What’s happening in the world of USRPs?

NI: Sponsor Talk

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Chief SDR Engineer
Let’s pick up where we left off…
Ettus USRP X410

Key RF Capabilities
- Frequency Range: 1 MHz - 7.2 GHz
- Signal Bandwidth: 400MHz
- Channels: 4 Rx - 4 Tx
- Max Power: Tx up to 22 dBm\(^1\) - Rx 0 dBm

Digital Capabilities
- FPGA Technology: Zynq Ultrascale+ RFSoC
- Interface Options: Dual QSFP28 (100/10 GbE), PCIe Gen 3 x8 (LabVIEW), RJ45 (1 GbE)
- Onboard IP: SD-FEC, DDC, DUC
- Software Support: UHD, GNU Radio, LabVIEW, ...
- Synchronization: Onboard GPSDO, External 10 MHz/PPS

Key Applications
- 5G / 6G Prototyping
- Signals Intelligence
- Wireless Communication
- Communications EW
- Software Defined Radio

\(^1\)see specification for details

June 2021
## USRP Product Portfolio Overview

<table>
<thead>
<tr>
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</tr>
</thead>
<tbody>
<tr>
<td><strong>Frequency</strong></td>
<td>70 MHz – 6 GHz</td>
<td>3 MHz-6 GHz (N32X)</td>
<td>*10 MHz – 6 GHz</td>
<td>70 MHz – 6 GHz</td>
<td>1 MHz – 7.2 GHz</td>
</tr>
<tr>
<td><strong>Analog Bandwidth</strong></td>
<td>56 MHz</td>
<td>200 MHz (N32X)</td>
<td>*160 MHz</td>
<td>56 MHz</td>
<td>400 MHz</td>
</tr>
<tr>
<td><strong>Channels</strong></td>
<td>2 Tx, 2 Rx</td>
<td>2 Tx, 2 Rx (N32X)</td>
<td>2 Tx, 2 Rx</td>
<td>2 Tx, 2 Rx</td>
<td>4 Rx, 4 Tx</td>
</tr>
<tr>
<td><strong>RF Performance</strong></td>
<td>Good</td>
<td>Best</td>
<td>Best</td>
<td>Good</td>
<td>Better</td>
</tr>
<tr>
<td><strong>Architecture</strong></td>
<td>Integrated</td>
<td>Integrated</td>
<td>*Configurable w/</td>
<td>Integrated</td>
<td>Integrated</td>
</tr>
<tr>
<td><strong>Communication</strong></td>
<td>USB</td>
<td>10 GbE or PCIe</td>
<td>10 GbE or PCIe</td>
<td>1/10 GbE</td>
<td>100/10/1 GbE or PCIe</td>
</tr>
<tr>
<td><strong>Synchronization</strong></td>
<td>2x2 MIMO</td>
<td>Up to 128x128 (N32X)</td>
<td>*2x2 MIMO</td>
<td>2x2 MIMO</td>
<td>4x4 MIMO</td>
</tr>
<tr>
<td><strong>SW Support</strong></td>
<td>GNU Radio, C++, Python, MatLab, LabVIEW</td>
<td>GNU Radio, C++, Python, MatLab, RFNoC</td>
<td>GNU Radio, C++, Python, MatLab, RFNoC, LabVIEW, LabVIEW FPGA</td>
<td>GNU Radio, C++, Python, MatLab, RFNoC</td>
<td>GNU Radio, C++, Python, RFNoC, LabVIEW</td>
</tr>
<tr>
<td><strong>Key Features</strong></td>
<td>Low SWAP-C, Highly portable</td>
<td>Stand Alone, Wide bandwidth, Multi-Channel Sync Ready (N32X)</td>
<td>*Configurable RF Front End, Programmable FPGA</td>
<td>Low SWAP, Embedded Deployable, Standalone</td>
<td>RFSOC Based, 5G Ready, Wide Band, Multi-Channel</td>
</tr>
</tbody>
</table>
In the meantime,...
UHD Update Cycles

- X410 GPIO API
- X410 250 Msps MCR
- Support more hardware revisions
- B200 sync improvements, N320 IQ-balance/DC-offset improvements, …

- X410 Full 4x4 100 GbE streaming
- X410 DRAM Record/Replay Support
- X410 Full GPIO Support incl. timed commands

- Raw UDP streaming API
- Extension API
- Vivado 2021.1 Upgrade

- Countless cleanups, Boost compatibility patches, Fedora/Windows/Ubuntu compatibility patches, bugfixes, CMake patches, documentation improvements, stale code cleanup, RFNoC improvements, …
NI SDR System Support
OAI Reference Design for 5G System Prototyping with USRP

