Software Defined Radio Hardware Survey

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SDR - Boston

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Outline

• Feature Comparison
  – USRP versus USRP2
  – USRP N2x0 and USRP E1x0

• Overview of Daughterboards’ Capabilities

• Software Interfaces
  – UHD
  – MATLAB, Simulink, and LabVIEW

• Other Ettus Hardware and Roadmap

• Alternative Hardware Options
USRP versus USRP2

Original USRP
- USB 2.0
- 12-bit ADC 64 MS/s
- 14-bit DAC 128 MS/s
- 8 MHz Max Bandwidth
  - With 16 bit I/Q samples
- 2x2 MIMO with 1 USRP

USRP2 (EOL)
- Gigabit Ethernet
- 14-bit ADC 100 MS/s
- 16-bit DAC 400 MS/s
- 25 MHz Max Bandwidth
  - With 16 bit I/Q samples
- 2x2 MIMO with 2 USRP2s

http://www.ettus.com/products
http://www.olifantasia.com/drupal2/node/6
USRP N2x0 Series

- Gigabit Ethernet
- 14-bit ADC 100 MS/s
- 16-bit DAC 400 MS/s
- 25 MHz Max Bandwidth
  - With 16 bit I/Q samples
- USRP2 Improvements
  - More capable FPGA
  - Reprogram over Ethernet, instead of SD card
- 2 Gbps high-speed serial interface for expansion or MIMO

N200: Xilinx® Spartan® 3A-DSP1800 FPGA
N210: Xilinx® Spartan® 3A-DSP3400 FPGA
USRP E1x0 Series

- 720 MHz OMAP™3 (ARM® Cortex™ A8 processor & TI C64x+ DSP)
- Xilinx® Spartan® 3A-DSP1800 FPGA (E100), 3A-DSP3400 FPGA (E110)
- Two 64 MS/s 12-bit ADCs and Two 128 MS/s 14-bit DACs (I and Q)
- 100 Mbit Ethernet Interface
- 512MB RAM
- 4GB microSD Card
- Runs a Full Distribution of Angstrom Linux
  - Supports SSH and X
Comparison of FPGA Resources

- **USRP (Altera Cyclone)**
  - There isn’t much room left, if any

- **USRP2 (Xilinx Spartan 3 - XC3S2000 FPGA)**
  - General Logic: 59% free
  - Memory: 3% free
  - DSP Resources: The FPGA does not have DSP Resources

- **USRP N200 and E100 (Xilinx Spartan 3A DSP - XC3SD1800A FPGA)**
  - General Logic: 46% free
  - Memory: 50% free
  - DSP Resources: 80% free

- **USRP N210 and E110 (Xilinx Spartan 3A DSP - XC3SD3400A FPGA)**
  - General Logic: 63% free
  - Memory: 66% free
  - DSP Resources: 88% free

- The limited memory left in the USRP2 FPGA severely limited any additional development

http://www.ettus.com/faq#resources
A Cautionary Note

• Streaming to disk is possible at 25 MS/s but processing the data at that rate is a significant challenge
  – Need a RAID array for long recordings

• Don’t expect them to just work out of the box – These are development tools, you have to tell them exactly what to do

• Takes quite a bit of effort to do anything more than record data (even that takes a bit of doing), or transmit a tone

• On the positive side, there are many examples that come with the UHD now, which go a long way toward getting you started
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• Alternative Hardware Options
TX or RX Only Daughterboards

- BasicRX – 1-250 MHz IF
- BasicTX – 1-250 MHz IF
  - These require an external RF frontend
- LFRX – DC-30 MHz
- LFTX – DC-30 MHz
- TVRX2 – 50-860 MHz Dual (Real Only) Receiver
  - UHD Only
- DBSRX2 – 800 MHz - 2.4 GHz Receiver
  - UHD Only
Transceivers

- **XCVR2450** – 2.4-2.5 GHz and 4.9-5.9 GHz, 100 mW
  - (Half Duplex Only)

