SOLUTION
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RF Data Recording for AI/ML in 5G/6G Research with the USRP

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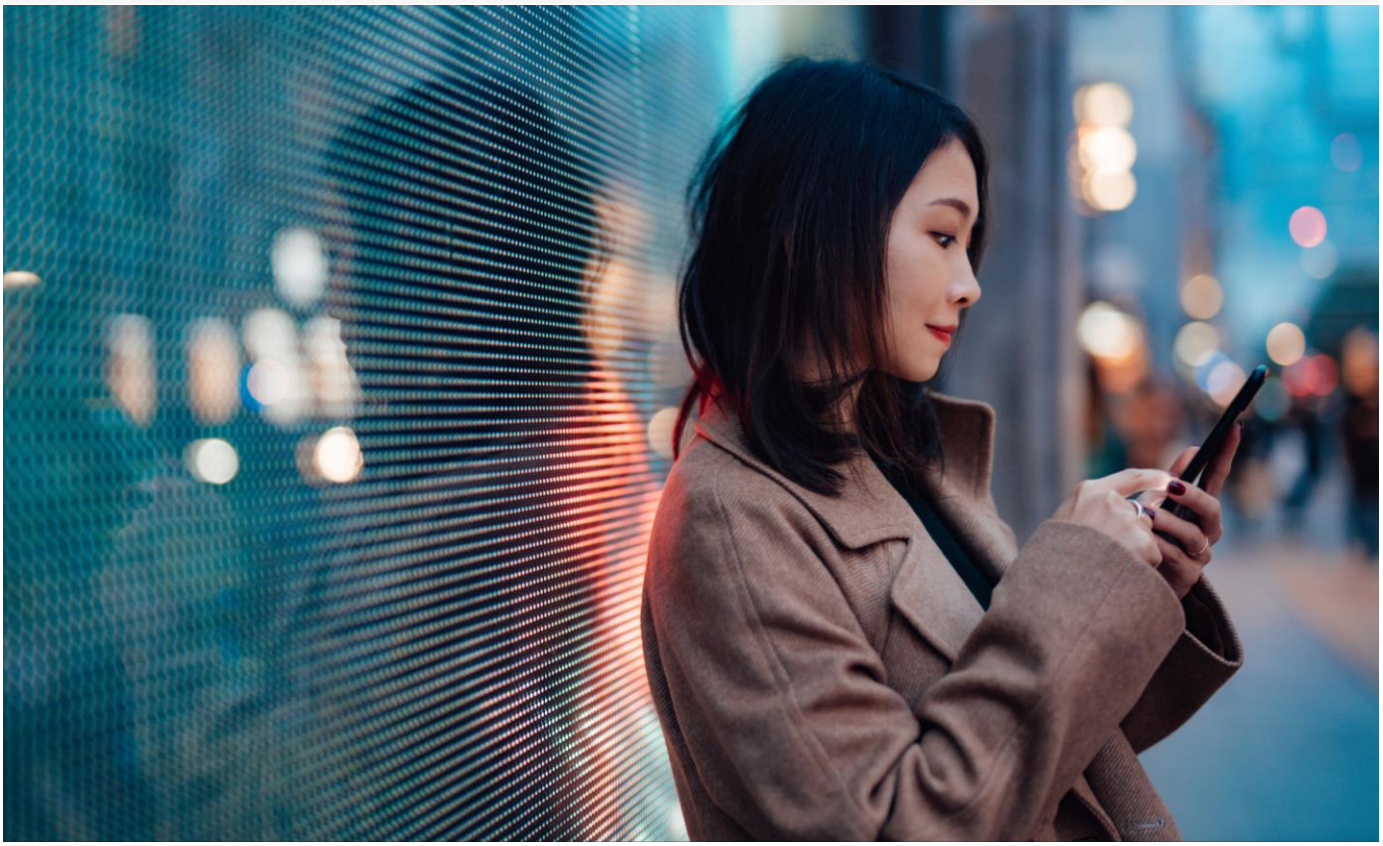
6G is anticipated to offer enhanced features such as higher data transfer speeds, reduced latency, improved reliability, and more advanced networking capabilities that surpass those of its predecessor. To accelerate 6G research, NI is exploring the power of AI/ML technology to provide researchers with advanced tools for optimizing system performance, analyzing data, and developing intelligent networking capabilities.



