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: 5º
  - Can observe 85% of the entire Celestial Sphere
- Slew Rates: Azimuth - 40º/min; Elevation - 20º/min

Telescope Structure

Blind Pointing:
(1 point/focus)

$$\sigma_2 \approx 5 \ \ arc\,\mathrm{sec}$$
$$\sigma(\ focus\ ) \approx 2.5 \ \ mm$$

Offset Pointing:
(90 min)

$$\sigma_2 \approx 2.7 \ \ arc\,\mathrm{sec}$$
$$\sigma(\ focus\ ) \approx 1.5 \ \ mm$$

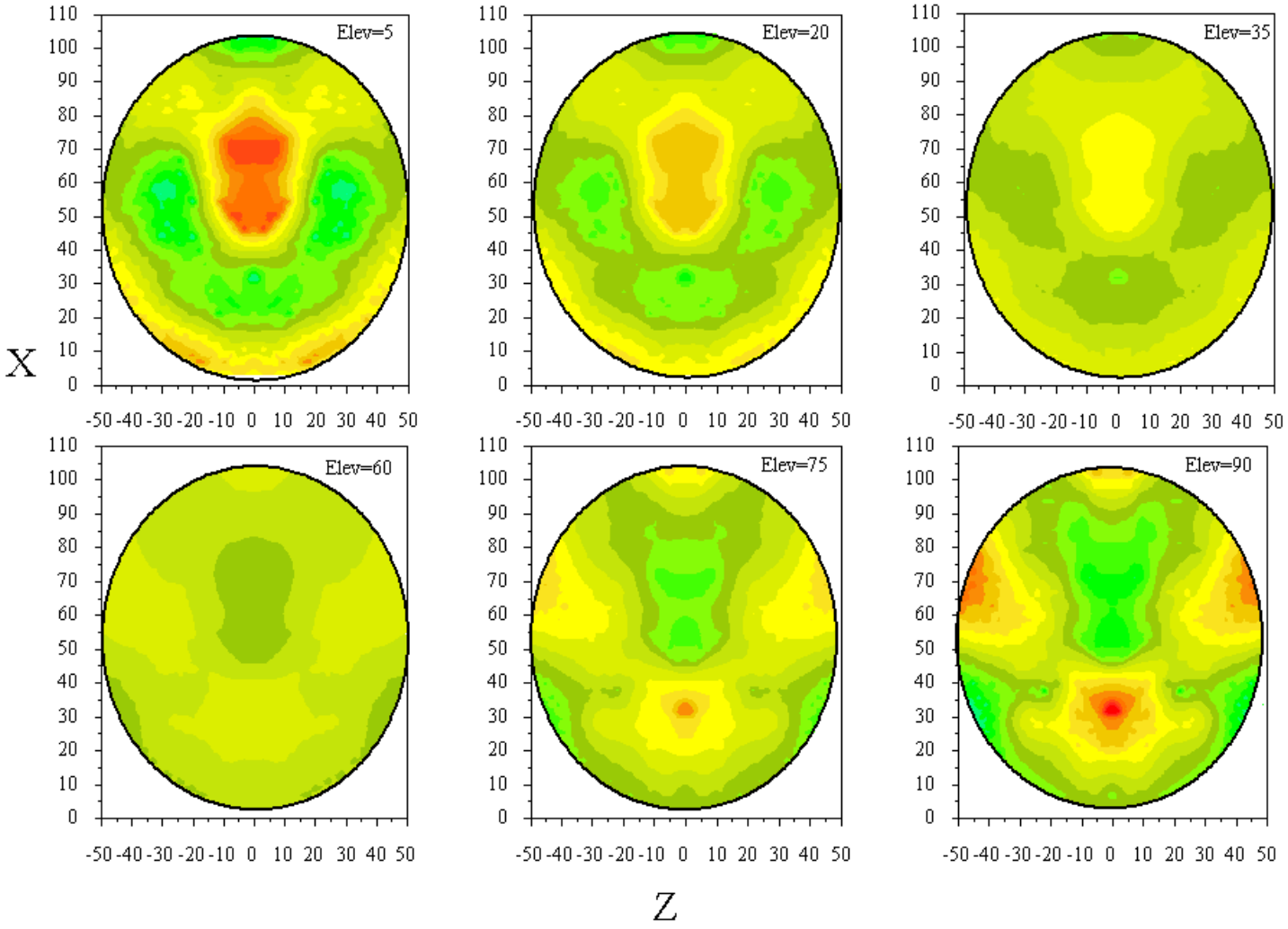
Continuous Tracking:
(30 min)