- **RFX900** – 750-1050 MHz, 200 mW

- **RFX1200** – 1150-1450 MHz, 200 mW

- **RFX1800** – 1.5-2.1 GHz, 100 mW

- **RFX2400** – 2.3-2.9 GHz, 50 mW

Note: The RFX series, the TVRX2, and the XCVR2450 have an RSSI measurement that can be read from software.
Wideband Daughterboards

**WBX**
- 50 MHz to 2.2 GHz
- 15 to 20 dBm TX output power, 25+ dB output power control range
- 5-10 dBm IIP3 on receive
- 40-55 dBm IIP2
- NF of 5-7 dB

**SBX**
- 400 MHz to 4.4 GHz
- 16 to 20 dBm TX output power, with 32dB of power control range
- 0 dBm IIP3 on receive
- 5-7 dB NF below 3 GHz
- 7-10 dB NF between 3 and 4 GHz
- 10-13 dB NF between 4 and 4.4 GHz

*NF -> Noise Figure*
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Universal Hardware Driver (UHD)

- UHD is now the only supported driver for the USRP family.

- Only the USRP and USRP2 work with GNURadio driver.

- UHD allows the use of all of the USRPs with GNURadio, C++, MATLAB, Simulink, LabVIEW, or other VRT-49 compliant software.

- UHD gives the USRP the ability to transmit or receive at a precise time if you have either the onboard GPSDO or if your host computer is synched to an external GPS receiver.

- Unless you have a good reason not to, use the UHD.
The MathWorks
Simulink and MATLAB

• Simulink has supported the USRP2 in the last few releases
  – Only works for low rate data rate applications < 1MS/s
  – Not very mature, but they may try to improve this to stay competitive since National Instruments acquired Ettus Research

• MATLAB now includes wrapper functions for the UHD commands, so you can quickly and easily control any USRP (except the E1x0) from MATLAB

• Supported Functions
  – Set and Get - Rx and Tx frequency (Fc and LO offset), gain, rate, freq range, gain range
  – Get motherboard/daughterboard description
  – Report list of attached USRPs
  – Start Rx stream, receive Rx data, report Rx overruns
  – Start Tx stream, send Tx data, report Tx underruns
• There is a Windows-only driver available for the USRP2, and they are coming out with a version that will support all of the USRPs, except the E1x0 series.

• The main benefit would be if you already have test instruments that you control from a Windows machine.

• LabVIEW is poorly supported on Linux anyway (for example the modulation toolkit is Windows only), so this will almost certainly stay a Windows-only product.
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## GPS Disciplined Oscillator (GPSDO)

### Specs

<table>
<thead>
<tr>
<th>Specification</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 PPS Accuracy</td>
<td>±50ns to UTC RMS (1-Sigma) GPS Locked</td>
</tr>
<tr>
<td>Holdover Stability</td>
<td>&lt;±11μs over 3 hour period at +25C</td>
</tr>
<tr>
<td>1 PPS Output (OCXO Flywheel Generated)</td>
<td>3.3VDC CMOS</td>
</tr>
<tr>
<td>RS-232 Control</td>
<td>NMEA and SCPI-99 Control Commands, Integrated into UHD</td>
</tr>
<tr>
<td>GPS Frequency</td>
<td>L1, C/A 1574MHz</td>
</tr>
<tr>
<td>GPS Antenna</td>
<td>Active or Passive</td>
</tr>
<tr>
<td>GPS Receiver</td>
<td>50 Channels, Mobile, WAAS, EGNOS, MSAS capable</td>
</tr>
<tr>
<td>Sensitivity</td>
<td>Acquisition -144dBm, Tracking -160dBm</td>
</tr>
<tr>
<td>Time to First Fix (TTFF)</td>
<td>Cold Start: &lt;45 sec, Warm Start: 1 sec, Hot Start: 1 sec</td>
</tr>
<tr>
<td>Allan Deviation (ADEV)</td>
<td>1E-11 at 1s</td>
</tr>
<tr>
<td>Warm Up Time / Stabilization Time</td>
<td>&lt;5 min at +25C to 1E-08 Accuracy</td>
</tr>
<tr>
<td>Supply Voltage (Vdd)</td>
<td>6VDC</td>
</tr>
<tr>
<td>Power Consumption</td>
<td>&lt;1.8W Max, 1.35W Typical</td>
</tr>
<tr>
<td>Operating Temperature</td>
<td>0C to +60C</td>
</tr>
<tr>
<td>Storage Temperature</td>
<td>-45C to 8</td>
</tr>
</tbody>
</table>

