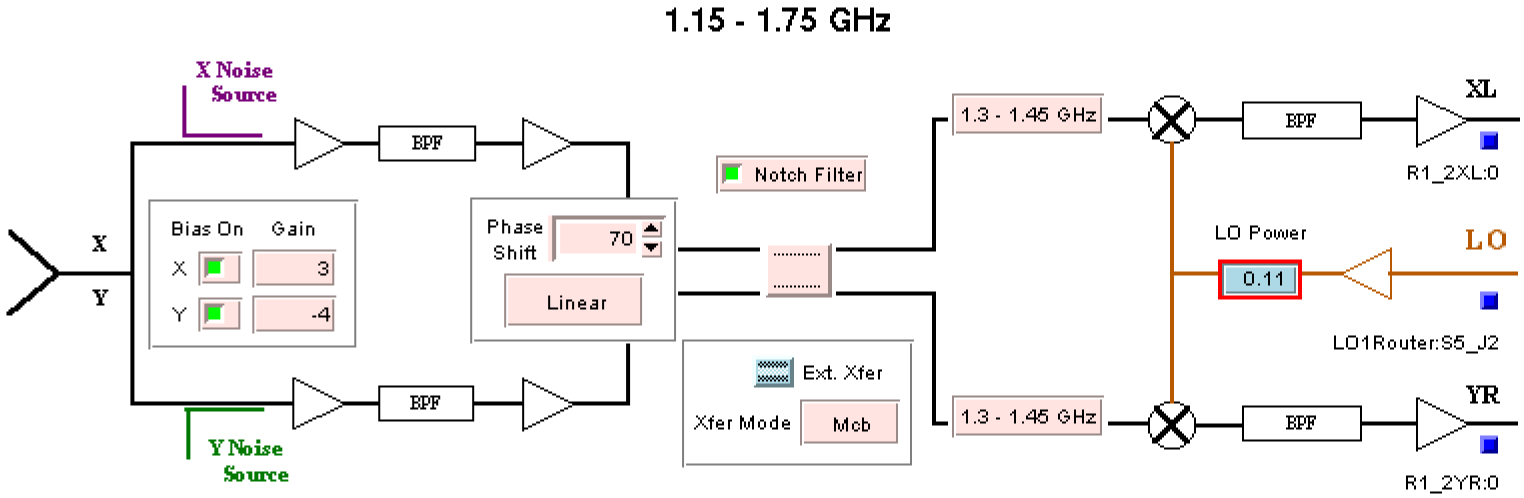
Observing Techniques with Single-Dish Radio Telescopes