$$\sigma_2 \approx 1 \ \ arc\,\mathrm{sec}$$

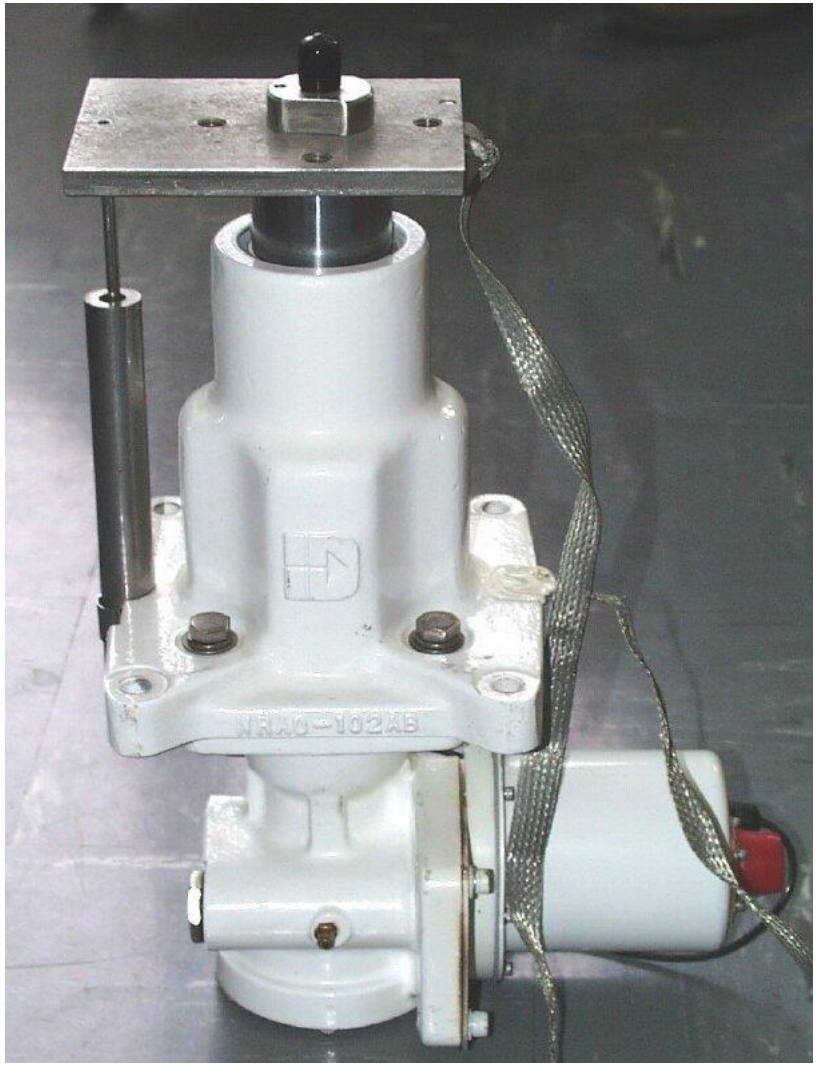
Telescope Structure

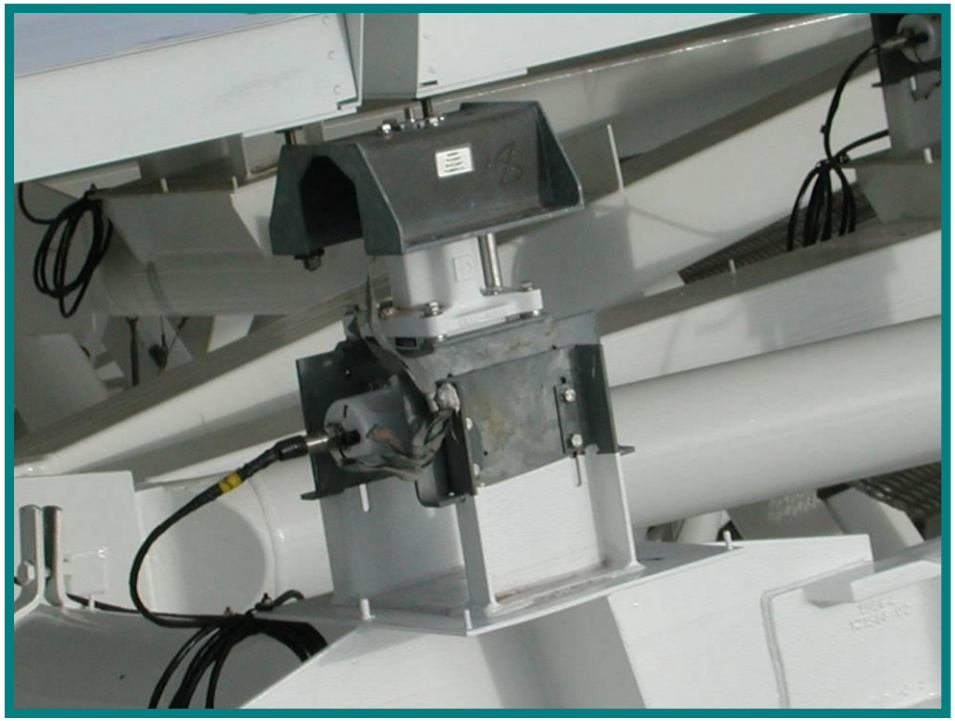
Active Surface

Surface Deformations from Finite Element Model



Active Surface





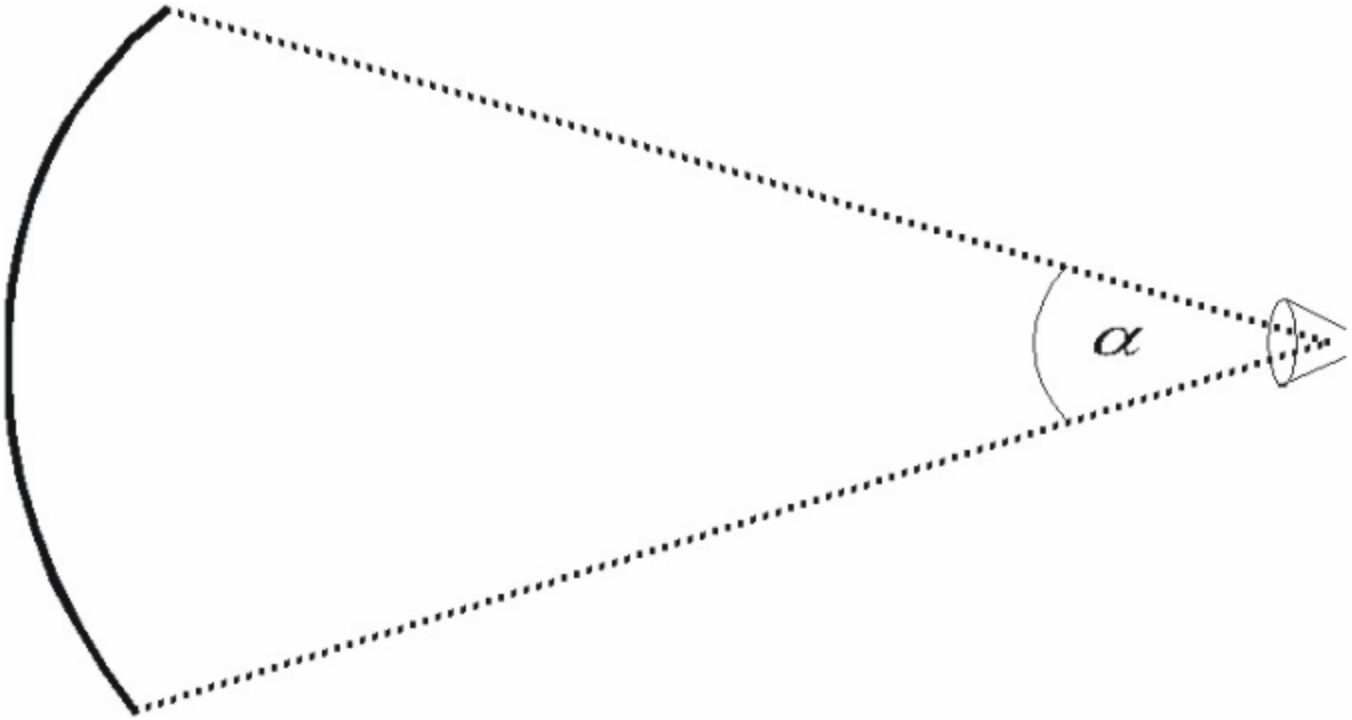
Telescope Optics

Rotating Turret with 8 receiver bays

Receivers

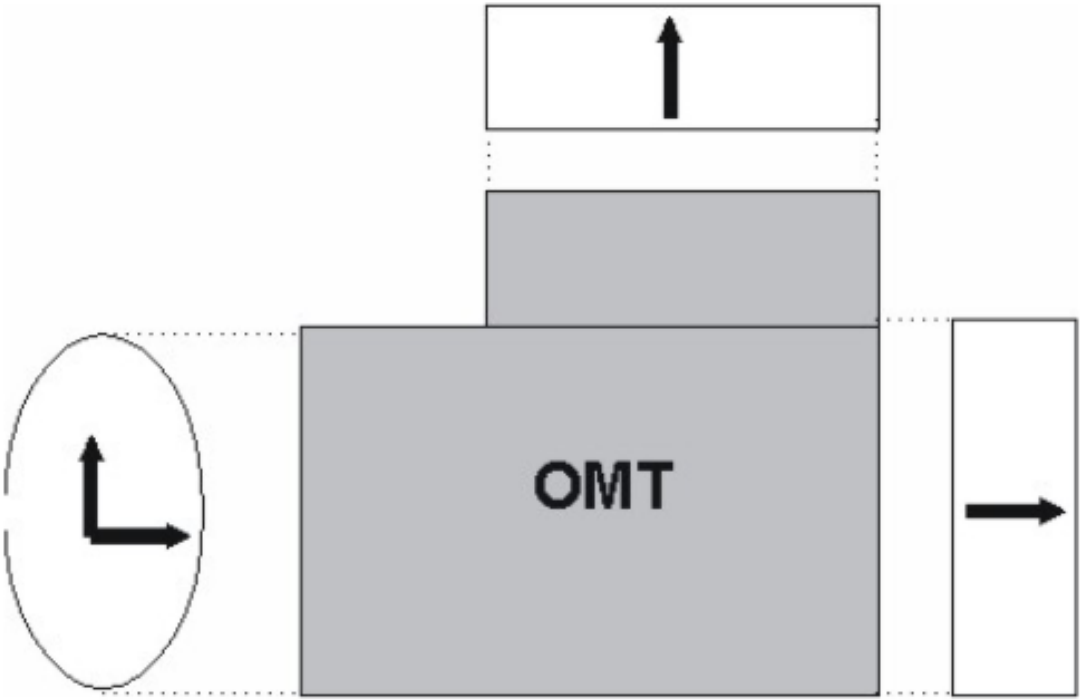
Receiver	Operating Range	Status
Prime Focus 1	0.29—0.92 GHz	Commissioned
Prime Focus 2	0.910—1.23 GHz	Commissioned
L Band	1.15—1.73 GHz	Commissioned
S Band	1.73—2.60 GHz	Commissioned
C Band	3.95—5.85 GHz	Being Upgraded
X Band	8.2—10.0 GHz	Commissioned
Ku Band	12.4—15.4 GHz	Commissioned
K Band 7-pixel	18—26.5 GHz	Commissioned
Ka Band	26—40 GHz	Commissioned
Q Band	40—50 GHz	Commissioned
W Band	68—92 GHz	Commissioned
Penn Array	86—94 GHz	Being Upgraded

