Introduction

After a brief presentation of Richard Prestage’s talk on

Open Source Radio Telescope

John Makous will give a longer presentation on

Digital Signal Processing in Radio Astronomy – a Research Experience for Teachers
Open Source Radio Telescope

• http://opensourceradiotelescopes.org/
• a resource for radio astronomy telescope construction at any level, from simple feed horns to phased-array feeds and interferometers.
• Discussion Forums
• Telescope Designs
• LightWork Memo Series
• Additional Resources:
  ▪ Larger Scale Home Built Radio Telescope, Radio Astronomy Supplies
  ▪ Canadian Centre for Experimental Radio Astronomy (CCERA)
  ▪ Digital Signal Processing in Radio Astronomy (DSPIRA)
  ▪ Society of Amateur Radio Astronomers (SARA)
  ▪ Such A Lovely Small Antenna (SALSA)
Digital Signal Processing in Radio Astronomy – a Research Experience for Teachers

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Outline

• Introduction
• Design and construction
• Operation and capabilities
Introduction – Horn Telescopes

• This talk is the result of 2 summers attending the RET DSPIRA program at WVU and GBO.

• The horn telescopes described here are designed to detect the 21 cm radio waves transmitted by neutral atomic hydrogen (HI) emitted by interstellar hydrogen in the galaxy.
Horn Telescope Design

Horn
- aluminized insulation board
- 60 cm x 75 cm horn opening

Stand - constructed from 2” x 2” and 2” x 4” wood

Waveguide & Antenna
- 4 ½ ” x 6 ½ ” metal can
- ¼ wave antenna: 5.25 cm
Low noise amplifier:
• optimized for 21 cm radio waves at 1420.4 MHz
• gain = 50 db
• Stabilized for operation in urban environments
Horn Telescope Operation

Software Defined Radio (SDR)

• **Airspy radio**
  – 24 MHz – 1800 MHz range
  – 10 MHz bandwidth

• **Gnuradio program:**
  – used to perform the signal processing
  – free & open source
Horn Telescope Calibration

Calibrated Scans on the Run
Horn Calibration

- Signals detected include inputs from extraneous sources

\[ P_{\text{measured}} = G \times (T_{\text{object}} + T_{\text{system}}) \]

- Calibration involves measuring spectra of 2 known temperatures
  - “\( T_{\text{hot}} \) = temperature of ground = 300 K (assumed)"
  - “\( T_{\text{cold}} \) = temperature of empty sky = 10 K (assumed)"

These are all functions of frequency
Horn Calibration

- By collecting spectra of the ground and empty sky, the gain and system temperature can be determined:

\[
G = \frac{P_{\text{hot}} - P_{\text{cold}}}{T_{\text{hot}} - T_{\text{cold}}}
\]

\[
T_{\text{system}} = \frac{T_{\text{hot}} - T_{\text{cold}}(P_{\text{hot}}/P_{\text{cold}})}{(P_{\text{hot}}/P_{\text{cold}}) - 1}
\]
Calibration on the Fly

- We built a gnuradio block to accommodate calibration runs that can be incorporated into the live display during a run.
Features of the Calibration Block & Display

- Adjust signal scale
- Collection/Display Option
- Print display to file
- Write to .h5 file
- System Temperature
- Gain
- Histogram
Calibration Procedure

1. Point and collect cold calibration
2. Point and collect hot calibration
3. Choose Spectrum with Calibration
Calibrated Spectrum Displayed

\[ T_{\text{sys}} \cong 75 \text{ K} \]
Future Modifications

1. Integration input
2. Save calibrations for future runs
Horn Telescope Performance

• Can detect neutral hydrogen (HI) from the Milky Way Galaxy.
Students can measure the Doppler shift of the hydrogen signal from the expected 1420.4 MHz ➔ the MW galaxy is rotating!
MWG Rotation Curve
from horn data 7/26/18

Rotational Velocity (km/s)

Distance from Galaxy Center (kpc)
Possible Projects

- Interferometry
- Pulsar detection
- Fast Radio Burst detection
Implementation in the classroom

Utilizing a horn telescope covers many STEM standards:

• Math – in all phases of use
• Engineering & Technology – build/design horns, test/modify cycle
• Computer programming – gnuradio, python
• Astronomy
  – radio waves, EM spectrum, signals, energy
  – telescopes: purpose & design, astronomical measurements
  – structure and motion of galaxies
• Physics
  – Kepler’s laws, motions of galaxies, dark matter
# Rich in Science Standards

## NGSS HS.Space Systems

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<th>Science &amp; Engineering Practices</th>
<th>Disciplinary Core Ideas</th>
<th>Crosscutting Concepts</th>
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<td>Developing and using models</td>
<td>ESS1.B – Kepler’s laws, orbits, etc.</td>
<td>Scale, Proportion, and Quantity</td>
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<td>PS4.B – EM Radiation</td>
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<td>Constructing Explanations and Designing Solutions</td>
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NGSS: Next Generation Science Standards
SUMMARY

Horn telescopes offer:

• Rich STEM experience for students
• Hands-on science – learn by doing
• Ability for students to develop and/or test models of nature
• Ability for students to experience a part of the world of digital signals
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