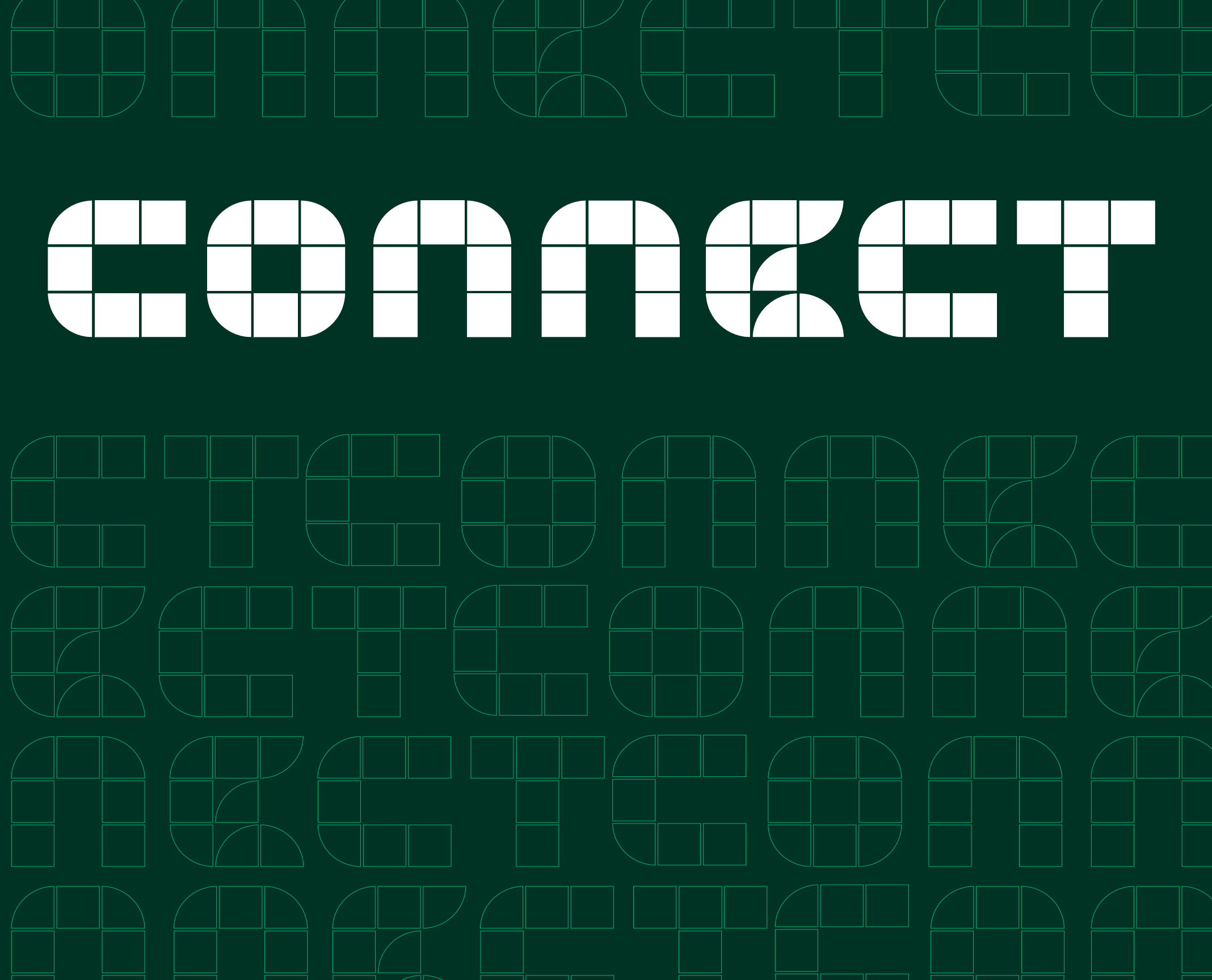
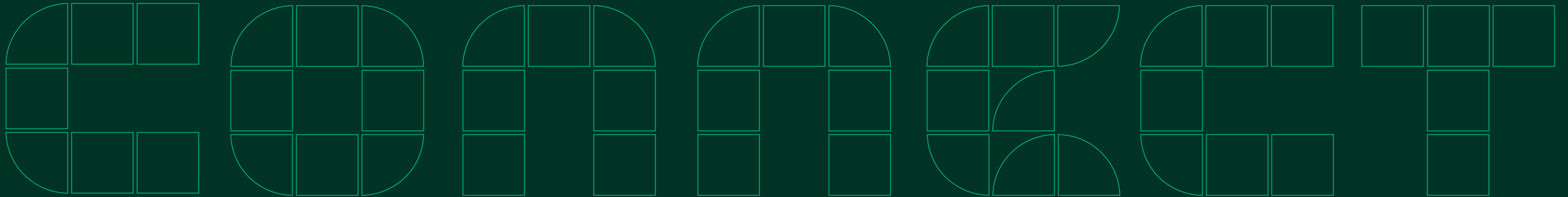


