Development of satellite communication labs using low cost embedded devices for the improvement of education standard of satellite communication concepts in Pakistani universities

Muhammad Tahir Mushtaq
Assistant Professor
School of System and Technology, University of Management and Technology, Lahore

Salman Mahmood
Researcher
School of System and Technology, University of Management and Technology, Lahore

Hassaan Bin Ahmad
Researcher
Department of Electrical Engineering, Capital University of Science and Technology, Islamabad
Contents

- Objective of Research Laboratory
- Equipment
- Software
- Experiments
- Projects
- Cost Efficiency
- Conclusion
Objective of Research Laboratory

• **To develop cost efficient setup:**
  - which can develop capability of students on international and state of the art standards
  - for radio-communication, Internet of Things (IoT) and climate-change research in Pakistan
  - which can wirelessly transmit various types of data on different modulation schemes using same hardware
  - which can receive and decode various types of radio signals
  - which can be used as both ground and space segments of satellite communication system
Equipment Used

- Realtek Software Defined Radio (RTL SDR)
- Quadrifilar Helix Antenna (QHA)
- Raspberry Pi 2 and 3 (Rpi)
- Hackrf One
RTL SDR

- RTL SDR (RTL2832u chipset) works on the principals of radio tuning circuit
- USB dongle size receiver also known as DVB TV tuner
- Has frequency range of 30 MHz to 1.7 GHz
- Has a micro coaxial antenna input which makes it capable of other antenna attachments
- Receives & shows different features of a signal in generic SDR software
Quadrifilar Helicoidal/Helix Antenna

- Used for receiving polar orbit satellite’s transmissions.
- Designed for circularly polarized signals.
- A right-handed circularly polarized antenna was constructed.

<table>
<thead>
<tr>
<th>Dimensions</th>
<th>Big Loop</th>
<th>Small Loop</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>0.26 (\lambda)</td>
<td>0.238 (\lambda)</td>
</tr>
<tr>
<td>Diameter</td>
<td>0.173 (\lambda)</td>
<td>0.156 (\lambda)</td>
</tr>
<tr>
<td>Leg Size</td>
<td>0.56 (\lambda)</td>
<td>0.508 (\lambda)</td>
</tr>
</tbody>
</table>

\(\lambda\) is the wavelength
QHA for NoAA Weather Satellites (137 MHz)
Raspberry Pi 2b

- It is a credit card sized Linux based computer
- Quad core processor
- 1 GB RAM
- 4 USB ports
- 3.5mm audio jack
- HDMI output
- 40 GPIO
Continued....(1)
Hackrf One

- HackRF One is a Software Defined Radio peripheral
- It is capable of transmission or reception of radio signals from 1 MHz to 6 GHz
- Designed to enable test and development of modern and next generation radio technologies
- It is an open source hardware platform that can be used as a USB peripheral or programmed for stand-alone operation
Continued....(1)

- half-duplex transceiver
- up to 20 million samples per second
- 8-bit quadrature samples (8-bit I and 8-bit Q)
- compatible with GNU Radio, SDR#, and more
- Software-configurable RX and TX gain and baseband filter
- Software-controlled antenna port power (50 mA at 3.3 V)
- SMA female antenna connector
- SMA female clock input and output for synchronization
- convenient buttons for programming
- internal pin headers for expansion
- Hi-Speed USB 2.0
- USB-powered
Software

- SDR#
- GNU Radio
- Pycharm
**SDR# (sdr sharp)**

- SDR# is a simple, intuitive, small and fast PC-based DSP application for Software Defined Radio such as RTL SDR and Hack RF
- It has visual indicator/graph plots such as waterfall, FFT Sink for spectrum analysis
- It demodulates WFM, NFM, AM, SSB, LSB, CW signals
- It can record signals and apply various DSP schemes to achieve desired result
- It is compatible with various other decoding/deciphering software through plugins
GNU Radio

• It is a free software development toolkit that provides signal processing blocks to implement software-defined radios and signal-processing systems

• It can be used with external RF hardware or without hardware in a simulation-like environment

• Its flowgraphs can be written in either C++ or Python programming language

• It is widely used in academic, and commercial environments to support both wireless communications research and real-world radio systems.
GNU Radio

Options
ID: top_block
Generate Options: QT GUI

TCP Source
Address: 127.0.0.1
Port: 1.234k
Mode: Server

Packet Encoder
Samples/Symbol: 1
Bits/Symbol: 1
Preamble: Access Code: Pad for USRP: No Payload Length: 1

Variable
ID: samp_rate
Value: 44.1k

Variable
ID: sps
Value: 50

Constellation Modulator
Constellation: ces(m=2)
Differential Encoding: Yes
Samples/Symbol: 50
Excess BW: 350m

Variable
ID: rc_taps
Value: firdes.root_raised...

Variable
ID: nlifs
Value: 25

Constellation Object
ID: BPSK
Symbol Map: 0, 1
Constellation Points: -1, 1
Rotational Symmetry: 4
Dimensionality: 1

Complex To Real

Multiply

Audio Sink
Sample Rate: 44.1KHz

Audio Source
Sample Rate: 44.1KHz

Low Pass Filter
Decimation: 1
Gain: 1
Sample Rate: 44.1k
Cutoff Freq: 1.6k
Transition Width: 600
Window: Hamming
Beta: 6.76

Polyphase Clock Sync
Samples/Symbol: 50
Loop Bandwidth: 63m
Taps: rc_taps
Filter Size: 25
Initial Phase: 12
Maximum Rate Deviation: 1.5
Output SPS: 1

Costas Loop
Loop Bandwidth: 50m
Order: 2

Complex To Real

Binary Slicer

Differential Decoder
Modulus: 2

Packet Decoder
Access Code: Offset: 0

LMS DD Equalizer
Gain: 10m
Num. Taps: 8
Samples per Symbol: 1
Constellation Object: ...=2>

Feed Forward AGC
Num Samples: 1.024k
Reference: 1.55

QT GUI Constellation Sink
Number of Points: 1.024k
Autoscale: No

TCP Sink
Address: 127.0.0.1
Port: 9.989k
Mode: Client
PyCharm is an integrated development environment (IDE) used in computer programming, specifically for the Python language.