The Future of Wireless Communication

Wireless communication is undergoing rapid evolution, with 5G paving the way for even more advanced capabilities in 6G. 6G is expected to enable a range of exciting use cases. These applications will set a new standard for requirements in the different dimensions. Meeting these requirements will rely on a range of enabling technologies, such as utilizing extremely wide bandwidths at frequencies once thought impractical for commercial wireless. Additionally, Artificial Intelligence and Machine Learning (AI/ML) principles have been employed to enhance network efficiency and effectively manage the complexities associated with network operations. Overall, 6G is expected to elevate wireless communication to new heights, enabling a wide range of exciting new applications while meeting the demanding requirements of today's connected world.

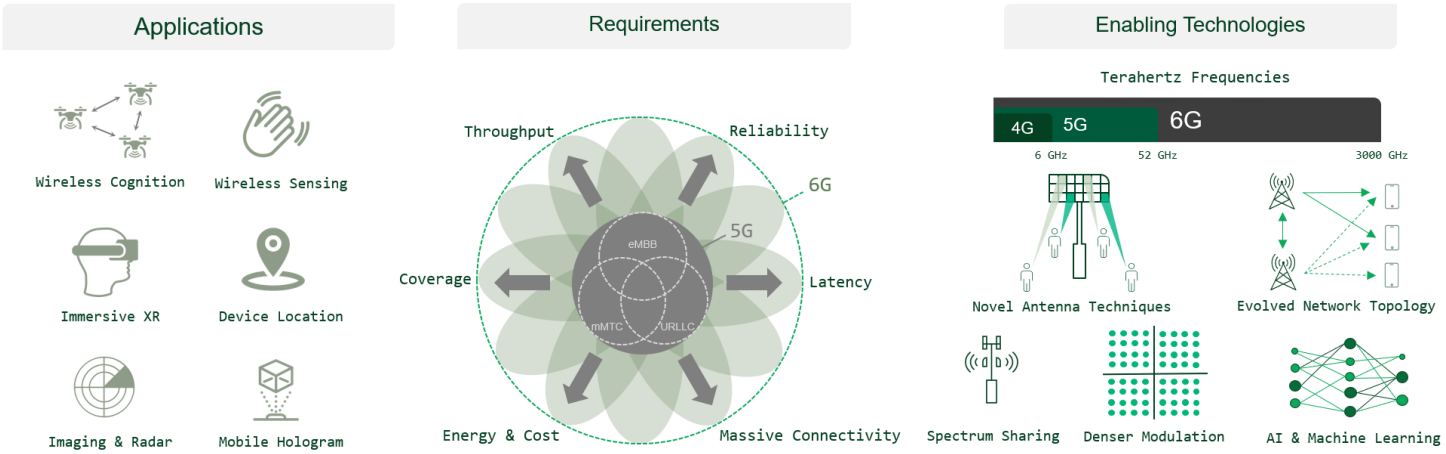
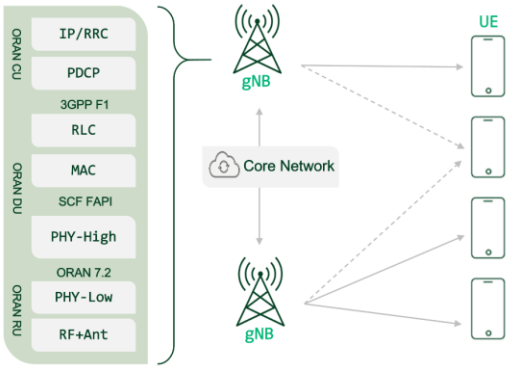


FIG 1 | What 6G Could Enables

Unlock the Full Potential with AI/ML

AI/ML principles are expected to be increasingly integrated into 5G and 6G networks. For example, AI/ML algorithms can enable intelligent and data-driven decision-making at different layers of 5G NR protocol stack:



- **Network**: 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

FIG 2 | Application Areas of AI/ML in 5G NR Radio Protocol Stack

Navigating the Obstacles of RF Data Set Collection for AI/ML

AI/ML models must get trained with data to serve a specific purpose and the performance is highly correlated to the quality of data sets one has available. Since both channel models and storage formats of data are diverse, making it difficult to compare models and adopt broader datasets for researchers. Also, there is no common tools to get RF datasets in an effective way. To create robust models, large data sets representable for a wide variety of potential scenarios are required using synthetic or simulation data but also data from real-world.