Reflector Feeds



And More Feeds

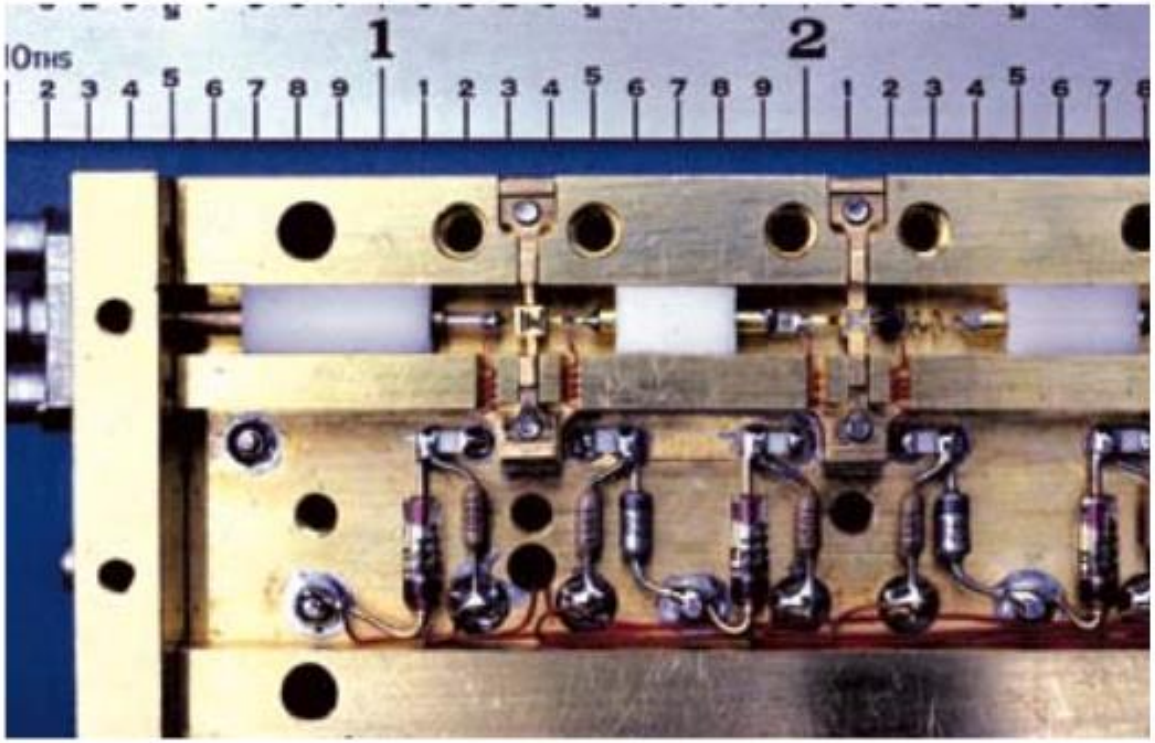
Linear Polarization

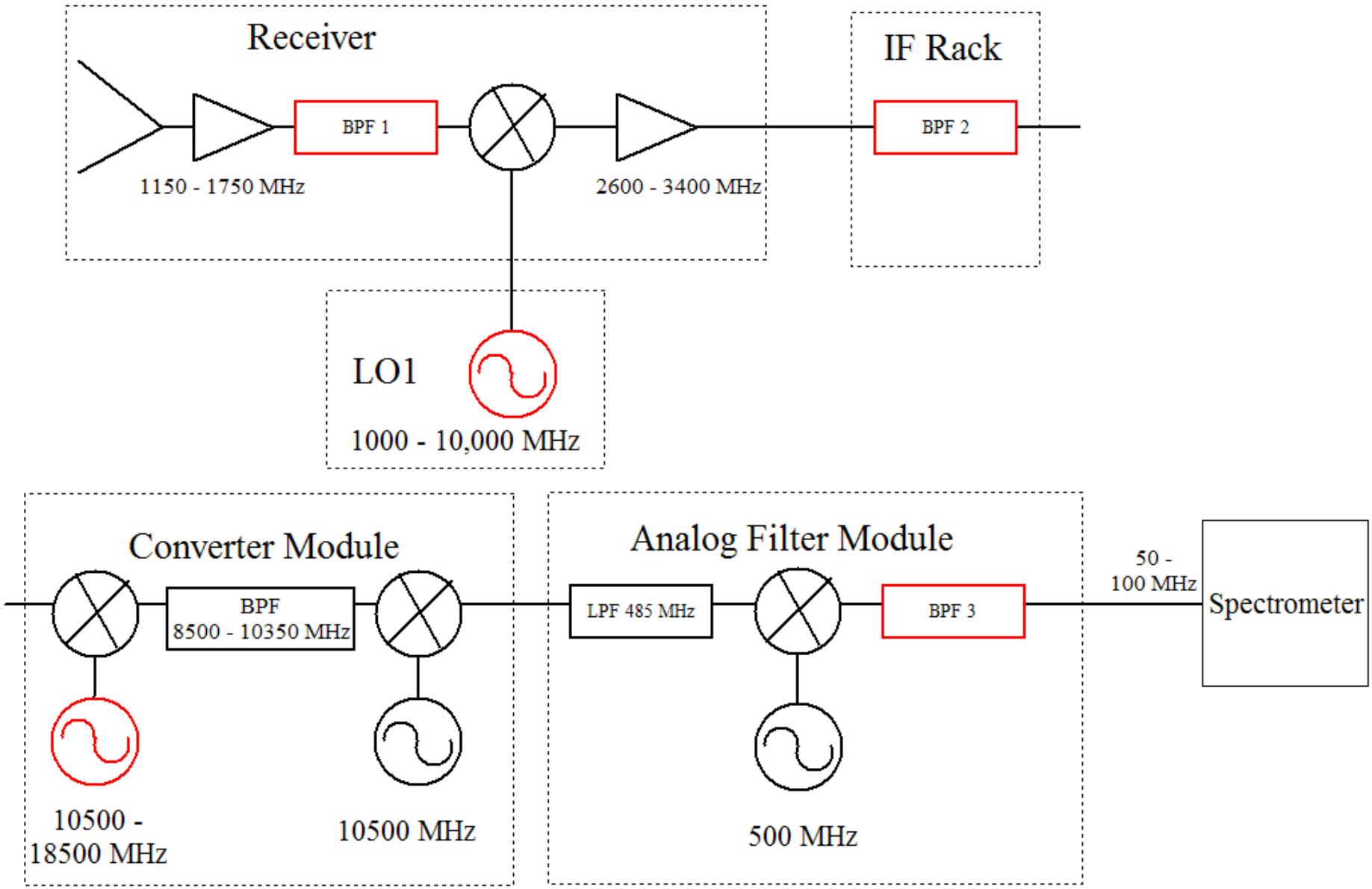


Orthomode Transducer

A Variety of OMTs

A HFET LNA

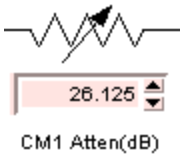



Receiver
BPF 1
1150 - 1750 MHz
2600 - 3400 MHz
IF Rack
BPF 2
LO1
1000 - 10,000 MHz
Converter Module
BPF
8500 - 10350 MHz
10500 -
18500 MHz
10500 MHz
Analog Filter Module
LPF 485 MHz
BPF 3
500 MHz
50 -
100 MHz
Spectrometer

Typical Components

Amplifiers

Mixers

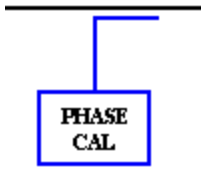


Attenuators

Power Detectors

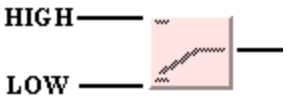
Synthesizers

Splitters



Couplers

