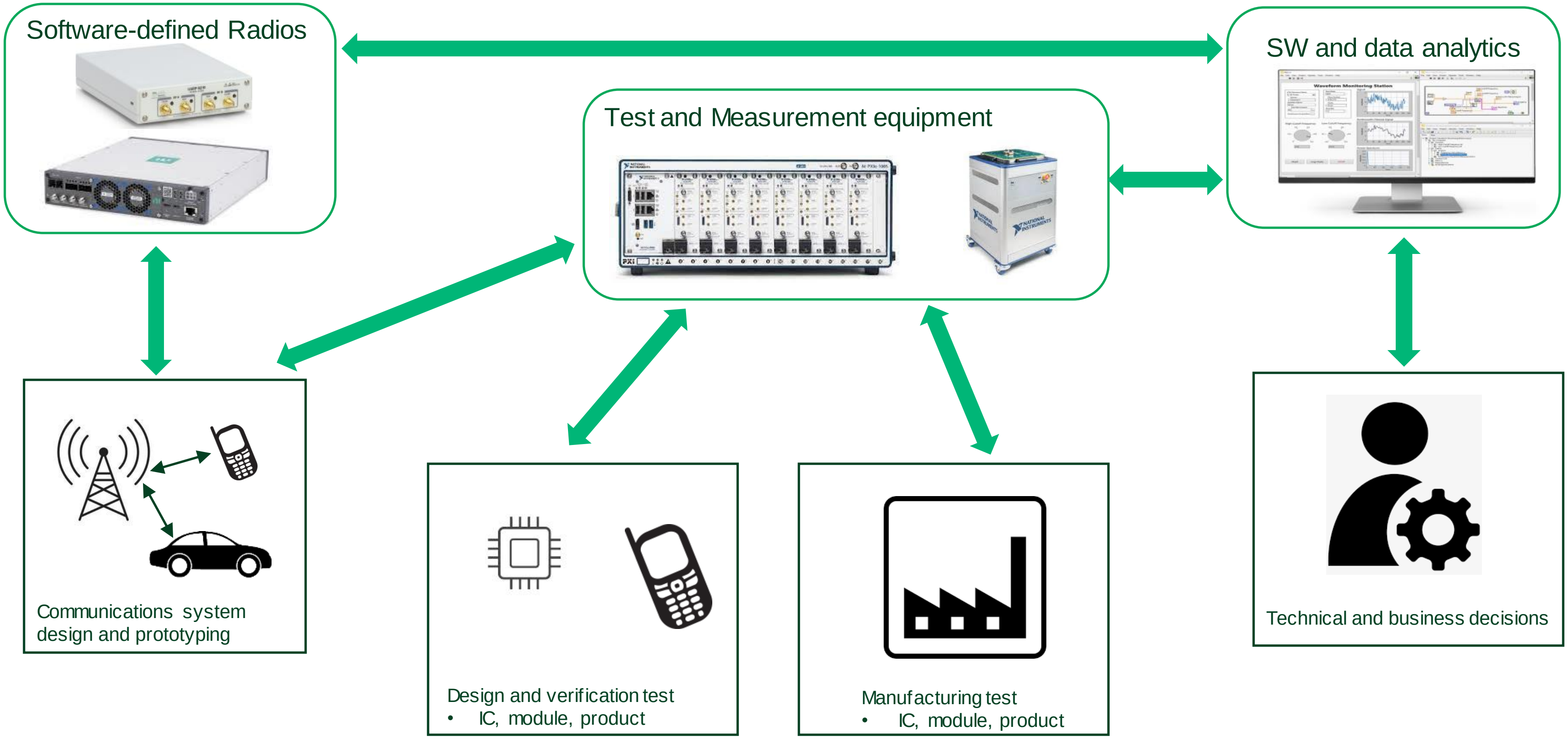
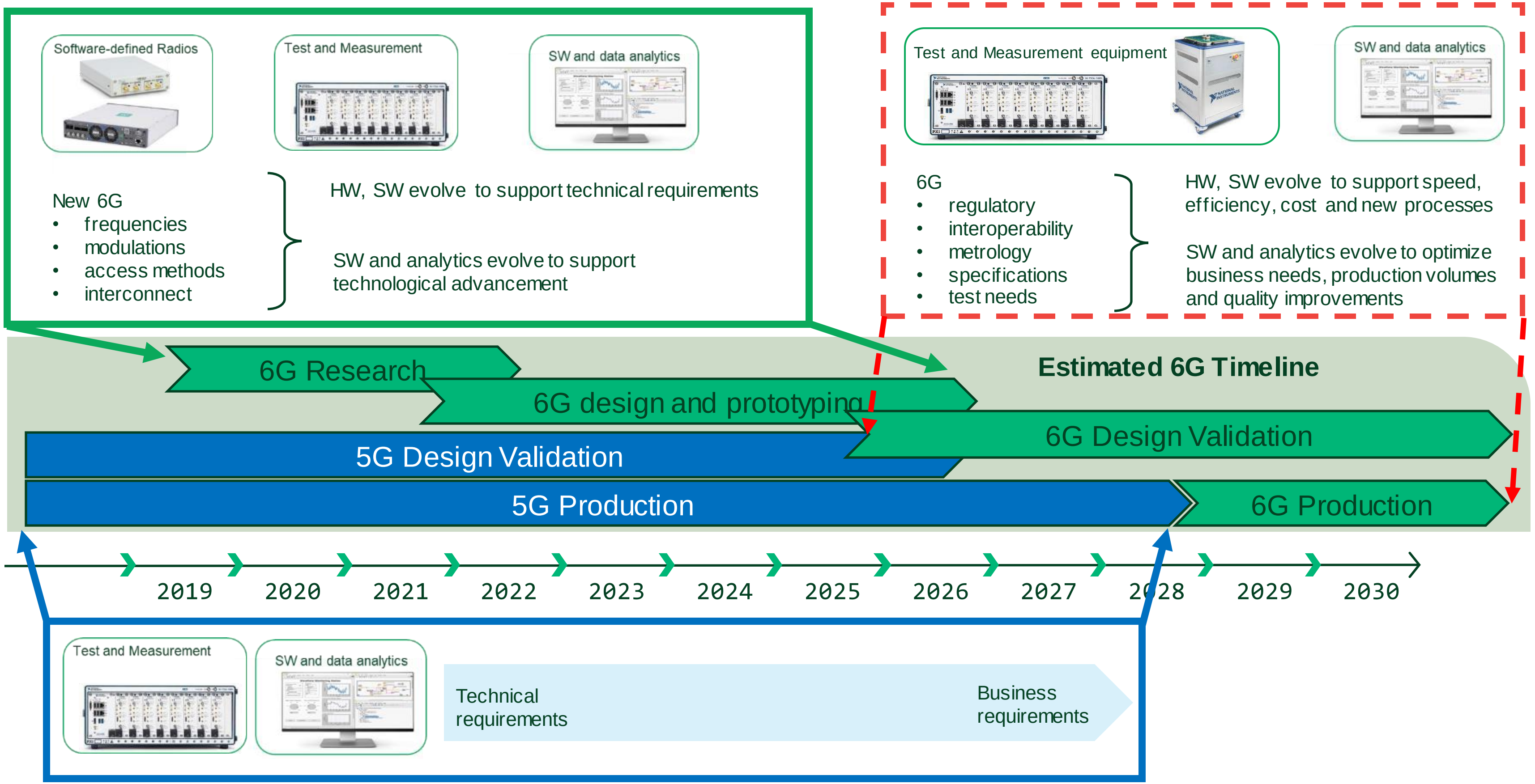


NI Products and offerings in wireless communications



NI products must evolve ahead of business needs



Enabling the 6G vision through test, measurement and prototyping: How NI's research enables the evolution to 6G!

