Single-Dish Radio Telescopes

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Telescope Optics

Prime Focus: Retractable boom
Gregorian Focus: 8-m subreflector - 6-degrees of freedom
Telescope Structure

- Fully Steerable
- Elevation Limit: 5°
- Can observe 85% of the entire Celestial Sphere
- Slew Rates: Azimuth - 40°/min; Elevation - 20°/min
Telescope Structure

Blind Pointing: 
(1 point/focus)

\[ \sigma_2 \approx 5 \, \text{arc sec} \]
\[ \sigma(\text{focus}) \approx 2.5 \, \text{mm} \]

Offset Pointing: 
(90 min)

\[ \sigma_2 \approx 2.7 \, \text{arc sec} \]
\[ \sigma(\text{focus}) \approx 1.5 \, \text{mm} \]

Continuous Tracking: 
(30 min)

\[ \sigma_2 \approx 1 \, \text{arc sec} \]
Telescope Structure
Active Surface

Surface Deformations from Finite Element Model
Active Surface
Telescope Optics

Rotating Turret with 8 receiver bays
## Receivers

<table>
<thead>
<tr>
<th>Receiver</th>
<th>Operating Range</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime Focus 1</td>
<td>0.29—0.92 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>Prime Focus 2</td>
<td>0.910—1.23 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>L Band</td>
<td>1.15—1.73 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>S Band</td>
<td>1.73—2.60 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>C Band</td>
<td>3.95—5.85 GHz</td>
<td>Being Upgraded</td>
</tr>
<tr>
<td>X Band</td>
<td>8.2—10.0 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>Ku Band</td>
<td>12.4—15.4 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>K Band 7-pixel</td>
<td>18—26.5 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>Ka Band</td>
<td>26—40 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>Q Band</td>
<td>40—50 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>W Band</td>
<td>68—92 GHz</td>
<td>Commissioned</td>
</tr>
<tr>
<td>Penn Array</td>
<td>86—94 GHz</td>
<td>Being Upgraded</td>
</tr>
</tbody>
</table>
Reflector Feeds
And More Feeds
Linear Polarization

Orthomode Transducer
A Variety of OMTs
A HFET LNA
Typical Components

- **Amplifiers**
- **Mixers**
- **Attenuators**
- **Power Detectors**
- **Synthesizers**
- **Splitters**
- **Couplers**
- **Filters**
- **Switches**
- **Multipliers**
Types of Filters

Edges are smoother than illustrated
Types of Mixers

- $f_{IF} = n*f_{LO} + m*f$
- $n$ and $m$ are positive or negative integers, usually 1 or -1
- Up Conversion : $f_{IF} > f$
- Down Conversion : $f_{IF} < f$
- Lower Side Band : $f_{LO} > f$
  - Sense of frequency flips
- Upper Side Band : $f_{LO} < f$
Example Switches

CM1 Output:
- All Pass
- 0.5-1.0 GHz
- All Pass
- LPF 550 MHz

CFFilter:
- 50-100 MHz
- 25-37.5 MHz
- Spare
- External
40-Ft System
Quiz 1: Determine values for the first LO for the 40-ft when...

• Observing HI at 1420.41 MHz
• Observing OH at 1665.6 MHz
Receiver Room
Typical Receiver

1.15 - 1.75 GHz
Multi-beam Receiver
Local Oscillator and Switching Matrix
IF Rack – Input switching Matrix, IF Filters, Power Balancing Attenuators, and Drivers for 8 Optical Fibers
Power Balancing/Leveling and Non-Linearity

![Graphs showing power balancing and non-linearity](image-url)
Converter and Analog Filter Racks, Spectrometer
Converter Rack – Receivers for Optical Fibers, LO2 and LO3, Power Balancing Attenuators, Output Switches to Backends and AFR
Analog Filter Rack

For 12.5 and 50 MHz Slow-Speed Spectrometer Samplers: LO4 and Filters

For 200 and 800 MHz High-Speed Spectrometer Samplers: Input Switches and Filters.
Quiz 2: Determine values for red components
Quiz 2: Determine values for red components

- **Goal**: Observe simultaneously 1420 MHz and 1665 MHz with the 50 MHz wide (75 MHz center frequency) mode of the Spectrometer

- **Parameters**:
  - BPF1 can be: 1100–1800, 1600-1750, 1300-1450, or 1100-1450 MHz
  - All mixers are LSB. Hint: first two mixers up convert, the last two down convert.
  - BPF2 can be: 2990-3010, 2960-3040, 2840-3160, 2360-3640, 5960-6040, 5840-6160, or 5360-6640 MHz
  - BPF3 can be: 50-100 or 25-37.5 MHz
  - See block diagram for other parameters

- **Hint**: Work from the receiver down the chain until you get stuck, then from Spectrometer up. Try 1420 MHz first, then add in 1665 MHz.