Dr. Ron Maddalena

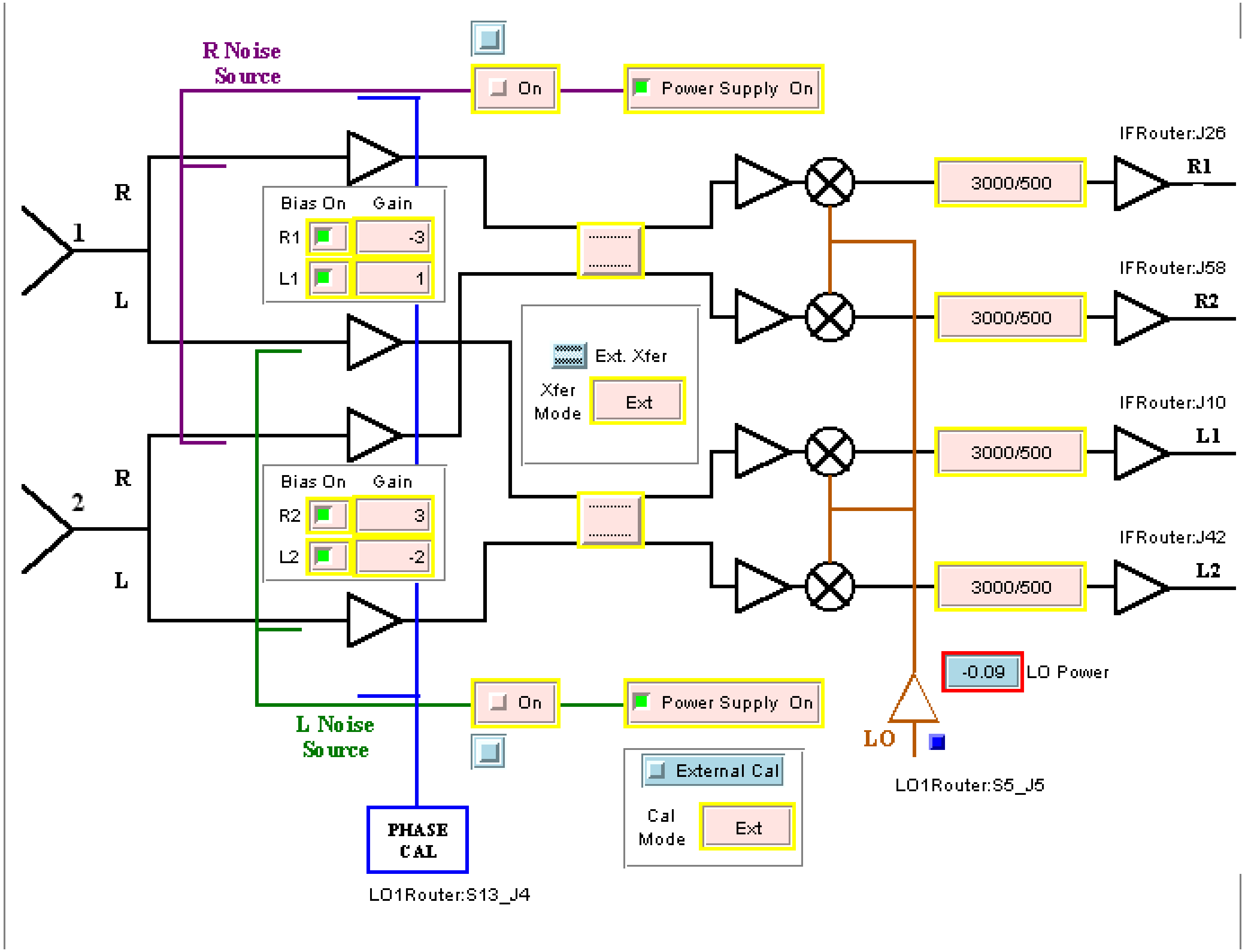
National Radio Astronomy Observatory

Green Bank, WV

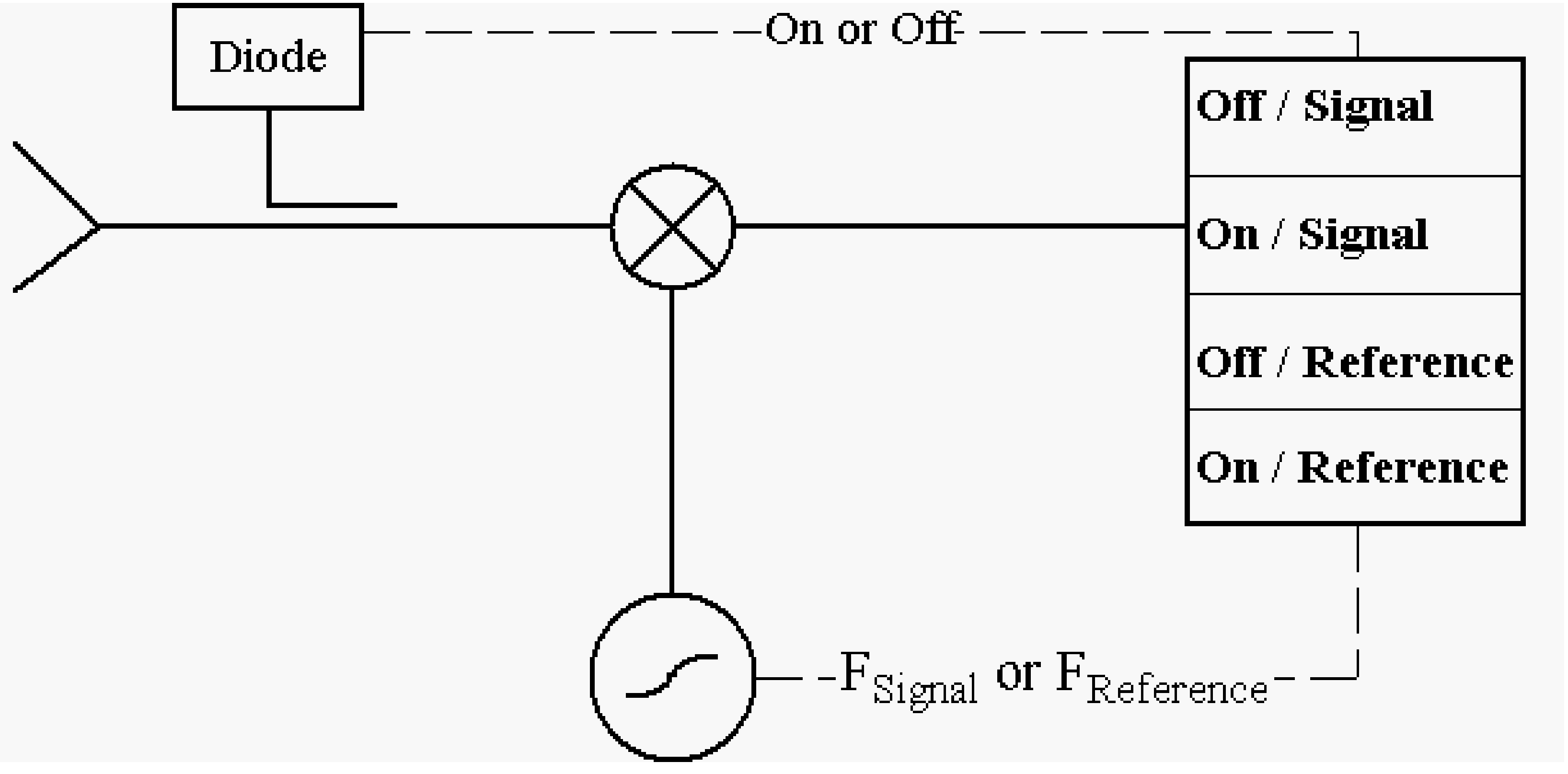
Typical Receiver



Dual Feed Receiver

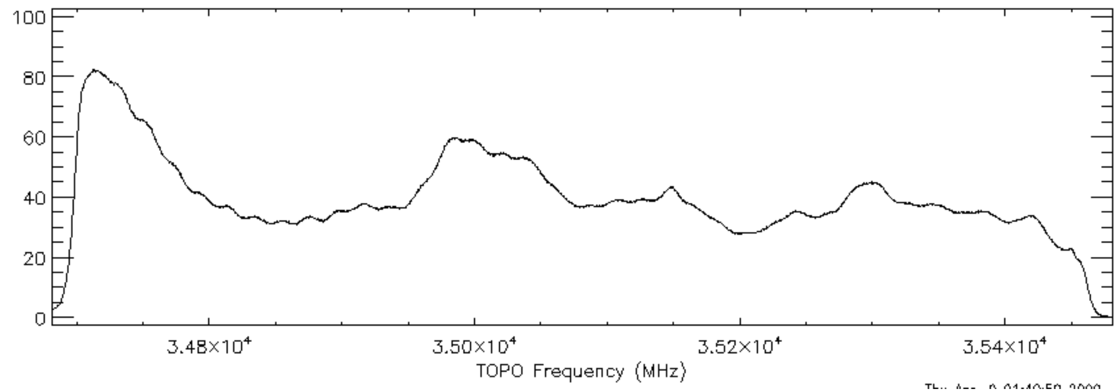


Model Receiver

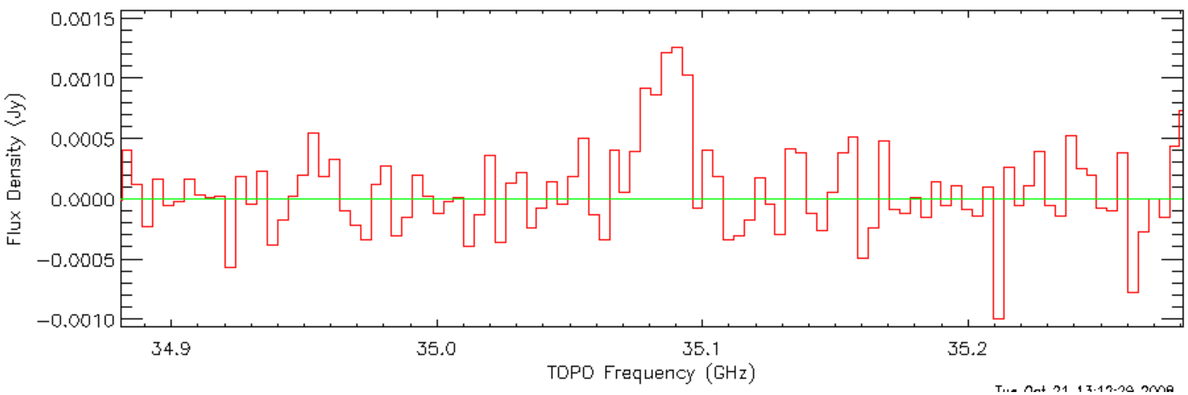


Spectral-line observations

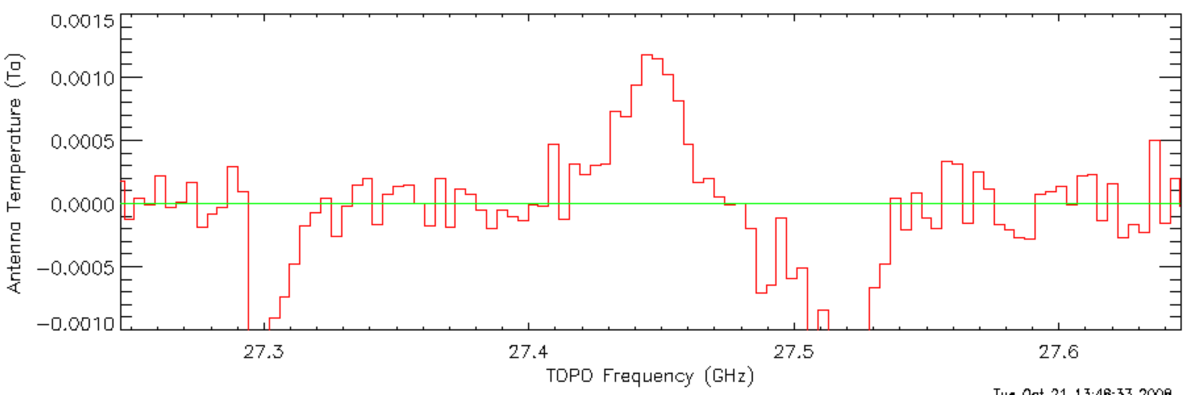
Raw Data



Reduced Data – High Quality



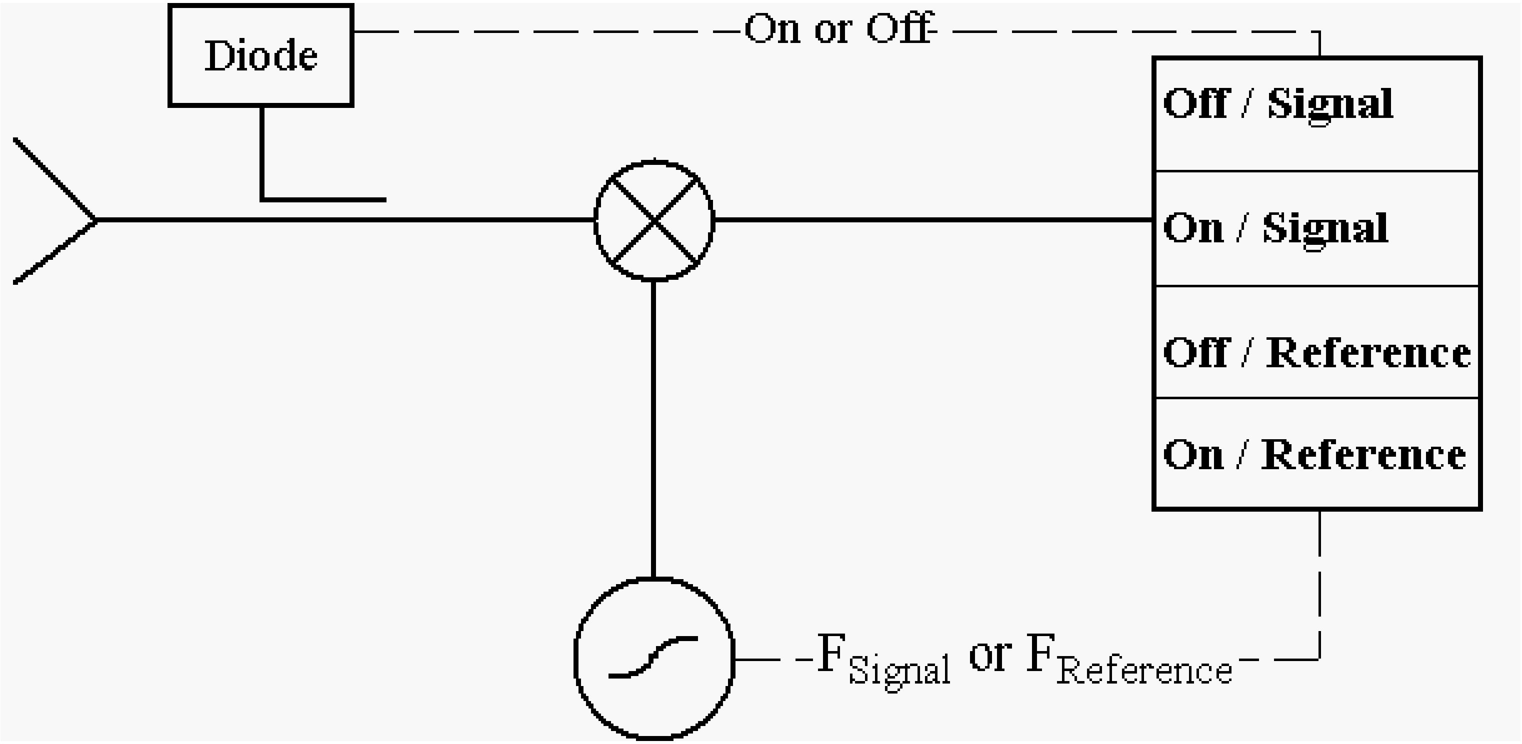
Reduced Data – Problematic



Reference observations

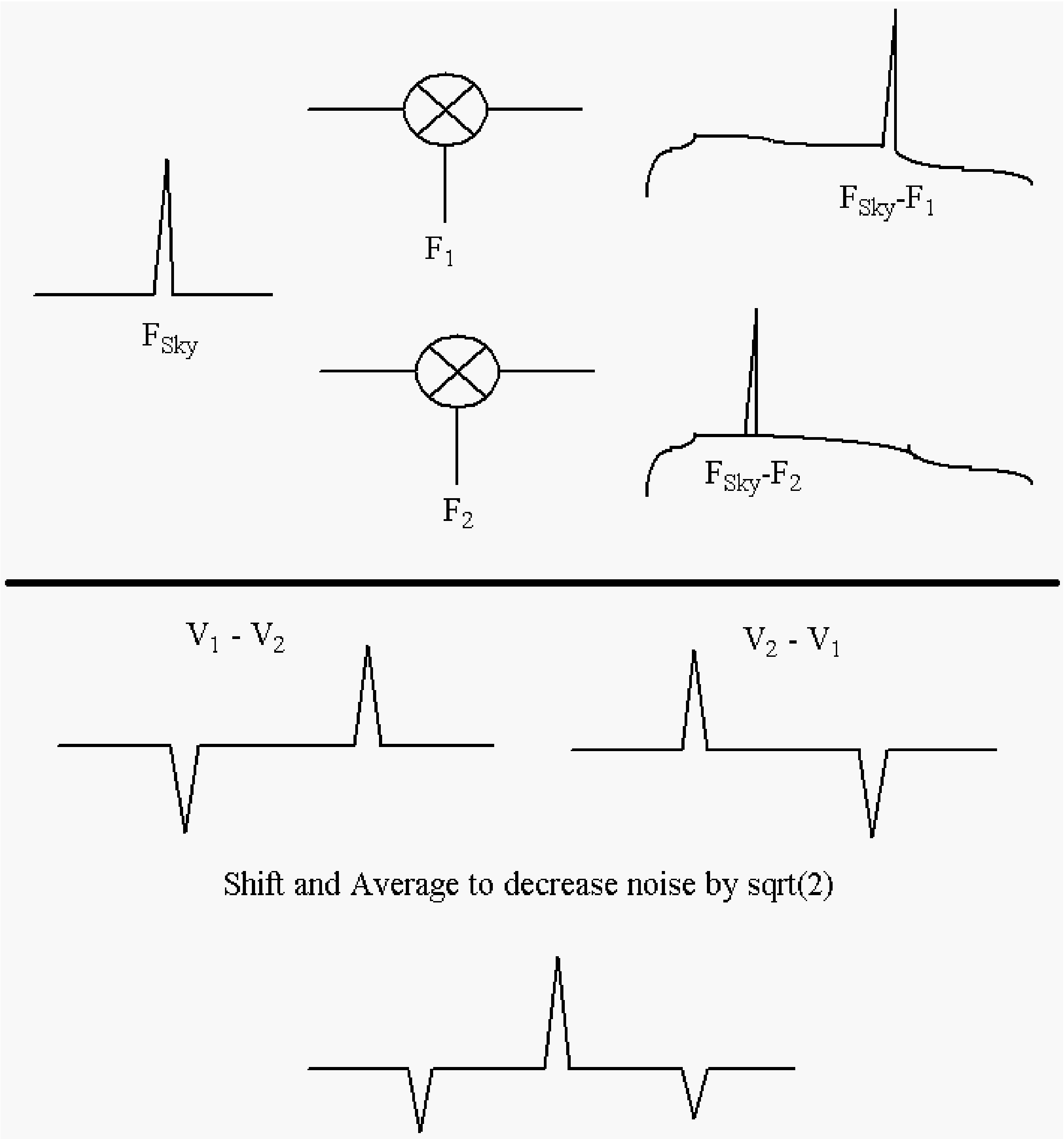
- Difference a signal observation with a reference observation
- Types of reference observations
  - Frequency Switching
    - In or Out-of-band
  - Position Switching
  - Beam Switching