# connect



# O-RAN and mmWave w/ USRP X410

Markus Unger, Neel Pandeya

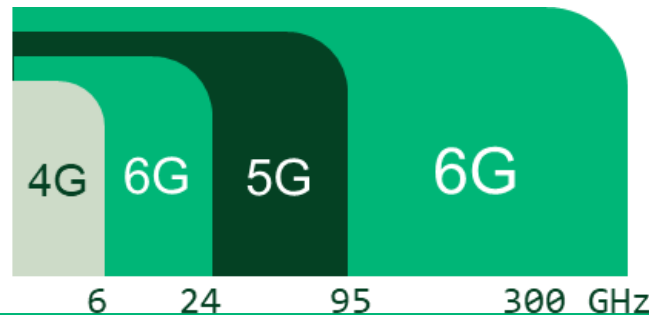


## **NI's approach to wireless comms research and prototyping**

# Enabling Technologies for 6G

## 6G New Spectrum

7-24GHz FR3, Sub-THz FR4

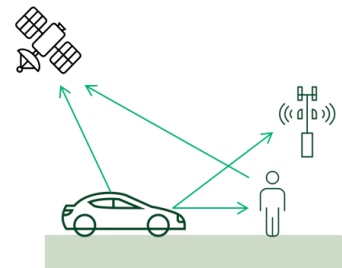


## 6G New Applications

NTN

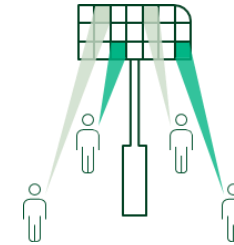


Integrated Sensing & Comms

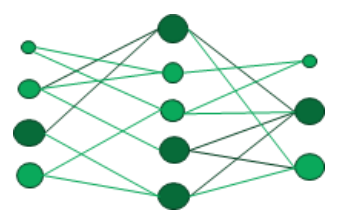


## 6G Spectral Optimization

MIMO



ML & AI



6G Sub-THz (100 - 300 GHz) Research

subTHz measurement  
Offering

subTHz Research  
Offering

VST3 + VDI  
up/downconverter

FR3 (7-22 GHz)  
FR2 (24- 28 GHz)  
O-RAN Research

OAI FR2 / FR3 Bundles  
O-RU

LabVIEW Bundles

USRP + TMYTEK

Non Terrestrial Networks /  
Satellite Communications

OAI Bundle  
LabVIEW Bundle

TT&C Partner Soln

NTN Channel Emulator

USRP + TMYTEK

Sensing &  
Communications  
Research

Barkhausen Example  
Leading case study

Zengyi Partner Soln

USRP + TMYTEK

MIMO Research

OAI Bundle

LabVIEW MIMO  
Bundle

USRP Platform

PHY Layer AI / ML  
research  
O-RAN Research

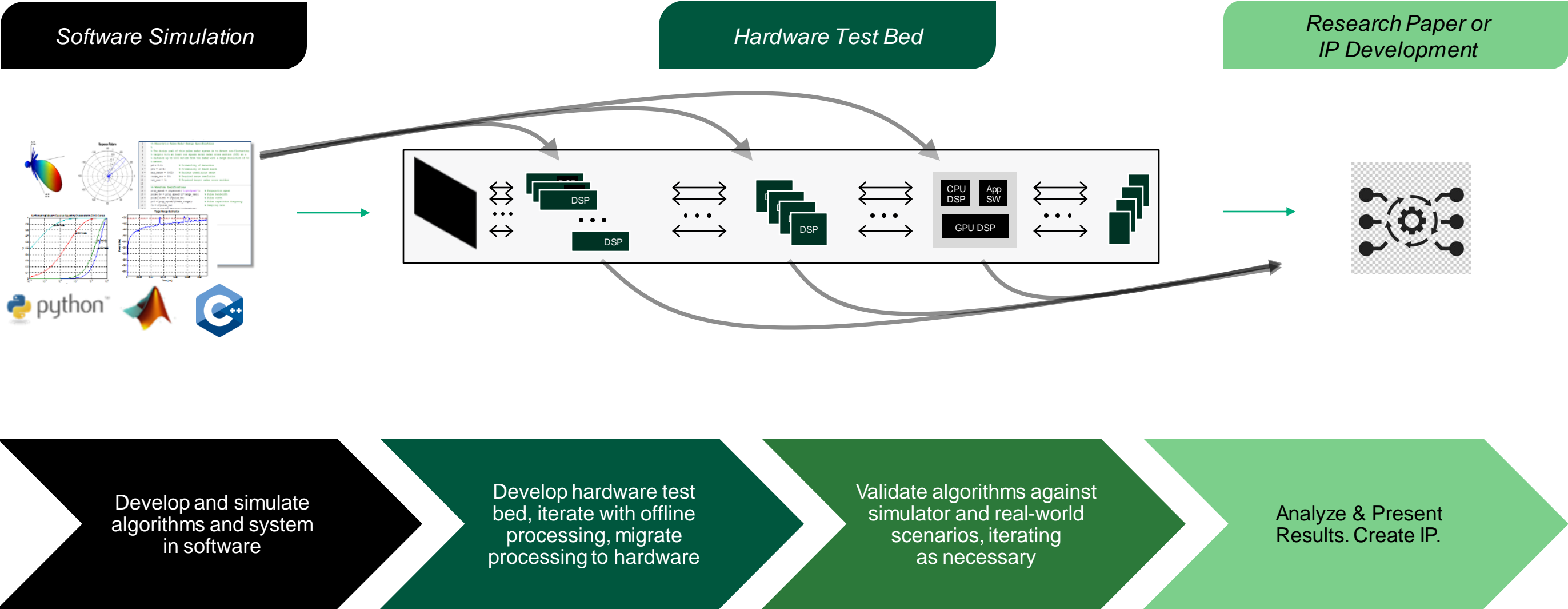
AI / ML OAI Reference

O-RU Reference

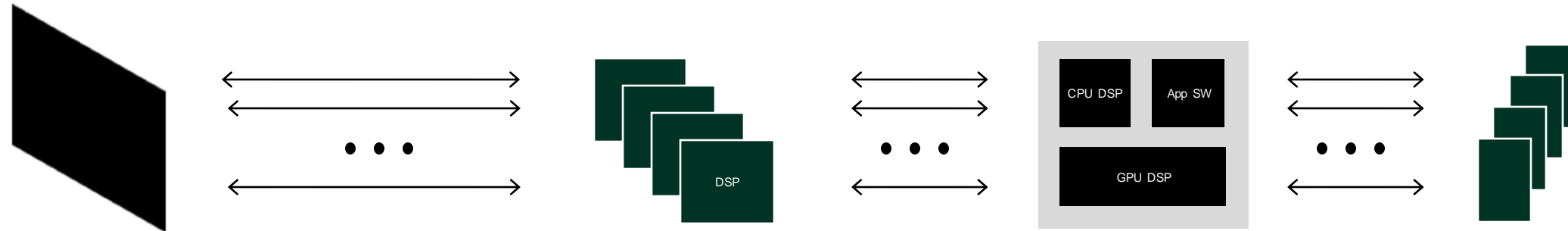
AI / ML Model training  
Offering

USRP Platform

# Wireless Systems – From Concept to Reality



# NI Building Blocks For SDR



## RF/uW Instrumentation

44 GHz, 1 GHz  
BW VST



23 GHz, 2 GHz BW  
VST **(New Released)**



USRP

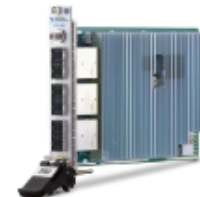


## FPGA Data Aggregation and Processing

UltraScale+ FlexRIO



24 MGT Data  
Aggregator



## CPU/GPU Compute

Octocore Xeon  
Controller



Cabled PCIe



Third Party  
Servers



## High-speed Storage

4 TB, 5 GB/s  
RAID

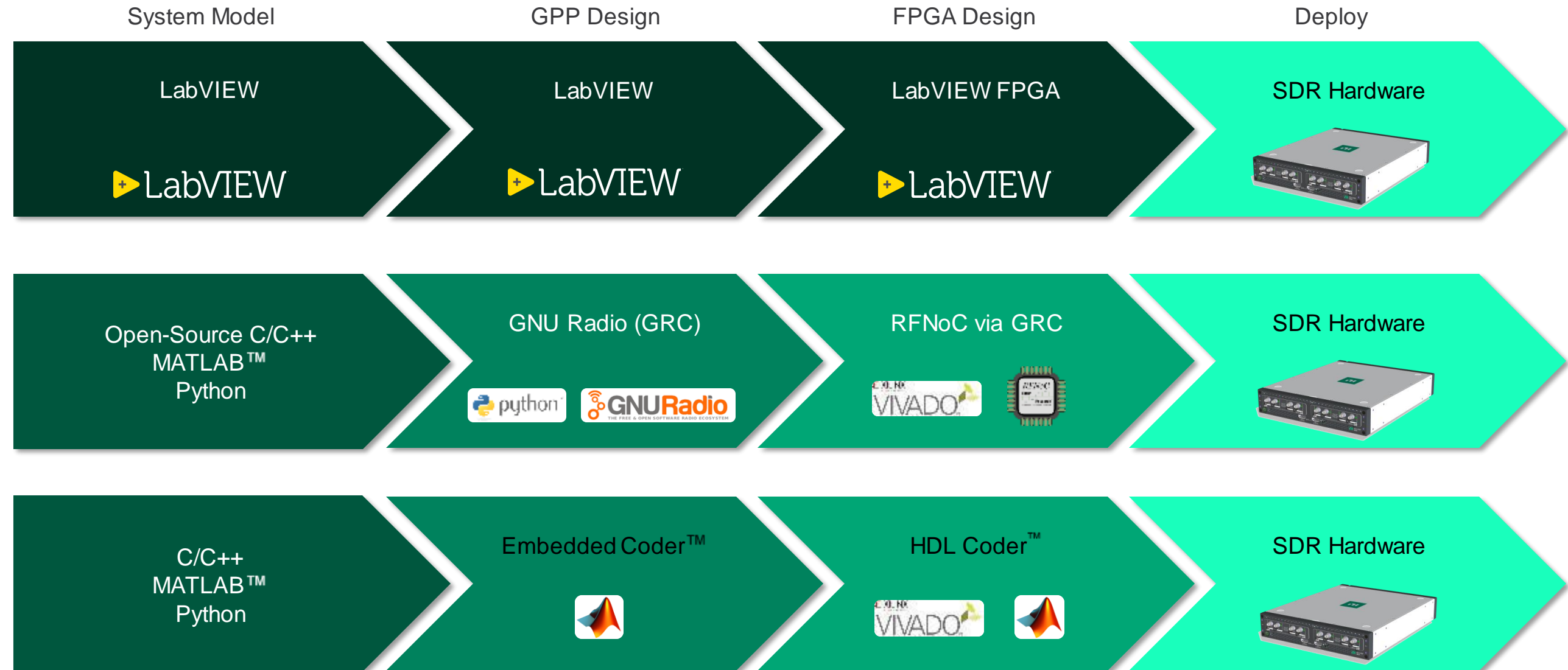


24 TB, 5 GB/s  
RAID



+ *Many More*

# USRP Supports Many Tool Flows







# NI Ettus USRP X410

Shaping the future of Wireless Communications

Full Support for UHD, RFNoC, GNU Radio and LabVIEW

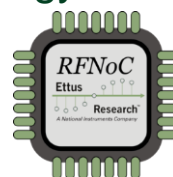


Multiple Development Tool Chains



UHD, C/C++, Python

FPGA Technology



Frequency : 1 MHz - 7.2 GHz  
Bandwidth: 400MHz  
Channels: 4X Tx , 4 Rx  
Max TX Power: up to 22 dBm<sup>1</sup>  
Max RX Power: 0 dBm

<sup>1</sup> see specification for details



Huge amount of FPGA Resources  
Dual QSFP28  
PCIe Gen 3 x8 Data Interface  
Built In SD-FEC IP Core  
GPS Synchronization Ready



# NI Ettus USRP X440 Product Overview

## IF Capabilities

Front-End Conn:	Balun coupled, MMPX
IF Range:	30 MHz – 4 GHz*
Bandwidth:	Up to 1.6 GHz* / channel, 4 GHz / total
Direct Sampling:	Flexible, up to 4 GSps 2 independently configurable rates (4 channels each)
Number Channels:	8 (TX/RX or TRX)
Phase Coherency:	Yes (sample based)
TX output level:	< 0 dBm full scale
RX input level:	10 dBm full scale

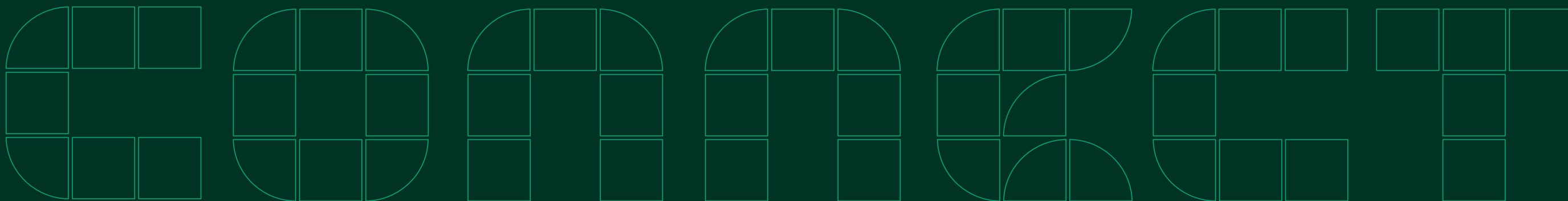
\* IF-Bandwidth combination limitations apply because of Nyquist zones and gaps

## Digital Capabilities

- Xilinx Zynq Ultrascale+ RFSOC ZU28DR-2
- Built-in quad core ARM processor
- Streaming Interface: Dual 100GEth via QSFP28
- Synchronization: 10 MHz / PPS, GPSDO, IF
- Software: Open source (GNU Radio, RFNoC, UHD)
- GPIO for Front-End control via UHD API or FPGA
- 2x 12 lanes via HDMI with SPI protocol support



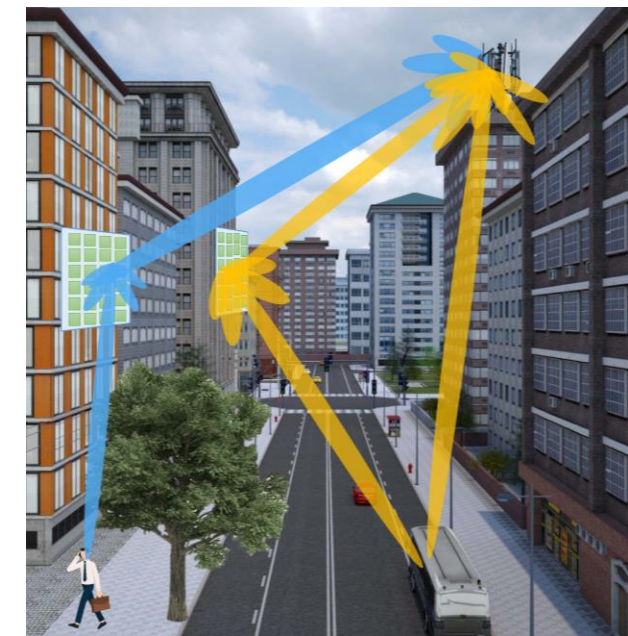
Shown at demo floor



## **Wideband Record and Playback for Offline Processing**

# Record and Playback Applications

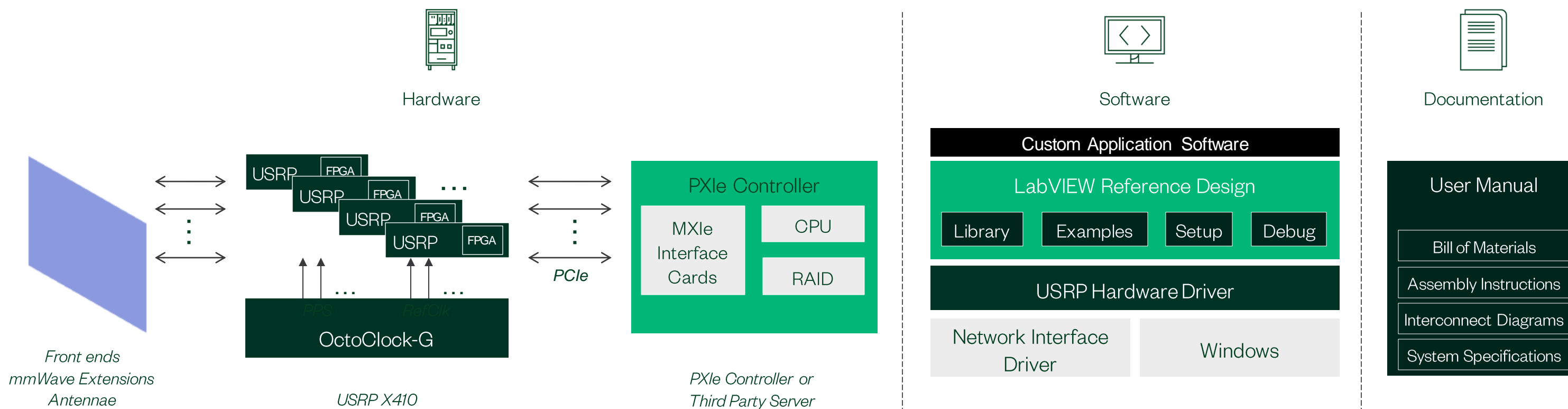
- Channel measurements
- Communication & Sensing
- Reconfigurable Intelligent surface (RIS)
- mmWave Beamforming & Beam steering
- MIMO Applications

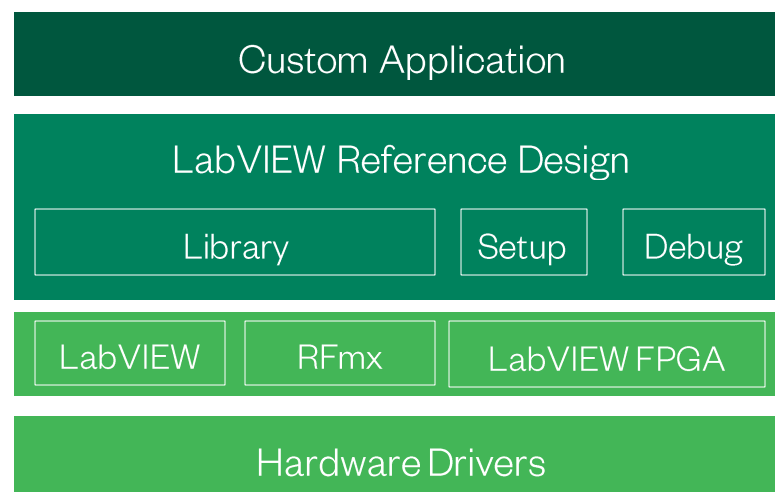




# LabVIEW Reference Architecture for Transmitting, Recording and Playback of Wideband RF Signals

Enables Wireless researchers struggling to rapidly prototype new concepts to move quickly from software simulation to hardware demonstration, ultimately turning novel concepts into fielded capability faster





## LabVIEW Reference Design

- Software for 5G NR, Streaming, mmWave Extension

## USRP Driver

- Control USRP Functionality

## LabVIEW FPGA

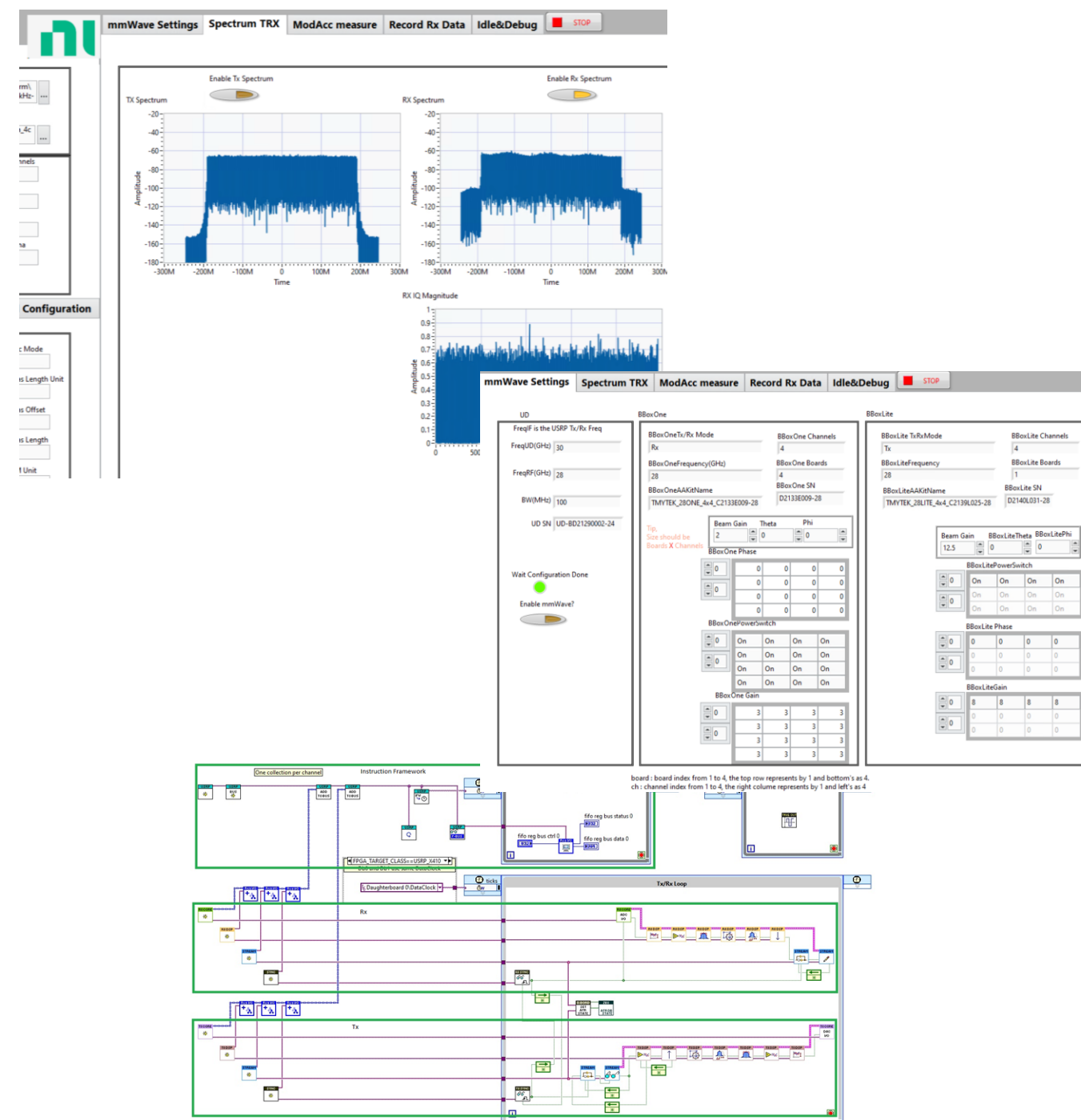
- Enables FPGA processing in USRP

## NR RFmx

- Generate/Analysis 5G waveform

## mmWave Extension

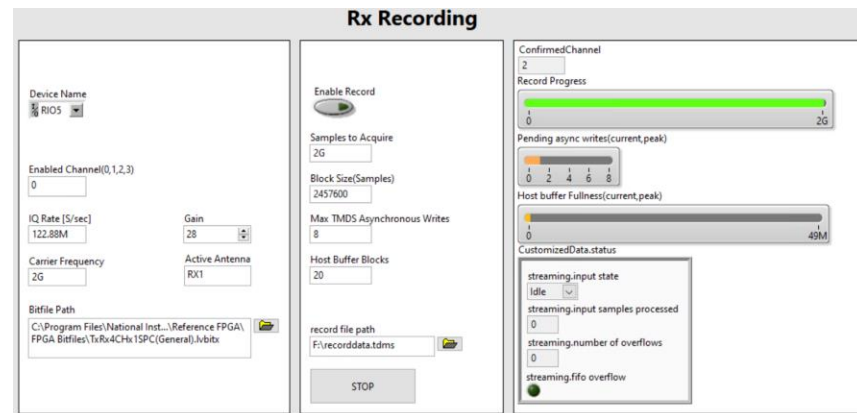
- DLL/APIs/Control Kit for RF and beamforming control



