ECE 598HH: Advanced Wireless Networks and Sensing Systems

Lecture 3: Part 2: Software Defined Radio Tutorial

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Software Defined Radios

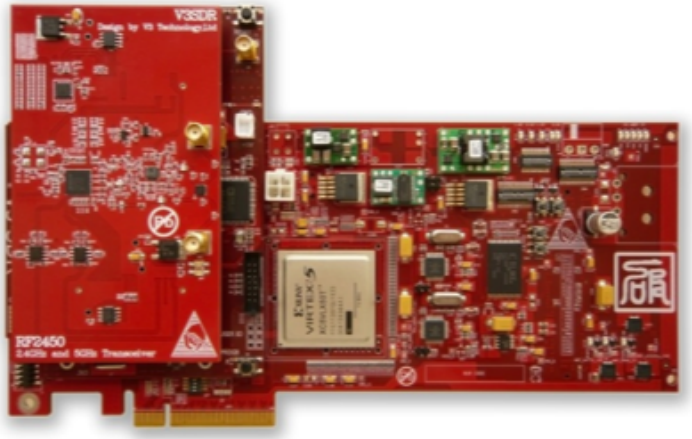
- Idea: Flexibility, Portability, Multifunction …
  - Programmable Radio Frontend:
    - Change Center Frequency, Bandwidth, Sampling Rate, Gain, ….
  - Baseband Processing in Software:
    - Implement baseband functions on host in software (C++, Python, …)
    - Implement some function on FPGA.

Many Open Source SDR Platforms

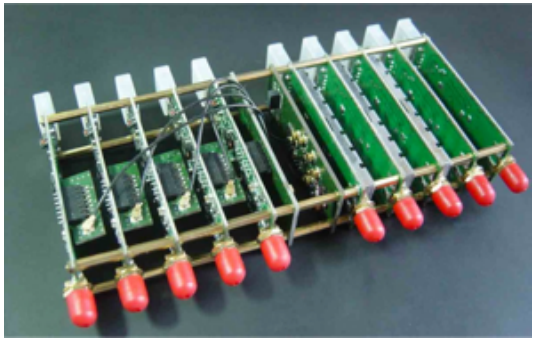
USRP: Universal Software Radio Peripheral (Ettus)

Warp: Wireless Open Access Research Platform (Rice)

SORA: SOftware-defined Radio (Microsoft)



RTL-SDR



GNU-Radio USRP Platform

USRP: Universal Software Radio Peripheral (Ettus)

- What is GNU Radio?
- Basic Concepts
- Developing Applications
- UHD

- What is GNU Radio?
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- Developing Applications
- UHD

BASEBAND PROCESSING

DIGITAL & RF FRONTEND

ANTENNA

Up to 25 Msps
Complex Baseband
Sample Stream

USB 2.0 – 8 Msps
GbE – 25 Msps
I/Q

Up to ~80 MHz
Passband,
DC - ~6GHz
(db dependent)

GNU Radio Host Application

Ettus Research USRP (FPGA-based)

External RF Electronics

Baseband Modulation/Demodulation

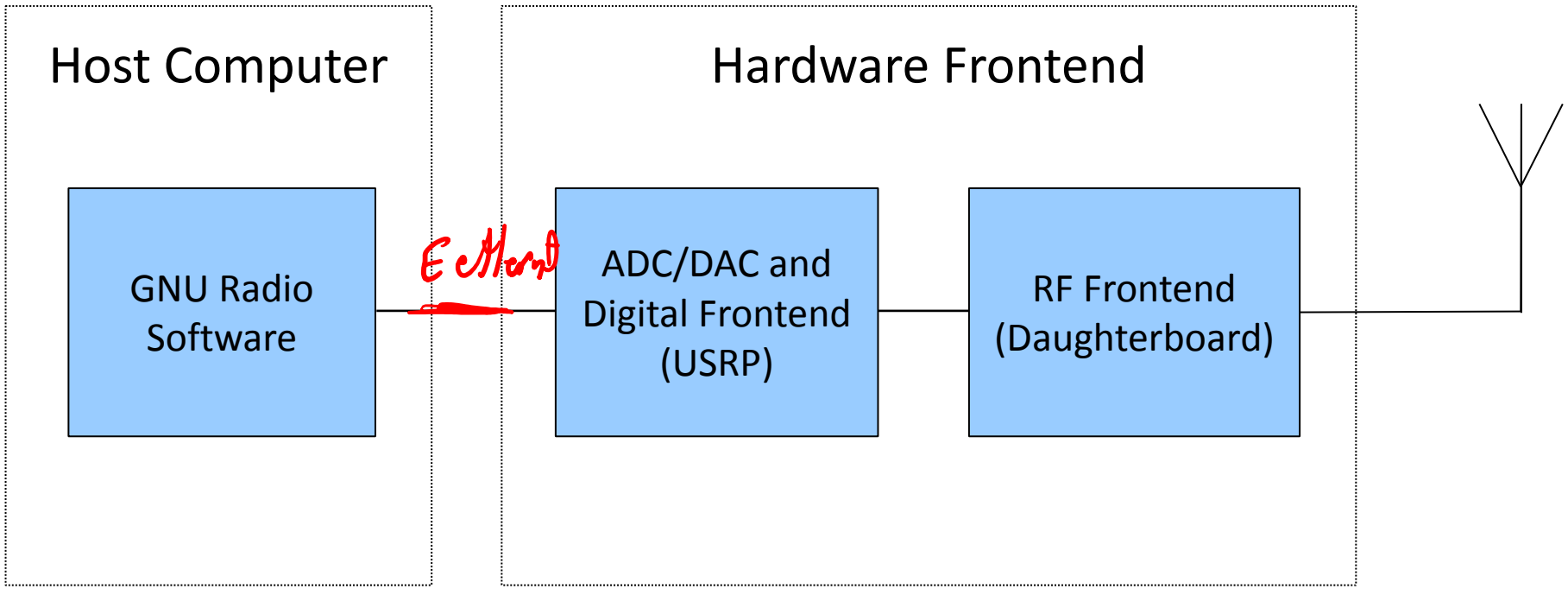
Up/Down Conversion ADC/DAC Interpolation/Decimation