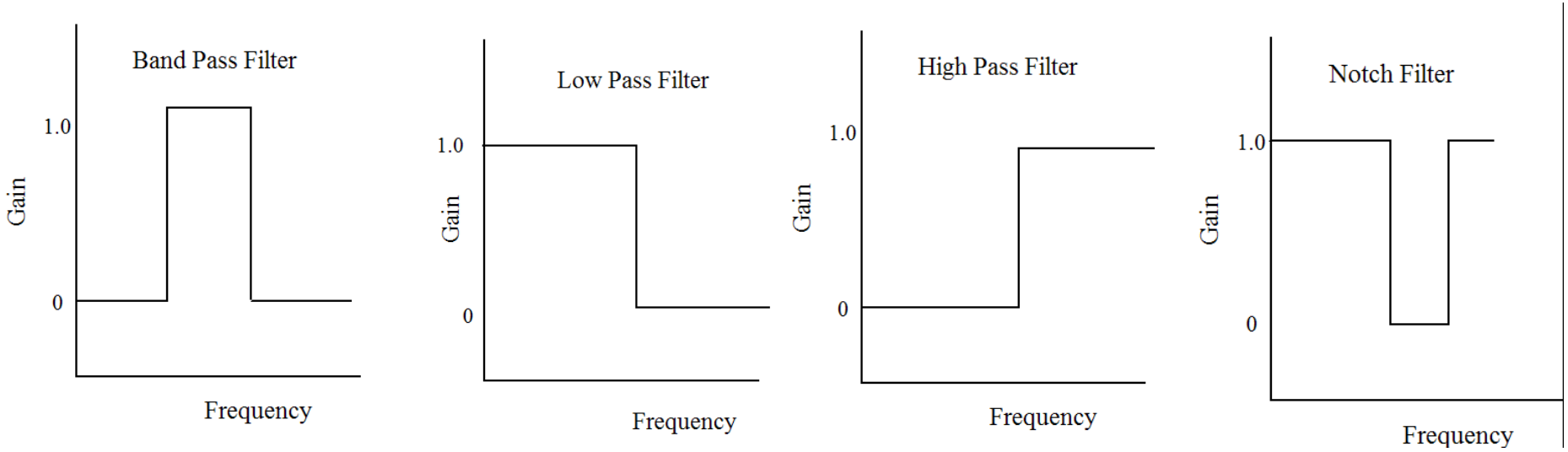
Filters



Switches

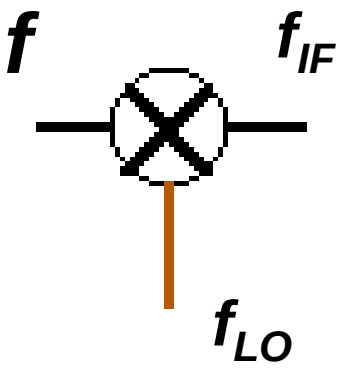
Multipliers

Types of Filters



Edges are smoother than illustrated

Types of Mixers



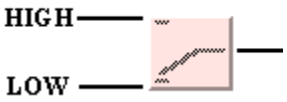
$f_{IF} = n*f_{LO} + m*f$

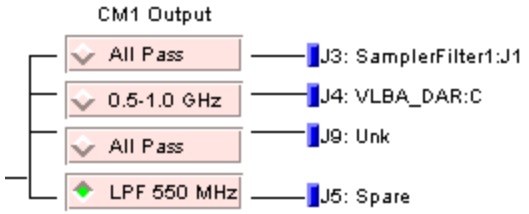
- ***n and m are positive or negative integers, usually 1 or -1***

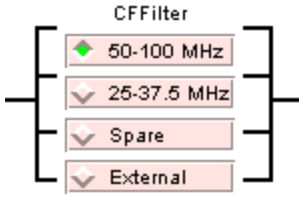
- ***Up Conversion : $f_{IF} > f$***
- ***Down Conversion : $f_{IF} < f$***

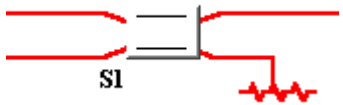
- ***Lower Side Band : $f_{LO} > f$***
  - ***Sense of frequency flips***
- ***Upper Side Band : $f_{LO} < f$***