    - Move Subreflector
    - Receiver beam-switch
  - Dual-Beam Nodding
    - Move telescope
    - Move Subreflector

Frequency switching

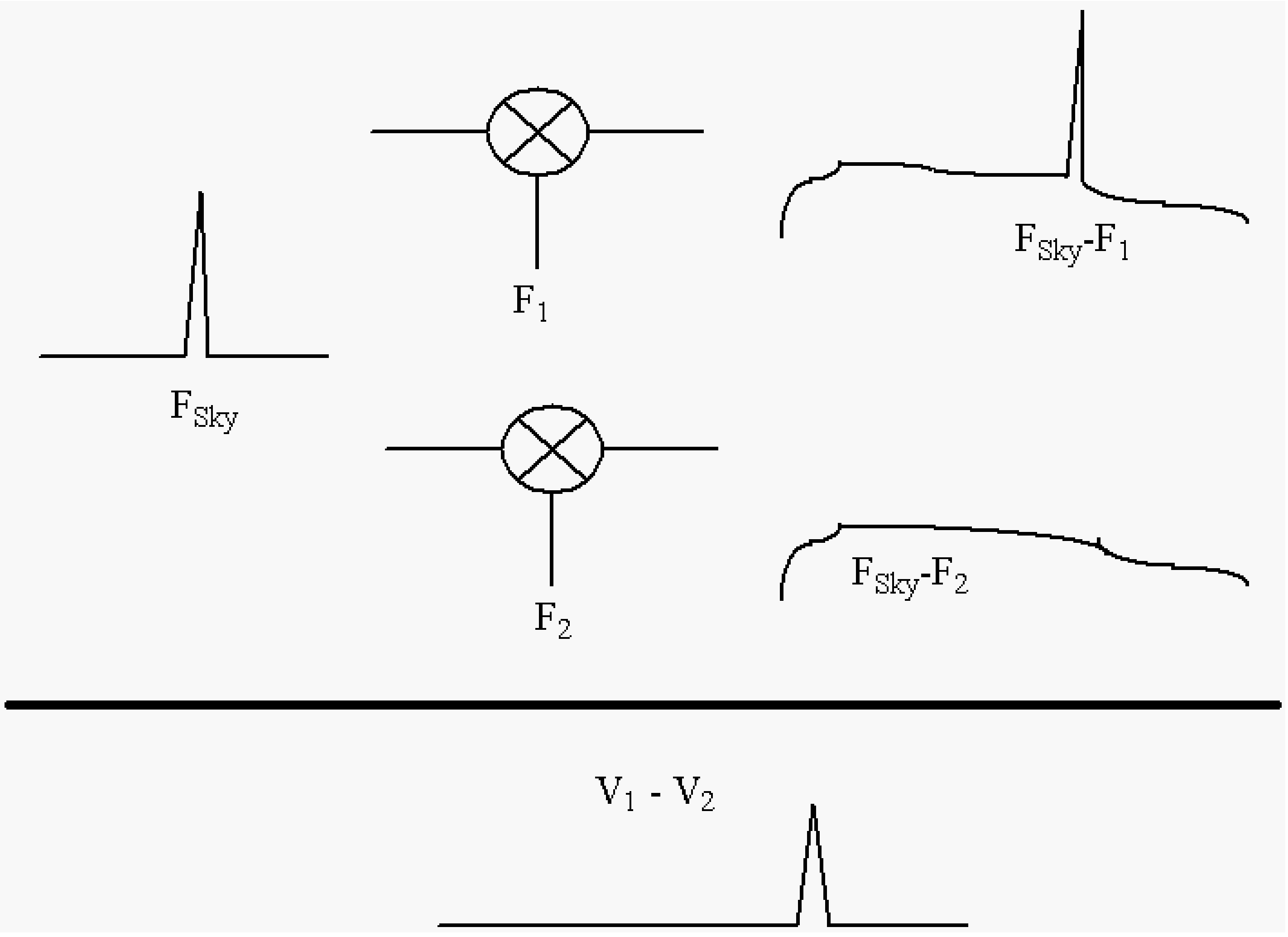


- Eliminates bandpass shape from components after the mixer
- Leaves the derivative of the bandpass shape from components before the mixer.

In-Band Frequency Switching



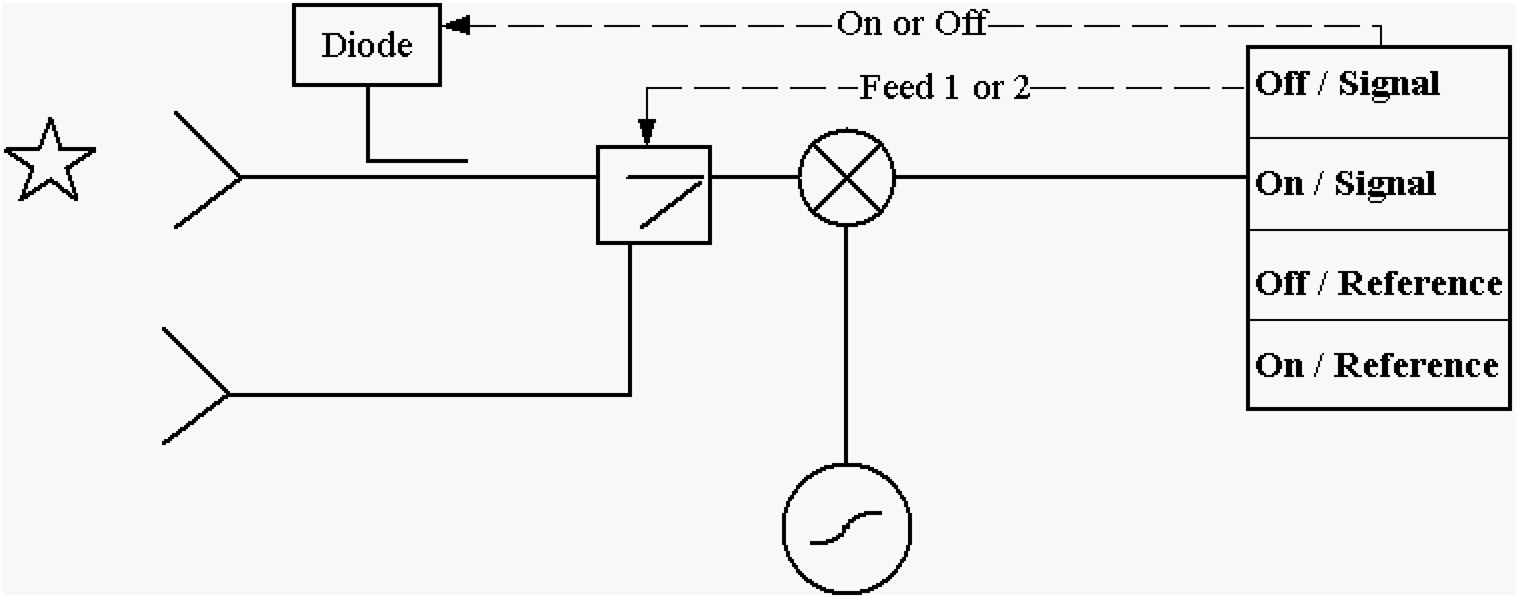
Out-Of-Band Frequency Switching



Position switching

- Move the telescope between a signal and reference position
  - Overhead
  - ½ time spent off source
- Difference the two spectra
- Assumes shape of gain/bandpass doesn’t change between the two observations.
- For strong sources, must contend with dynamic range and linearity restrictions.