Low Noise Rx Power Amp for TX

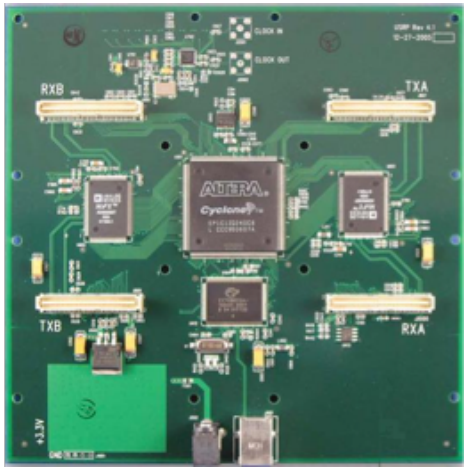
What is GNU Radio?

- Software toolkit for signal processing
  - Providing a fast, low-cost way to test algorithms and waveform design
- USRP (Universal Software Radio Peripheral)
  - Hardware TX/RX frontend

GNU Radio Components



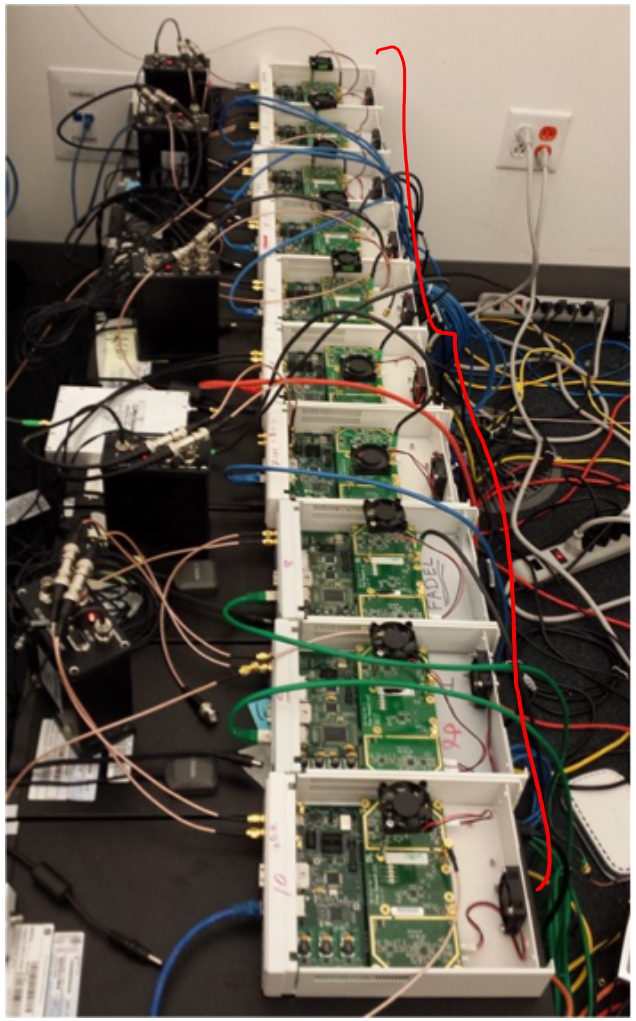
USRP1



- Features:
  - Frequency Range: DC-6 GHz
  - Connectivity for Two, Complete Tx/Rx chains
  - Two Dual 64 MS/s 12-bit ADCs
  - Two Dual 128 MS/s, 14-bit DACs
  - Up to 16 MS/s USB Streaming
  - Altera Cyclone FPGA