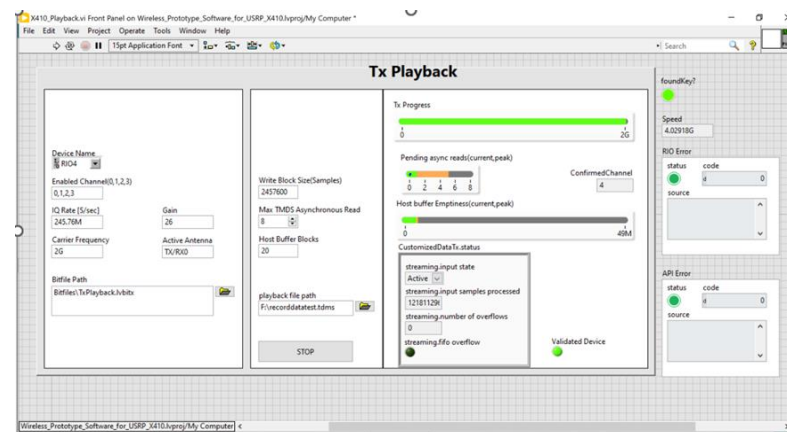


# LabVIEW Reference System

## Rx Recording UI



## Tx Playback UI



## 5G NR Waveform UI



TMYTek-NI mmWave  
Front-end  
(Optional)



NI Ettus USRP X410



PXI controller (Host)



NI PXIe RAID SSD  
(Storage)



# TMYTEK mmWave Devices



## UD Box 5G - Single & Dual Channel

**RF:** 24 - 44 GHz

**IF:** 0.01 - 14 GHz

**Tunable LO:** 24 - 44 GHz

**Conversion Loss:** 13 dB (typ.)

10 MHz output and 100 MHz input/output

Synchronization



## BBox One 5G

**RF:** 24.25 - 27.5 GHz; 26.5 - 29.5 GHz;  
37-40 GHz

**Band:** n258, n257, n260

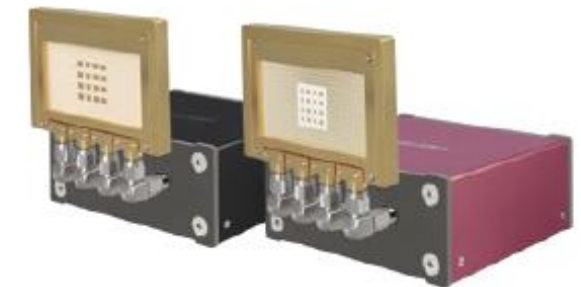
**RF Channels:** 16

Tx/Rx Half Duplex

Individual Gain and Phase Control

**Beam control interface:** SPI

**API:** LabVIEW, MATLAB, Python, C#, C++



## BBox Lite 5G

**RF:** 26.5 - 29.5 GHz; 37 - 40 GHz

**Band:** n257, n260

**RF Channels:** 4

Tx/Rx Half Duplex

Individual Gain and Phase Control

Shown at demo floor

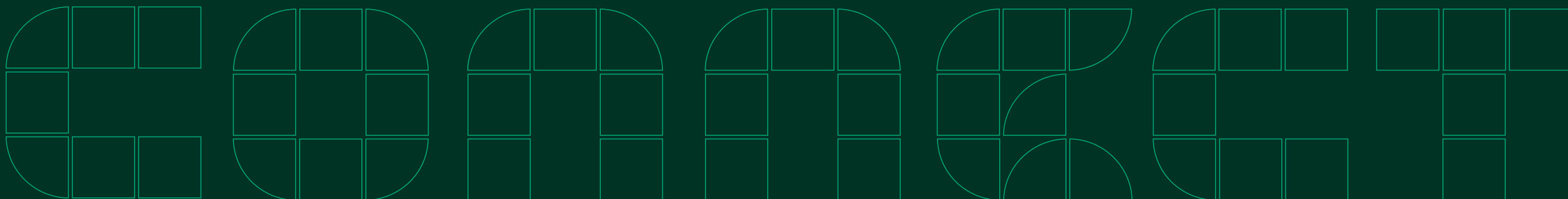




# System Technical Specification

Parameters	X410 Only		X410 + mmWave Extension
Frequency Band	1M-7.2GHz		28GHz
Channels	4		1
Digital Interface	PCIe		PCIe
Recording IQ Rate	1 channel	491MSps	491MSps
	2 channels	491MSps	
	4 channels	245.76MSps	
Storage	4TB with 8267		4TB with 8267
Software	LabVIEW 2021(64-bit)		LabVIEW 2021(64-bit)





# **OpenAirInterface (OAI) Reference Architecture**

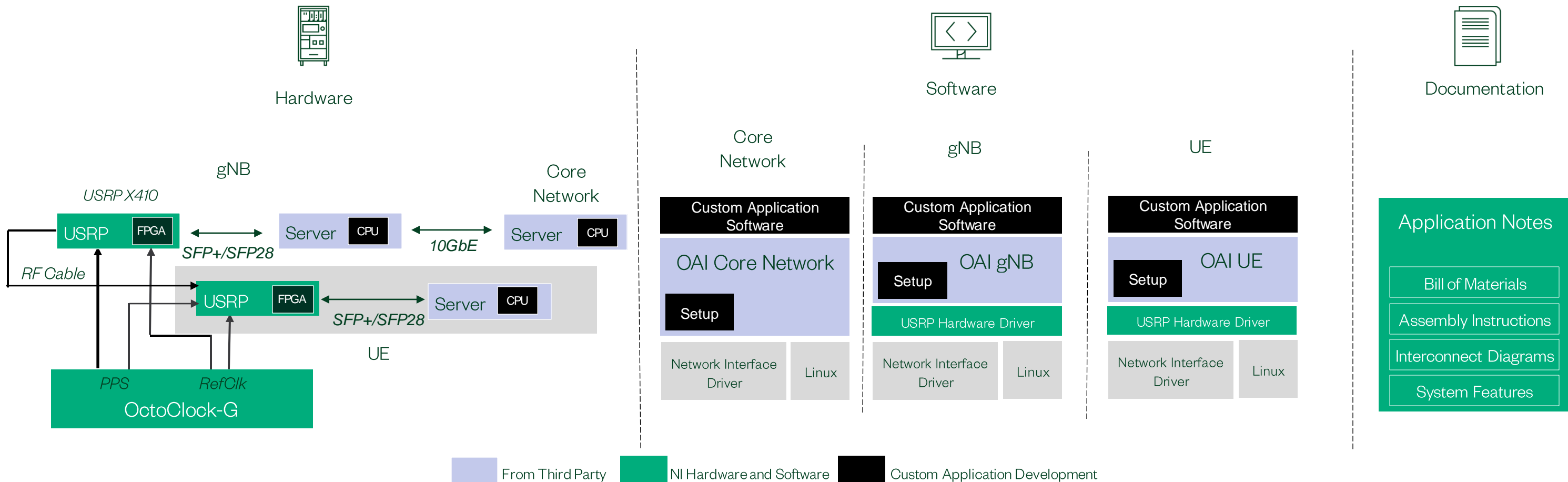
## Strategic Partnership with OAI

- “With this new relationship, we will bring this collaboration to a new level and make sure that OAI will get the best out of current and future platforms from NI.”

Florian Kaltenberger – OAI Director

# OAI Reference Architecture for 5G System Prototyping with NI USRP

Bridging the gap between theoretical and practical issues around 5G system deployment and implementation for enabling engineers and researchers to rapidly develop and test novel use-cases



Please find more technical details in: [OAI Reference Architecture with 5G and 6G research with the USRP Application Notes](#)

# System Features and Demo Configurations

Full end-to-end setup for 5G SA wireless research and prototyping.

OpenAirInterface (OAI) 5G stack and USRP Hardware Driver (UHD) are open source.

Connects to wireless modem module UE, COTS handset UE\*, and USRP based software UE.

User applications like video streaming and connection to the internet are possible.

Allows both over-the-air (OTA) and cabled operation.

## Demo Configuration (USRP X410 and Quectel UE/X410 UE) :

- 5G-NR SA, TDD Duplexing
- 40 MHz Bandwidth
- 30 kHz SCS
- 64 QAM DL, SISO
- FR1 Band n78 (3.361 GHz)
- DL iperf data rate up to 80Mbps
- 61.44Msps sample rate on USRP

*\*For the COTS UE, RD is still working on this.*



# OAI Reference Architecture Hardware and Software Mapping

Hardware

## Core Network

OAI CN (+ PDN Server)



## OAI gNB



REF Clock (if needed)



UHD



SMA Cables / Antennas

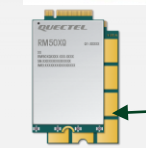


UHD

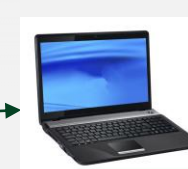
## UE



COTS UE\*



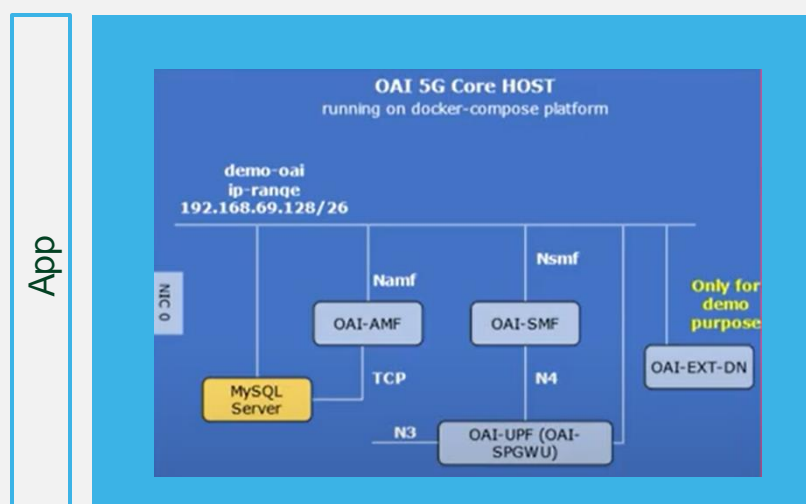
Modem UE



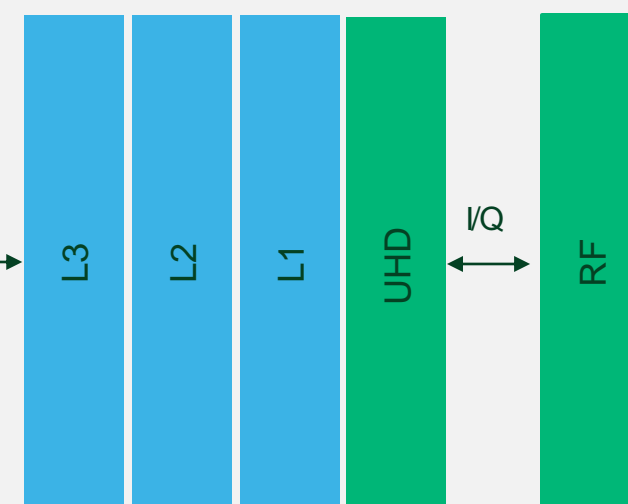
OAI software UE

Software

OAI  
NI  
Closed

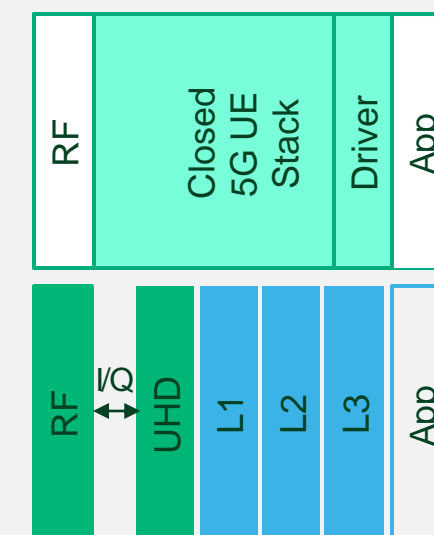


all on x86  
(docker containers)