Beam switching – Internal switch



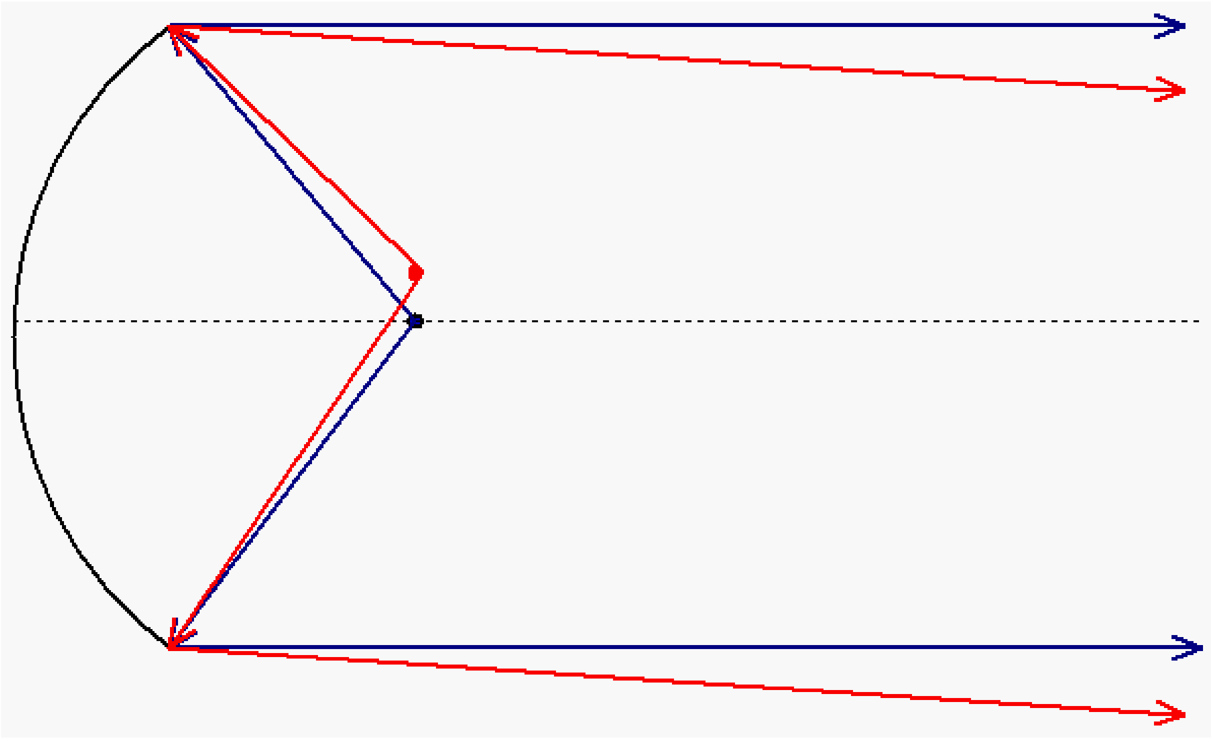
- Difference spectra eliminates any contributions to the bandpass from after the switch
- Residual will be the difference in bandpass shapes from all hardware in front of the switch.
- Low overhead but ½ time spent off source

The Atmosphere

- Opacity
  - Tsys = Trcvr + Tspill +
    Tcmb * exp(-Tau*AirMass) +
    Tatm * [exp(-Tau*AirMass) – 1]
  - Air Mass ~ 1/sin(Elev) for Elev > 15
- Stability
  - Tsys varies quickly with time
  - Worse when Tau is high
- Helps that the atmosphere is in the near field