- Onboard GPS receiver allows precise time-stamping of samples for TX and RX
- Can query time from software
- Generates 1PPS and 10 MHz outputs
QR-210 – Special Order

• 4-Channel Phase Coherent Receiver
• 700 MHz-3 GHz (4 GHz Optional)
• Onboard GPS-Locked OCXO
• 14-bit ADCs 120 MS/s
• 50 MHz Instantaneous Bandwidth
• Virtex 5 SXT FPGA
• SFDR > 80 dB
• Noise Figure < 8 dB
• 10 Gigabit Ethernet and PCI Express x4
## Products on 2012 Roadmap

<table>
<thead>
<tr>
<th>B100</th>
<th>2 x 2 MIMO System</th>
</tr>
</thead>
<tbody>
<tr>
<td>Replacement for original USRP</td>
<td>USRP N210 class specs</td>
</tr>
<tr>
<td>USB 2.0</td>
<td>Gigabit Ethernet</td>
</tr>
<tr>
<td></td>
<td>Hybrid between USRP and USRP N210</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>CBX</th>
<th>New and Improved E series USRP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Available around Q1 2012</td>
<td>Dual Core Processor</td>
</tr>
<tr>
<td>2 – 6 GHz</td>
<td>Higher Bandwidth Bus</td>
</tr>
<tr>
<td></td>
<td>Higher End FPGA</td>
</tr>
</tbody>
</table>
10G Ethernet in the Next Year

- Gigabit Ethernet is the bottleneck for the instantaneous bandwidth that the USRPs can deliver (except for the embedded series, which are processor limited).

- This update will obviously open up the pipe.

- The issue now will be whether the host computer hardware can handle it, as well as daughterboard analog filters.

- Solid state drives may be able to handle this data rate, but the host computer will still require a RAID array to record for long periods of time.
Conclusions on Ettus Roadmap

• Adding capability

• Improving performance

• Documentation will probably remain limited, although the documentation for UHD has improved dramatically

• Trying to penetrate higher end market, while maintaining lower cost options for students and professors
Model Guide

• **USRP** – Modest bandwidths (<=8 MHz complex), less precision (12 bit ADC), and/or more channels per box

• **USRP E1x0** – Embedded computer, great if you have size, weight, and power (SWaP) constraints. Also allows for FPGA processing, unlike the USRP

• **USRP2 (EOL)** – More bandwidth (<=25 MHz complex), more precision (14 bit ADC), and clock synchronization

• **USRP N200** – Same benefits as USRP2, and you get a more capable FPGA, and you can reprogram the FPGA over Ethernet, instead of reprogramming the SD card

• **USRP N210** – Same as above except an even larger FPGA

• If you can wait 6 months there should be some new models available – B100, 2x2 MIMO, improved embedded version
Important Links  
(A ton of information here)

- Ettus Research Home Page  
  - [http://www.ettus.com/](http://www.ettus.com/)

- UHD Wiki  
  - This site has all of the schematics under the Documents tab

- UHD Manual  

- USRP Users Mailing List  
  - You can either join the list here, or browse the archives. Both are recommended
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Alternative Hardware Options

- **WARP Board**
  - [http://warp.rice.edu/trac/wiki/FPGA%20Board](http://warp.rice.edu/trac/wiki/FPGA%20Board)

- **Lyrtech Small Form Factor**

- There are others as well, however unless you have very specific requirements that the Ettus hardware line doesn’t meet, I recommend going with one of the USRPs
Questions?

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Backup Slides
Hard to use the DSP, development tools are very difficult to setup.