It provides code analysis, a graphical debugger, an integrated unit tester, integration with version control systems (VCSes), and supports web development with Django.
Pycharm

```python
for line in lines:
    # Use plain text quotation extracting algorithm
    markers = mark_message_lines(lines)
    return_flags = []
    process_marked_lines(lines, markers, return_flags)
    lines_were_deleted, first_deleted, last_deleted = return_flags

if lines_were_deleted:
    # collect checkpoints from deleted lines
    for i in xrange(first_deleted, last_deleted):
        for checkpoint in line_checkpoints[i]:
            quotation_checkpoints[checkpoint] = True
else:
    if cut_quotations:
        return html.tostring(html_tree_copy)
    else:
        return msg_body

# Remove tags with quotation checkpoints
html_quotations.delete_quotation_tags()
```
Experiments

• Signal Reception
  ▫ RTL SDR and SDR#
  ▫ Hackrf and SDR#
  ▫ Hackrf and GNU Radio

• Signal Transmission
  ▫ Raspberry Pi 2 using python
  ▫ Hackrf and GNU Radio
Projects

- **Weather Base station using RTL SDR, QHA and SDR Sharp**

- **Implementation of Software Defined Radio (RF Transmitter using Raspberry Pi 2)**
  - FM Transmission
  - AM Transmission
  - SSTV Transmission
  - VFO Transmission

- **NBFM transmission using Hackrf one and Gnu Radio**
Weather Base station using RTL SDR, QHA and SDR Sharp

- National Oceanic and Atmospheric Administration (NOAA) Satellite Data was received and decoded using RTL SDR

- For NOAA 18 satellite a Quadrifilar Helicoidal Antenna was designed to receive a signal at 137.9 MHz.

- A special Trifilar Balun was constructed keeping in regard the female micro co-axial socket of RTL SDR.

- Orbitron was used for Satellite Tracking

- At Latitude of 31 and Longitude 74 (Lahore), data was fed to a SDR Sharp and decoded using different decoding schemes

- WXtoIMG a freeware was used to converts the signal into the image
Continued...(1) Signal Receiving Setup
Continued…(2)

**ORBITRON**
(For Satellite positioning)

**SDR Sharp**
(For recording NOAA APT signal)

**WXTOIMG**
(For decoding the APT Signal)

**Audacity [Optional]**
(For fine-tuning received data signal)
Continued…(3) Results

July 17, 2015
July 23, 2015
July 24, 2015
July 25, 2015
Implementation of Software Defined Radio (RF Transmitter)

- RPi 2 was used for:
  - FM transmission
  - AM transmission
  - SSTV transmission
Continued...(1) Frequency Modulation

137.893.766
Amplitude Modulation

Continued…(2) Amplitude Modulation
Continued…(3) SSTV

431.970.913

12/18/2015 9:27:27 PM

12/18/2015 9:27:21 PM
NBFM transmission using Hackrf One and Gnu Radio

- Reads raw data values in binary
  - File Source
    - File: ../011001-e02-16kHz.wav
    - Repeat: Yes
    - Add begin tag: ()
  - Short To Float
    - Scale: 1
  - Multiply Const
    - Constant: 30u
- 16-bit short to floating point (Real)
- Variable
  - ID: center_freq
  - Value: 150M
- To standardize, multiplied with 3e-6
- Options
  - ID: top_block
  - Generate Options: QT GUI
- Variable
  - ID: samp_rate
  - Value: 210k
- NBFM Transmit
  - Audio Rate: 32k
  - Quadrature Rate: 64k
  - Tau: 5u
  - Max Deviation: 5k
  - Preemphasis High Corner Freq: -1
- Multiply Const
  - Constant: 32.768k
- To avoid distortion
- Low Pass Filter
  - Decimation: 2
  - Gain: 1
  - Sample Rate: 210k
  - Cutoff Freq: 16k
  - Transition Width: 32k
  - Window: Hamming
  - Beta: 6.76
- osmocom Sink
  - Sample Rate (sps): 210k
  - Ch0: Frequency (Hz): 150M
  - Ch0: Freq. Corr. (ppm): 0
  - Ch0: RF Gain (dB): 10
  - Ch0: IF Gain (dB): 20
  - Ch0: BB Gain (dB): 20
  - Ch0: Bandwidth (Hz): 1k
- QT GUI Sink
  - FFT Size: 2.048k
  - Center Frequency (Hz): 150M
  - Bandwidth (Hz): 210k
  - Update Rate: 10
The transmitted signal
Total Cost for equipment

- Total cost of QHA and Balun ~$78
- Raspberry Pi 2 ~$35
- RTL SDR ~$15
- HackRF One ~$300
Conclusion

• Students can present more precise predictions for weather & natural disasters

• This setup is cost efficient data centre and laboratory

• Studying such data will help to induce solutions at university level

• Up to date laboratory facilities are under development for more research possibilities

• This research focuses only on weather and amateur radio satellite but there are many unexplored possibilities

• This transceiver acts as satellite communication system by fulfilling the requirement of text, image and audio transmission

• This setup can also act as base station for communication in remote places as well as urbanized areas.
Questions
• Thank you very much