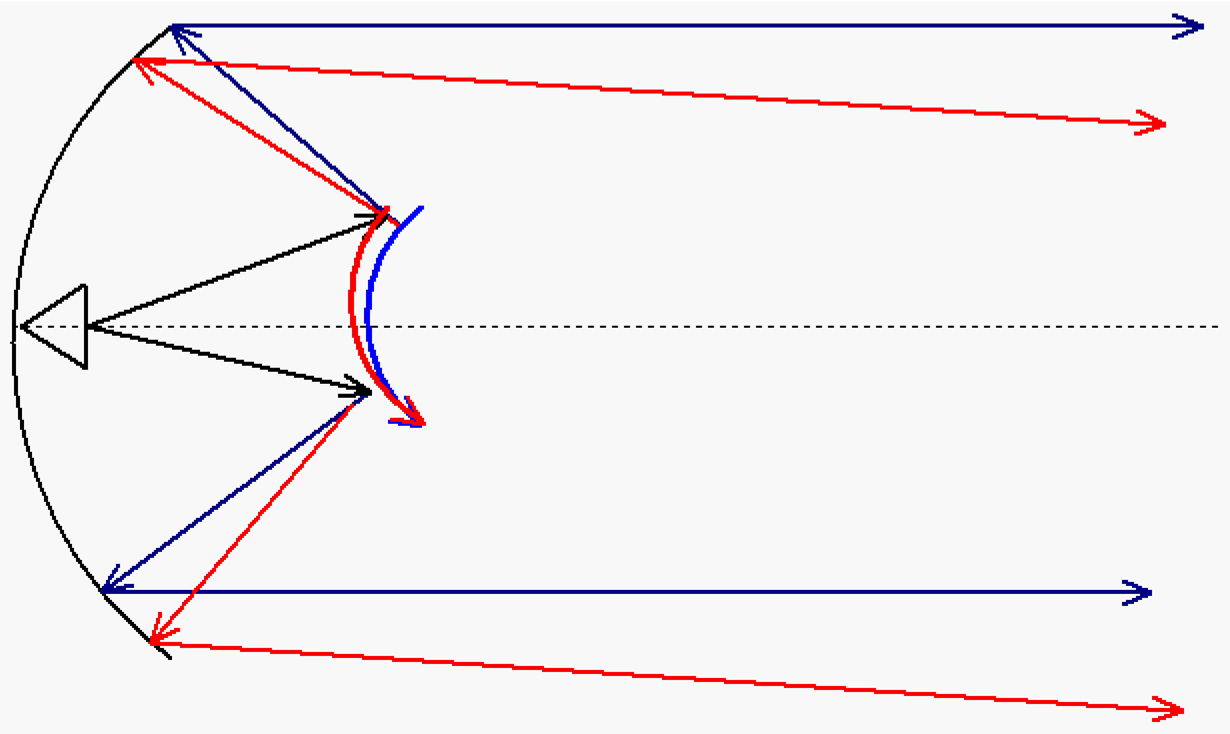
Atmosphere is in the near field

- Common to all feeds in a multi-feed receiver

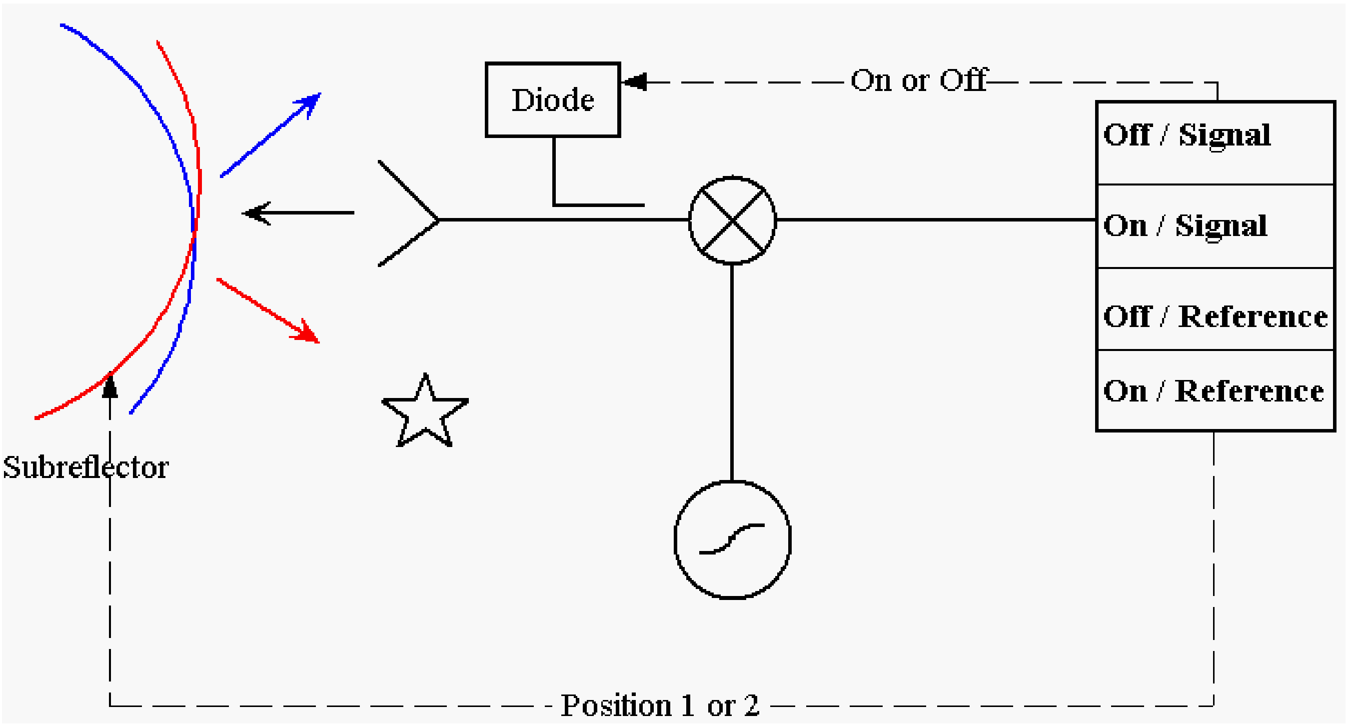


Atmosphere is in the near field

- Common to data taken in both positions of the subreflector

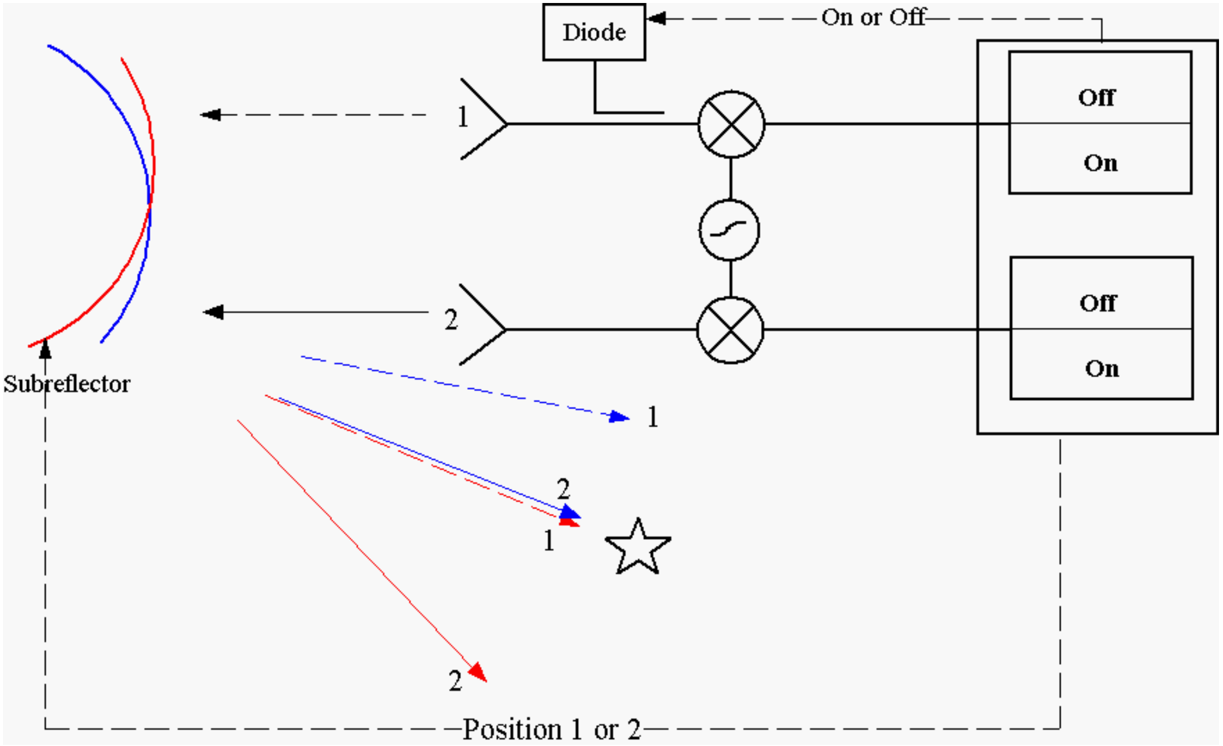


Beam Switching – Subreflector or tertiary mirror



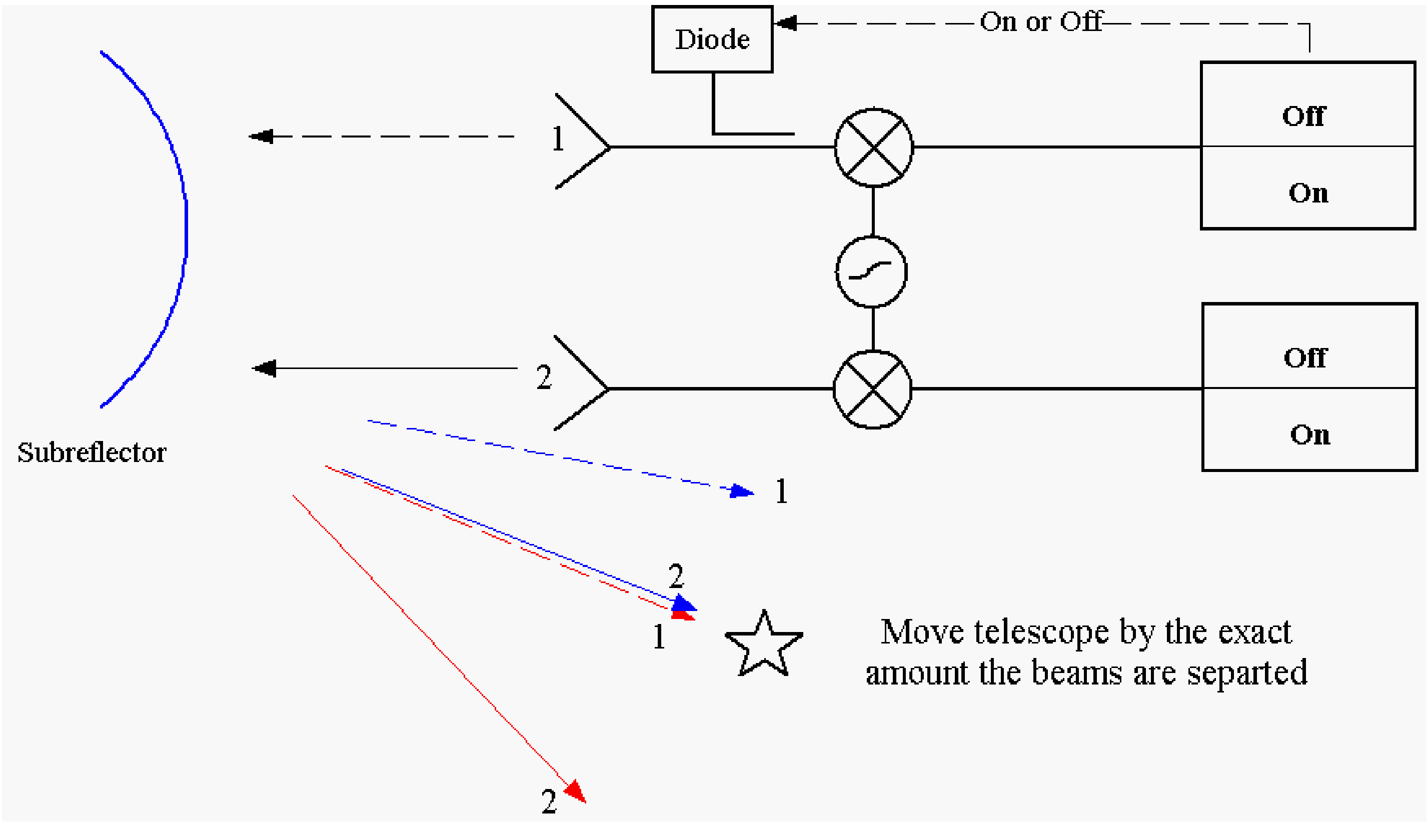
- Optical aberrations
- Difference in spillover/ground pickup
- Removes any 'fast' gain/bandpass changes
- Low overhead. ½ time spent off source

Nodding with dual-beam receivers - Subreflector or tertiary mirror



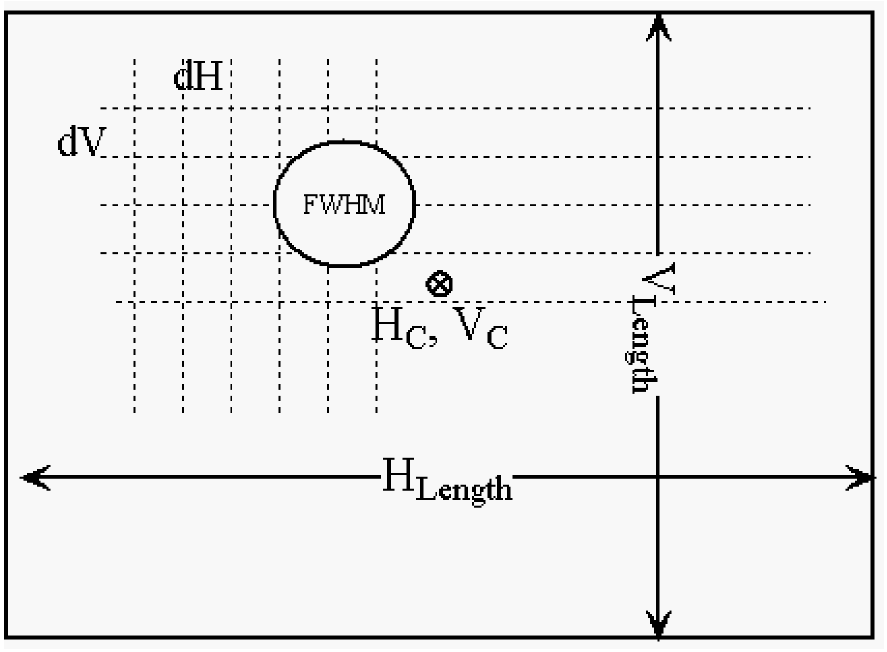
- Optical aberrations
- Difference in spillover/ground pickup
- Removes any ‘fast’ gain/bandpass changes
- Low overhead. All the time is spent on source

Nodding with dual-beam receivers - Telescope motion



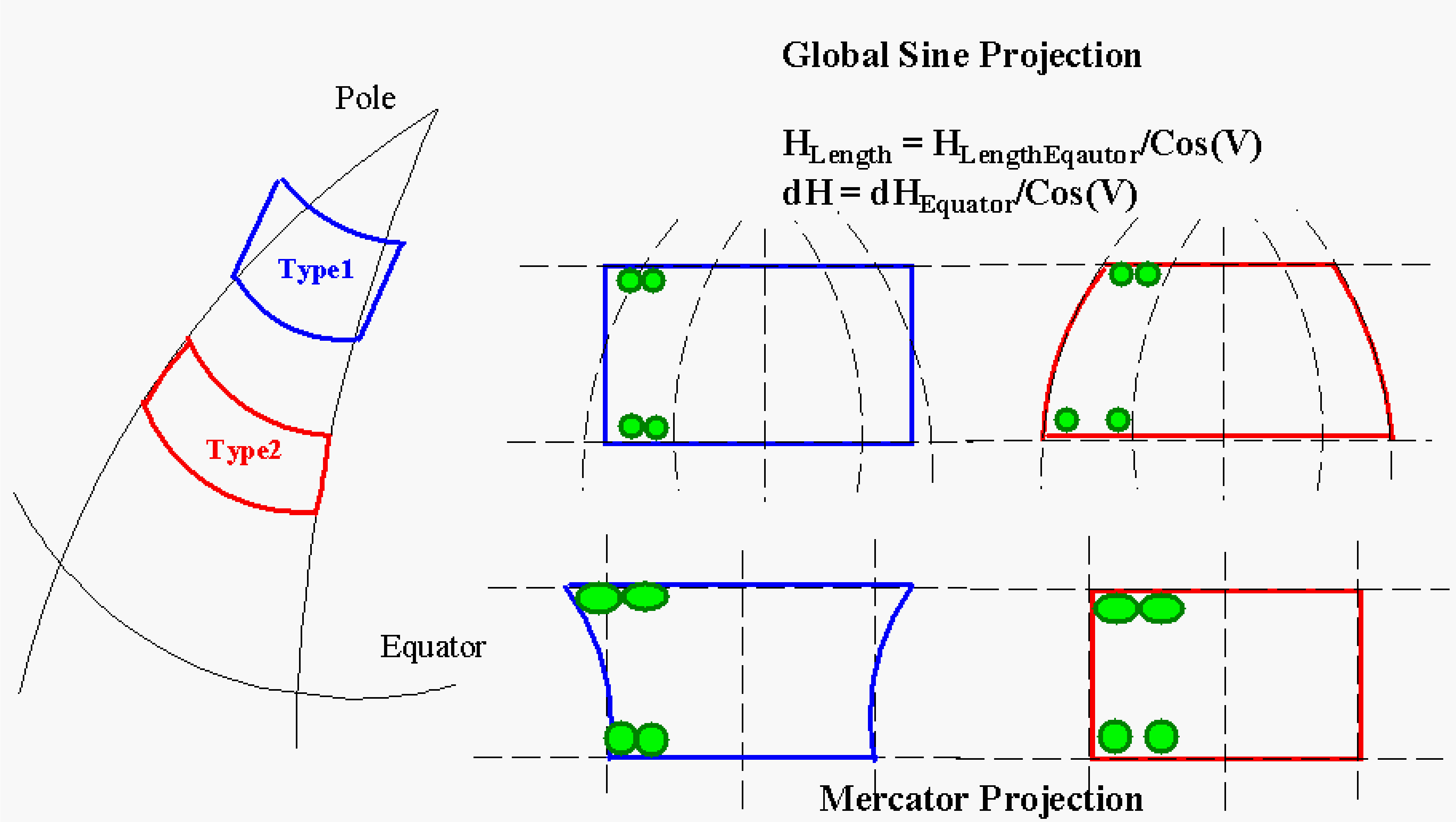
- Optical aberrations
- Difference in spillover/ground pickup
- Removes any ‘fast’ gain/bandpass changes
- Overhead from moving the telescope. All the time is spent on source