USRP2/N200/N210

- Features:
  - Frequency Range: DC-6 GHz
  - 100 MS/s 14-bit ADC
  - 400 MS/s, 16-bit DAC
  - Up to 25 MS/s through Gigabit Ethernet Streaming (50 MS/s at 8 bits per sample)
  - Xilinx Spartan XC3SD3400A FPGA: 2368K Memory, 53K logic cells
  - MIMO Extension/ External Clock Synchronization

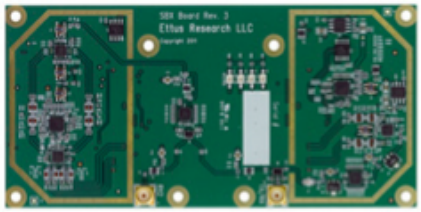


USRP X300/310

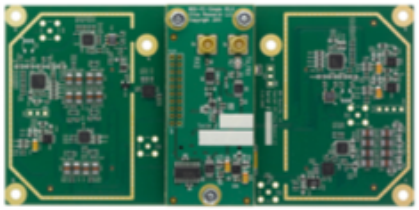
- Features:
  - Frequency Range: DC-6 GHz
  - Two 200 MS/s 14-bit ADC
  - Two 800 MS/s, 16-bit DAC
  - Up to 200 MS/s through 10 Gigabit Ethernet or PCI Express
  - Xilinx Kintex-7 FPGA: 28620K memory, 406K logic cells
  - MIMO Extension External Clock Synchronization

USRP Daughter Boards

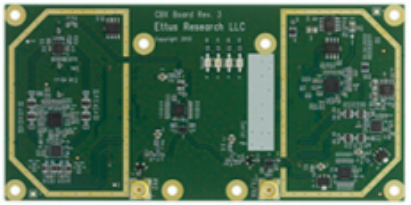
- Define Bandwidth, Frequency Range, Gain



SBX: 400MHz-4.4GHz
(40MHz/120MHz)



WBX: 40MHz-2.2GHz
(40MHz/120MHz)



CBX: 1.2GHz-6GHz
(40MHz/120MHz)

UBX: 10MHz-6GHz
(40MHz/160MHz)