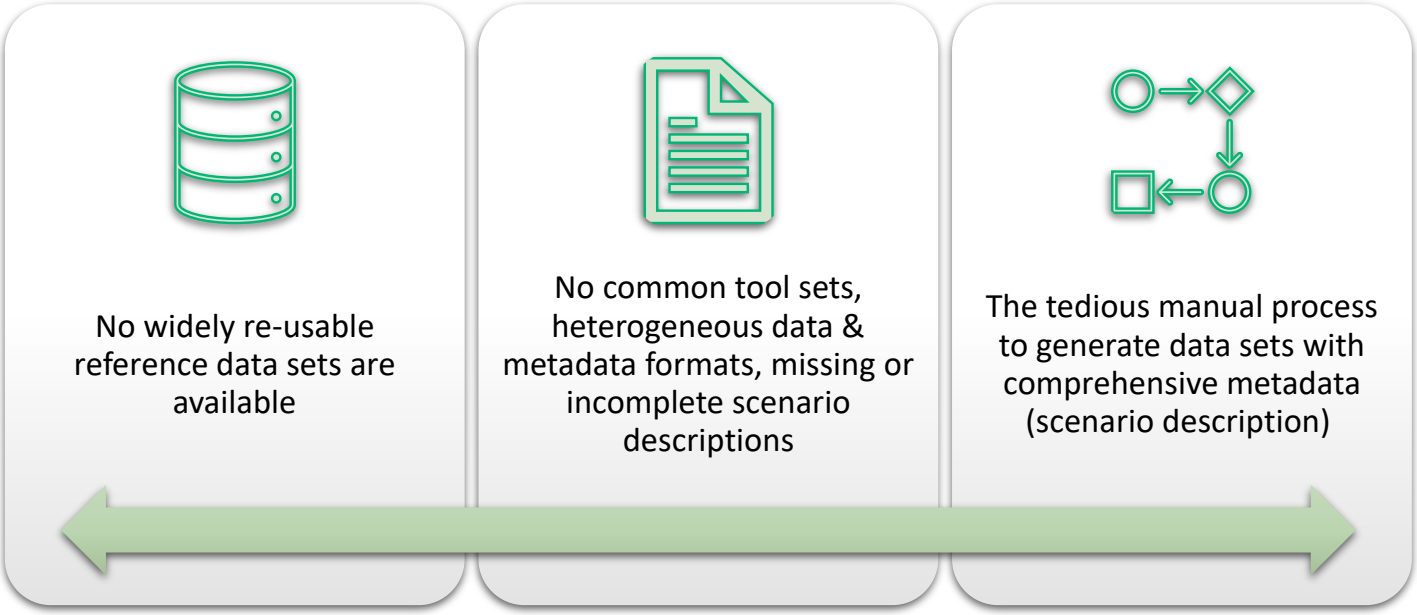


FIG 3 | Pain Points in RF dataset Collection

To expedite the advancement of AI/ML in 6G research, it is necessary to have a standard method to generate data sets that are:

- Large, with the standardized format and comprehensive scenario description
- High-quality, with representability of wide-range potential scenarios
- From the real world, with additional effects like RF impairments and channel properties for robustness improvement

NI and Northeastern University are working together to offer a complete solution, RF Data Recording for AI/ML in 5G/6G Research with the USRP, that enables users to collect application-specific RF data sets in a standard format to optimize AI/ML algorithms for various purposes.

Note: To learn more about how NI helps record RF data, visit Non-standard Waveforms from UAVs Dataset.

RF Data Recording for AI/ML in 5G/6G Research with the USRP Overview

RF Data Recording for AI/ML in 5G/6G Research consists of multiple NI USRP transceiver devices connected to a Linux server and controlled by a Python-based RF Data Recording API. It supports a scalable number of USRPs served as transmitter and receiver stations, each with its parameter configuration. The recorded data is stored in a data set library and is usually pre-processed before training, validating, and testing the model.