Mapping with a single pixel

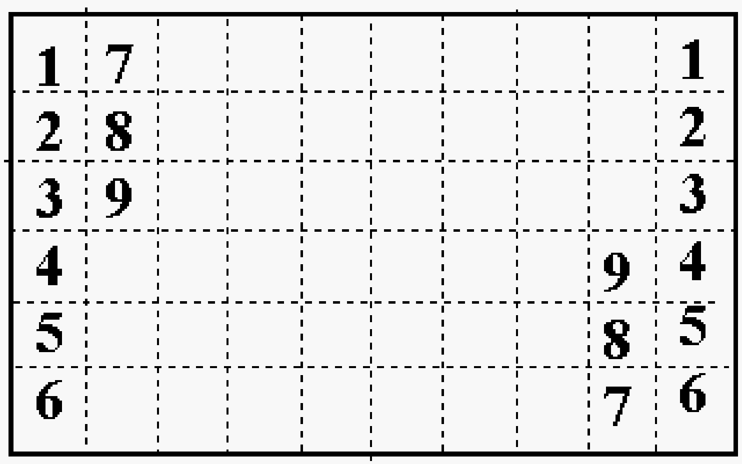


- Map has a center
- Width x Height
- Spacing
  - Nyquist sampling = λ / 2D radians or less
  - Typically 0.9 λ / 2D radians
  - Loosely related to FWHM beamwidth (~1.2 λ / D radians)

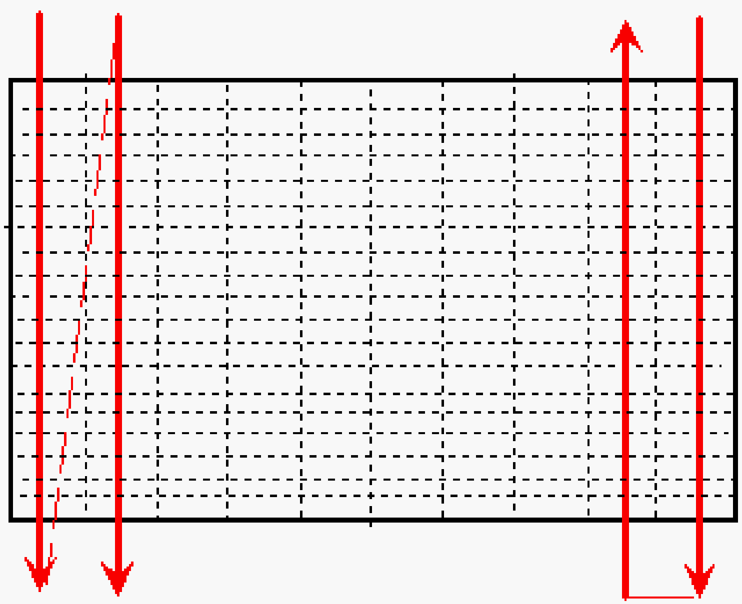
Projection effects

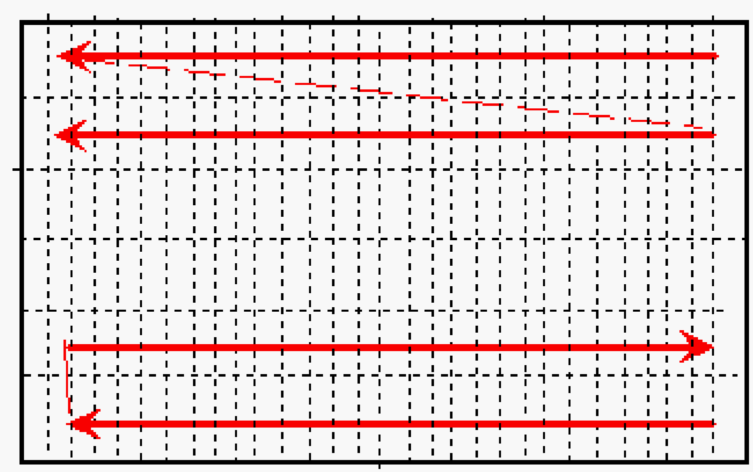


Types of maps



- Point map
  - Sit, Move, Sit, Move, etc.
- On-The-Fly Mapping
  - Mangum, Emerson, Greisen 2008, Astro& Astroph.
  - Slew a column or row while collecting data
  - Move to next column row
  - Basket weave
  - Should oversanple ~3x Nyquist along direction of slew



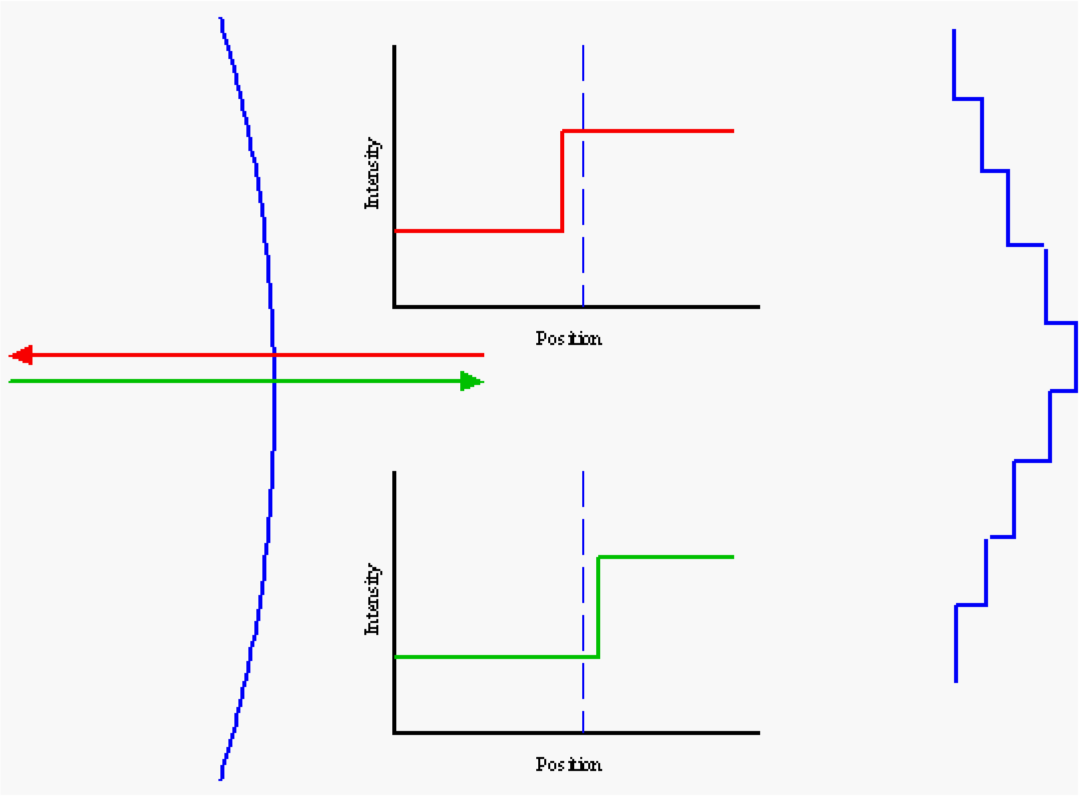


Other mapping issues

- Non-Rectangular regions
- Sampling “Hysteresis”
- Reference observations
  - Use edge pixels @ no costs
  - Interrupt the map
  - Built-in (frequency/beam switching, nodding, etc.)
- Basketweaving

“Hysteresis”