all on x86

SMA Cables / Antennas



all on x86

COTS  
UE

OAI  
UE





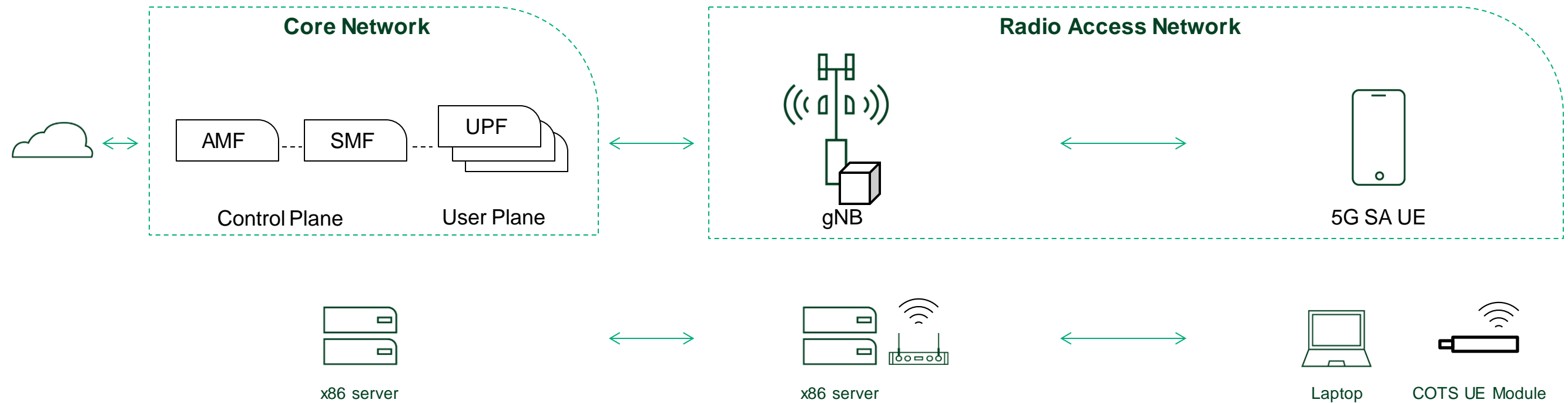
# OAI FR1 System with USRP



## Demo Configuration :

- 5G-NR SA, TDD Duplexing
- 40 MHz Bandwidth
- 30 kHz SCS
- 64 QAM DL, SISO
- FR1 Band n78 (3.361 GHz)
- DL iperf data rate up to 80Mbps
- 61.44Msps sample rate on USRP

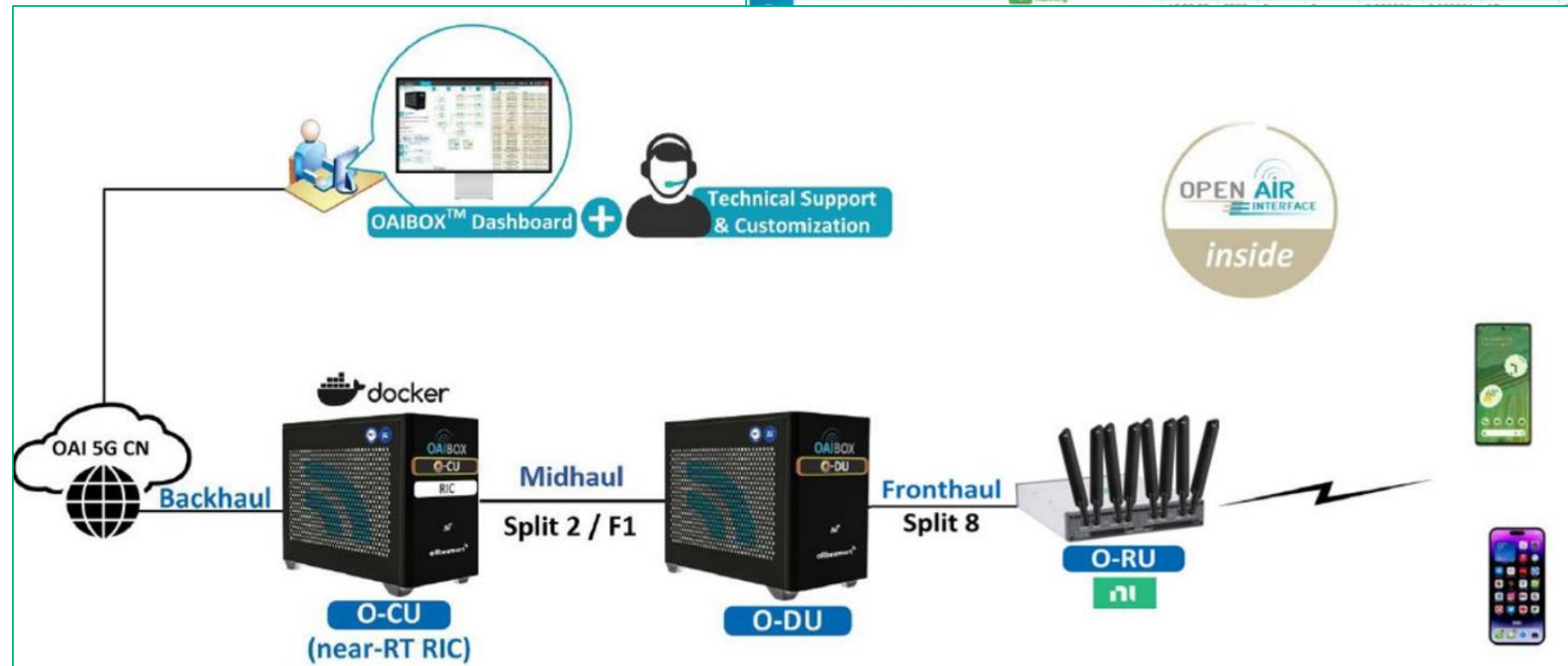
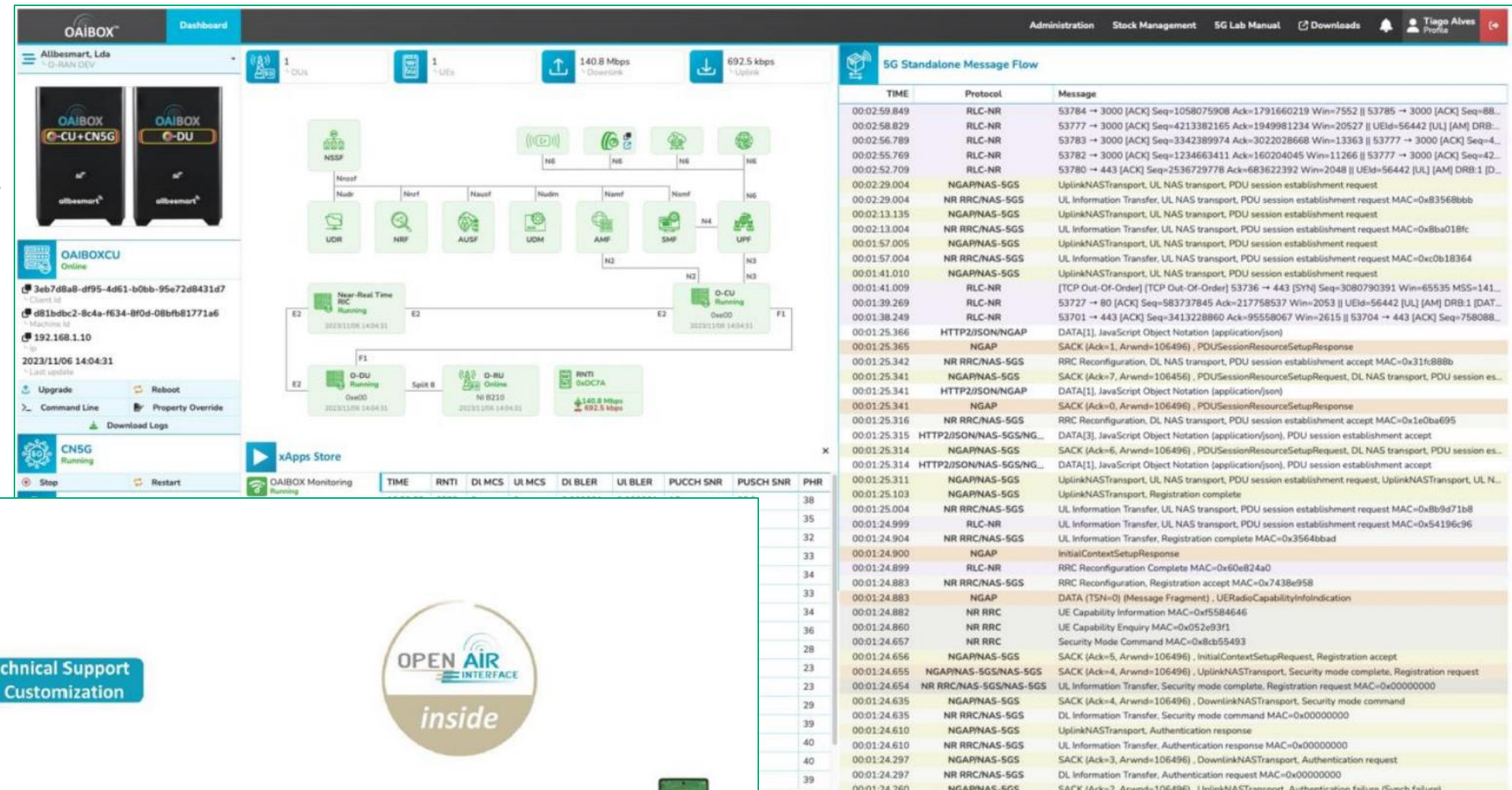
## 5G System Architecture





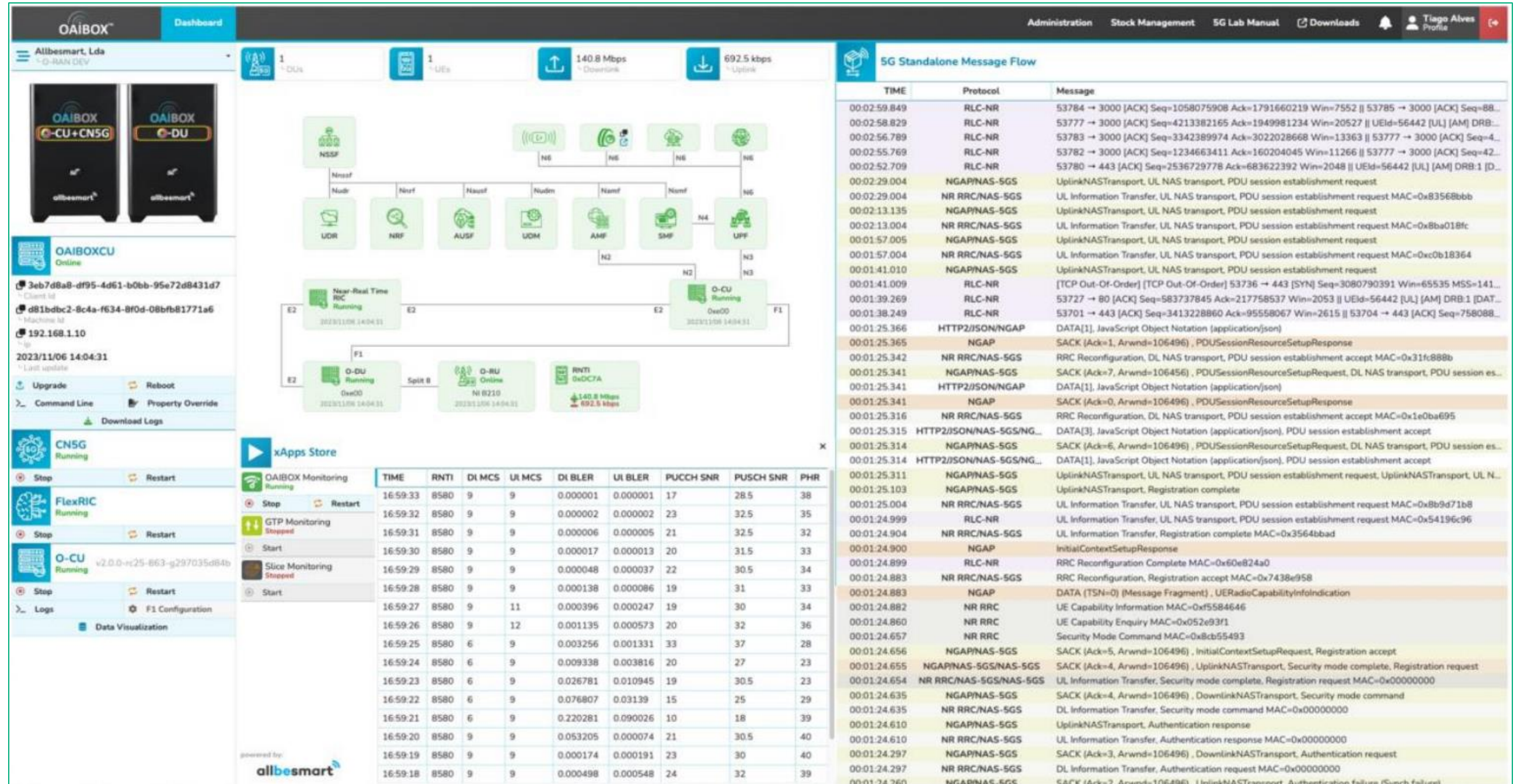
# OAI BOX

- Pre-evaluated ready-to-run system
- Scalable across USRP multiple variants
- Extensible to mmWave and OTA
- Dashboard for operational ease-of-use