Example Switches

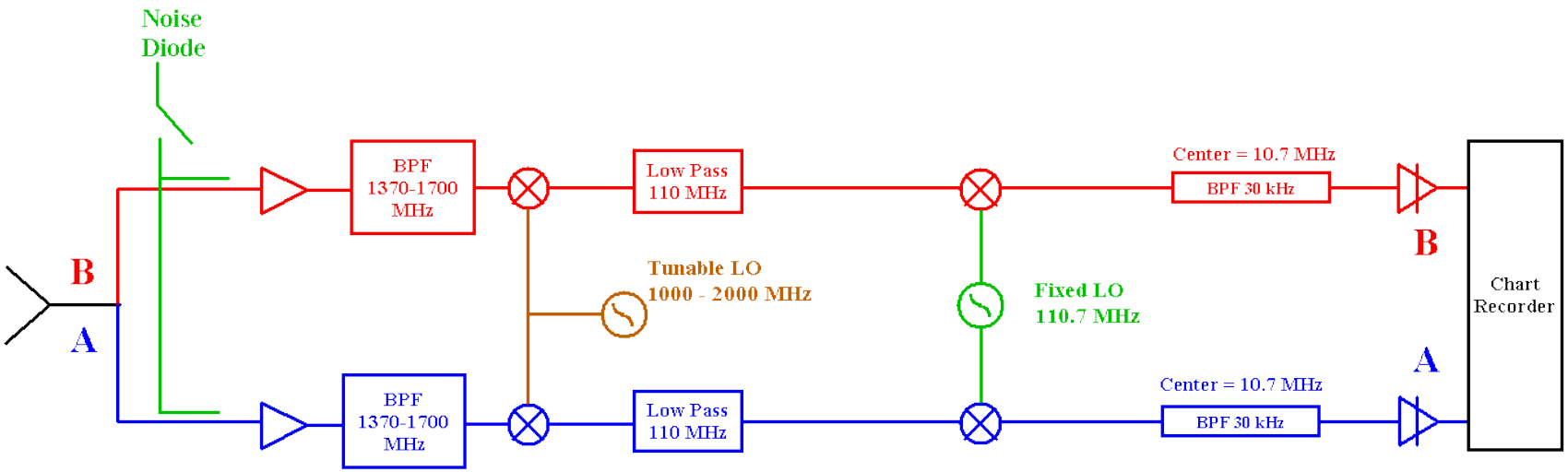






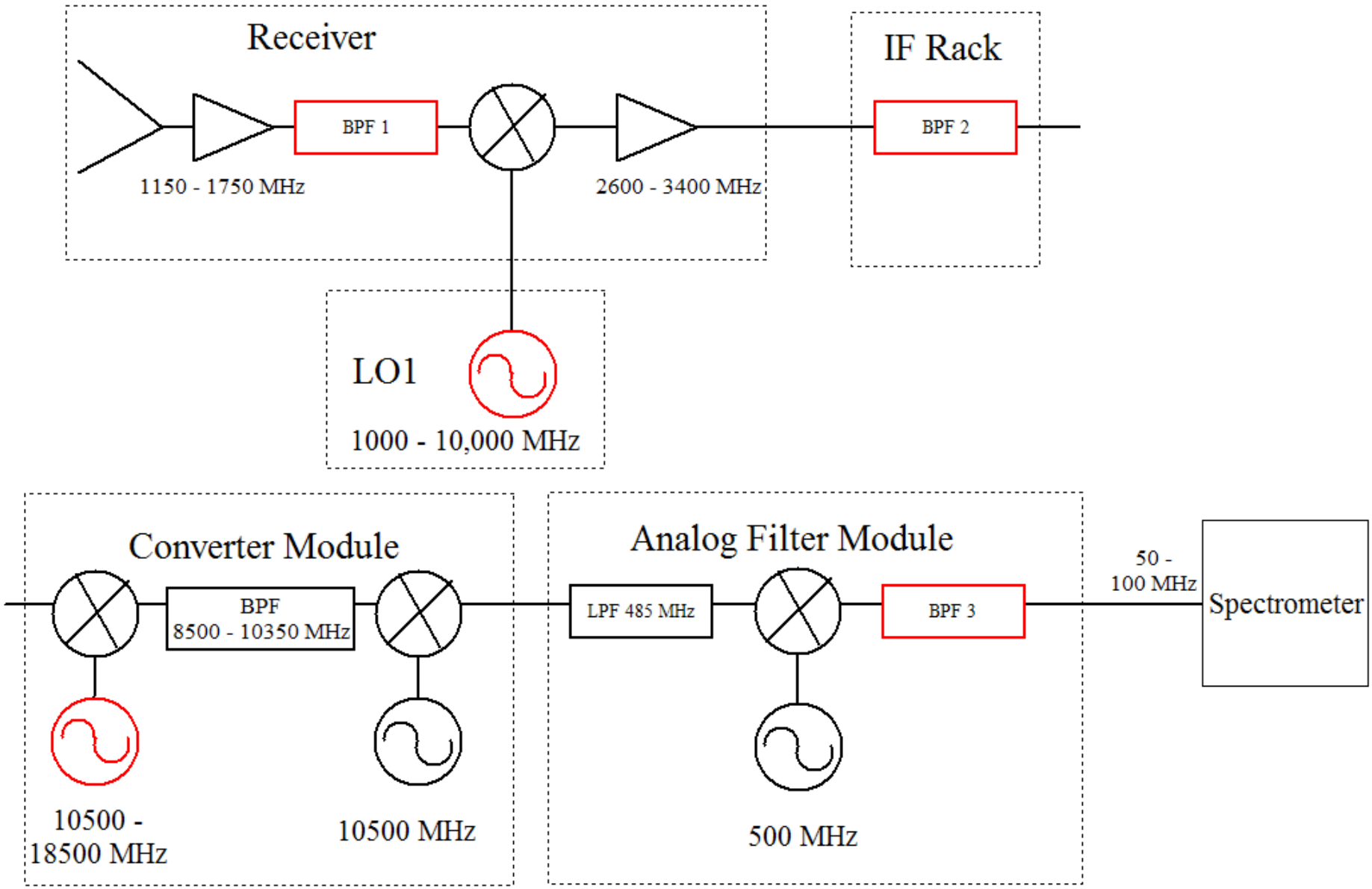


40-Ft System

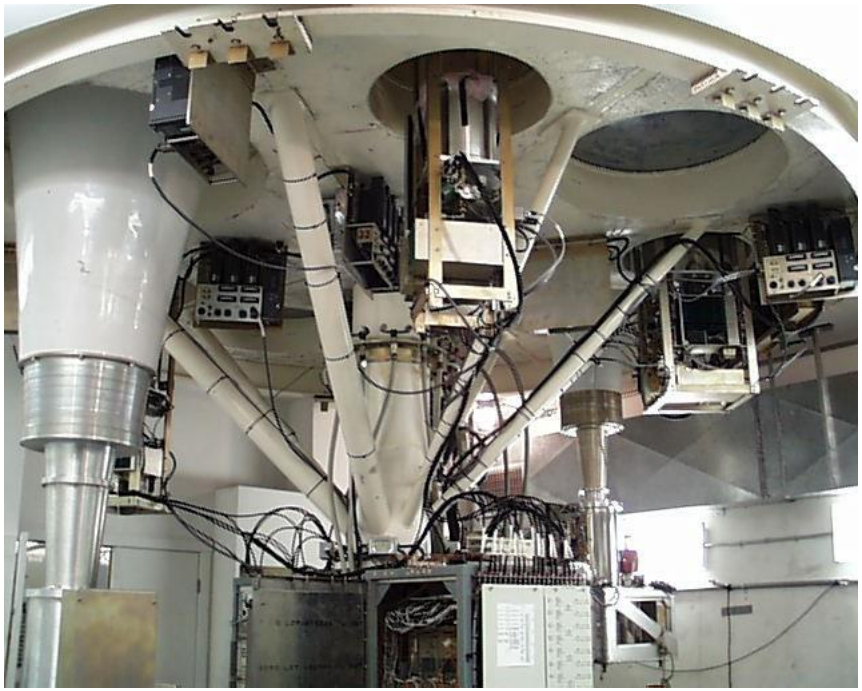

Noise
Diode
B
A
BPF
1370-1700
MHz
BPF
1370-1700
MHz
Low Pass
110 MHz
Low Pass
110 MHz
Tunable LO
1000 - 2000 MHz
Fixed LO
110.7 MHz
Center = 10.7 MHz
BPF 30 kHz
Center = 10.7 MHz
BPF 30 kHz
B
A
Chart
Recorder