- From inaccurate time tags for either telescope positions or data samples

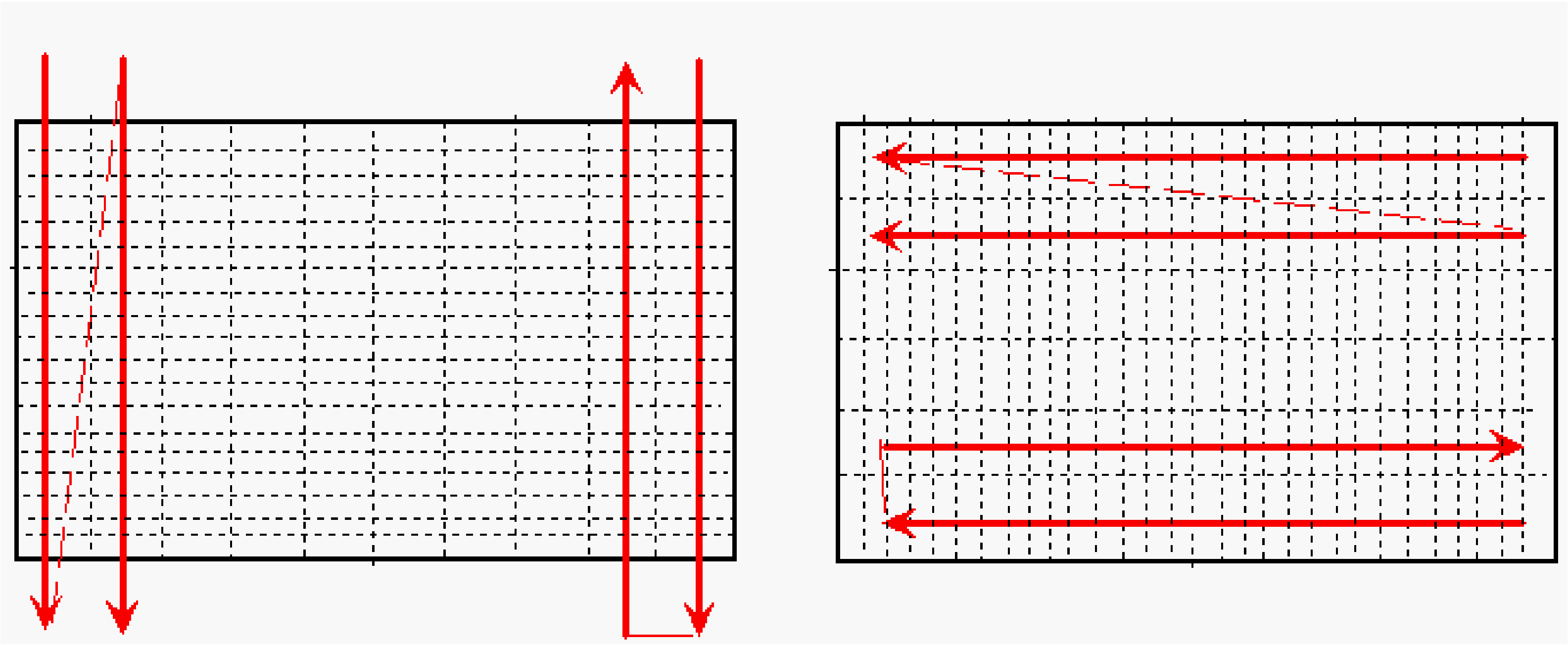


Other mapping issues

- Non-Rectangular regions
- Sampling “Hysteresis”
- Reference observations
  - Use edge pixels @ no costs
  - Interrupt the map
  - Built-in (frequency/beam switching, nodding, etc.)
- Basketweaving

Basketweaving

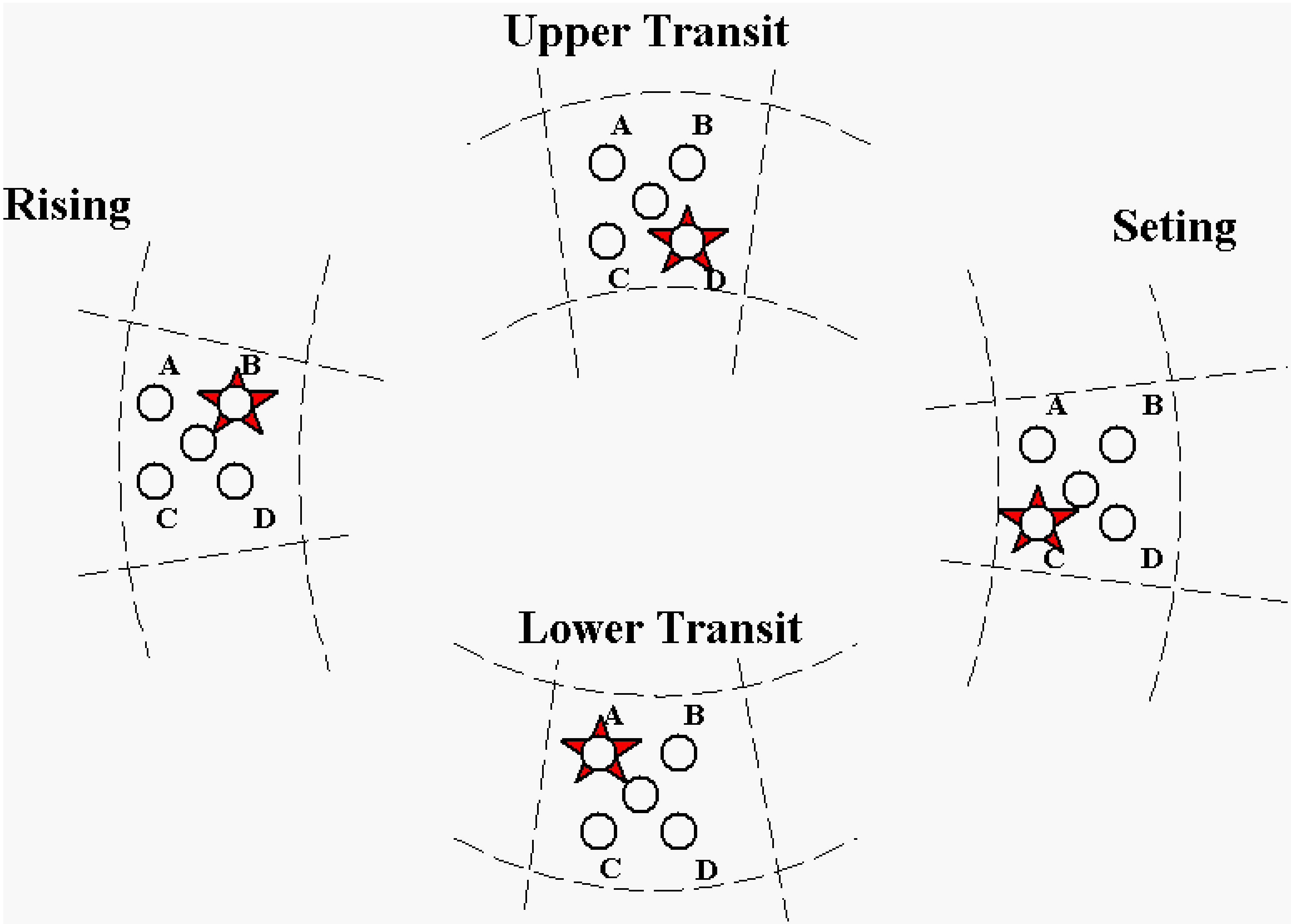
- $S(\theta,\varphi) = [I_{Source}(\theta,\varphi) + I_{Atmosphere}(\theta,\varphi)] \otimes P_{ant}(\theta,\varphi)$
- I_{Source} is correlated between the 2 maps
- $I_{Atmosphere}$ is not correlated



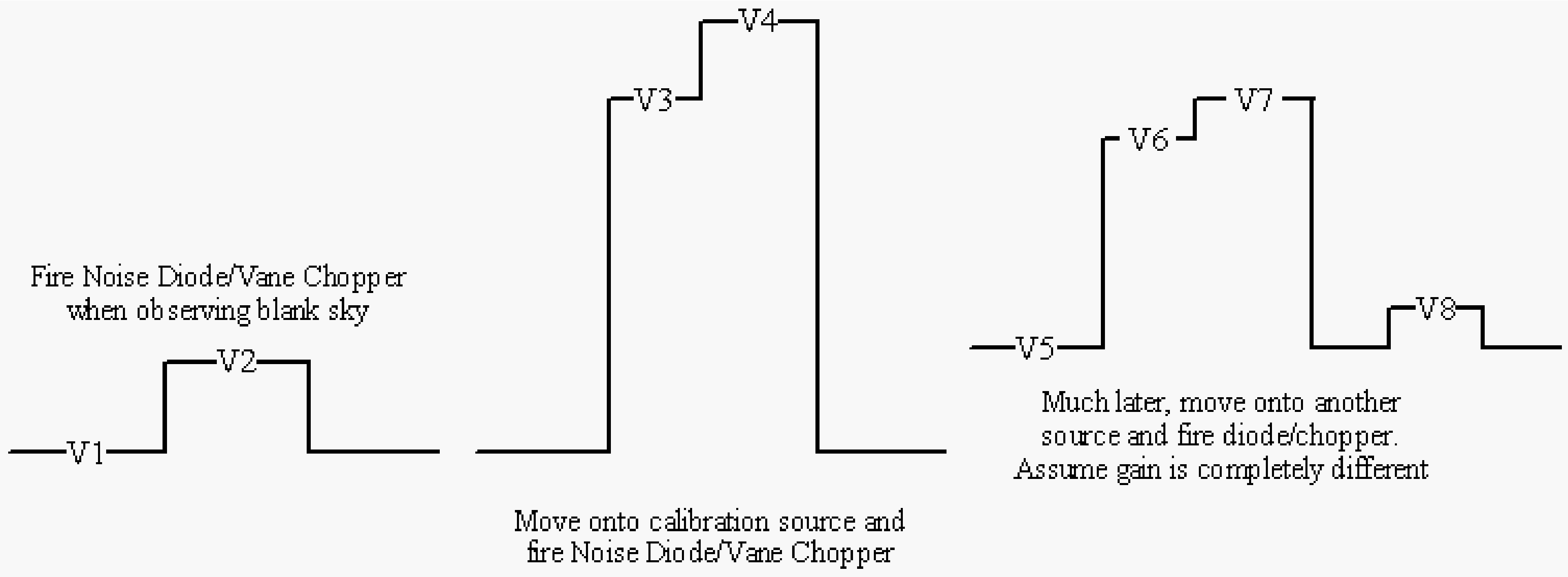
Mapping with multi-pixel receivers

- Useful when object larger than beam separation
- Uniform sampling difficult
- Redundant sampling
  - $S(\theta,\varphi) = [I_{Source}(\theta,\varphi) + I_{Rcvr}(\theta,\varphi)] \otimes P_{ant}(\theta,\varphi)$
  - I_{Source} is correlated between the 2 maps
  - I_{Rcvr} is not correlated
- Field rotation