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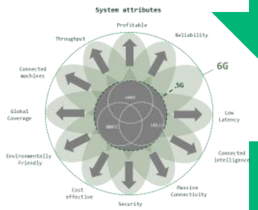

6G Vision

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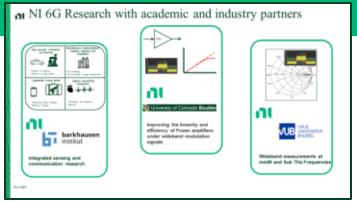

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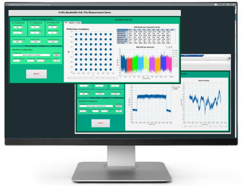

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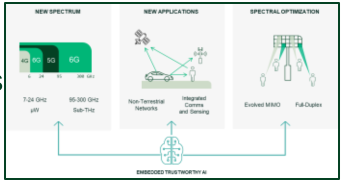

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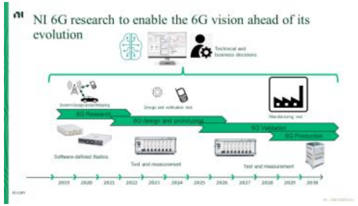
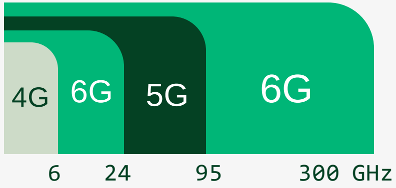


6G themes: Challenges and opportunities for NI

NEW SPECTRUM



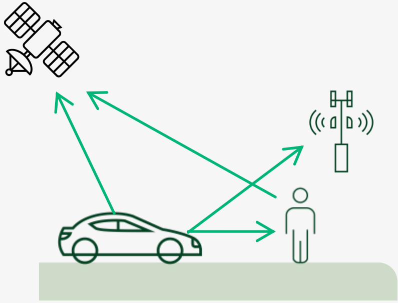
7-24 GHz

μW

95-300 GHz

Sub-THz

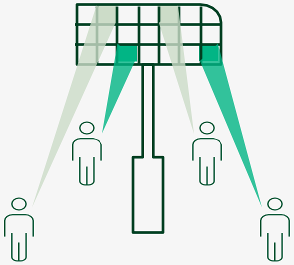
NEW APPLICATIONS



Non-Terrestrial Networks

Integrated Comms and Sensing

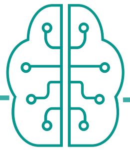
SPECTRAL OPTIMIZATION



Evolved MIMO

Full-Duplex

Spectrum sharing

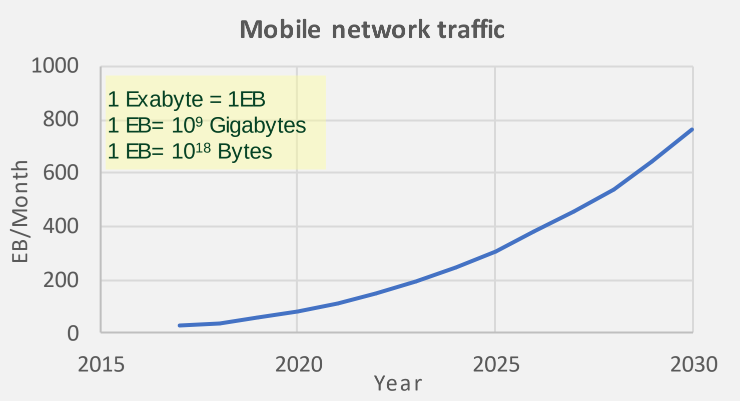


EMBEDDED TRUSTWORTHY AI

The need for new spectrum: higher frequencies

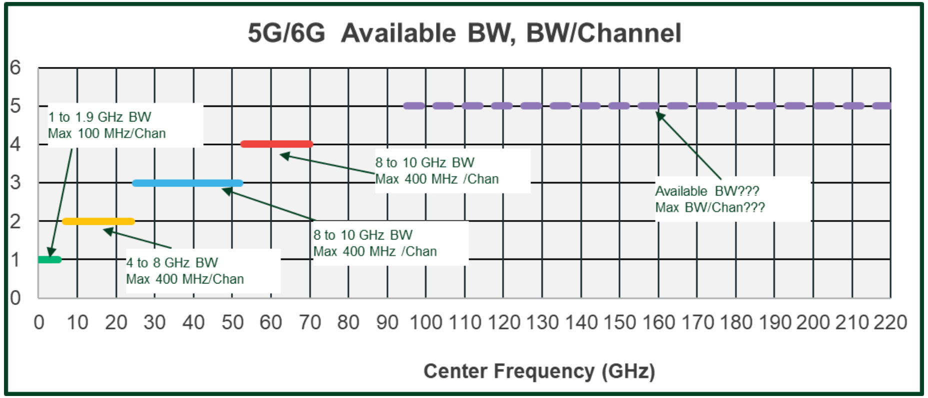
Economical use of higher frequencies

- uW (7 – 24 GHz)
- mmW (24-52 GHz)
- **Sub THz** frequencies (100 to 300 GHz



Mobile network data traffic has doubled every two years since 2017

- Expected to grow from 149 EB in 2022 to 760 EB in 2030



Multi GHz of contiguous BW is available at higher frequencies

- μW, mmW frequencies for SDR, VST, other test equipment
- **Immature measurement science for sub-THz Frequencies**
- **Multi-GHz BW is a challenge for both analog and digital signal processing**

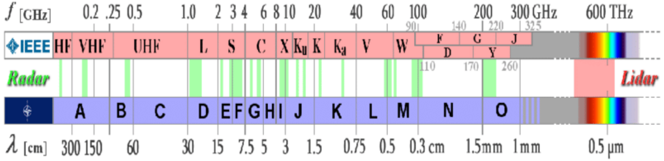
Spectral Optimization : Spectrum sharing

Governments have historically assigned valuable spectrum to legacy owners.

- Much of this spectrum is unused in any given location.
- Old technology uses this spectrum inefficiently.

Maritime comms and Radar

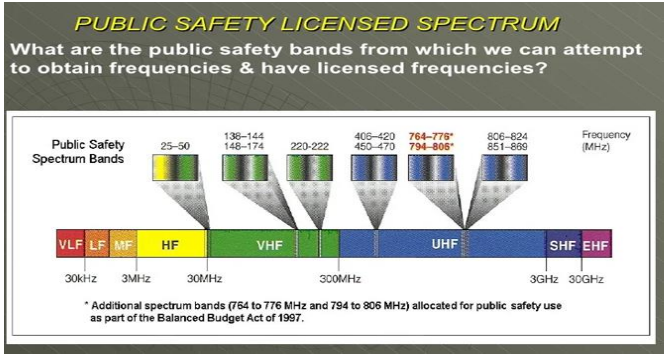
Aviation comms and Radar



Spectrum sharing would allow some of this unused spectrum to carry wireless communications signals

- Give priority to life-critical applications
- Use when/where spectrum is vacant
  - Listen-before-talk protocols
  - Dynamic spectrum allocation
  - National/regional coordination of spectrum usage

Public safety



Spectrum sharing technology can also allow more efficient partitioning.