5G cellular architecture

Core Network
- AMF
- SMF
- UPF

Radio Access Network
- gNB
- 5G SA UE

Control Plane
User Plane

x86 server

x86 server

Laptop
COTS UE Module
Using OAI + USRP for your 5G research

**Hardware**

- **OAI CN (+ PDN Server)**
- **Core Network**
- **OAI gNB**
- **UE**

**Software**

- **OAI**
- **NI**
- **Closed**

All on x86 (docker containers)
Open Architecture for Radar/EW/Comms Research

Validated design pattern enables researchers struggling to rapidly prototype new concepts to move quickly from software simulation to hardware demonstration, ultimately turning novel concepts into fielded capability faster.
Open Architecture for Radar/EW/Comms Research

- Higher system-level support
- More documentation, reference designs, recommended hardware, assembly best practices, ...
- Get results faster by avoiding all the pitfalls!
New UHD Features
UHD Extension API

- More RF conditioning is moving outside the box
- RF Extensions: Bespoke modules for specific RF applications
- What if the extension requires its own software control? => Enter the UHD Extension API!
- Many internal APIs were moved public to allow easy integration into UHD-based applications

RF Extension (filters, up/down converters, amplifiers, antenna control, …)

USRPs
The SC2430 NR Signal Conditioning Module (SCM) is a front-end solution that provides signal conditioning and amplification for Software Define Radio (SDR) systems.

It was designed specifically for use in conjunction with the NI Ettus-USRP X410. In this configuration, its input and output radio characteristics are compliant with select 3GPP 5G/NR standards for 5G NR User Equipment (UE) and gNodeB (gNB) implementations.
The SC2430 Signal Conditioning Module (SCM) can be tightly integrated with the NI Ettus X410 USRP (4 Tx/Rx Channels w/ 400 MHz BW).

An SCM extension for the Ettus USRP Hardware Driver (UHD) has been created and is available on SCT’s Github repository.

When enabled, the driver extension provides users with seamless control of the SCM via the X410. For example, when setting X410 gain, the driver will recognize presence of the SCM and distribute the desired system gain between both units to optimize performance. Likewise, when setting operating frequency, the relevant Band Pass Filters (BPF) will be selected in the SCM.

An optional override function exists to provide users with SCM specific control. For example, users may prefer to bypass the internal 5G band-specific filters for other applications.

Mechanically, bracket options exist to support bench top (shown below) or rack mount configurations.
**RF Channel Block Diagram**

- **BPF Bypasses 300 MHz to 7125 MHz**
  - **BPF Band A**: 1880 MHz to 2600 MHz (n39, n40, n41, n53, n38)
  - **BPF Band B**: 3300 MHz to 4200 MHz (n78, n77, n48)
  - **BPF Band C**: 4400 MHz to 5000 MHz (n79)
  - **BPF Band D**: 5150 MHz to 5925 MHz (n46, n47)
  - **BPF Band E**: 5925 MHz to 7125 MHz (n96)

- **LPF Bypasses 300 MHz to 7125 MHz**
  - **LPF Band 1**: 1880 MHz to 2600 MHz (n39, n34, n41, n53, n38)
  - **LPF Band 2**: 3300 MHz to 5000 MHz (n78, n77, n48, n79)
  - **LPF Band 3**: 5150 MHz to 7125 MHz (n46, n47, n96)

**Notes**

1. **On the transmit site, wider BPF that lump several adjacent NR Bands are implemented.**

2. **On the transmit site, wider BPF that lump several adjacent NR Bands are implemented.**

3. **Each path of this bank contains an LNA combined with the following NR Band channel filters:**

<table>
<thead>
<tr>
<th>NR Band</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>n39</td>
<td>2010 MHz - 2025 MHz</td>
</tr>
<tr>
<td>n30</td>
<td>2570 MHz - 2620 MHz</td>
</tr>
<tr>
<td>n39</td>
<td>1880 MHz - 1920 MHz</td>
</tr>
<tr>
<td>n40</td>
<td>2300 MHz - 2400 MHz</td>
</tr>
<tr>
<td>n41</td>
<td>2496 MHz - 2690 MHz</td>
</tr>
<tr>
<td>n46</td>
<td>5150 MHz - 5925 MHz</td>
</tr>
<tr>
<td>n47</td>
<td>5655 MHz - 5925 MHz</td>
</tr>
<tr>
<td>n48</td>
<td>3550 MHz - 3700 MHz</td>
</tr>
<tr>
<td>n77</td>
<td>3300 MHz - 4000 MHz</td>
</tr>
<tr>
<td>n78</td>
<td>3300 MHz - 3800 MHz</td>
</tr>
<tr>
<td>n79</td>
<td>4400 MHz - 5000 MHz</td>
</tr>
<tr>
<td>n90</td>
<td>2496 MHz - 2690 MHz</td>
</tr>
<tr>
<td>n96</td>
<td>5925 MHz - 7125 MHz</td>
</tr>
</tbody>
</table>