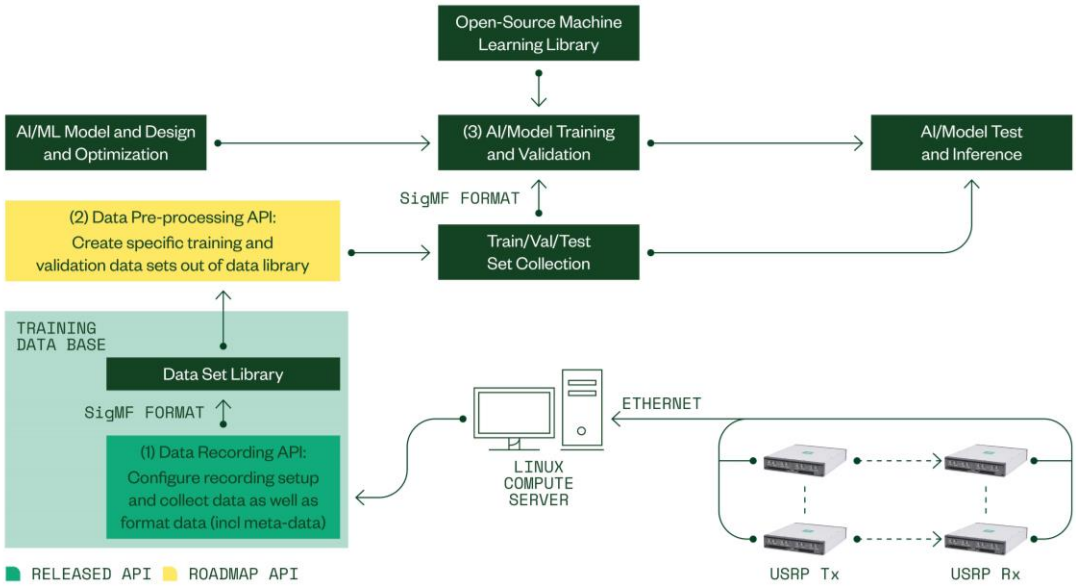


FIG 4 | Approach to Accelerate AI/ML Research

Key Advantages

- Open source and freely available on GitHub
- Facilitates hassle-free setup for experimentation and data set collection
- Distributed testbed setups possible for data recording due to ETH connection of USRP devices
- Scalable transceiver stations with individual parameter configuration (e.g., frequency, bandwidths, Tx/Rx gains)
- JSON- or YAML-based single configuration file to define data recording campaign with the definition of parameter settings as single, list, or range of values
- Instant conversion of recorded IQ data to SigMF format proposed by the open-source group as standard for RF AI/ML data sets

Solution Details

A Validated Design Pattern

The following resources are available to users:

01 Complete bill of materials including USRP, cables, and other hardware required for system assembly

02 User manual including system set-up instructions

03 Reference software code in Python can be easily accessed on GitHub

System Architecture

The RF data recording system architecture for 5G/6G research with the USRP provides hardware, software, and documentation that accelerates engineers' and researchers' ability to rapidly develop and test novel use cases.