The iPhone 4 has a 1GHz ARM Cortex A8.

*GPMC* → General Purpose Memory Controller
Old Daughterboards

• **TVRX**
  – 50-860 MHz Receiver
  – 6 MHz Bandwidth
  – Based off a TV tuner module
  – 8 dB noise figure is typical
  – Only board that’s not MIMO capable

• **DBSRX**
  – 800 MHz – 2.4 GHz Receiver
  – 3-5 dB noise figure
  – Software controllable filter from 1-60 MHz

• **RFX2200**
  – 2-2.4 GHz Transceiver
  – 6-10 dB noise figure
  – 100 mW output power

None of these daughterboards are available anymore
WBX Detailed Specifications

- **Transmit**
  - 50-100 mW (17-20 dBm) from 50 MHz to 1.2 GHz
  - 30-70 mW (15-18 dBm) from 1.2 GHz to 2.2 GHz
  - 25+ dB output power control range under software control

- **Receive**
  - Noise figure of 5-7 dB
  - IIP3 of 5-10 dBm
  - IIP2 of 40-55 dBm
  - At every frequency there is a gain setting which gives a noise figure of less than 8 dB while simultaneously giving an IIP3 of better than 0 dBm and an IIP2 of better than 40 dBm
### Full Specs on QR-210

The Ettus Research QR-210 is a 4-channel phase-coherent receiver system designed for wide bandwidth surveillance, SIGINT, and COMINT applications in the 700 MHz to 3 GHz range (4 GHz optional). The receivers are designed for high dynamic range in harsh RF environments. Built around the core Virtex 5 FPGA, the system is capable of 30 MHz instantaneous bandwidth with direction-finding (DF) and MIMO processing, and can generate up to 8 beams simultaneously.

<table>
<thead>
<tr>
<th>General</th>
<th>RF Specs</th>
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<tbody>
<tr>
<td>• 4 channel phase coherent 700 MHz to 3 GHz Receiver (4 GHz optional)</td>
<td></td>
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<tr>
<td>○ Optimized for phased arrays, direction finding (DF) and MIMO applications</td>
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<tr>
<td>• Onboard GPS-locked OCXO</td>
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<tr>
<td>• Standard 1U 19” Rackmount enclosure</td>
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<tr>
<td>• 14-bit 120 MS/s Quadrature ADCs</td>
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<tr>
<td>• 30 MHz instantaneous bandwidth on each antenna</td>
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<tr>
<td>• Beamforming and MIMO processing in the Virtex 5 SXT FPGA or on the host computer</td>
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<tr>
<td>• Consumes less than 60 Watts</td>
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<tr>
<td>• Expandable up to 32 antennas</td>
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<tr>
<td>• Time-stamped samples accurate to better than 10ns</td>
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<tr>
<td>• Works with GNU Radio, LabVIEW, or other VITA-49 compliant software</td>
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<tr>
<td>• Remotely upload new FPGA code and firmware</td>
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</tr>
<tr>
<td>• IIP2 &gt;40dBm</td>
<td></td>
</tr>
<tr>
<td>• IIP3 &gt;0dBm</td>
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<tr>
<td>• Noise Figure &lt;8 dB</td>
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<tr>
<td>• SFDR &gt;80dB</td>
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<tr>
<td>• Very Low Phase Noise YIG oscillator</td>
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<tr>
<td>○ &lt; -100 dBC/Hz @ 10kHz</td>
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<tr>
<td>○ &lt; -120 dBC/Hz @ 100kHz</td>
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<tr>
<td>○ &lt; -140 dBC/Hz @ 1 MHz</td>
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<tr>
<td>• Built In Calibration hardware and software</td>
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<tr>
<td>Ports:</td>
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<tr>
<td>Dual Gigabit Ethernet</td>
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<td>10 Gigabit Ethernet</td>
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<tr>
<td>PCI Express x4 (over cable)</td>
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<tr>
<td>External 10 MHz and 1 PPS inputs</td>
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<tr>
<td>MIMO Expansion</td>
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