Quiz 1: Determine values for the first LO for the 40-ft when…

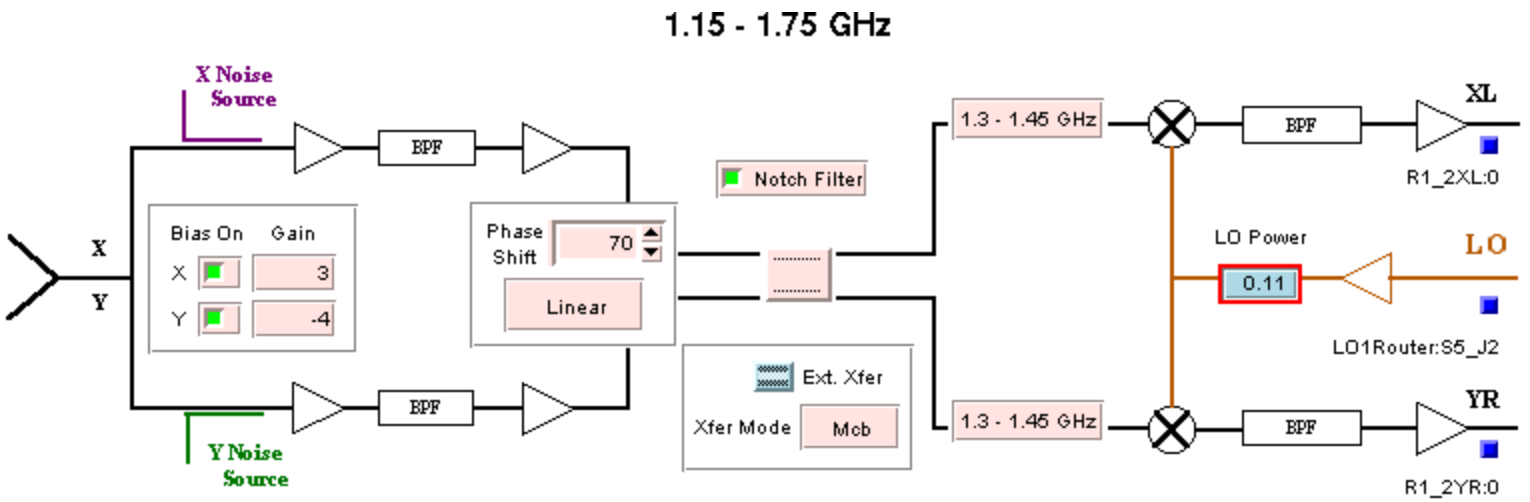
- Observing HI at 1420.41 MHz
- Observing OH at 1665.6 MHz

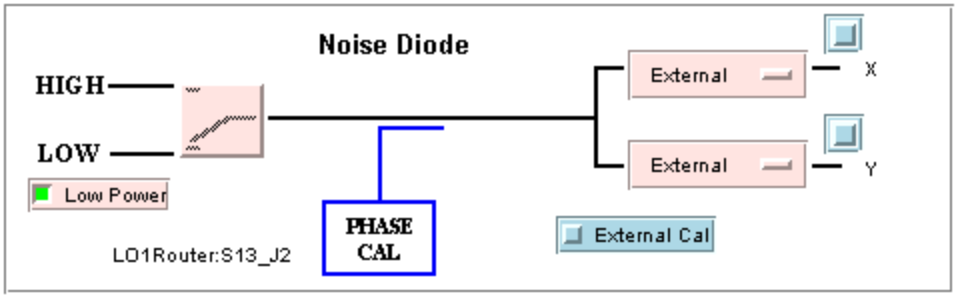

Receiver
BPF 1
1150 - 1750 MHz
2600 - 3400 MHz
IF Rack
BPF 2
LO1
1000 - 10,000 MHz
Converter Module
BPF
8500 - 10350 MHz
10500 -
18500 MHz
10500 MHz
Analog Filter Module
LPF 485 MHz
BPF 3
500 MHz
50 -
100 MHz
Spectrometer