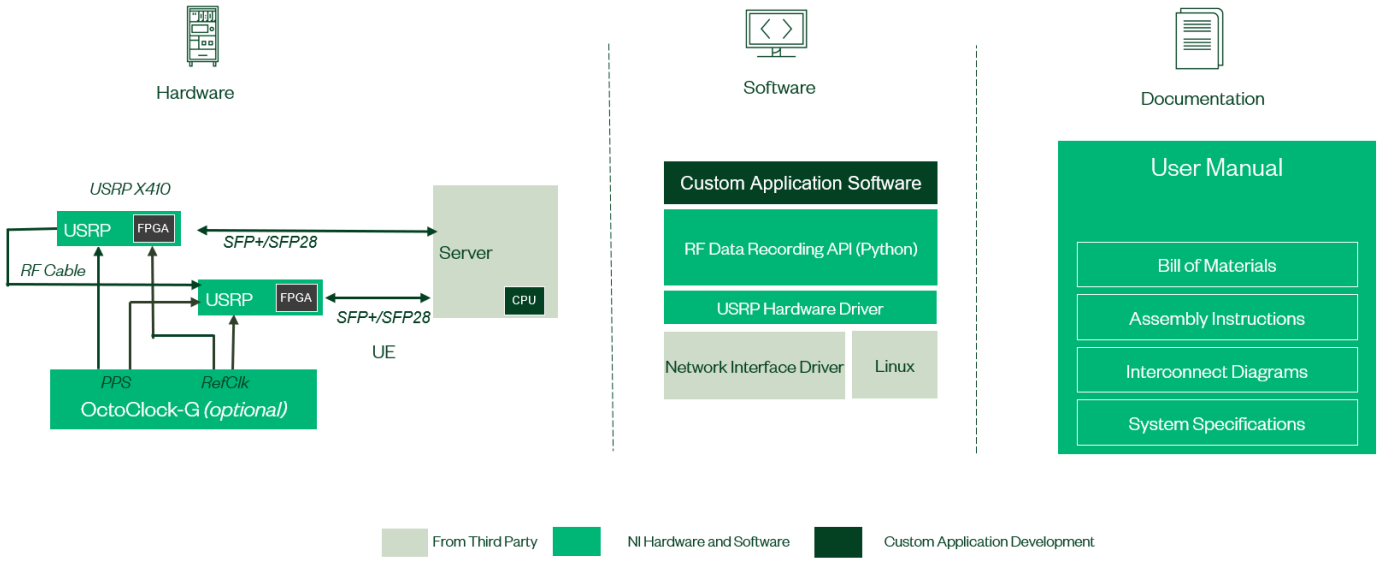


FIG 5 RF Data Recording System Architecture for 5G/6G research

The solution is based on the NI USRP platform to generate real-world RF data sets in an easy and automated way which could be critical in determining how the algorithms perform in the real world. The recorded data sets are saved in the SigMF format, an open-source standard specifying a way to describe sets of recorded digital signal samples. In addition, metadata such as data properties and scenario descriptions, are provided in JSON files that are human-readable and easily portable into various software environments. This allows the recorded data sets to be used in various research and application areas, including research on AI/ML for 5G/6G wireless communications.

Note: For system setup as well as more technical details, visit NI RF Data Recording API Application Note.

Software Components

With a few clicks, the RF Data Recording API can generate real-world RF data sets using the NI USRP SDR platform at different configurations. Its flexible architecture allows for different recording use cases. Such as any system, the RF Data Recording API has the inputs, processing units, and outputs described as follow.

Inputs:
- Configuration file in JSON or YAML format
- Wireless Link Parameter Map Dictionary (YAML file)
- Pre-generated waveforms (NR, LTE, Radar, WiFi)

Processing units:
- Software: The RF data Recording API code on top of the UHD Python API
- Hardware: Linux Server and NI USRPs

Outputs:
- SigMF data: Binary file includes collected raw data
- SigMF metadata (JSON format)

