SDR Applications in Radio Astronomy at Shirley's Bay

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About Me

• Software developer currently working in media security (DRM).
  – 20 years in network and network security design with Nortel.
  – Former Security Area Director, IETF
  – Former WG Chair AFT and ITRACE working groups
  – Published several RFCs
  – Inventor of record on 11 patents
  – 35 years in computing/software/networking

• Involved in small-scale radio astronomy since 1986

• Began using/promoting SDR techniques in small-scale RA in 2004.

• Contributor to Gnu Radio

• Contractor to Ettus Research
In The Beginning...
In The Beginning...

- Analog RF processing
- Analog detection
  - Originally chart-recorder output
  - Analog recorders
  - Eventually computers capturing detector output with emergence of ADC technology
Idealized DSP receiver
Idealized DSP Receiver...

- If we weren't constrained by practicalities, we could build receivers with extremely-high sample-rates, >100dB dynamic range
  - No filtering required
  - Sample everything
  - Digital fabric takes care of band-selection, etc
- Modern RA receivers actually fairly close to this ideal
  - A few Gsps
  - A few (2-6) bits of ADC
- Arrays of FPGAs for sample processing
Compromise: An SDR receiver
Compromise: An SDR receiver

- Do “thin” analog RF processing—get to analog baseband as soon as possible
- Quadrature sample to produce complex digital baseband
- Spread digital processing fabric between cheap FPGA and capable, commodity, PC
  - FPGA typically does DDC/rate-conversion
- Limited bandwidth (from RA perspective)
  - Increase in flexibility
  - Experiment using cheaper hardware
  - Software tools allow non-FPGA/DSP people to play
Where does SDR “fit in”

- Observing bandwidths often quite large
  - Sample-rate too high for processing strictly on host computer
  - May require FPGA assistance
- Some projects at an observatory aren't necessarily high-bandwidth.
  - Riometers
    - Fielded an SDR multi-frequency riometer at NRCan site near Ottawa
    - KAIRA doing spectral riometry with SDR techniques
  - Spectral-line observations
    - Galactic red-shift only about 2MHz at 21cm
  - Low-frequency observations (below 2GHz)
    - Often RFI-limited anyway
    - Features are bright(ish)
  - RFI monitoring
    - Already doing that at DRAO
  - Pulsar monitoring for bright pulsars
    - Can de-disperse in real-time on ordinary computer
Where does SDR “fit in” (cont)

• New experimental techniques can be modeled and tested at low-bandwidths, with SDR techniques, prior to committing to a high-bandwidth design, with FPGA arrays.

• Excellent training/teaching tool—cheap hardware, learn processing techniques in software on ordinary PCs.

• “Hybrid” astronomy using man-made signals encountering cosmic 'stuff'.
  − Measuring solar corona with X-band science beacons.
SDR host-side tools: Gnu Radio

- **Gnu Radio framework**
  - In development since 2003
  - Uses a *dataflow* model to connect DSP blocks to achieve desired functionality
  - GUI tool to allow easy lay-out of *flow-graphs*
  - 1000-2000 users worldwide

- **Supports many different types of SDR hardware**
  - Simple audio interface for low-bandwidth things
    - Can be used for VLF SID observations, for example
  - *Ettus Research USRP* (more later)
  - *RTLSDR dongles* (more later)
  - Nuand *BladeRF*
  - HackRF
  - *AirSpy*
  - *Others*
Gnu Radio: GRC graphs

Options
ID: really_simple_tp
Generate Options: WX GUI

Variable
ID: samp_rate
Value: 2.56M

osmocom Source
Sample Rate (sps): 2.56M
Ch0: Frequency (Hz): 300M
Ch0: Freq. Corr. (ppm): 0
Ch0: DC Offset Mode: Off
Ch0: IQ Balance Mode: Off
Ch0: Gain Mode: Manual
Ch0: RF Gain (dB): 40
Ch0: IF Gain (dB): 20
Ch0: BB Gain (dB): 20

Single Pole IIR Filter
Alpha: 0.625n

Complex to Mag^2

Keep 1 in N
N: 2.56M

WX GUI Scope Sink
Title: Scope Plot
Sample Rate: 1
T Scale: 850
Trigger Mode: Auto
Y Axis Label: Counts
Gnu Radio Demo: B100 interferometer

- We'll show the construction of a really-simple two-element correlation interferometer with a USRP B100 + TVRX2.
Sample observations: Solar flux at transit

10.7cm/2.6cm Solar transit: 2014-07-03

10.7cm Peak (SFU): 166.86
2.6cm Peak: (SFU) 23.69
Tmin(10.7): 10K Tmin(2.6): 5.0K
Tsys(10.7): 135K Tsys(2.6): 95K
Fc(10.7): 2.79GHz Fc(2.6): 10.685GHz
Sample observations: H1 spectrum