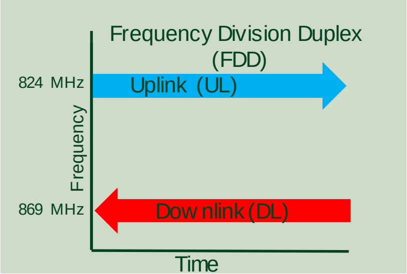
- Among various wireless providers
- Satellites sharing cellular spectrum

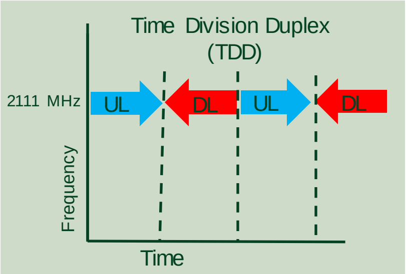
Satellite

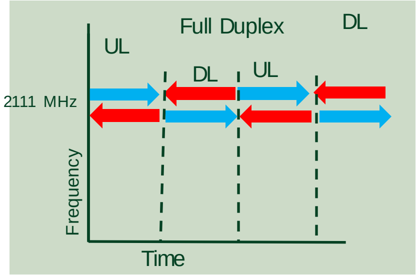
TV

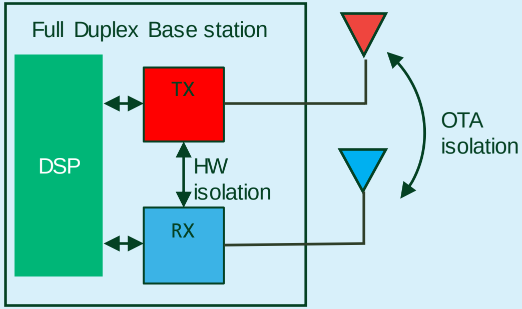
- SDR SW to emulate and study spectrum sharing
- Testing of spectrum sharing functions
- **SW and data analytics to monitor spectrum sharing function, compliance, interoperability**

Spectrum Optimization: Full Duplex Operation









Full Duplex Radio

- A full duplex radio must simultaneously do the following:
  - **Transmit a strong signal with** enough power to overcome the path loss to the intended receiver.
  - **Receive a weak signal** from the intended transmitter that has gone though the path loss, at the same frequency as the transmitted signal.

Full duplex Advantages

- Twice the BW at the same time
- Twice the time at the BW
- Lower latency

Full duplex Disadvantages

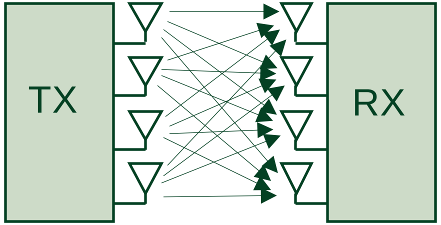
- Strong TX signals must be removed from weak RX signals

Full duplex operation will likely need a combination of:

- Over-the-air (OTA) isolation
  - TX antenna to RX antenna
- HW isolation
  - Directional devices
  - Shielding
- DSP
  - Removal of TX (Known) from RX
    - Digital compensation for non-linear effects
- AI/ML to adjust for environmental and thermal changes in coupling

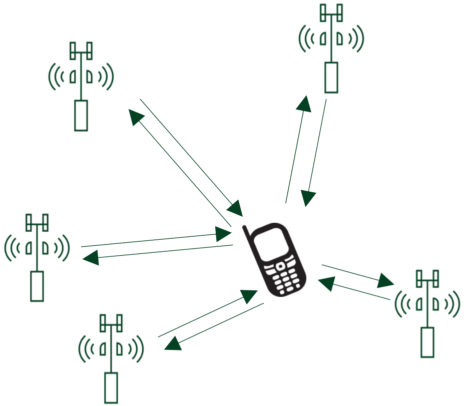
- SDRs that can perform full duplex operations
- Full duplex functionality will require
  - Over-the air-testing
- **Improved TX-RX isolation in RF test equipment**

Spectrum Optimization: MIMO evolution



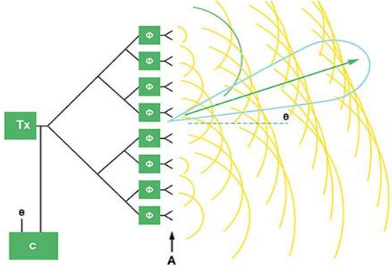
MIMO: multiple in multiple out

- TX and RX use multiple antennas
- Uses spatial diversity to increase data throughput for a given physical environment



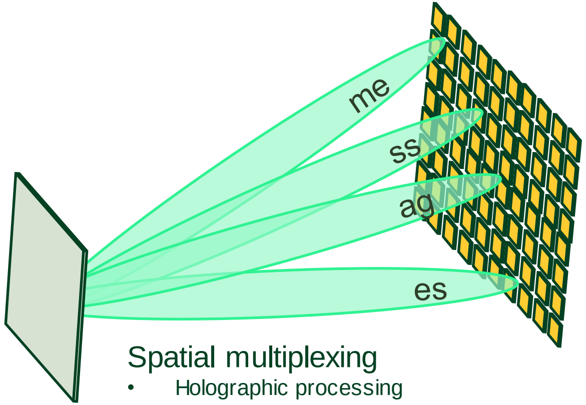
Distributed MIMO

- A form of MIMO where signals multiple bas stations that are not collocated are used along with multiple antennas for each TX and RX



Beamforming

- Sends RF power directionally
- Often realized with phased arrays



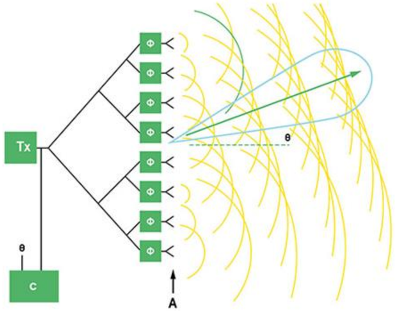
Spatial multiplexing

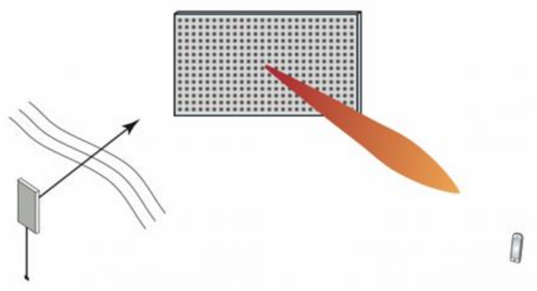
- Holographic processing
- A form of MIMO where data is distributed over space

- MIMO SW for SDRs
- Synchronize SDRs at a distance
- Encoding/decoding for spatial multiplexing
- **Build test equipment with lots of channels cost effectively**

New technology for managing RF beams:

Reconfigurable Intelligent Surfaces (RIS)