Basic TX/RX
1MHz-250MHz

LFTX/LFRX
0MHz-30MHz

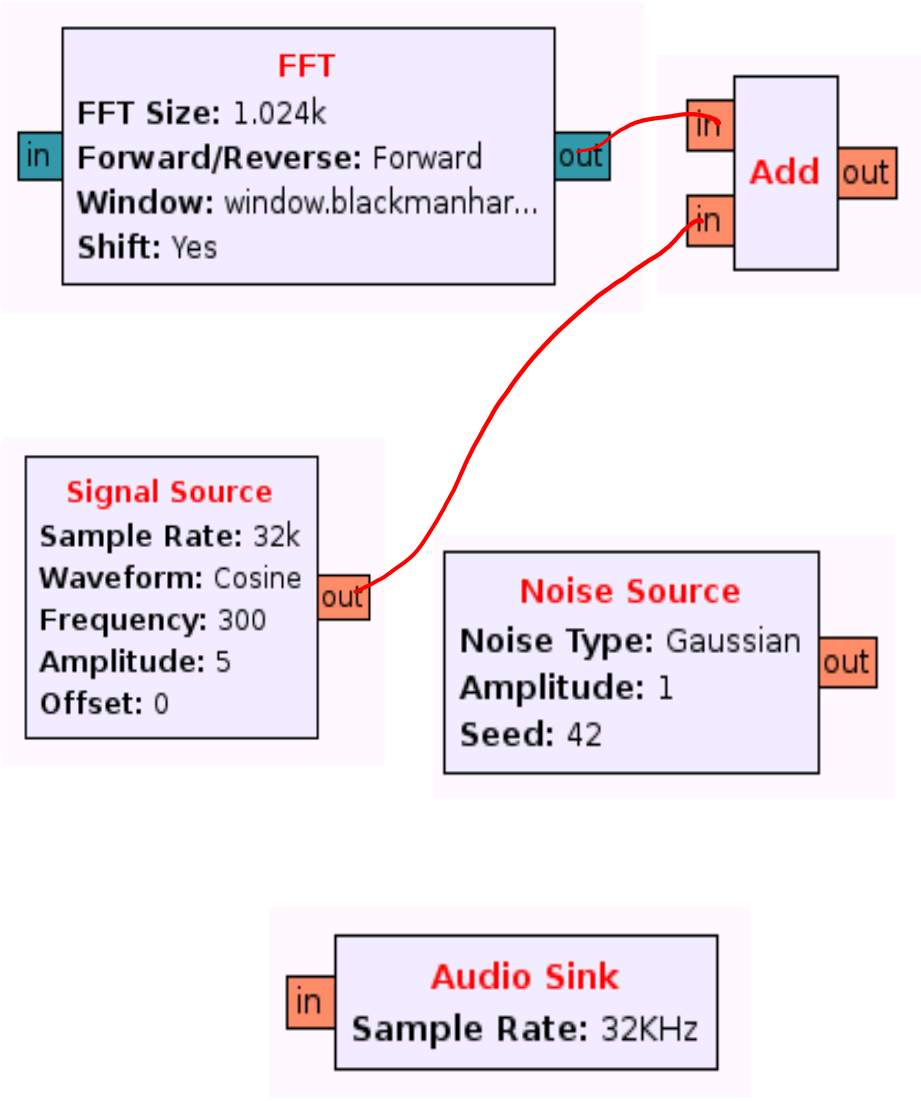
GNU Radio Software

- Open source (GPL)
- Existing examples: 802.11b, Zigbee, OFDM, DBPSK, DQPSK …
- Extensive library of signal processing blocks (C++)
- Modular design (flow graph)
- GNU Radio + UHD

- What is GNU Radio?
- Basic Concepts
- Developing Applications
- UHD

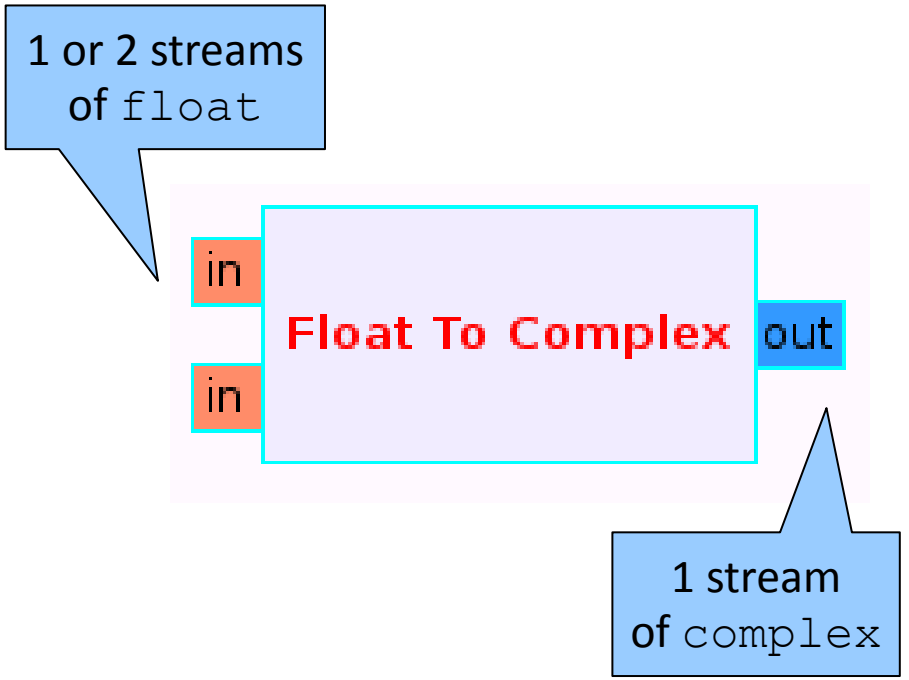
Blocks

- Signal Processing Block
  - Accepts input streams
  - Produces output streams
- Source: No input
  - noise_source, signal_source, usrp_source
- Sink: No outputs
  - audio_alsa_sink, usrp_sink