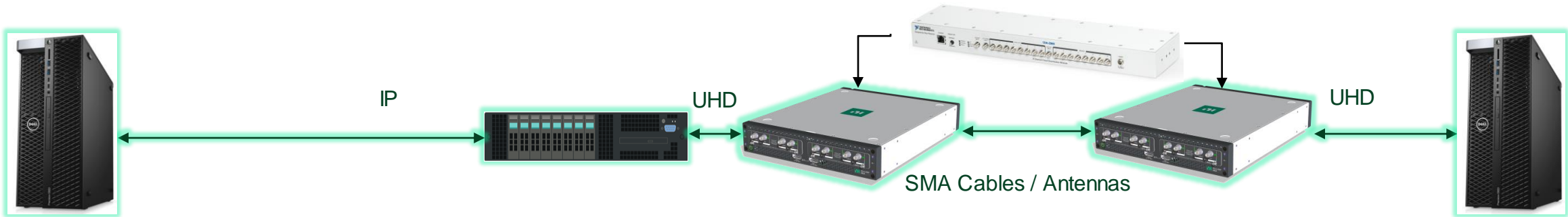




## OAIBOX



# Flexibility and Extensions



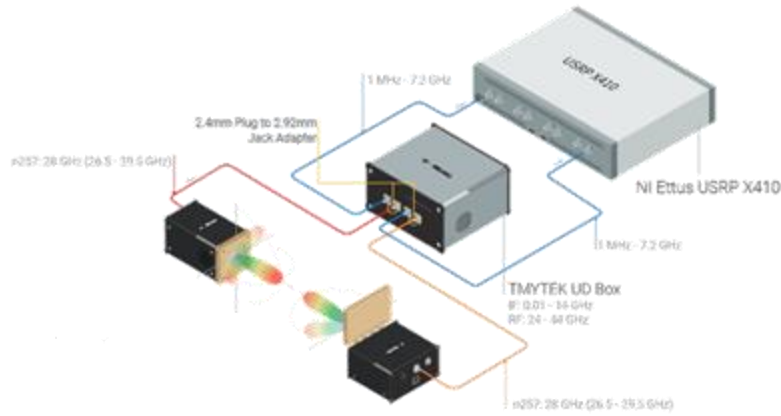
## Over-The-Air

SC2430 seamlessly integrates with USRP X410 and allows for amplification and filtering to adhere with spectral masks



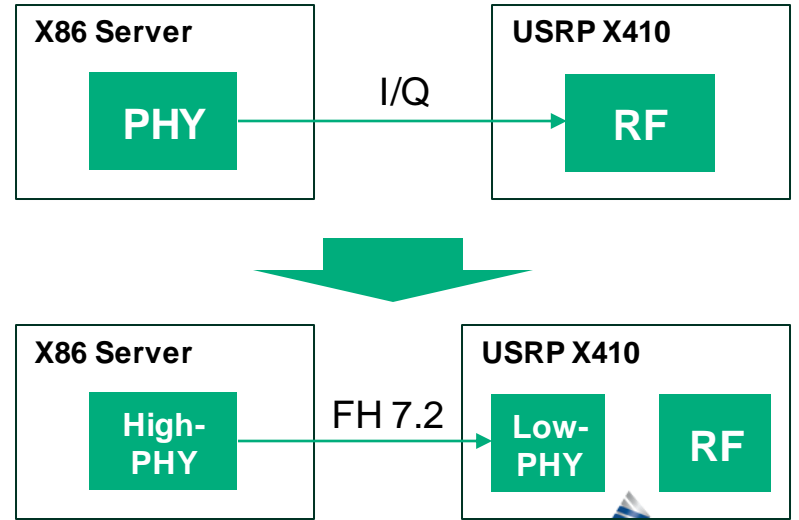
## mmWave / FR2

mmWave Frontends seamlessly integrate with USRP X410 for up- and downconversion



## USRP X410 O-RU

Move Low-PHY onto X410 to free up processing on DU





# TMYTEK mmWave Devices



## UD Box 5G - Single & Dual Channel

**RF:** 24 - 44 GHz

**IF:** 0.01 - 14 GHz

**Tunable LO:** 24 - 44 GHz

**Conversion Loss:** 13 dB (typ.)

10 MHz output and 100 MHz input/output

Synchronization



## BBox One 5G

**RF:** 24.25 - 27.5 GHz; 26.5 - 29.5 GHz;  
37-40 GHz

**Band:** n258, n257, n260

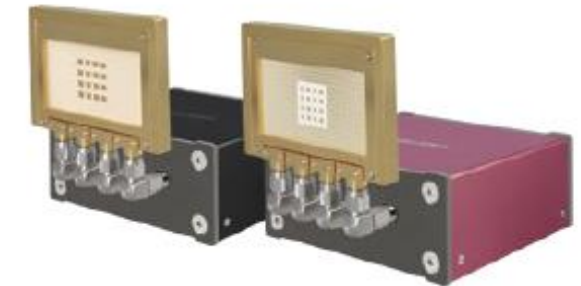
**RF Channels:** 16

Tx/Rx Half Duplex

Individual Gain and Phase Control

**Beam control interface:** SPI

**API:** LabVIEW, MATLAB, Python, C#, C++



## BBox Lite 5G

**RF:** 26.5 - 29.5 GHz; 37 - 40 GHz

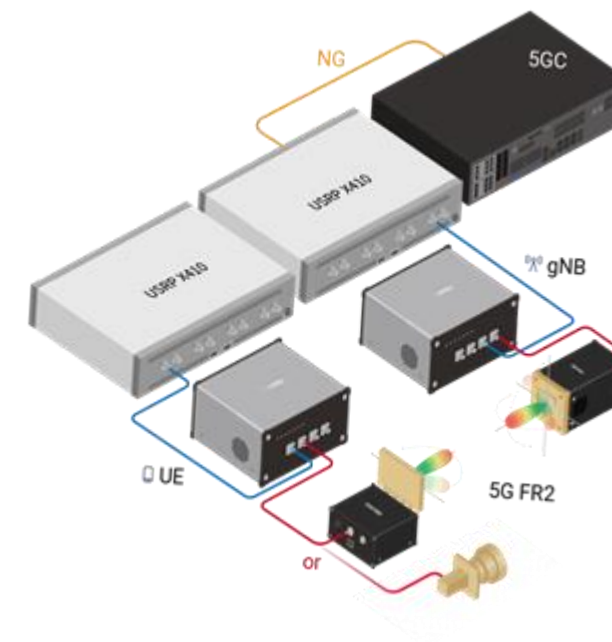
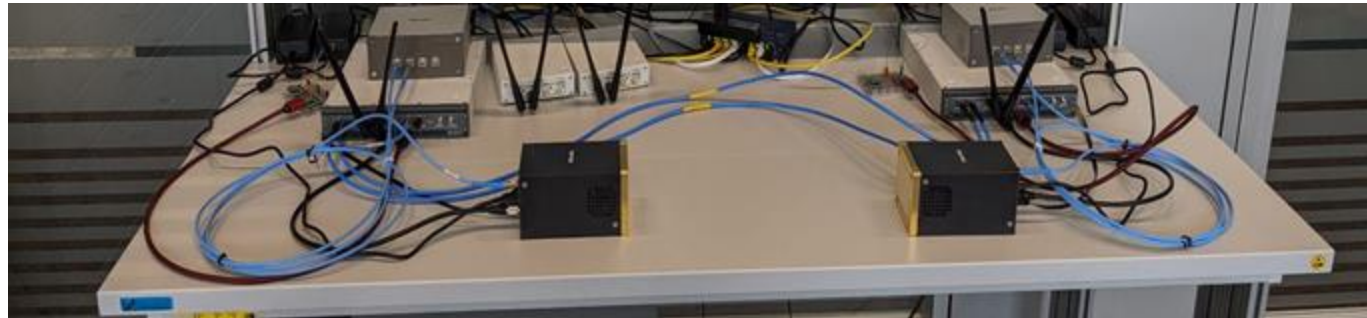
**Band:** n257, n260