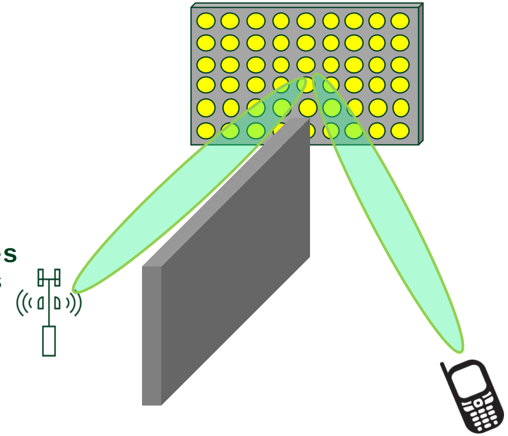


RIS as a beamformer

- A beamformer using a RIS has a single transmitter and an antenna with a fixed pattern.
- The wavefront from the antenna “shines” on a surface made up of many controllable reflectors.
- The reflectors are adjusted to create the desired beam.
- The individual reflectors have to be adjusted only fast enough to accommodate motion or changes in the propagating environment.
  - This is a BW of KHz not GHz.
  - Control can be easily done with a low-power CMOS processor

Conventional phase-array beamformer

- Uses individual phase shifters for each element

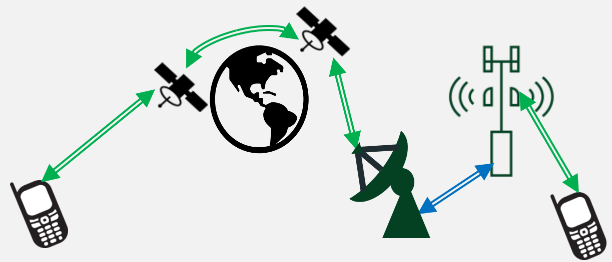


RIS used to direct a beam around obstacles

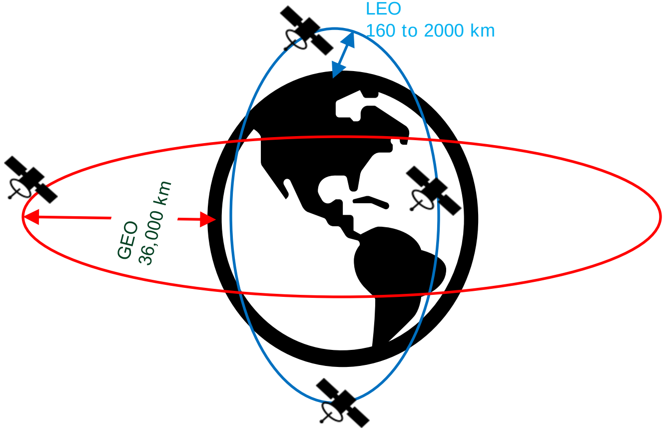
- A RIS can be used to direct signals around obstacles
- Both TX and RX can be moving.

- OTA testing of RIS functions
- **Using RIS in testing of beamforming devices**

New Application: Non-Terrestrial Networks (NTN)



6G Vision:
Same user equipment works for cellular and NTN



Ground-based phones have limited power and poor antennas.

- 100’s to 1000’s of satellites
- Low Earth Orbit (LEO)
- Very large antenna arrays in orbit

LYNK

iridium connected

amazon | project kuiper

STARLINK

Existing NTN: Specialized user equipment

- SDR application for emulating NTN links
- Testing satellite, ground station HW
- **SW/data analysis tools to predict failures and extend satellite useful life?**

New application: Integrated sensing and communications (ISAC)

Autonomous vehicles, robots, farm machinery,…

- Location, velocity, proximity to other objects as well as communication

Humans Augmented human sensing

- Gesture recognition

Communications systems …

- TX/RX, interference location
- Improved beamforming

Integrating Communications and sensing functions

- Optimized size, weight, power, spectrum efficiency

It's a phone
It's a radar
It's VR

6G equipped robotic tractor

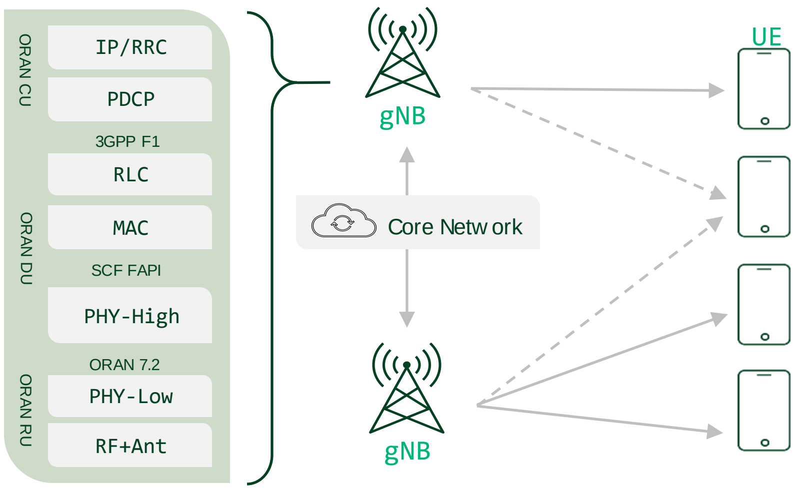
Communicates with operators located anywhere.
Locates itself, hazards, obstacles
Detects debris, anomalies, boundaries
Identifies weeds, pests, etc.
Makes decisions based on what it senses

- Testing radar as well as communications waveforms and functions in IC and modules that include ISAC
- Prototype sensing waveforms and functions in SDRs
- **Need to test devices that transmit and receive at the same time, same frequency.**

AI/ML in 6G communications

Wireless / Mobile Communications

- **Network Level:** Data flow management, network parameter optimization
- **MAC:** Time/Frequency/Spatial resource scheduling (spectrum sharing), (mmWave) Beam acquisition / selection & tracking
- **PHY:** Channel estimation & equalization, symbol detection, channel en/decoding
- **RF:** Spectrum sensing, Digital pre-distortion



6G is bringing AI/ML to the physical layer and RF

- Provide tools for obtaining training data sets.
- **New paradigm in signal processing means that outputs not uniquely determined from inputs.**
  - **How do you test AI/ML-based products?**
  - **AI to test AI?**
- **Can AI/ML be used for optimizing RF performance of NI equipment?**

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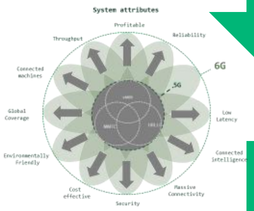
Wireless History



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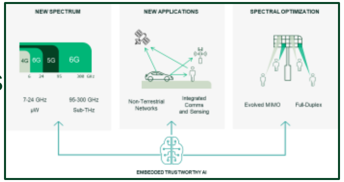
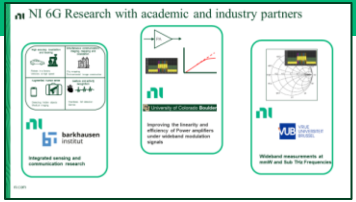


6G Research at NI



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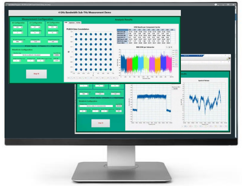