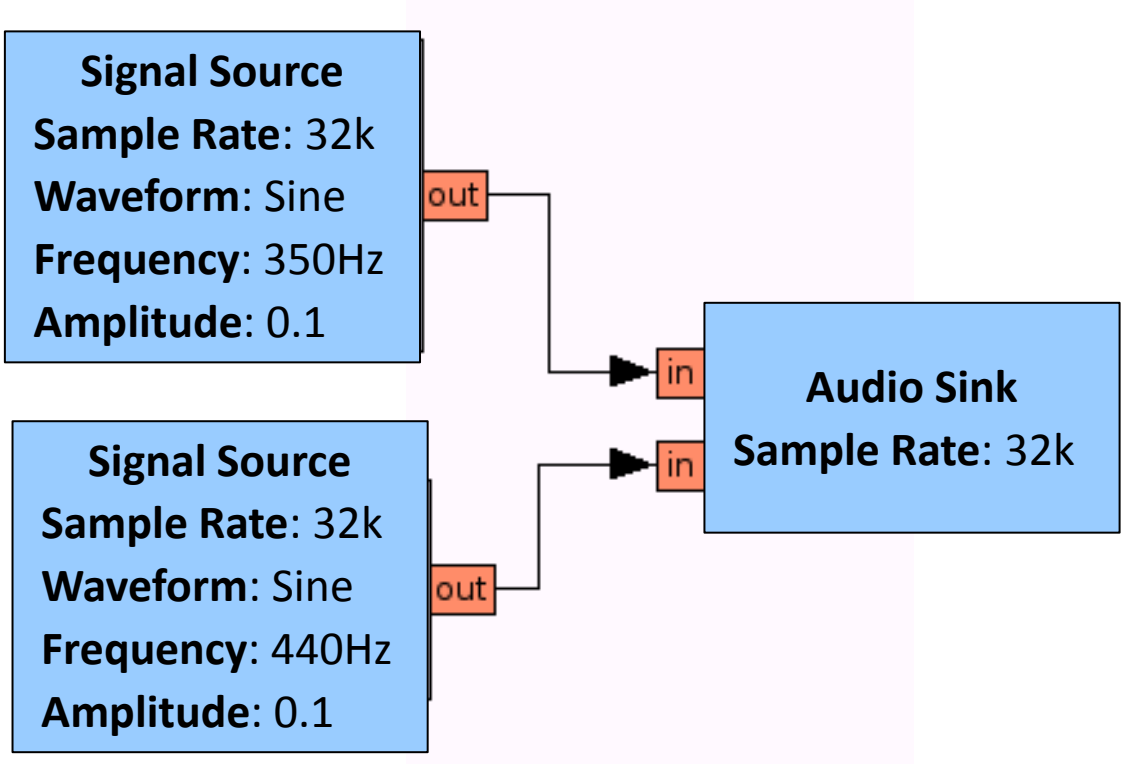
Data Types

- Blocks operate on certain data types
  - float, complex, int, char …
  - Vectors
- IO Signature:
  - Number of input ports
  - Number of output ports
  - Item size of each port



Flow Graph

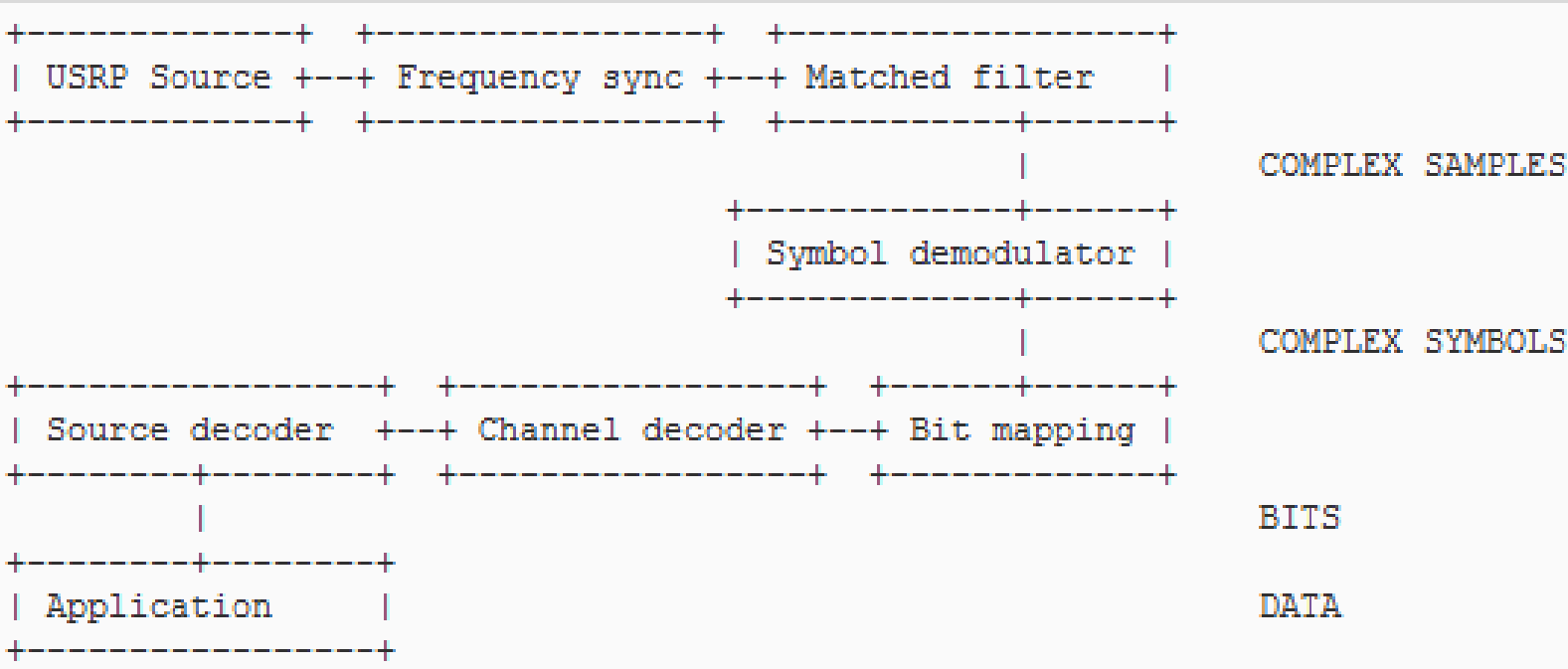
- Blocks composed as a flow graph
  - Data stream flowing from sources to sinks