- **Record values for LO1 and both LO2’s; settings for BPF1, 2, and 3; and values for all Intermediate Frequencies.**
<table>
<thead>
<tr>
<th>Spectrum</th>
<th>Spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sideband</strong></td>
<td><strong>Sideband</strong></td>
</tr>
<tr>
<td>lower</td>
<td>lower</td>
</tr>
<tr>
<td><strong>IF</strong></td>
<td><strong>IF</strong></td>
</tr>
<tr>
<td>1200</td>
<td>1200</td>
</tr>
<tr>
<td><strong>Sky</strong></td>
<td><strong>Sky</strong></td>
</tr>
<tr>
<td>-2770</td>
<td>-2770</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td><strong>Bandwidth</strong></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>Polarization</strong></td>
<td><strong>Polarization</strong></td>
</tr>
<tr>
<td>linear_y</td>
<td>linear_y</td>
</tr>
<tr>
<td><strong>Noise Diode</strong></td>
<td><strong>Noise Diode</strong></td>
</tr>
<tr>
<td>lowCal</td>
<td>lowCal</td>
</tr>
<tr>
<td><strong>Sinusoid</strong></td>
<td><strong>Sinusoid</strong></td>
</tr>
<tr>
<td><strong>IF</strong></td>
<td><strong>IF</strong></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td><strong>At LO</strong></td>
<td><strong>At LO</strong></td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

**From: SamplerFilter8:J5**

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**Feed: RxrPF_1:YFD_342**
- Freq: 270 to 420 MHz
- Polarization: linear_y
- Form: 1

**Tone: RxrPF_1:C342Y**
- Freq: 0 MHz

**Filter: RxrPF_1:FL342_5Y**
- Freq: 270 to 420 MHz

**Mixer: RxrPF_1:MXYRD**
- LO: 1430 MHz
  - Component: LO1A: synthesizer
  - Lower Sideband: IF0 = 1430 - IFi

**Filter: RxrPF_1:FLYRD03**
- Freq: 1040 to 1120 MHz

**Filter: RxrPF_1:FLYRD**
- Freq: 960 to 1200 MHz

**Attenuator: RxrPF_1:ChannelD**
- Output Port: IF: IF: Conditioner: J4
- Input Port: IF: IF: Conditioner: J8
- Input Port: IF: Router: J23
- Input Port: IF: Router: J67
- Input Port: OpticalDriver3: J1
- **Attenuator: OpticalDriver3: attenuator**
- Output Port: OpticalDriver3: J2
- Input Port: OpticalReceiver3: J1
- Output Port: OpticalReceiver3: J5

**Mixer: ConverterModule8:MX2**
- LO: 13500 MHz
  - Component: LO2_04: synthesizer
  - Lower Sideband: IF0 = 13500 - IFi

**Filter: ConverterModule8:FL1**
- Freq: 8500 to 10350 MHz

**Mixer: ConverterModule8:MX3**
- LO: 10500 MHz
  - Component: LO3Distribution1: synthesizer
  - Lower Sideband: IF0 = 10500 - IFi

**Filter: ConverterModule8:FL2**
- Freq: 0 to 2200 MHz

**Attenuator: ConverterModule8:AT1**
- Output Port: ConverterModule8: J3
- Input Port: SamplerFilter8: J1

**Filter: SamplerFilter9:FL1**
- Freq: 800 to 1600 MHz

**Output Port: SamplerFilter8:J5**

**Input Port: Spectrometer: J8**
GBT – Astrid does all the hard work for you.....

```python
configLine = ""
receiver  = "Rcvr1_2"
beam      = "B1"
obstype    = "Spectroscopy"
backend   = "Spectrometer"
nwin      = 2
restfreq  = 1420.4058, 1665.0
deltafreq = 0, 0
bandwidth = 12.5
swmode    = "tp"
swtype    = "none"
swper     = 1.0
swfreq    = 0.0, 0.0
tint      = 30
```

```python
vlow   = 0
vhigh  = 0
vframe = "Isrk"
vdif   = "Radio"
noise  = "lo"
pol    = "Linear"
nchan  = "low"
spect.levels = 3
""
```

**Front End + Back End**
Model Receiver

\[ F_{\text{Signal}} \text{ or } F_{\text{Reference}} \]
• Observe blank sky for 10 sec
• Move telescope to object & observe for 10 sec
• Move to blank sky & observe for 10 sec
• Fire noise diode & observe for 10 sec
• Observe blank sky for 10 sec
Continuum - Point Sources
On-Off Observing
Continuum - Point Sources
On-Off Observing

• Known:
  • Equivalent temperature of noise diode or calibrator \( (T_{\text{cal}}) = 3 \text{ K} \)
  • Bandwidth \( (\Delta \nu) = 10 \text{ MHz} \)
  • Gain = 2 K / Jy

• Desired:
  • Antenna temperature of the source \( (T_\text{A}) \)
  • Flux density \( (S) \) of the source.
  • System Temperature \( (T_s) \) when OFF the source
  • Accuracy of antenna temperature \( (\sigma_{TA}) \)
SINGLE CHANNEL POLARIMETER
Number of lags

\[ R(t) = \sum_{n=0}^{\text{Number Lags}} V(t) \cdot V(t + n \cdot \Delta t) \]

\[ S(\text{Frequency}) = DFT(R(t)) \]

Bandwidth = \( \frac{1}{2\Delta t} = \frac{\text{Sampling Frequency}}{2} \)

Resolution = \( \frac{\text{Bandwidth}}{\text{Number of lags}} \)