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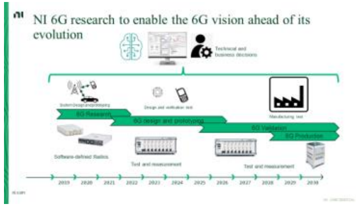
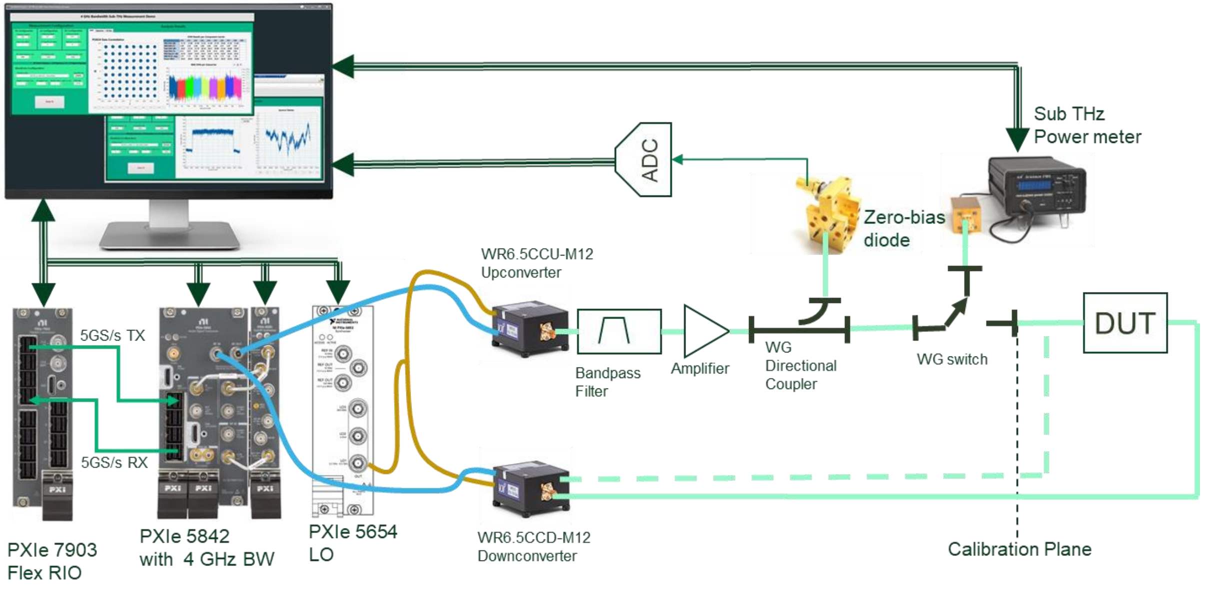


Sub THz research.

Research leading to system offering
- NI + 3rd Party Components
- Sub THZ system design
- Calibration
- Automation SW



Target capabilities
- Emulate Sub THz link
- Wideband Channel sounding
- Wideband modulation generation and analysis
- Spectrum analysis

- 4 GHz BW @ 110 to 170 GHz
- Extendable to other Sub THz bands
- RX/TX Measurements
- Calibrated power, channel flatness
- Spectrum analysis
- Real time data streaming

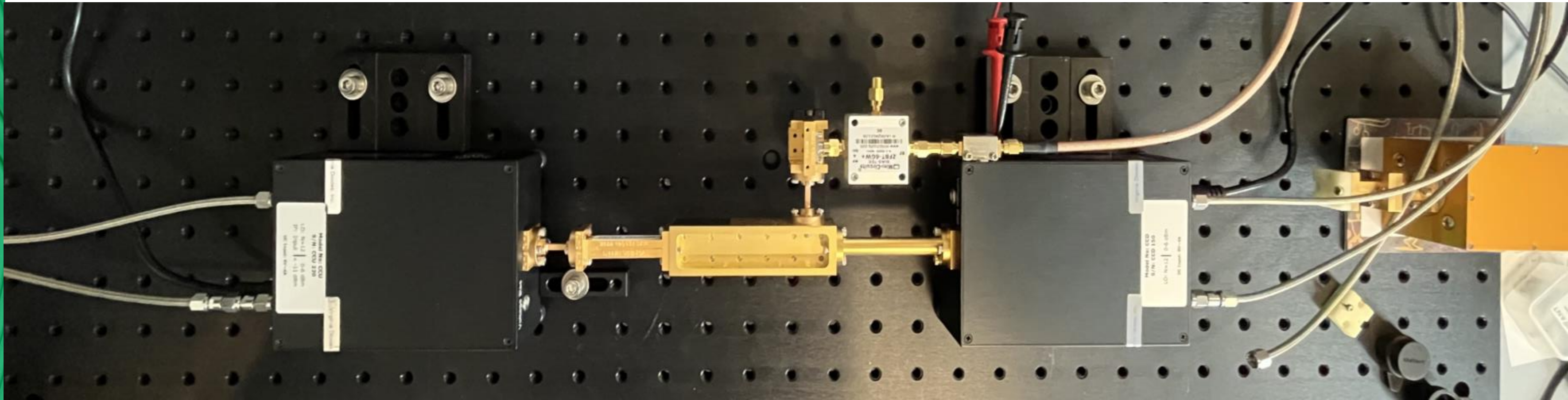
Sub THz challenge: Metrology above 100 GHz

NI's Goal: Enable measurements at mmWave and sub-THz with the same confidence and ease of sub-6GHz

Overview: Understand the uncertainty and accuracy in the measurement of RF signals in the sub-THz frequency domain

Exploring new technologies

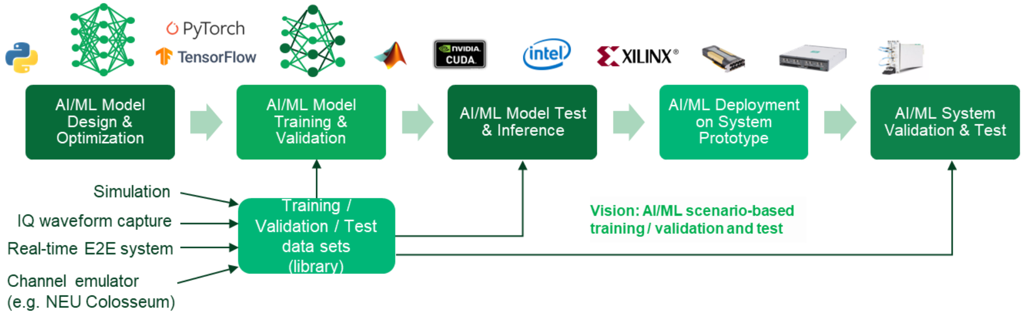
- Traceable standards and transfer mechanisms
- Conducted and OTA measurement interfaces
  - New connector and antenna technology needed to be explored for test



Research into AI/ML in RF Wireless

AI/ML Research goals

- Simplify Adoption of AI-ML Technologies for RF Wireless
  - Acquire and manage **real-world data** needed to train and validate AI/ML systems
  - Encourage standardized and **open data and meta-data formats**
  - **Test** these systems at under variable conditions
  - Support / Improve the **ML workflow** from design to test to real-world deployment