**RF Channels:** 4

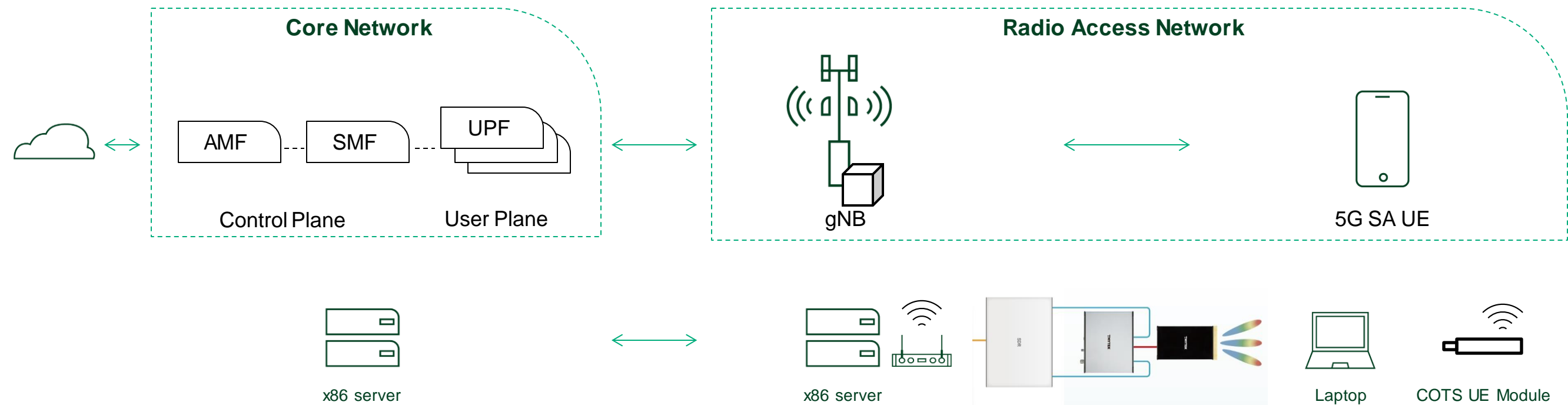
Tx/Rx Half Duplex

Individual Gain and Phase Control

Shown at demo floor

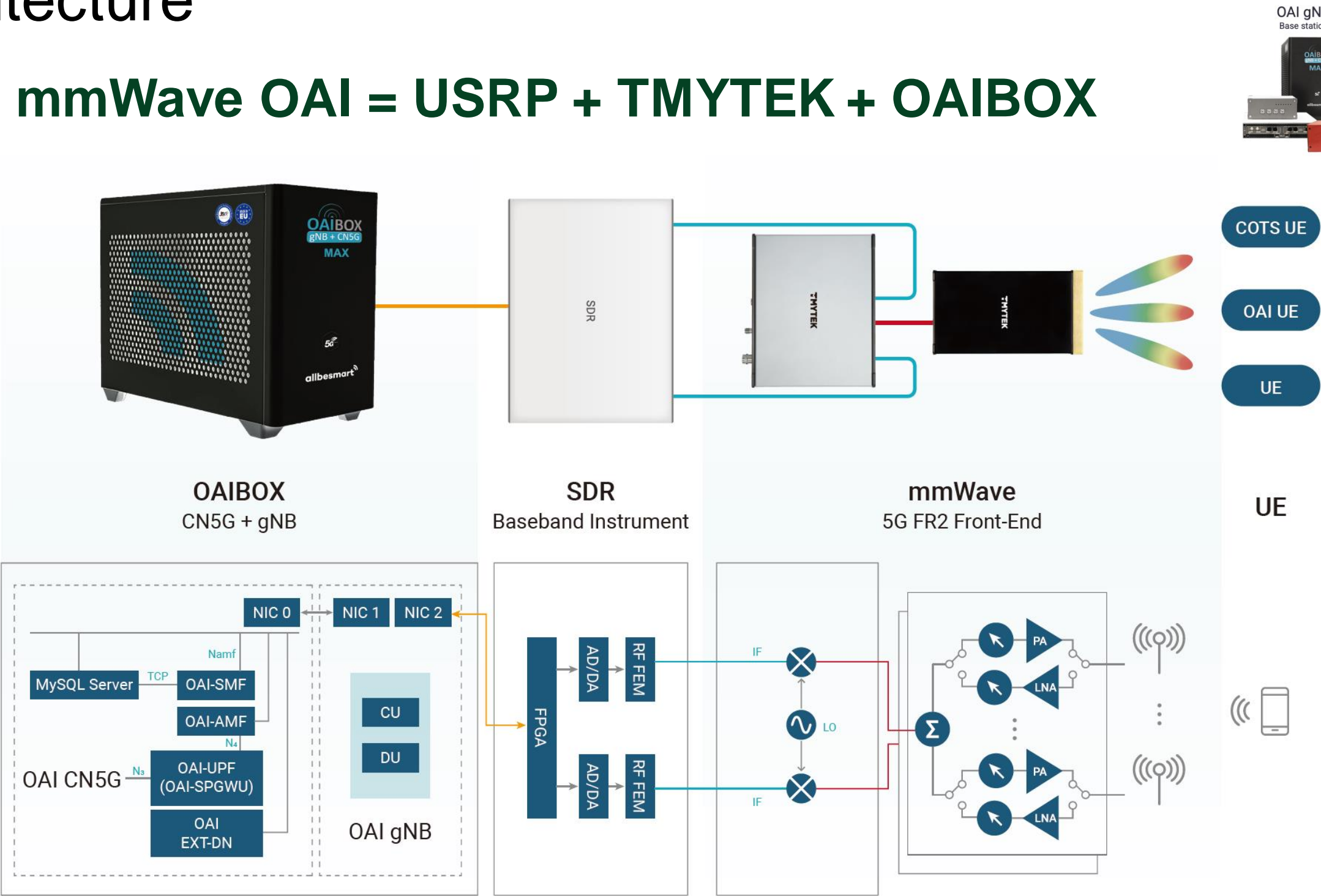


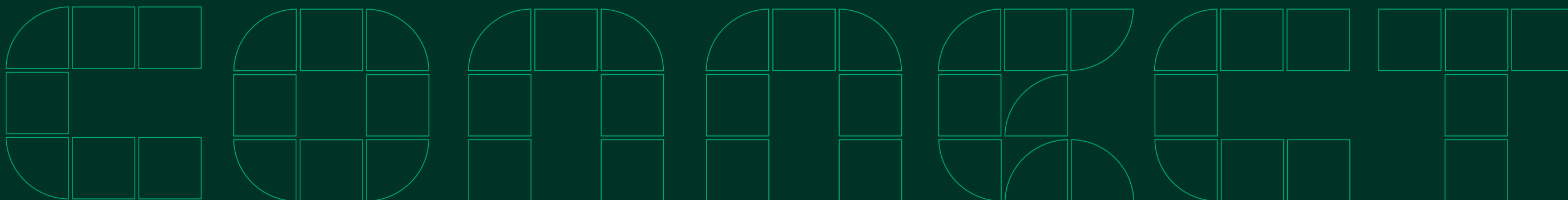
## 5G System Architecture



# mmWave (FR2) Capability for OAI Reference Architecture

mmWave OAI = USRP + TMYTEK + OAIBOX





# **USRP X410 based ORAN O-RU Radio Unit**

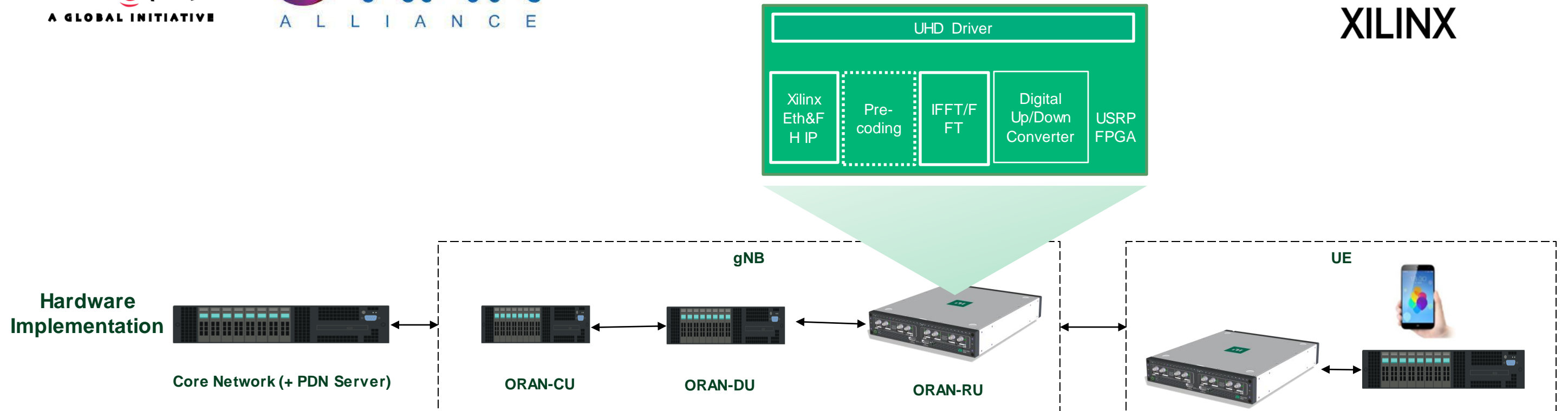




# NI O-RU Emulator

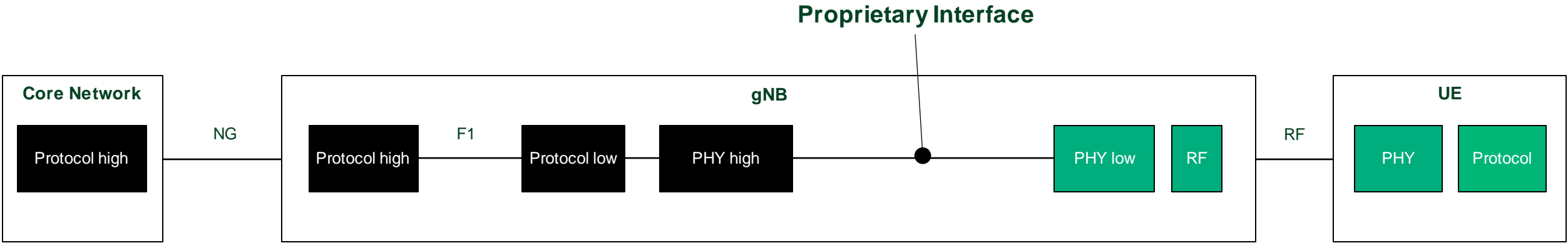
**FH:** Front Haul  
**CU:** Centralized Unit  
**DU:** Distributed Unit  
**RU:** Radio Unit

Re-build the software framework to make NI USRP X410 to be compatible to O-RAN standard and accelerate the software simulation to hardware demonstration by providing detailed application notes.

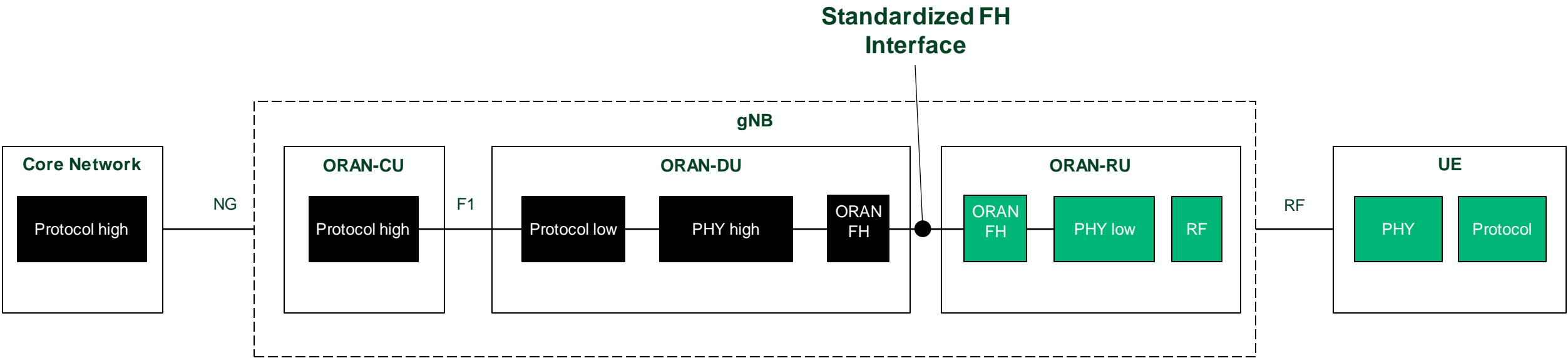


# ORAN Functional Split

Traditional System



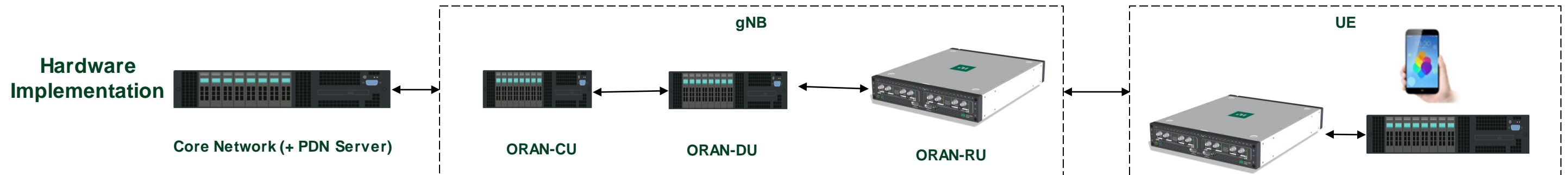
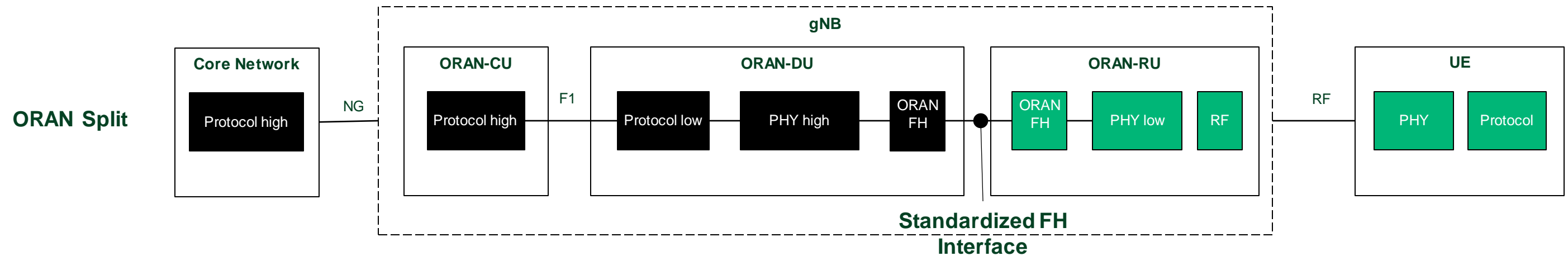
ORAN Split



De-compose the radio access network into functional blocks w/ standardized interfaces

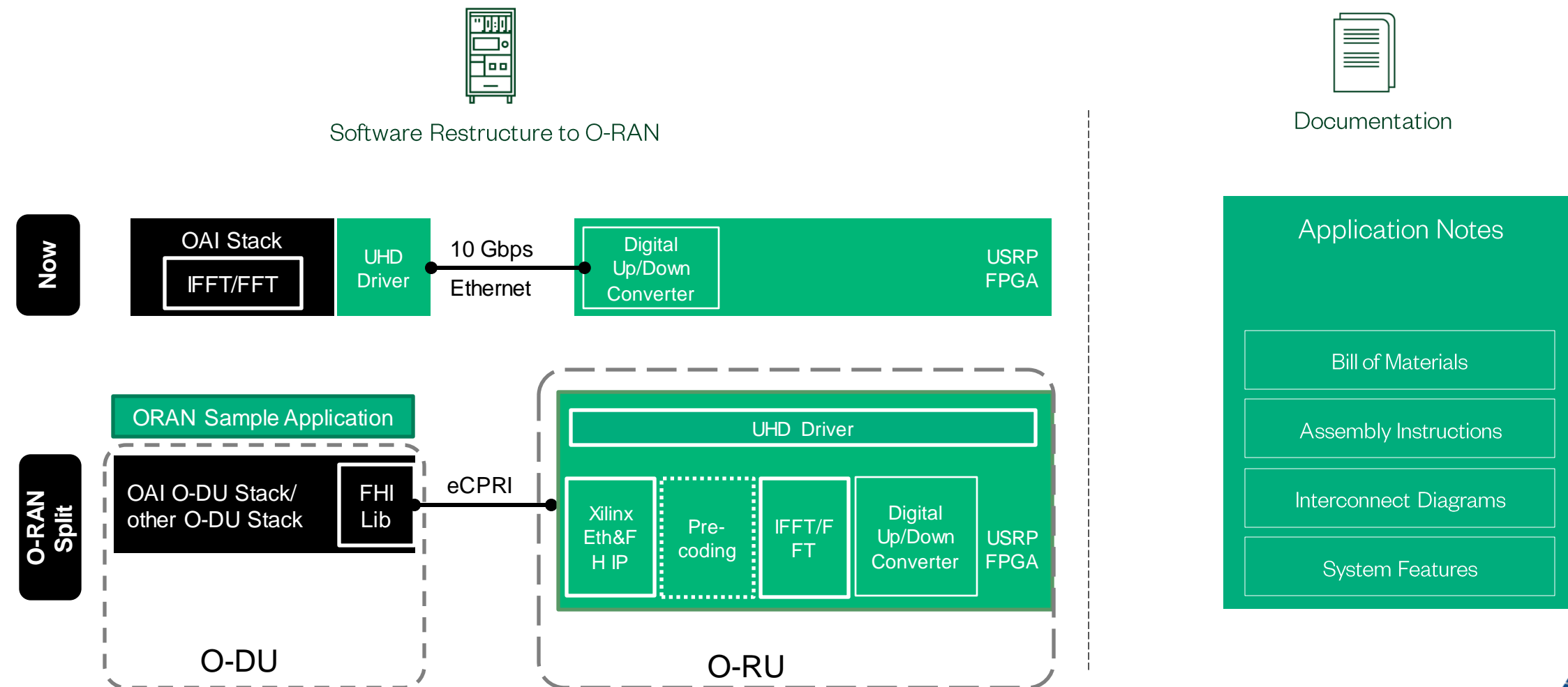
# ORAN O-RU Emulator Solutions

The NI real time O-RU Emulator is an open software personality that enables the USRP-X410 to act as a powerful software defined 5G NR radio unit based on the 7-2 split defined by ORAN alliance. The solution allows customers to emulate a 5G NR base-station by connecting the flexible and open RU to an ORAN based 5G DU and CU. The offering is primarily targeted to build testbeds for 5G applications and 6G research



# Real-time O-RAN Emulator for 5G System Prototyping with the USRP X410

- Re-build the software framework to make NI USRP X410 to be compatible to O-RAN standard and accelerate the software simulation to hardware demonstration by providing detailed application notes.