Hydrogen line (DEC=41.00)

Power (dB)
-35.6
-35.8
-36
-36.2
-36.4
-36.6
-36.8
-37
-37.2
-37.4
-37.6
-37.8

Velocity (km/s) RES=0.155km/s
-150 -100 -50 0 50 100 150

Averaged from 19:50:00 to 20:10:00 (39 records)
'tmp228092'

Fc: 1420.4058MHz

<---1.5MHz (316.28km/s)--->

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Sample observations: VLF
Sample observations: Cygnus A @4GHz
Hardware: Getting started

- **RTL-SDR dongles**
  - RTL2832U DVB-T USB-2.0 chip
  - R820T tuner
  - Primarily designed as DVB-T tuner for Pcs
  - Semi-serendipitous “bypass mode” allows receiving down-sampled ADC samples from tuner.
  - 8-bits
  - Up to 2.56Msps
  - Tunable from 24.5MHz to 1750MHz
  - Available from many places
    - $10.00 or less on eBay
    - NooElec imports and sells from Markham, ON
  - Can be made semi-coherent with some work
Hardware: Moving up

- **Ettus Research** ([www.ettus.com](http://www.ettus.com))
  - Pioneered inexpensive SDR platforms in 2004
    - USRP1 sold thousands
  - Now extensive product line-up:
    - USRP1
    - B200 and B210 (DRAO has a B200) *
    - E310 *
    - X300 and X310
    - N200 and N210
    - E100 E110
    - * = no daughtercard required
  - Daughtercards to cover various frequency ranges:
    - WBX 25MHz to 2.2GHz
    - SBX 400MHz to 4.4GHz
    - CBX 1200MHz to 6GHz
    - UBX (pre-release) 10MHz to 6GHz
  - Ettus acquired by National Instruments in 2010
    - Much co-development and synergy in product lines
    - LabView support for some Ettus hardware: N2xx and X3xx

- Daughtercards to cover various frequency ranges:
Beyond SDR: Hybrid FPGA+SDR framework: RFNoC

- New development by Ettus Research, targetted at X3x0 and E310 platforms.
  - Take advantage of large FPGA fabric
  - Pre-defined “compute modules” in FPGA
  - Interconnect with a packet-switched crossbar.
    - Runtime configuration
    - Connect producer/consumer in easy, natural, way
  - Don't have to be a FPGA/verilog expert to leverage compute power of FPGA
  - Integrated into Gnu Radio
- BETA availabilty by end-of-year 2014.
- I'm encouraging them to implement RA-friendly modules sooner rather than later.
  - FFT+integrator+decimator module coming soon
Further explorations

- Ettus radios
  - http://www.ettus.com
- Gnu Radio main page
  - http://www.gnuradio.org
- RTLSDR starter page
  - http://sdr.osmocom.org/trac/wiki/rtl-sdr
- REDDIT channel for RTLSDR
  - http://www.reddit.com/r/RTLSDR
SBRAC Project

• Who are we?
  • A loose band of folks working to restore the 18m Kennedy dish on-site for small-scale radio astronomy observations.
  • Started by Gary Atkins (CSA) and Marcus Leech several years ago.
  • Apply inexpensive SDR techniques to all our observing.
SBRAC Project: Goals

• Educational outreach
  • Nobody teaches the instrumentation side of radio astronomy any more.
  • “Real” instruments have time booked **years** in advance. No opportunity for training exercises involving real instrumentation.

• Ongoing observational programs
  • Pulsar monitoring
  • Cosmic transient mapping at C-band
  • 21cm sky mapping
  • Other projects as time/money permit
SBRAC Project: Challenges

- **Site access**
  - Gary retired from CSA, access is now very problematic.

- **Power**
  - Main power pulled from Kennedy site decades ago. Not enough power to run motors.

- **Mechanicals**
  - No brake on the azimuth axis
  - Otherwise, everything else is in reasonable-but-aging, shape.

- **No routine access to the feed point**
  - Scaffolding had to be removed—too dangerous
  - Installed feed some time ago, based on best-guess at focal plane position. That guess was wrong.
SBRAC Project: So far...
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SBRAC Project: So far...
SBRAC Project: Going forward

- Assuming we can resolve access and feed-point issues:
  - Enough power to run receivers + computers
  - Can easily run in meridian-transit mode, with manual, or battery-assisted operation of elevation motor.
  - Allows mapping, and even pulsar observing for lower-frequency pulsars.
  - Could bring in generator to provide more power for motors—existing battery array is dying.

- If we cannot resolve those issues, then the project dies, and we pull out our equipment, tail between our legs.

- We look now to the *Friends of CRC* for help.