Specific Objectives

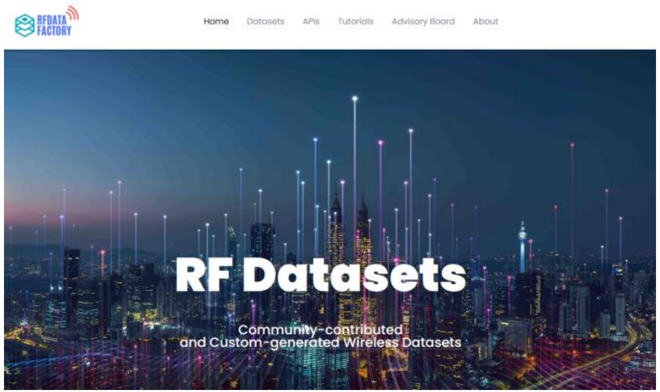
- Create a **reference architecture for data set recording**
  - Data collection & pre-processing APIs
  - Explore the use of existing NI software for data set management
- Understand AI/ML model **training & validation workflow** for RF / wireless

Partnership with **Northeastern University** to inform our AI/ML work and follow closely **3GPP AI/ML standardization** efforts

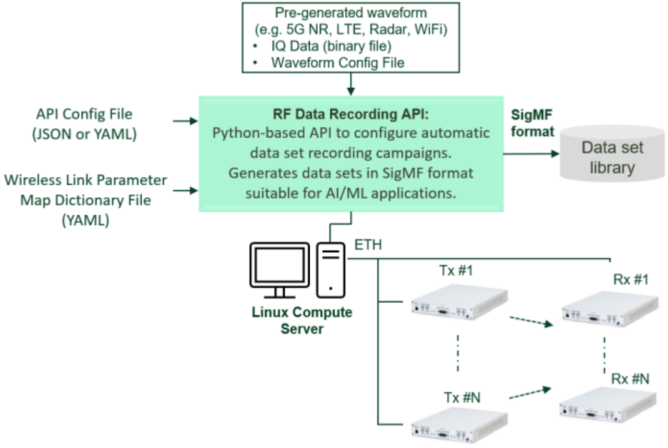
- DR. Kaushik Chowdhury

Streamline Real-World RF Data Set Recording

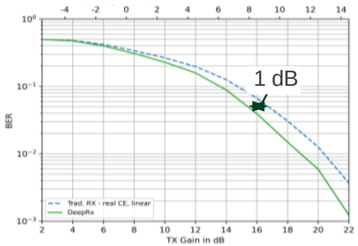
- AI/ML algorithms need **large data sets** representing a wide variety of potential scenarios
  - Simulation
  - Real-world
- **Challenges for AI/ML in RF wireless comms**
  - Lack of re-usable reference data
  - No common tool sets, disparate data & metadata formats, missing or incomplete scenario descriptions
  - Generating data sets with comprehensive metadata is often a manual process
- **NI & NEU** jointly created and published a Python based **AI/ML RF Data Recording API** leveraging NI's SDR platform
  - Real-world RF data set recording campaigns
  - **Open source and freely available on GitHub:** https://github.com/genesys-neu/ni-rf-data-recording-api
  - **Application note** about usage of data recording API available: https://knowledge.ni.com/KnowledgeArticleDetails?id=kA03q0000019mApCAI&l

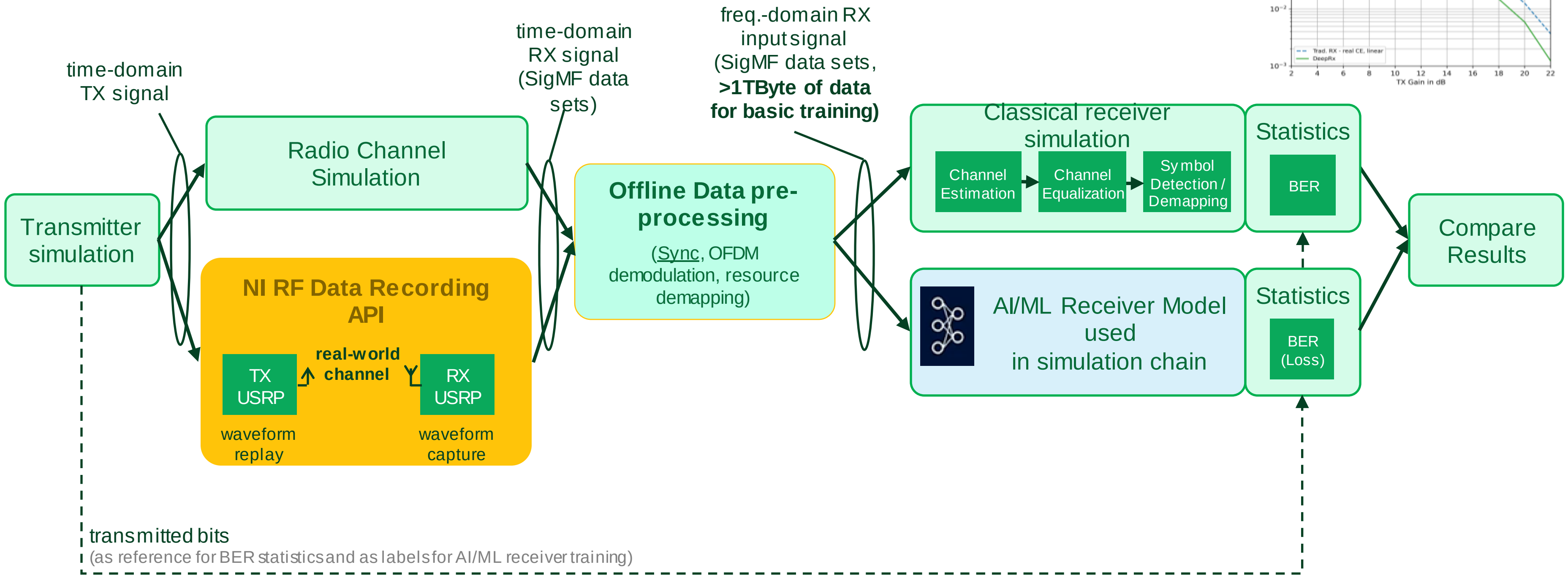


RF Data Factory project addresses the missing data set challenge (funded by NSF & coordinated by Northeastern University (NEU))

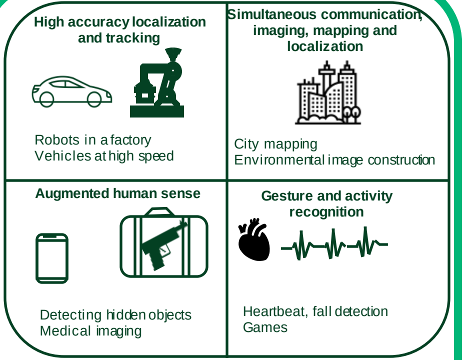


Example: Training and Validation of AI/ML Receiver Model in Simulation and Real-World Scenarios

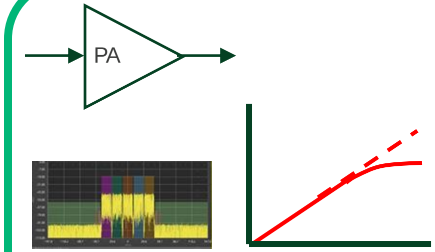




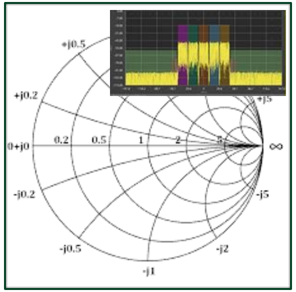
NI 6G Research with academic and industry partners



Integrated sensing and communication research



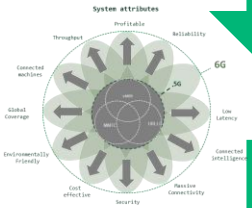
Improving the linearity and efficiency of Power amplifiers under wideband modulation signals



Wideband measurements at mmW and Sub THz Frequencies

Enabling the 6G vision through test, measurement and prototyping: How NI's research enables the evolution to 6G!