Example Code

```
#!/usr/bin/env python

from gnuradio import gr
from gnuradio import audio

class my_top_block(gr.top_block):
    def __init__(self):
        gr.top_block.__init__(self)

        sample_rate = 32000
        ampl = 0.1

        src0 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 350, ampl)
        src1 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 440, ampl)
        dst = audio.sink (sample_rate, "")
        self.connect (src0, (dst, 0))
        self.connect (src1, (dst, 1))

if __name__ == '__main__':
    try:
        my_top_block().run()
    except [[KeyboardInterrupt]]:
        pass
```

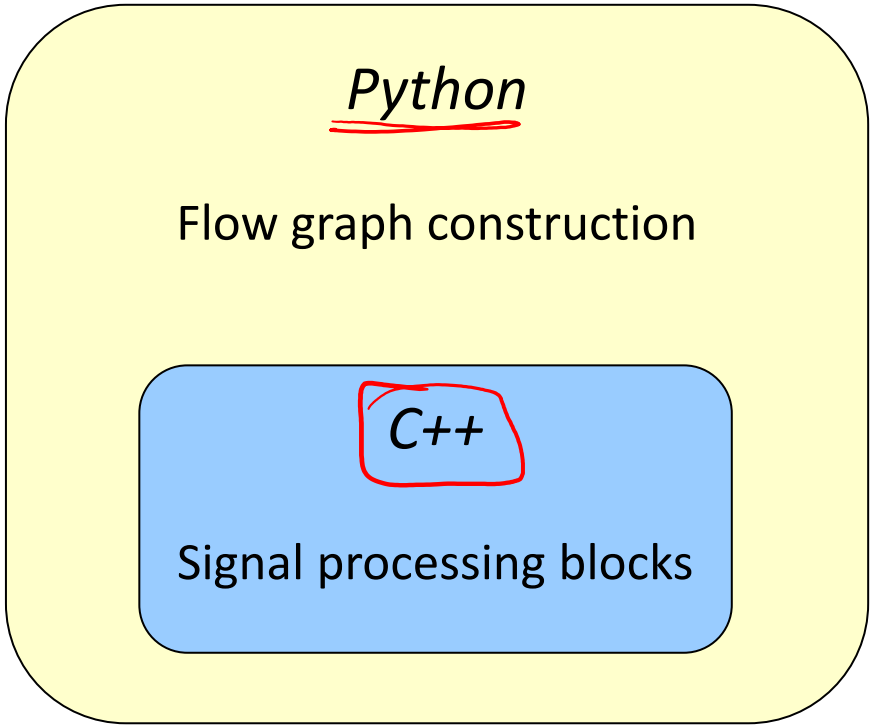
QPSK Demodulator Example



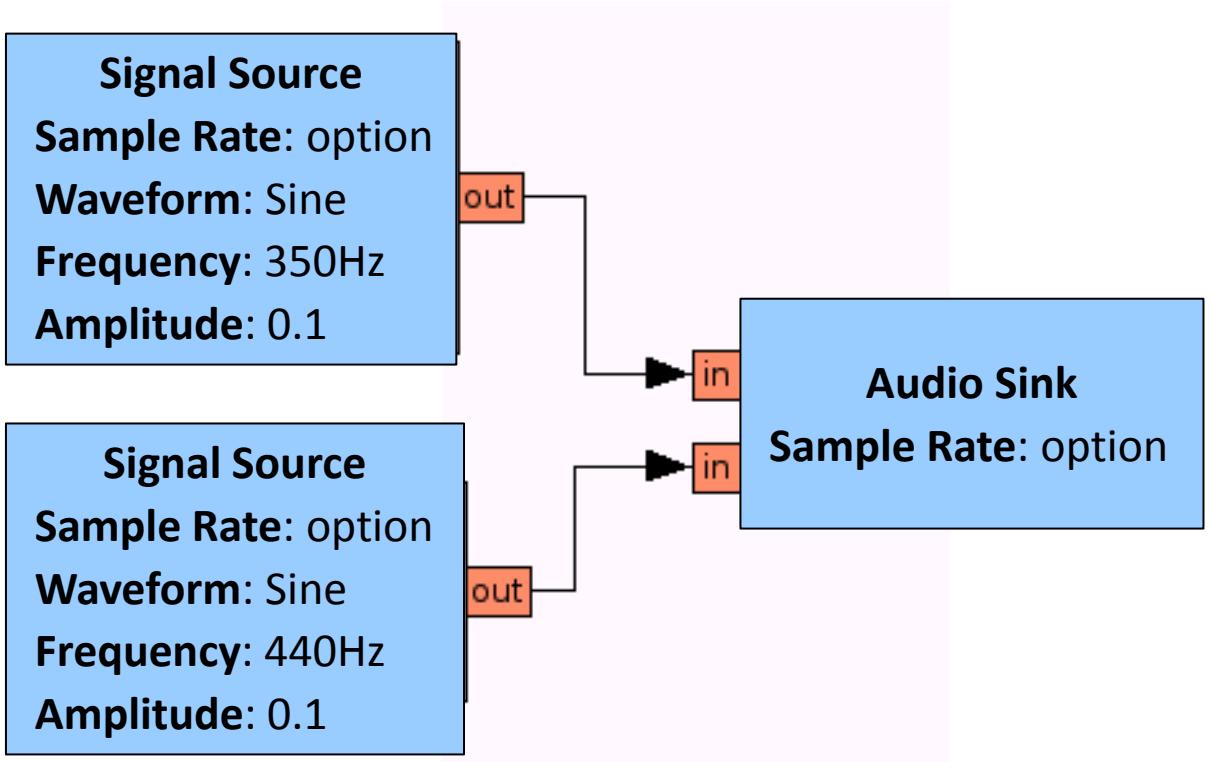
- What is GNU Radio?
- Basic Concepts
- Developing Applications
- UHD

Development Architecture

- Python
  - Flow graph construction
- C++
  - Signal processing blocks



Python Example



```
#!/usr/bin/env python

from gnuradio import gr
from gnuradio import audio
from gnuradio.eng_option import eng_option
from optparse import OptionParser

class my_top_block(gr.top_block):
    def __init__(self):
        gr.top_block.__init__(self)

        parser = OptionParser(option_class=eng_option)
        parser.add_option("-O", "--audio-output", type="string", default="",
                          help="pcm output device name.  E.g., hw:0,0")
        parser.add_option("-r", "--sample-rate", type="eng_float", default=48000,
                          help="set sample rate to RATE (48000)")
        (options, args) = parser.parse_args ()
        if len(args) != 0:
            parser.print_help()
            raise SystemExit, 1

        sample_rate = int(options.sample_rate)
        ampl = 0.1

        src0 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 350, ampl)
        src1 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 440, ampl)
        dst = audio.sink (sample_rate, options.audio_output)
        self.connect (src0, (dst, 0))
        self.connect (src1, (dst, 1))

if __name__ == '__main__':
    try:
        my_top_block().run()
