Software Defined Radio Hardware Survey

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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

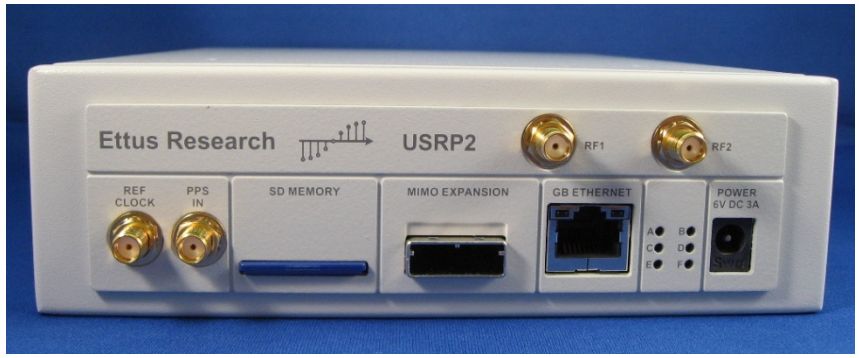
Original USRP

- 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

http://www.ettus.com/products

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.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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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

National Instruments - LabVIEW

- 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.

http://www.ni.com/

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GPS Disciplined Oscillator (GPSDO)

Specs

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

- 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

B100 • Replacement for original USRP • USB 2.0	**2 x 2 MIMO System** • USRP N210 class specs • Gigabit Ethernet • Hybrid between USRP and USRP N210
CBX • Available around Q1 2012 • 2 – 6 GHz	**New and Improved E series USRP** • Dual Core Processor • Higher Bandwidth Bus • Higher End FPGA

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/
- UHD Wiki
  - http://code.ettus.com/redmine/ettus/projects/uhd/wiki
  - This site has all of the schematics under the Documents tab
- UHD Manual
  - http://www.ettus.com/uhd_docs/manual/html/
- USRP Users Mailing List
  - http://lists.ettus.com/mailman/listinfo/usrp-users_lists.ettus.com
  - 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
- **Lyrtech Small Form Factor**
  - http://www.lyrtech.com/products/sff_sdr_development_platforms.php
- **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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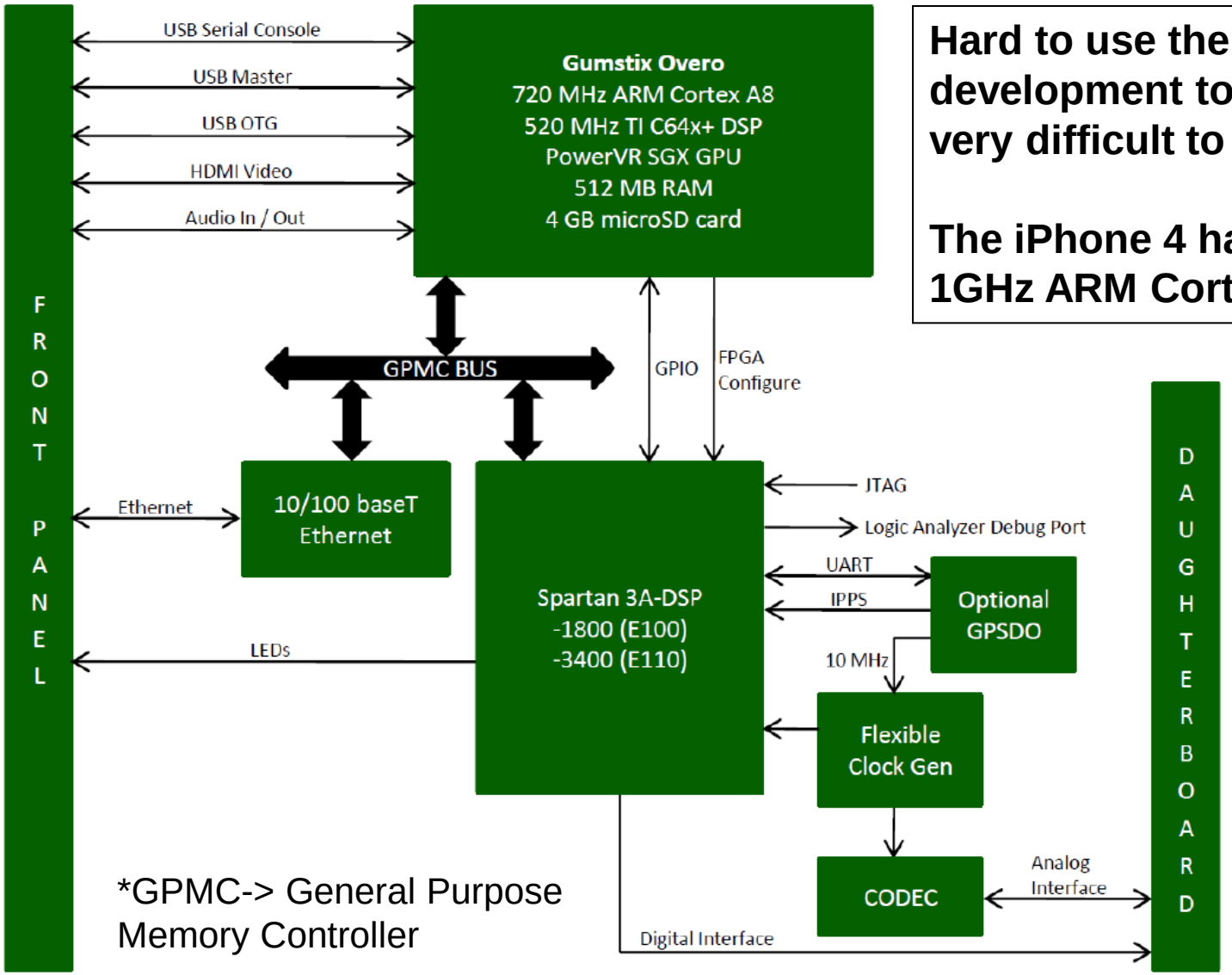
Backup Slides

E1x0 Block Diagram



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 0dBm 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.

General

- 4 channel phase coherent 700 MHz to 3 GHz Receiver (4 GHz optional)
  - Optimized for phased arrays, direction finding (DF) and MIMO applications
- Onboard GPS-locked OCXO
- Standard 1U 19" Rackmount enclosure
- 14-bit 120 MS/s Quadrature ADCs
- 30 MHz instantaneous bandwidth on each antenna
- Beamforming and MIMO processing in the Virtex 5 SXT FPGA or on the host computer
- Consumes less than 60 Watts
- Expandable up to 32 antennas
- Time-stamped samples accurate to better than 10ns
- Works with GNU Radio, LabVIEW, or other VITA-49 compliant software
- Remotely upload new FPGA code and firmware

RF Specs

- IIP2 >40dBm
- IIP3 >0dBm
- Noise Figure <8 dB
- SFDR >80dB
- Very Low Phase Noise YIG oscillator
  - < -100 dBc/Hz @ 10kHz
  - < -120 dBc/Hz @ 100kHz
  - < -140 dBc/Hz @ 1 MHz
- Built In Calibration hardware and software

Ports:

Dual Gigabit Ethernet

10 Gigabit Ethernet

PCI Express x4 (over cable)

External 10 MHz and 1 PPS inputs

MIMO Expansion