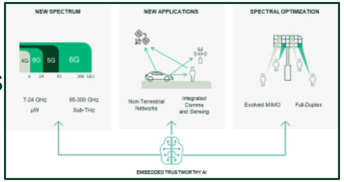
Wireless History



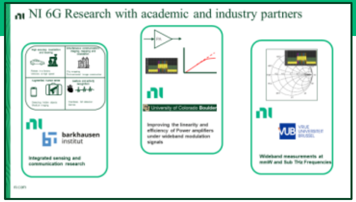
6G Vision

NI and the G's

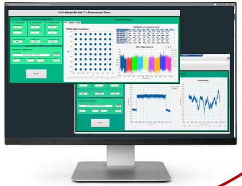
6G Themes



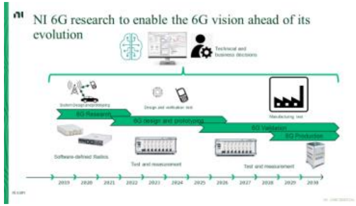
6G Research at NI



6G offerings and products from NI



Concluding remarks

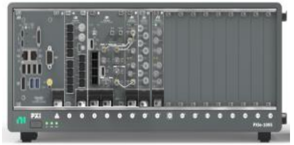


Two Platforms for RF Prototyping and Deployment

Low SWaP-C Prototyping with USRP

Differentiators:

- Broad portfolio of low-cost <$25k COTS SDRs
- Integration of RF with baseband and digital
- Open-source Software, wide toolchain adoption
- Enables software migration to hardware



High-performance Prototyping and Validation with PXI RF

Differentiators:

- One instrument for all FR1, FR2, and FR3 frequency ranges up to 54GHz
- Instrument-quality SDRs with latest ADC/DAC and RF Technologies
- Native mixed-signal capability (Digital, RF, Analog, etc.)
- Modularity and scalability supporting high channel counts
- Automated Sync Routines for Repeatable Phase Coherence
- Hardened Infrastructure for data streaming, real-time processing, and storage
- Future Real-Time 4 GHz BW with Co-Processor

Q2 2023

PXIe-5842 23GHz, 4 GHz IBW | Overview

Technology demonstrator

PXIe-5842 **with 4 GHz IBW**

- Expands instantaneous bandwidth from 2 GHz to ***4 GHz***
  - Above 8.8 GHz center frequency
- Real-time signal processing and control
  - ***Constant 5 GS/s*** sampling rate for RX ,TX I&Q
  - **20 GS/s** processing rate
- An ***US export license*** is required, P/N: 789379-01
- Shipping examples available for 5G NR EVM or streaming 4GHz to a PXIe-7903 co-processor

PXIe-7903 FPGA Coprocessor

Q2 2023

Release: Q2-2023

Summary:

- FlexRIO Co-processor and High-Speed Serial Instrument
- Largest, highest-performance FlexRIO FPGA
- High-speed streaming interface to one or more VST instruments

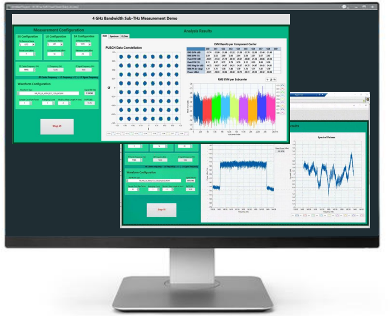
Key features:

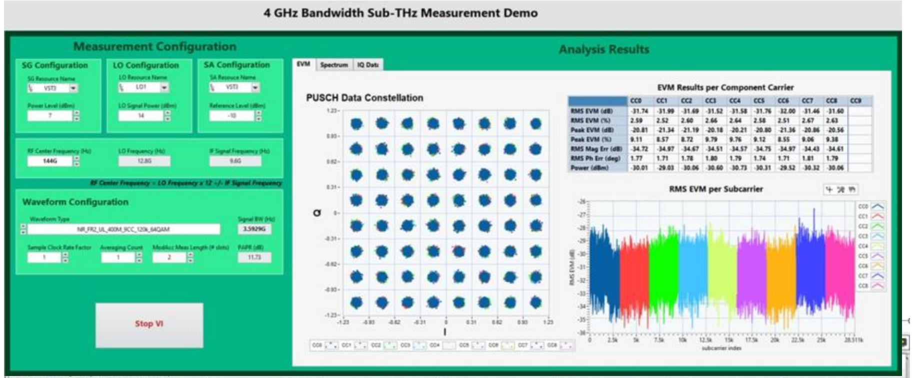
- VU11P FPGA
- 12 miniSAS zHD Connectors
- Initial protocol support: 100 GbE, Aurora
- Memory: ~25GB/s per Bank; 2 10GB Density per Bank

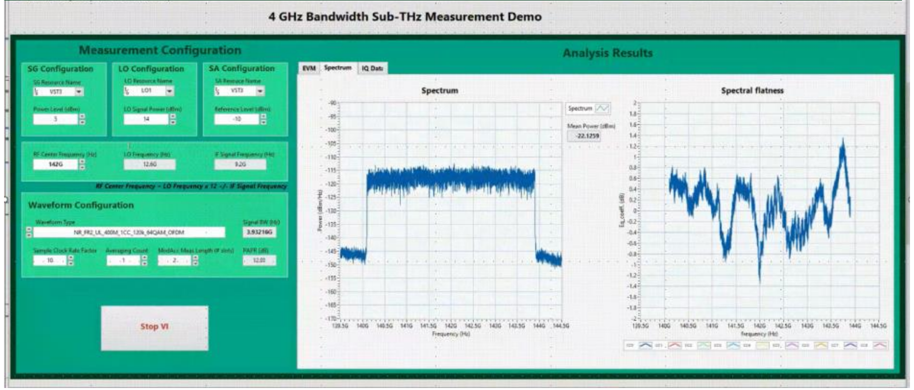
Speeds and feeds
- Up to 200 GbPS TX + 200 GbPS RX per port
- 3 ports

Sub-THz demo
- 10 GSPS at 16 bits TX+ 10 GSPS at 16 bits TX
- 150 GbPS TX + 160 GbPS RX

Sub THz system offering for research, design and prototyping



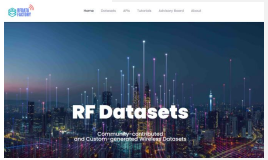




AI/ML Data Set Recording Reference Architecture

AI/ML Model Design & Optimization → AI/ML Model Training & Validation → AI/ML Model Test & Inference

Training Data Base



Data set library

Data pre-processing API: Create training and validation data sets

Train/Val/Test set collection

SigMF format

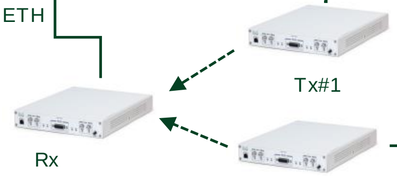
SigMF format

Data collection API: Data set & meta data file creation

Linux Compute Server (incl GPU)

ETH

ETH



Tx#1

Rx

X310 USRP

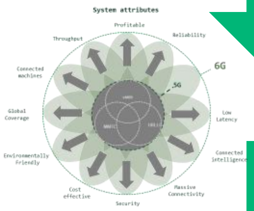
Tx#2

Current Achievements:

- ✓ Initial implementation of data collection API with automatic Tx waveform playback and Rx IQ data capturing using USRP / UHD including instant conversion to SigMF data set format – **API code published to GitHub**
- ✓ Initial implementation of data pre-processing API to read SigMF based data sets and create training/validation/test data sets as well as labels (targets) - **Successfully applied to an RF fingerprinting AI/ML model to ID 2x USRPs based on Rx IQ data**
- ✓ **CBRS – radar among LTE data transmission**

Enabling the 6G vision through test, measurement and prototyping: How NI's research enables the evolution to 6G!