    except KeyboardInterrupt:
        pass
```

Import modules from GNU Radio library

```
from gnuradio import gr
from gnuradio import audio
from gnuradio.eng_option import eng_option
from optparse import OptionParser
```

```
class my_top_block(gr.top_block):
    def __init__(self):
        gr.top_block.__init__(self)
```

Define container for Flow Graph

`gr.top_block` class maintains the graph

Define and parse command-line options

```
parser = OptionParser(option_class=eng_option)
parser.add_option("-O", "--audio-output", type="string", default="",
                  help="pcm output device name.  E.g., hw:0,0")
parser.add_option("-r", "--sample-rate", type="eng_float", default=48000,
                  help="set sample rate to RATE (48000)")
(options, args) = parser.parse_args ()
if len(args) != 0:
    parser.print_help()
    raise SystemExit, 1
```

Create and connect signal processing blocks

```
sample_rate = int(options.sample_rate)
ampl = 0.1

src0 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 350, ampl)
src1 = gr.sig_source_f (sample_rate, gr.GR_SIN_WAVE, 440, ampl)
dst = audio.sink (sample_rate, options.audio_output)
self.connect (src0, (dst, 0))
self.connect (src1, (dst, 1))
```

```
if __name__ == '__main__':
    try:
        my_top_block().run()
    except KeyboardInterrupt:
        pass
```

Run the flow graph when the program is executed

Creating Your Own Block

- Basics
  - A block is a `C++` class
  - Typically derived from `gr_block` class

- Three components
  - `my_block_xx.h`: Block definition
  - `my_block_xx.cc`: Block implementation
  - `my_block_xx.i`: Python bindings (SWIG interface)

Block Definition

```
#include <gr_sync_block.h>

class my_block_cc;

typedef boost::shared_ptr<6829_my_block_cc> 6829_my_block_cc_sptr;

6829_my_block_cc_sptr 6829_make_my_block_cc();

class my_block_cc : public gr_sync_block
{
private:
unsigned int d_count;

friend 6829_my_block_cc_sptr 6829_make_my_block_cc();

6829_my_block_cc();

public:
int work(int noutput_items,
         gr_vector_const_void_star &input_items,
         gr_vector_void_star &output_items);
};
```