Crafting Order from Chaos
Seamless integration into SDR Applications at UHD level

- RF Extensions that use the UHD Extension API can be used in existing UHD Applications without recompiling
- Dynamic DLL loading
- Transparent forwarding of RF commands to extension driver
Raw UDP Traffic to Remote Destination

USRP
- Radio
- RFNoC Transport Adapter
- MAC/PHY/SFP

UHD / Control
- RFNoC
- Rx Streamer

Remote Destination
- Socket
- User App

Supported in UHD > 4.3.0.0 (X310 Support slightly later)
Raw UDP Traffic to Remote Destination

- More **streaming flexibility**:
  - Stream to any network destination
  - Stream data with or without CHDR metadata
  - Seamless integration into RFNoC
  - Hand-optimize streaming endpoint for higher performance

- Raw-UDP-to-USRP streaming on the roadmap (“Tx”)
  - (Slightly more difficult on the user end)

- Use custom RFNoC blocks to **format output data**
  - For example, enable VITA 49.2 frames
We want to be able to use general purpose SDRs like the X410 for satellite ground stations, due to their flexibility, open source nature, and popularity. We currently use DIFI (a specific form of VITA 49.2) to pipe IQ samples between transceivers and software modems within each ground station. To use an X410 as a ground station digitizer, it must be able to output DIFI, and allow for control on a separate interface or onboard. By using NIs recent untangling of UHD's data and control plane, combined with a new RFNoC block we created, we can now use the X410 as a ground station digitizer. The RFNoC block can be found here [https://github.com/DIFI-Consortium/rfnoc-difi](https://github.com/DIFI-Consortium/rfnoc-difi).

Currently supports standard DIFI data packets. More DIFI functionality (e.g., context packets, timestamps) coming soon.

On Thursday there will be a talk on DIFI and gr-difi at GRCon [https://github.com/DIFI-Consortium/gr-difi](https://github.com/DIFI-Consortium/gr-difi) includes a CPU-based DIFI Source/Sink.

For more information on DIFI see [https://dificonsortium.org/](https://dificonsortium.org/).
What’s Next?
What do we do with our development?

- UHD Continuous Improvement
- Extension API
- Raw UDP Streaming
- RFNoC Streaming Improvements
- 5G/6G/EW/RDP/etc. Support
# NI Ettus USRP X440 Product Overview

## IF Capabilities

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Front-End Conn:</td>
<td>Balun coupled, MMPX</td>
</tr>
<tr>
<td>IF Range:</td>
<td>30MHz – 4GHz (direct sampling)</td>
</tr>
<tr>
<td>Bandwidth:</td>
<td>1GHz / channel, 4GHz / total</td>
</tr>
<tr>
<td>Direct Sampling:</td>
<td>Up to 4GSps</td>
</tr>
<tr>
<td></td>
<td>~1.8 GHz (1st Nyquist)</td>
</tr>
<tr>
<td></td>
<td>~3.6 GHz (2nd Nyquist)</td>
</tr>
<tr>
<td>Number Channels:</td>
<td>8 (TX/RX or TRX)</td>
</tr>
<tr>
<td>Phase Coherency:</td>
<td>Yes (sample based)</td>
</tr>
<tr>
<td>TX output level:</td>
<td>&lt; 0dBm full scale</td>
</tr>
<tr>
<td>RX input level:</td>
<td>10dBm full scale</td>
</tr>
</tbody>
</table>

**Integration with Custom Front-Ends for Radar and Comms/EW research and prototyping**

## Digital Capabilities

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

*subject to change*
Expected Use Cases

Direct Sampling:
- Configure ADC/DACs for your specific need
  - You will need to provide your own filtering
  - Supporting for frequencies up to 3.6 GHz*

IF Stage:
- Utilizing an Up/Down Converter this product become the transceiver stage.
- Using the extension API, UHD can manage your RF settings for you in a familiar way

Applications:
- Satellite ground stations
- Radar/Comms/EW Research with specific RF requirements
- …anything that requires many channels, high bandwidth

*subject to change
Summary
Past, Present, and Future of USRP at NI

- Existing portfolio of USRPs covers a large spectrum of applications
  - Different SW workflows
  - Research/Prototyping, Deployment, System Integration, Defense, Security, …
- UHD/RFNoC/USRP are being continuously improved
- New Products are being released