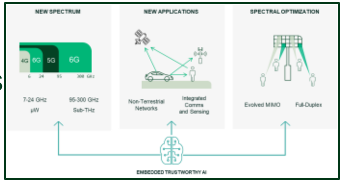
Wireless History



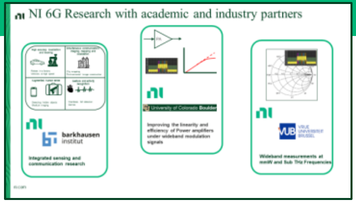
6G Vision

NI and the G's

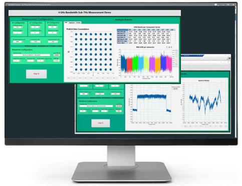
6G Themes



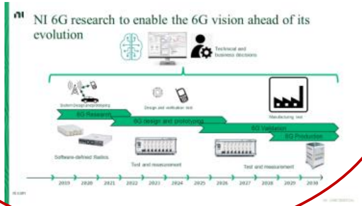
6G Research at NI



6G offerings and products from NI



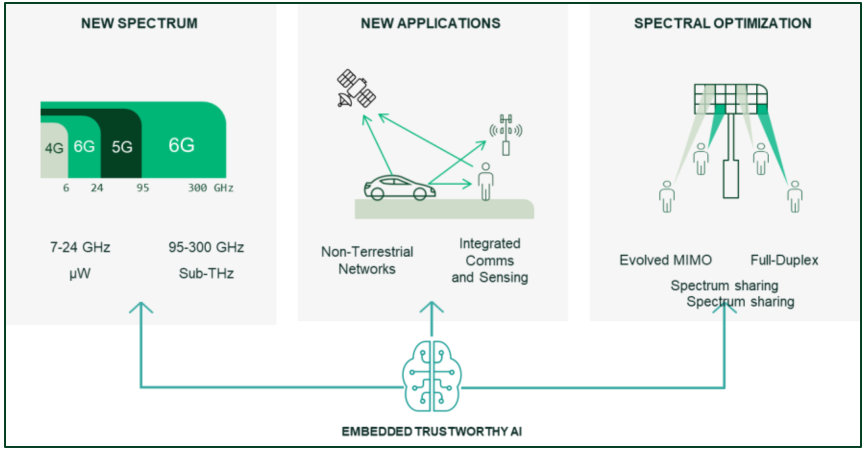
Concluding remarks

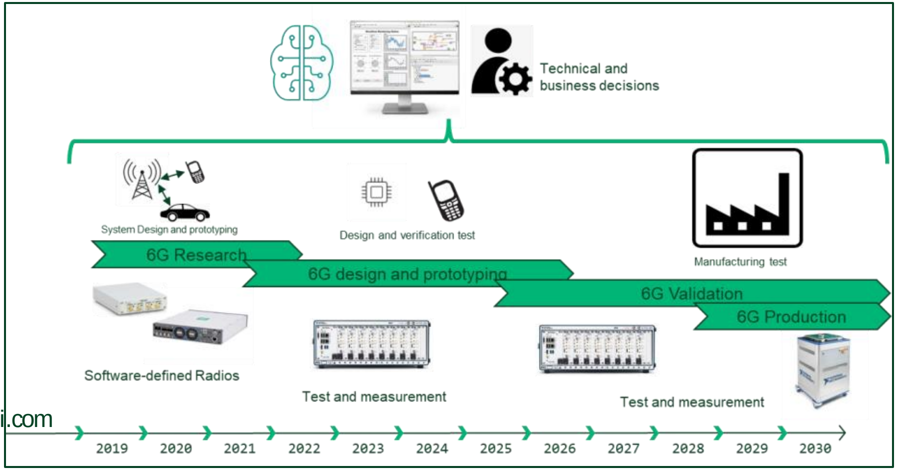


NI products and research enable the 6G vision

Early research and development

- New technology planned for 6G
  - Sub THz frequencies
  - AI/ML
  - Wide bandwidth measurements and signal processing
  - Semiconductor characterization under wideband stimulus
- 6G applications
  - Integrated sensing and communications
- More planned!





Industry leading products and offerings

- Software-defined-radios (SDR) for communications system prototyping
- Test and measurement equipment covering the frequencies, bandwidths and data rates planned for 6G
- Automation SW for test, measurement and prototyping
- AI/ML training data recording and management

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Deliver customer satisfaction by improving functionality and reliability

Improve the bottom line by reducing operational cost

Prepare for the future by adapting to evolving test needs

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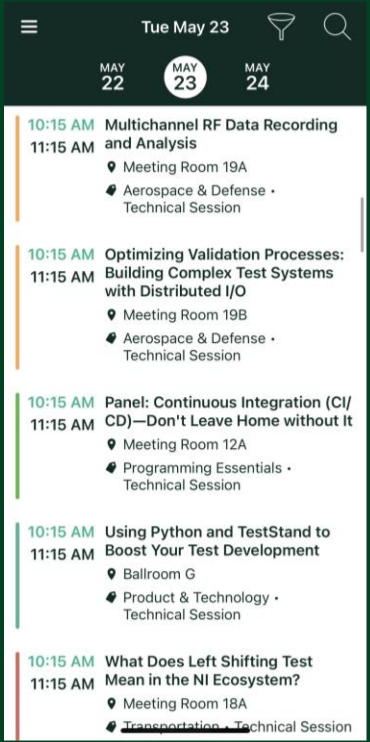
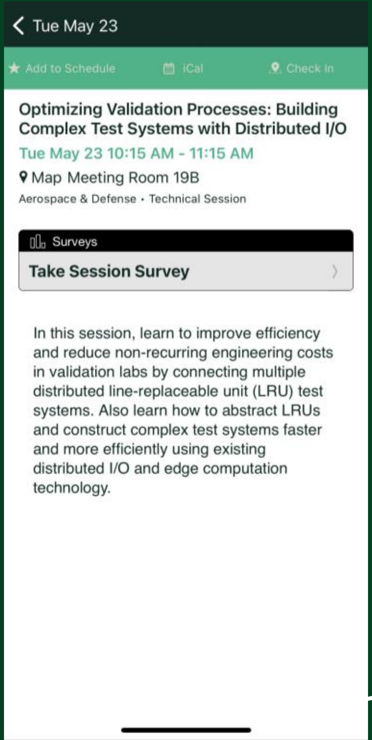
In the mobile app, click into the session you would like to provide feedback for





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