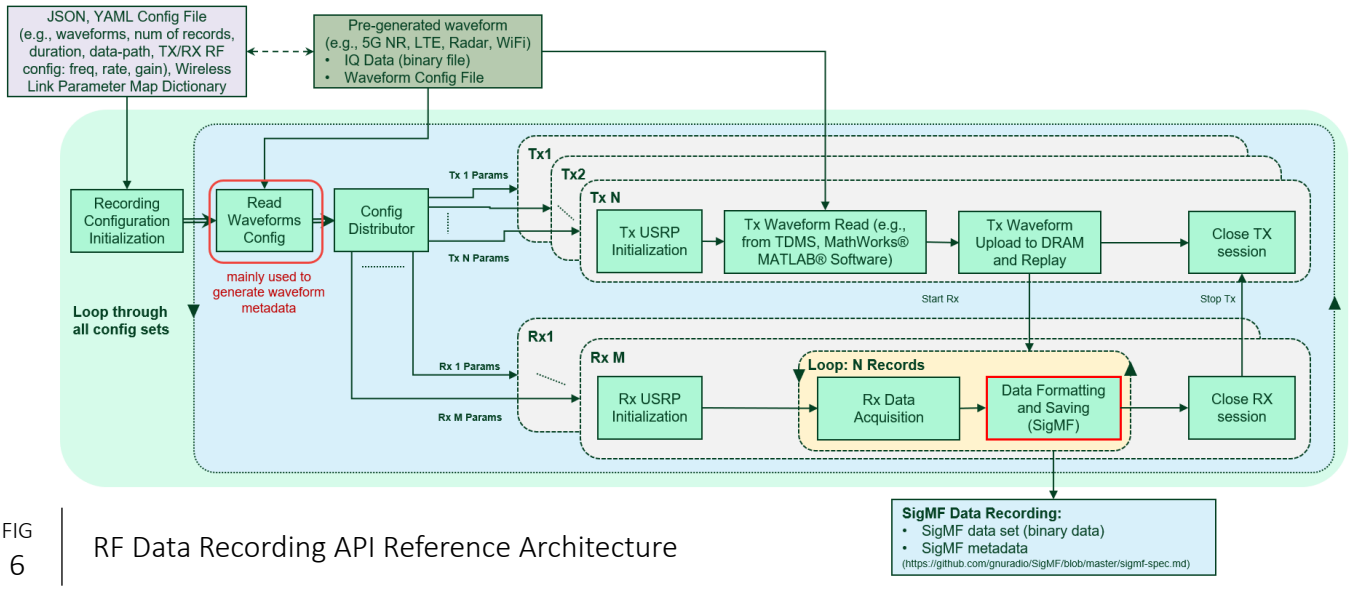


FIG 6 | RF Data Recording API Reference Architecture

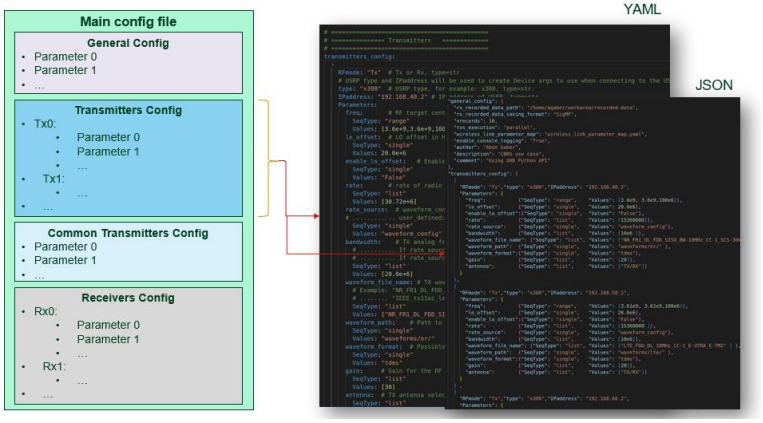


FIG 7 | An example of YAML/JSON RF data recording API configuration file

The RF Data Recording API provides configuration files in JSON or YAML format. JSON config files have a very compact configuration description, but parameters documentation is in the header of the file and far from the actual parameter's settings. Whereas YAML config files are not compact as JSON, their parameter's documentation is close to the related parameter settings.

Hardware Components

USRP X410 Software Defined Radio

The NI Ettus USRP X410 is the most powerful, multi-channel software-defined radio specially designed for prototyping high-performance wireless systems and performing over-the-air signal generation and analysis. The SDR is designed for frequencies from 1 MHz to 7.2 GHz and features a two-stage superheterodyne architecture with four independent TX and RX channels capable of 400 MHz of instantaneous bandwidth each.

Digital interfaces for data offload and control include two QSFP28 interfaces capable of 100 GbE, a PCIe Gen3 x8 interface. There are also standard command, control, and debug interfaces: USB-C JTAG, USB-C console, and Ethernet 10/100/1000. The USRP X410 is an all-in-one device built on the Xilinx Zynq UltraScale+ ZU28DR RF System on Chip (RFSoC) with built-in digital up-and-down conversion and onboard Soft-Decision Forward Error Correction (SD-FEC) IP.

FIG 8 NI Ettus USRP X410

USRP X310 Software Defined Radio

The NI Ettus USRP X310 is a high-performance, scalable software-defined radio (SDR) platform for designing and deploying next-generation wireless communications systems. The hardware architecture combines two extended-bandwidth daughterboard slots covering DC – 6 GHz with up to 160 MHz of baseband bandwidth, multiple high-speed interface options (PCIe, dual 10 GigE, dual 1 GigE), and a large user-programmable Kintex-7 FPGA in a convenient desktop or rack-mountable half-wide 1U form factor.

In addition to providing best-in-class hardware performance, the open-source software architecture of X310 provides cross-platform UHD driver support making it compatible with a large number of supported development frameworks, reference architectures, and open-source projects.

FIG 9 NI Ettus USRP X310

Note: For the detailed software environment set up with hardware configurations, please browse NI RF Data Recording API Application Note.

NI Services and Support

NI offers a variety of solution integration options customized to your application-specific requirements. You can use your own internal integration teams for full system control or leverage the expertise of our worldwide network of Alliance Partners to obtain a turnkey system.

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