Create instances of block

Method for processing input streams and producing output streams

Block Implementation

```
#ifdef HAVE_CONFIG_H
#include "config.h"
#endif

#include <my_block_cc.h>
#include <gr_io_signature.h>

6829_my_block_cc_sptr 6829_make_my_block_cc()
{
return 6829_my_block_cc_sptr(new 6829_my_block_cc());
}

6829_hw_sample_block_cc::6829_hw_sample_block_cc()
: gr_sync_block("my_block_cc",
                gr_make_io_signature(1, 1, sizeof(gr_complex)),
                gr_make_io_signature(1, 1, sizeof(gr_complex))),
  d_count(0)
{
}
```

Define input and output signatures

Block Implementation

```
int 6829_my_block_cc::work(int noutput_items,
                  gr_vector_const_void_star &input_items,
                  gr_vector_void_star &output_items)
{
const gr_complex* in = (const gr_complex*)input_items[0];
gr_complex* out = (gr_complex*)output_items[0];

memcpy(out, in, sizeof(*out) * noutput_items);

for (int i = 0; i < noutput_items; ++i)
        fprintf(stderr, "%u\t<%.6f, %.6f>\n",
                d_count++, in[i].real(), in[i].imag());

return noutput_items;
}
```

Copy input stream to output stream

Echo samples stderr

Return number of items processed

- What is GNU Radio?
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UHD (USRP Hardware Driver)

- Why UHD?
  - USRP
    - Libusrp
    - Libusrp-gnuradio
    - Python dboard code
    - C++ dboard code
    - Usrp_* examples and utils
  - USRP2
    - Libusrp2 (linux only)
    - libusrp2-gnuradio
    - C dboard code in FW
    - Usrp2_* examples and utils
  - USRP N+1?

- Having N drivers isn't going to scale …

UHD (USRP Hardware Driver)

- Single API for all USRP devices
  - C++ based API
  - All daughterboards
  - Inherent multi-channel support
    - Synchronization
    - Channel alignment
- Gnuradio–UHD Blocks
  - Source Block, Sink Block
  - Python, C++

UHD (USRP Hardware Driver)

- Send/receive samples
  - `device->send`(...) and `device->recv`(...)
- Set/get properties

Device Properties

- Set/get gain
- Set center frequency
- Set/get device time
- Set/get sample rate
- Antenna selection
- Frontend selection

⋮

Example: MIMO TX

```
sudo ./tx_samples_multi_from_file_repeat
--args="addr0=192.168.10.2,addr1=192.168.20.2"
--file_prefix="TX"
--rate=1000000
--freq=922000000
--ant="TX/RX"
--gain=10
--ref="external"
--num_transmits=10
--scale=0.5
```

= 922 MHz

Example: MIMO TX

```
sudo ./tx_samples_multi_from_file_repeat
--args="addr0=192.168.10.2,addr1=192.168.20.2"
```

tx_samples_multi_from_file_repeat.cpp

```
uhd::usrp::multi_usrp::sptr usrp = uhd::usrp::multi_usrp::make(args);
```

Example: MIMO TX

```
sudo ./tx_samples_multi_from_file_repeat
--args="addr0=192.168.10.2,addr1=192.168.20.2"
--file_prefix="TX"
--rate=1000000
--freq=922000000
--ant="TX/RX"
--gain=10
```

tx_samples_multi_from_file_repeat.cpp

```
usrp->set_tx_rate(rate, i);
usrp->set_tx_freq(freq, i);
usrp->set_tx_antenna(ant, i);
usrp->set_tx_gain(gain, i);
```

Example: MIMO TX

```
sudo ./tx_samples_multi_from_file_repeat
--args="addr0=192.168.10.2,addr1=192.168.20.2"
--file_prefix="TX"
--rate=1000000
--freq=922000000
--ant="TX/RX"
--gain=10
--ref="external"
```

tx_samples_multi_from_file_repeat.cpp

```
usrp->set_clock_config(uhd::clock_config_t::external());
```

- USRP
  http://www.ettus.com/resource
- GNU Radio
  http://gnuradio.org/redmine/projects/gnuradio/wiki
- Available Signal Processing Blocks
  http://gnuradio.org/doc/doxygen/hierarchy.html
- GNU Radio Mailing List Archives
  http://www.gnu.org/software/gnuradio/mailinglists.html
- USRP Mailing List
  http://lists.ettus.com/pipermail/usrp-users_lists.ettus.com/
- UHD
  http://ettus-apps.sourcerepo.com/redmine/ettus/projects/uhd/wiki