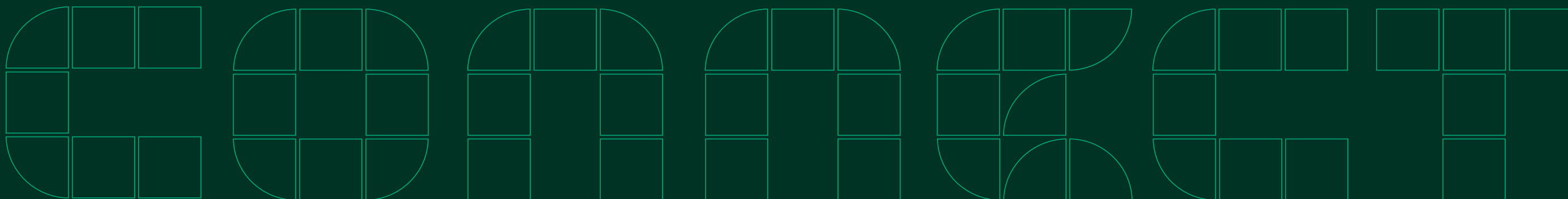




# Target Application and Specification

- Typical applications include:
- End to End O-RAN based testbed
- AI / ML research on different layers
- Network slicing, uRLLC research
- ISAC

System Specification	
Frequency Range	1 MHz to 7.2 GHz
Frequency Band	5G NR, FR1 - N78, N79 Flexible, Any <100MHz band in the Frequency range <ul style="list-style-type: none"> <li>• FR2 support in H1 2024 with TMYTEK U/D and BBox</li> </ul>
Number of Tx/Rx Channels	2Tx,2Rx <ul style="list-style-type: none"> <li>• 4T4R support in H1 2024 (dependent on FPGA resource)</li> </ul>
Duplex mode	TDD
FFT/IFFT	Flexible, up to 4096
Subcarrier Spacing (SCS)	30KHz Flexible, up to 120 KHz
Bandwidth	Flexible, up to 100 MHz
Output power per antenna	22 dBm
O-RAN Split	7-2 split CatA <ul style="list-style-type: none"> <li>• Beam forming support in H1 2024</li> <li>• Precoding support in H2 2024</li> </ul>
Fronthaul Ethernet Link	10Gbps (SFP+), <ul style="list-style-type: none"> <li>• S-plane support in H1 2024</li> <li>• 100Gbps (QSFP28) in H2 2024</li> <li>• No M-plane support planned</li> </ul>



# **OAI AI/ML Reference Architecture**



# AI/ML RF Data Recording API

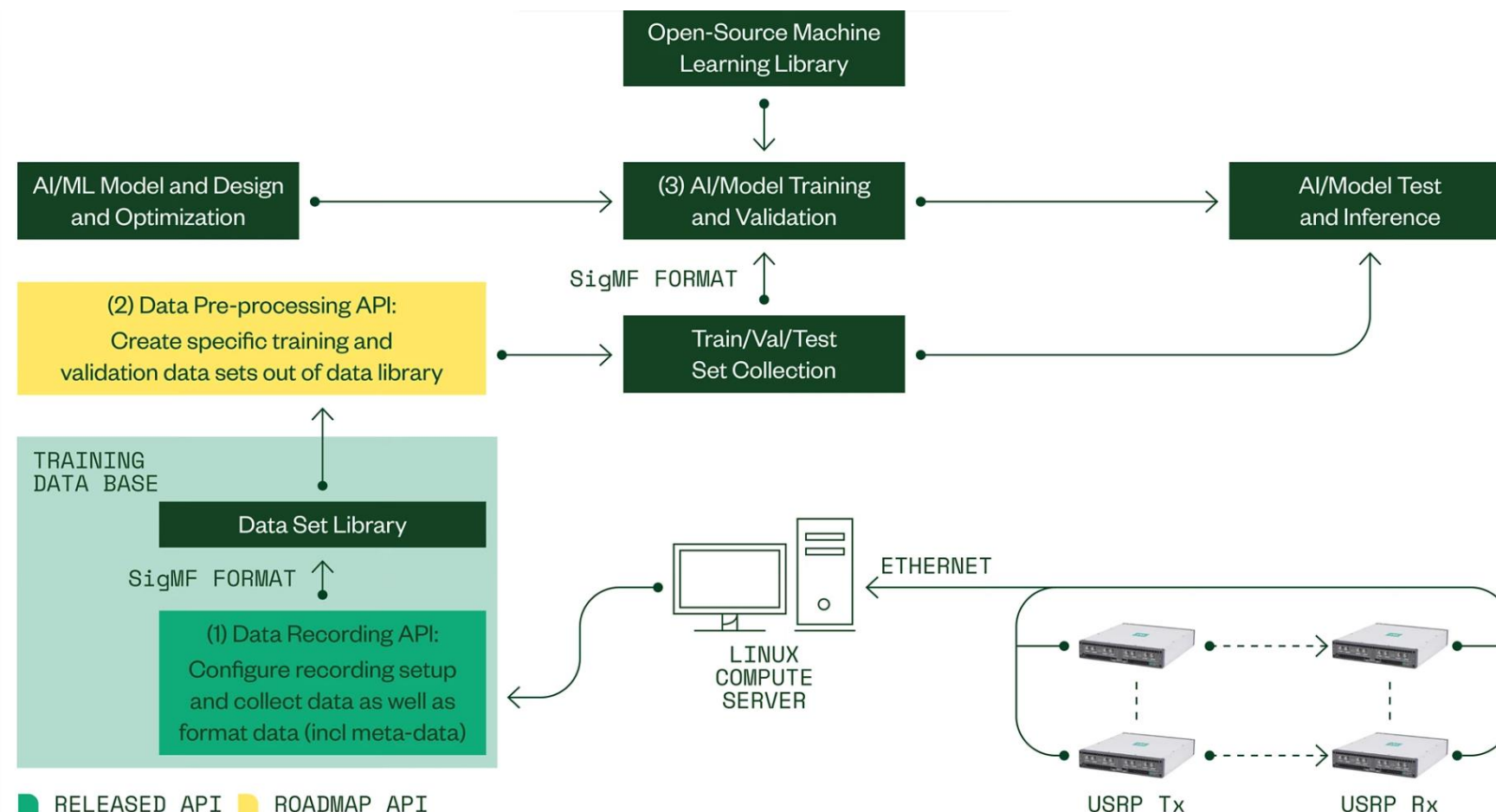
Joint work with



**Institute for the Wireless Internet of Things**  
at Northeastern University



**NI & NEU** jointly created and published an open-source, Python-based **AI/ML RF Data Recording API**, which leverages the USRP platform for the hassle-free and automated generation of real-world RF data sets.

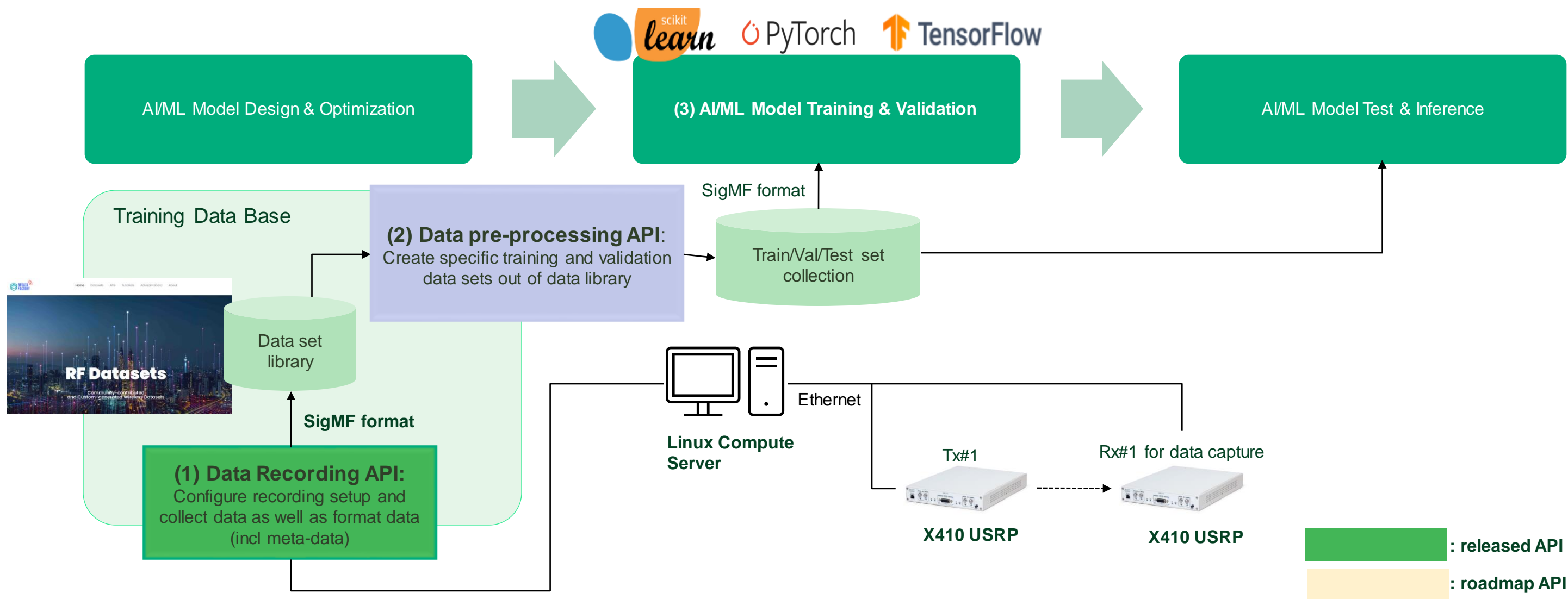


<https://www.ni.com/en/solutions/electronics/5g-6g-wireless-research-prototyping/empower-ai-ml-research-6g-networks-rf-data-recording.html>



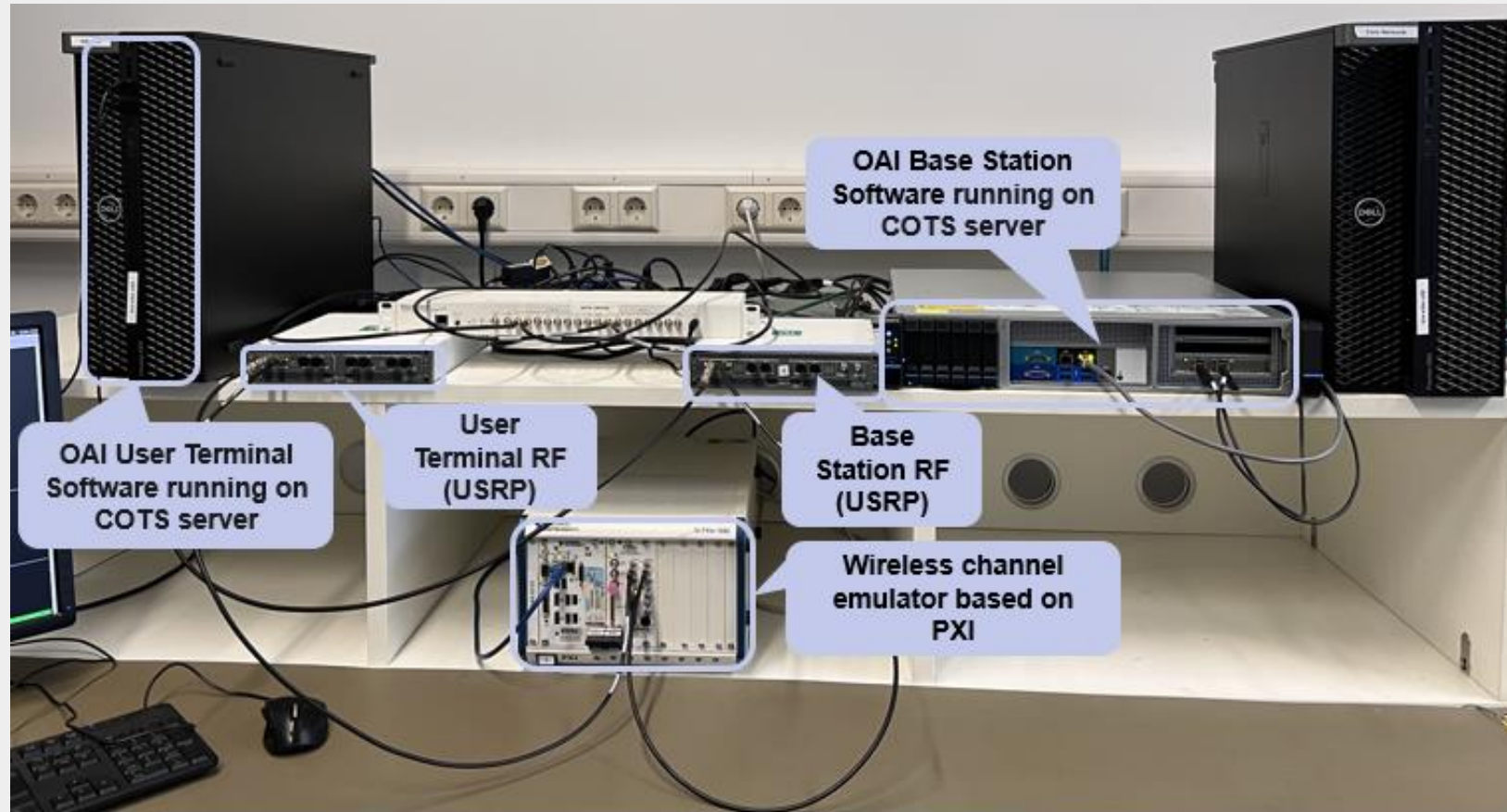
# NI Approach to Accelerate AI/ML Research

Accelerate the AI/ML research by streamlining the real-world data set recording campaigns over large parameter spaces with open source SigMF data set format.