Receiver Room

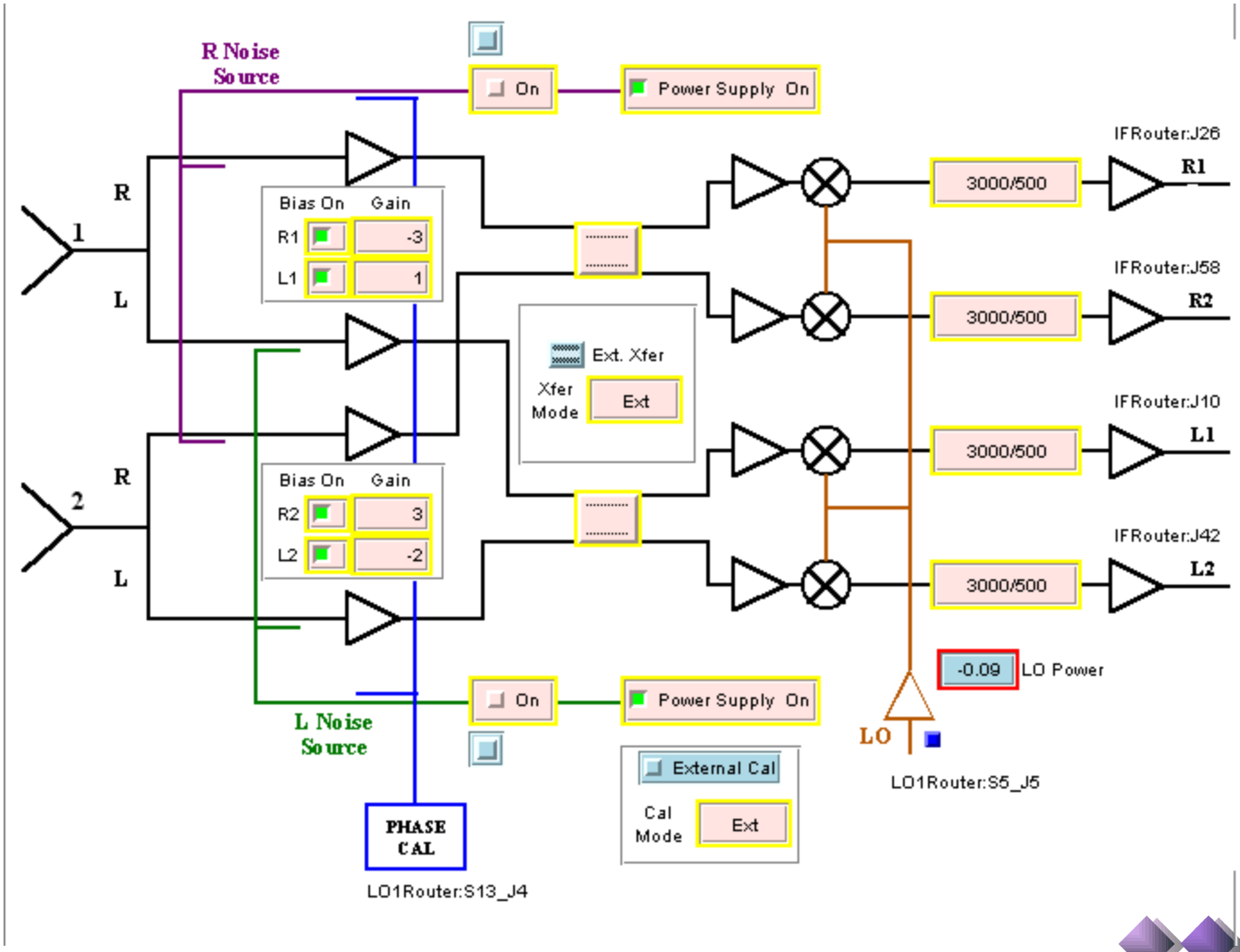


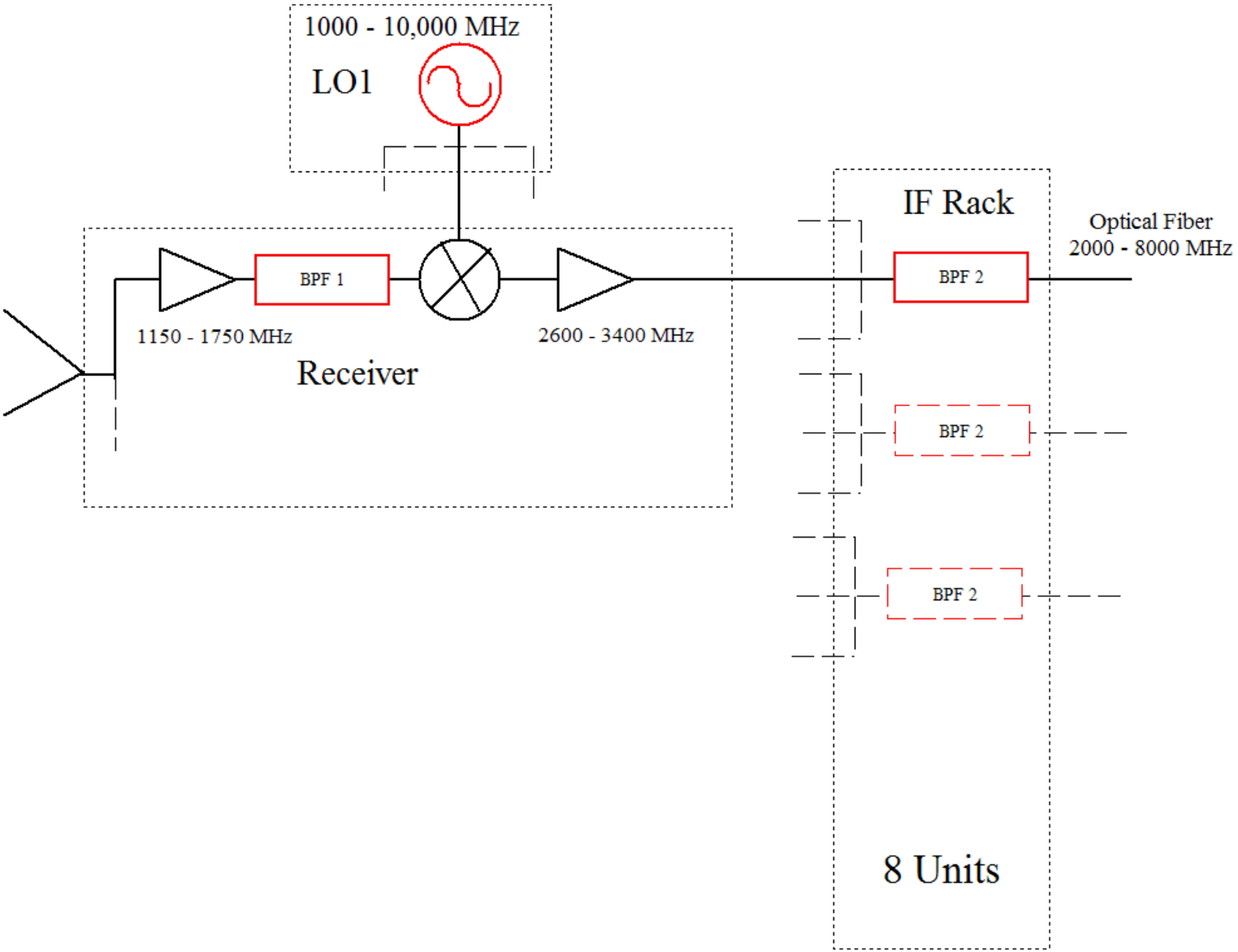
Typical Receiver



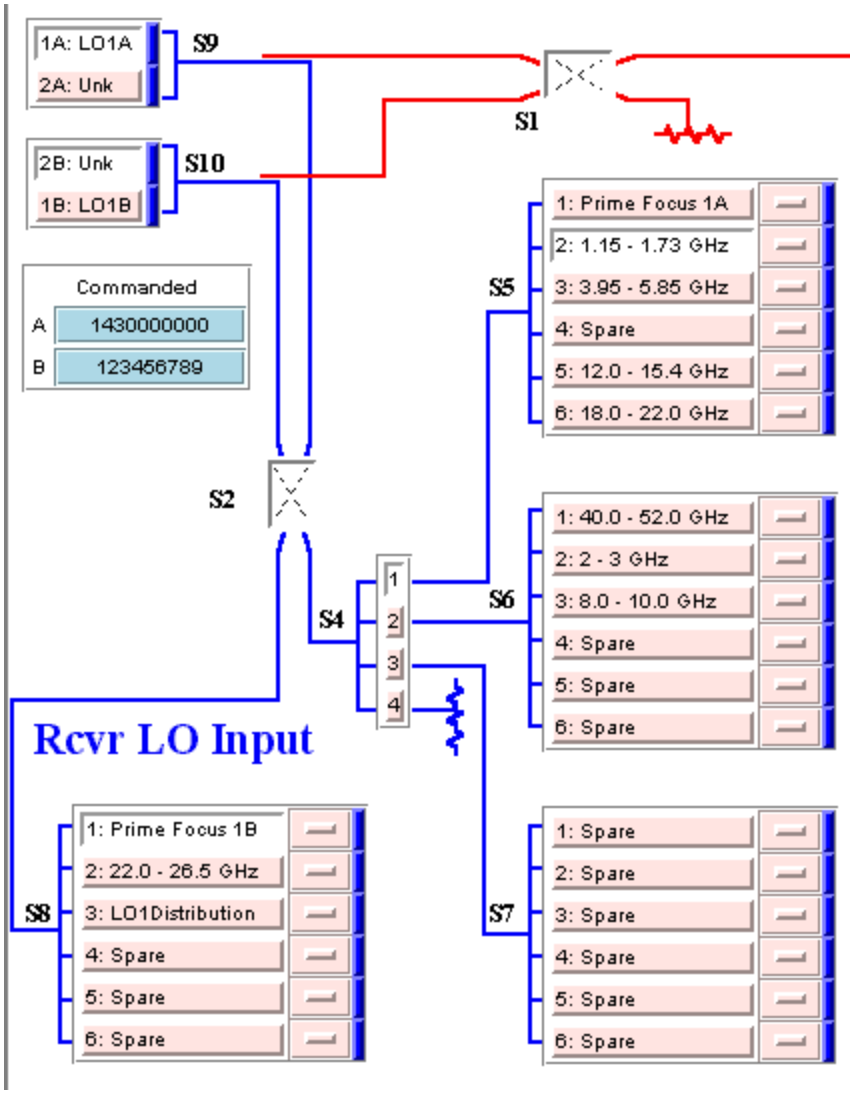


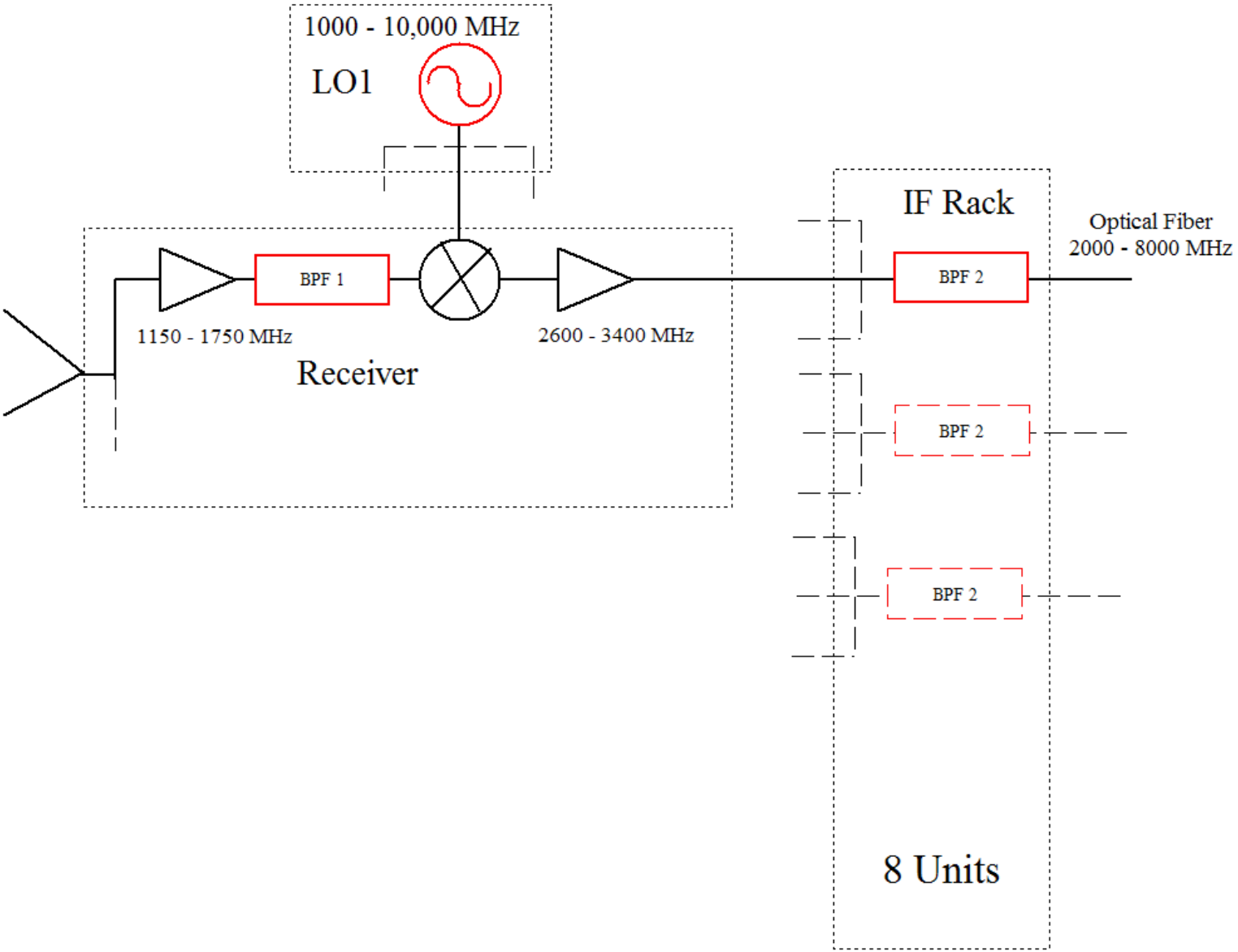
Multi-beam Receiver