Field Rotation

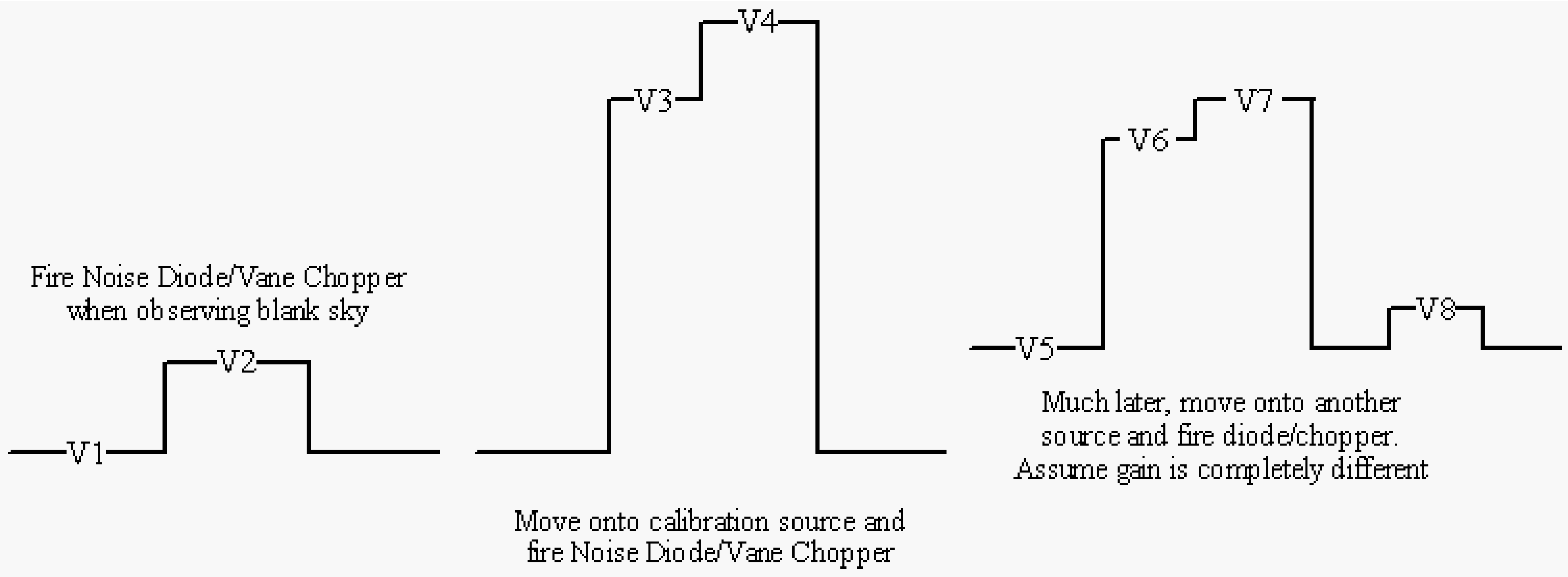


Astronomical Calibration



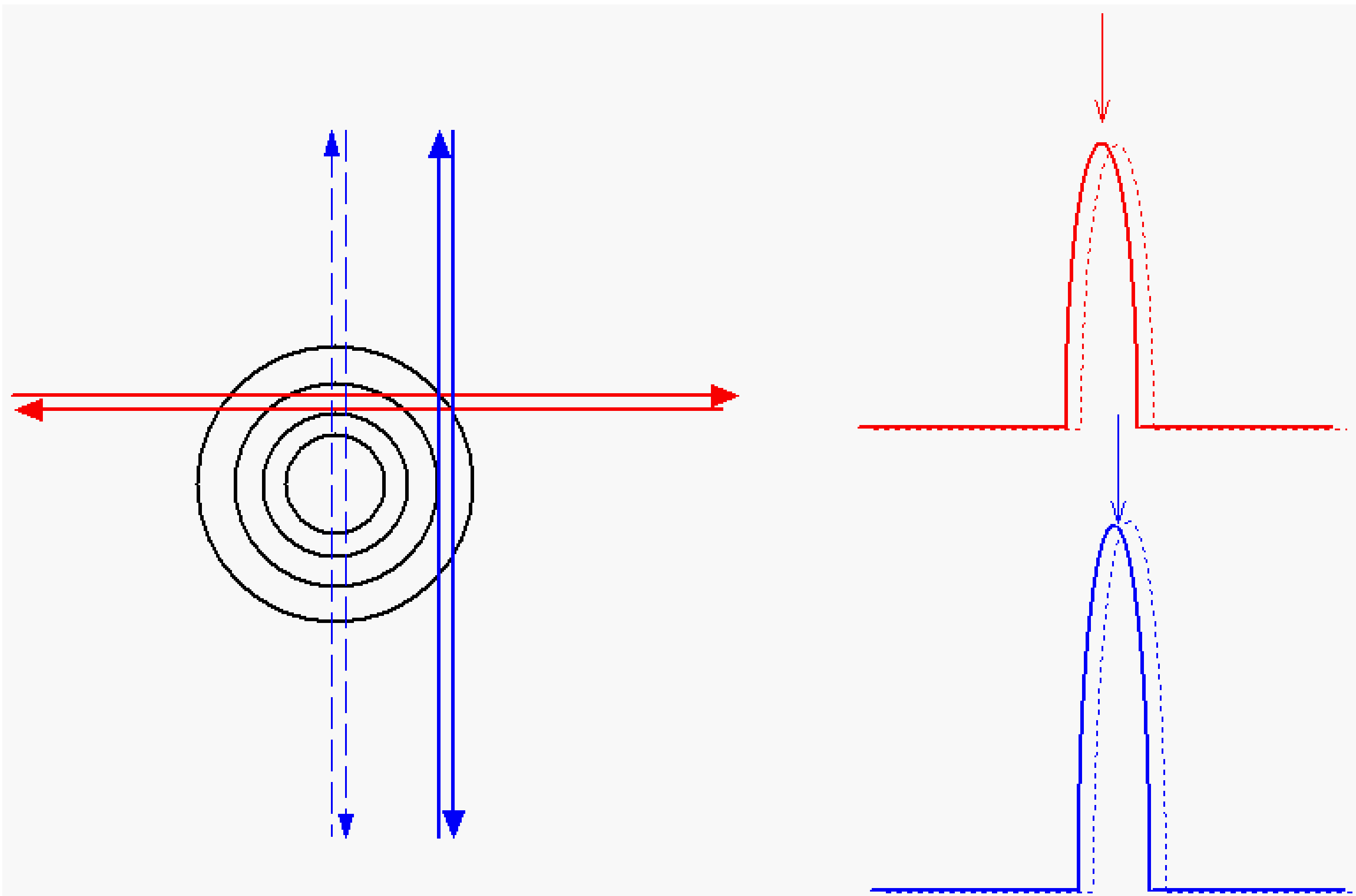
- Determine T_{cal} from calibrator:
  - A = (V2-V1) + (V4-V3)
  - B = (V4-V2) + (V3–V1)
  - $T_{cal} = (A/B) \cdot (\eta\ A_p\ S_{src} /2k) \cdot \exp(-Tau*AirMass)$

Astronomical Calibration

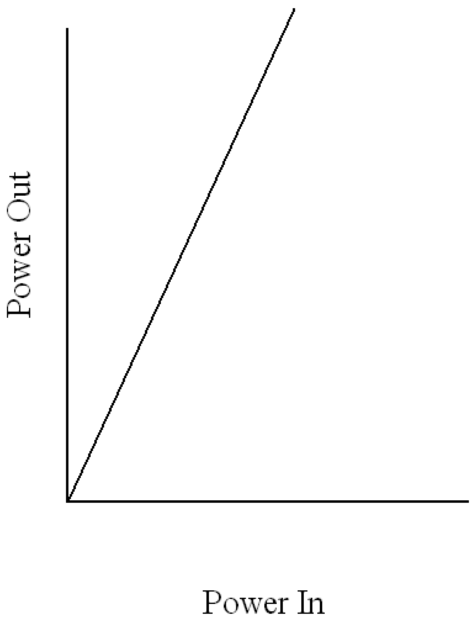


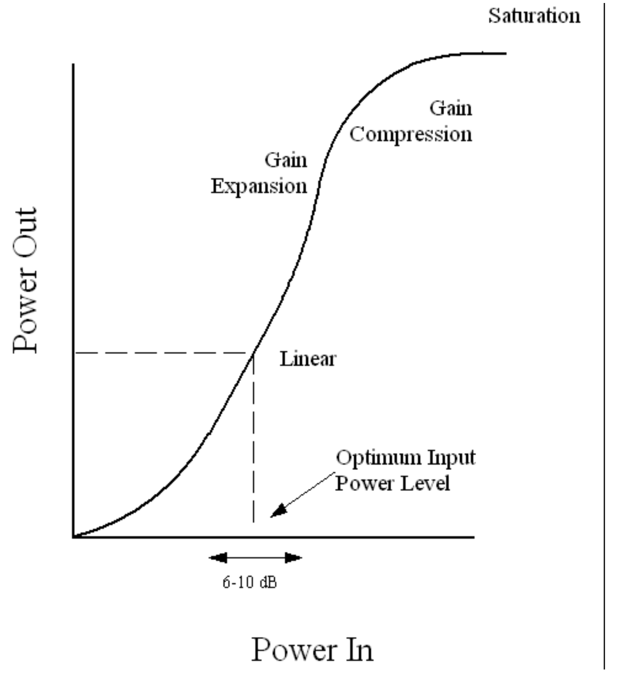
- Determine strength of unknown source
  - A = (V8-V5) + (V7-V6)
  - B = (V7-V8) + (V6–V5)
  - $T_A = (B/A) \cdot T_{cal}$
  - $S = 2kT_A/[\eta \text{ Ap } \exp(-\text{Tau}*\text{AirMass})]$

Calibration in Actual Practice



Power Balancing/Leveling and Non-Linearity





- If linear, then (V2-V1) – (V4-V3) should equal zero, to within the noise

Sensitivity

- Radiometer equation: $\sigma = T_{sys} / \mathrm{Sqrt}(BW \cdot t)$
  - But, we're always differencing observations.\
  - Hardware realities
- $\sigma = K_1 T_{sys} / \mathrm{Sqrt}(K_2 BW \cdot t_{effective} \cdot N_{pol} \cdot N_{avrg})$
  - K_1: Reflects backend sensitivity (e.g., 1.23 for a 3-level correlator)
  - K_2: Independence of samples (e.g 1.2 for correlator)
- $t_{effective} = t_{sig}\, t_{ref} / (t_{sig} + t_{ref})$
- N_{pol} = 1 or 2 (hardware dependent, assume unpolarized source)
- N_{avrg} = Number of independent data streams averaged together.
  - Position switching: 1
  - In-Band frequency switching: 2
  - Etc.