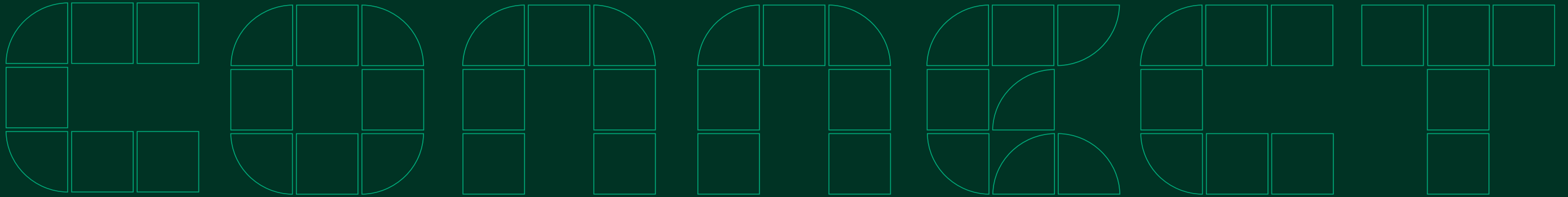
First in the world!

# System-Level Prototyping and Benchmarking for Embedded AI/ML



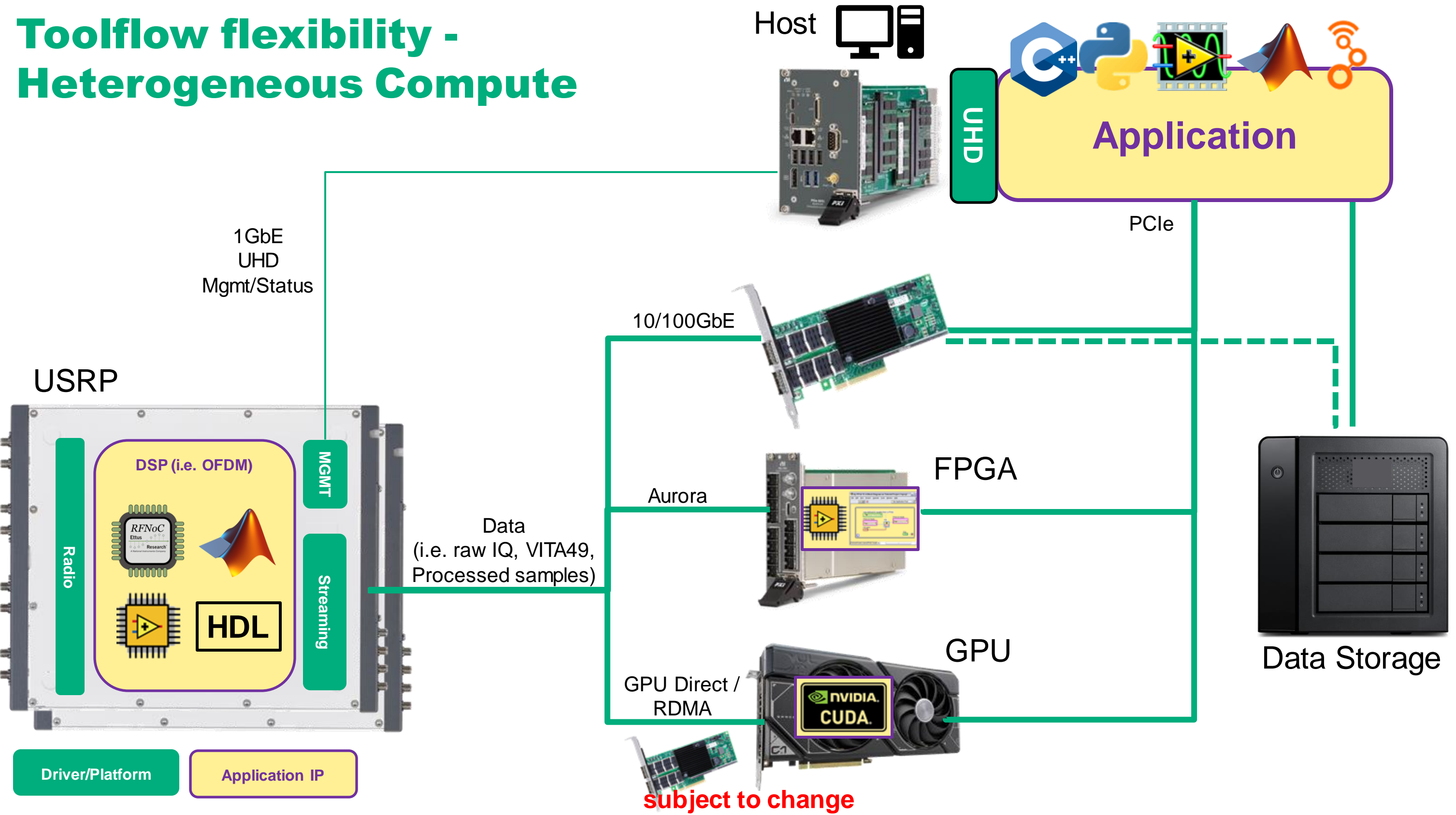
- Open-Air-Interface as system level IP using ORAN architecture and running on COTS CPU/ Server
- Neural receiver DUT running on Nvidia GPU and integrated into OAI through TensorFlow RT C-API
- NI internal VST & PXI based channel emulator





# **General SDR Toolflow Updates**

# Toolflow flexibility - Heterogeneous Compute





# Shown at demo floor



## MathWorks Wireless Testbench

### Workflows Supported

#### Workflow 1: Radio I/O

Transmit and capture wideband signals at up to 250 Msps

*Transmit/Capture using up to 2GB/4GB of on-board storage*

- ✓ 17s of 5G data @30.72 MSPS
- ✓ 6.5s of WLAN data @80 MSPS
- ✓ 2s at full N321 device rate (250MSPS)

#### Workflow 2: Intelligent Capture

Intelligent data capture with FPGA-based detectors and re-sampler

*Reduce data requirements by intelligently capturing only waveforms of interest by prebuilt detectors*

- ✓ Correlates the input signal with a known preamble sequence
- ✓ Supports correlating filters of up to 1024 taps at all sample rates
- ✓ Detect and capture a signal using signal energy as the trigger
- ✓ Farrow-based rate conversion

#### Workflow 3: Targeting

USRP Targeting

*Integrate custom IP blocks with RF Network-on-Chip (RFNoC™)*

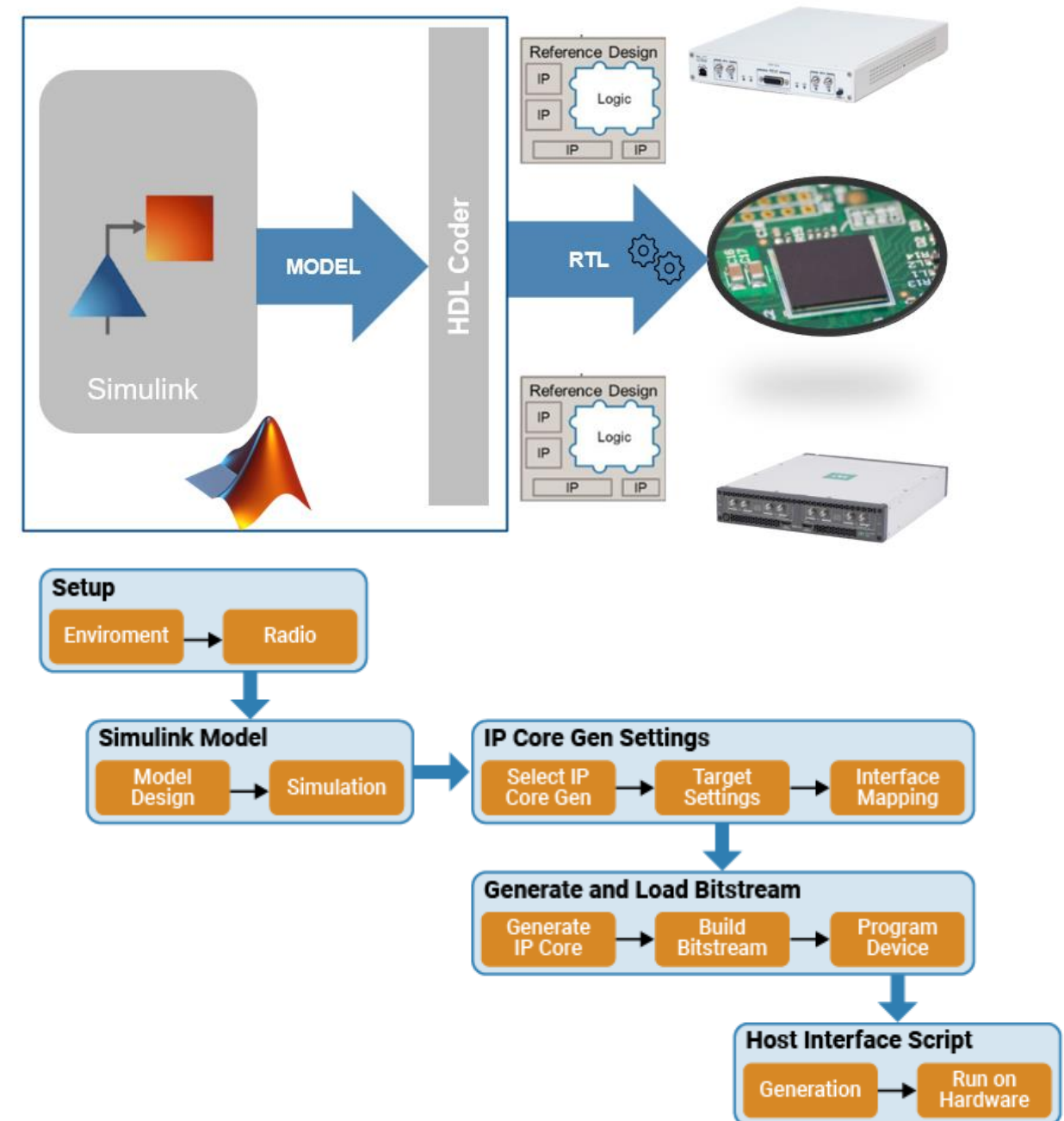
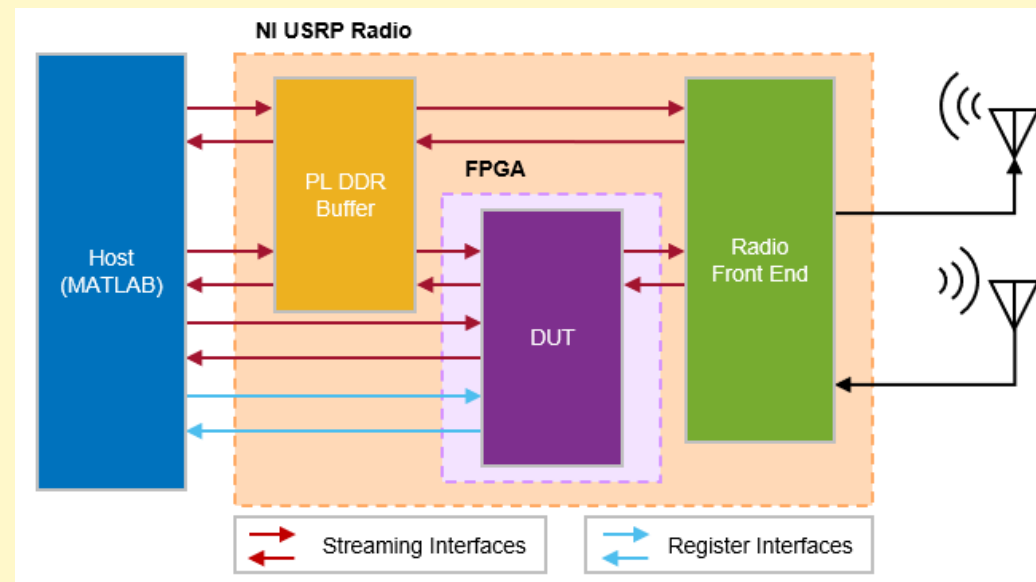
- ✓ Radio customization
- ✓ Rapid prototyping
- ✓ Easy to use

# Workflow 3: USRP Targeting

- Follows standard HDL Coder workflow.
- Generate bitstream and control from MATLAB

## Steps

1. Select Platform and parameters
2. Map DUT(user logic) IOs (data & register)
3. Generate HDL and wrap it as IP core (single click)
4. Generate Bitstream with User DUT (single click)
5. Generate MATLAB script to control DUT (single click)



# Deployable Front-End Integration



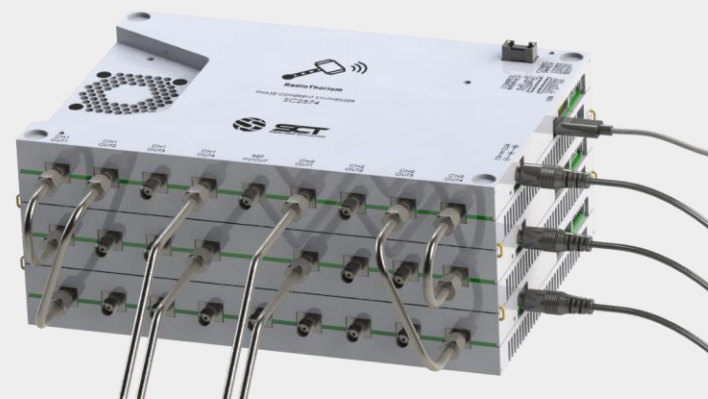
## SC2430 Over-the-Air communication

- Improved Tx Pout and Rx NF / Gain
- Integrated 5G NR Band Filters
- Seamless Integration with USRP via UHD Driver Extensions
- Multiple SRS and OAI customer deployed systems



## Thorium Up- / Downconverters

- SC2426 – 6-26GHz
- SC2444 – 24-44GHz
- SC2574 – Dual Channel Synth



## SC2441 Deployable High-Power RRU

- 4 Channels of 100 W (peak), 10 W (average) Each
- 5G NR Band N78 Cavity Filters providing > 60 dB Out of Band Rejection
- Customer verified using SRS 5G Stack