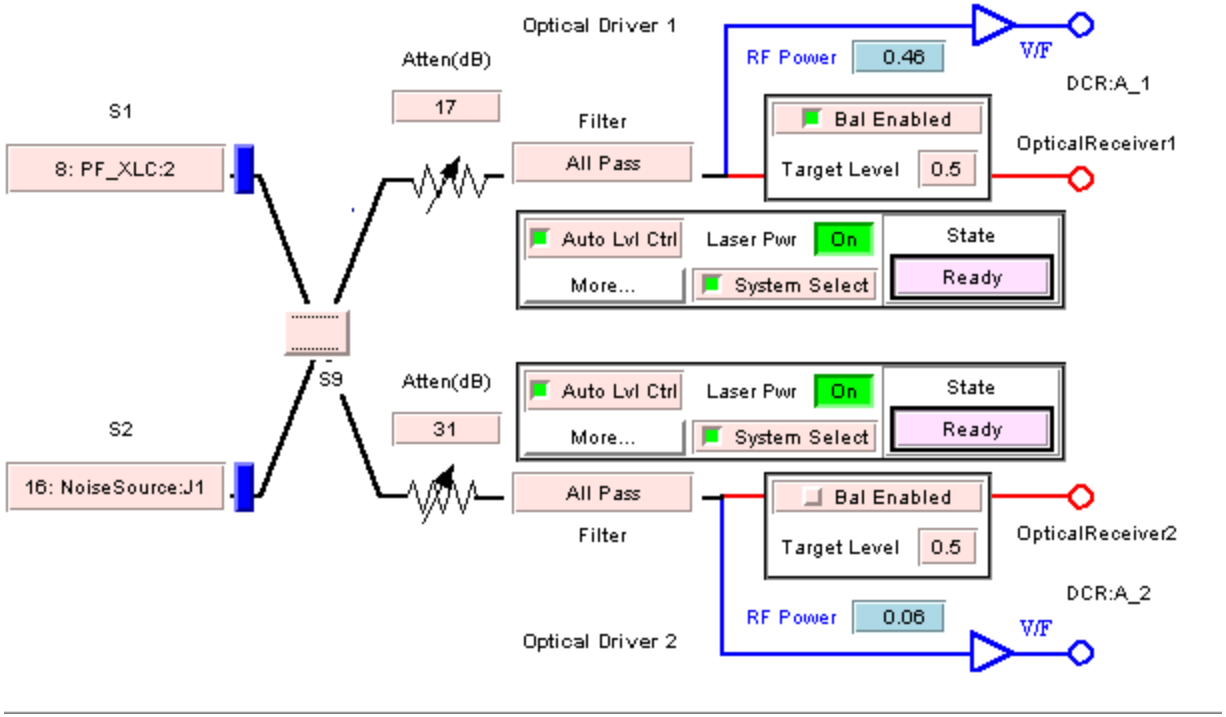

1000 - 10,000 MHz
LO1
IF Rack
Optical Fiber
2000 - 8000 MHz
BPF 1
BPF 2
1150 - 1750 MHz
2600 - 3400 MHz
Receiver
BPF 2
BPF 2
8 Units

Local Oscillator and Switching Matrix

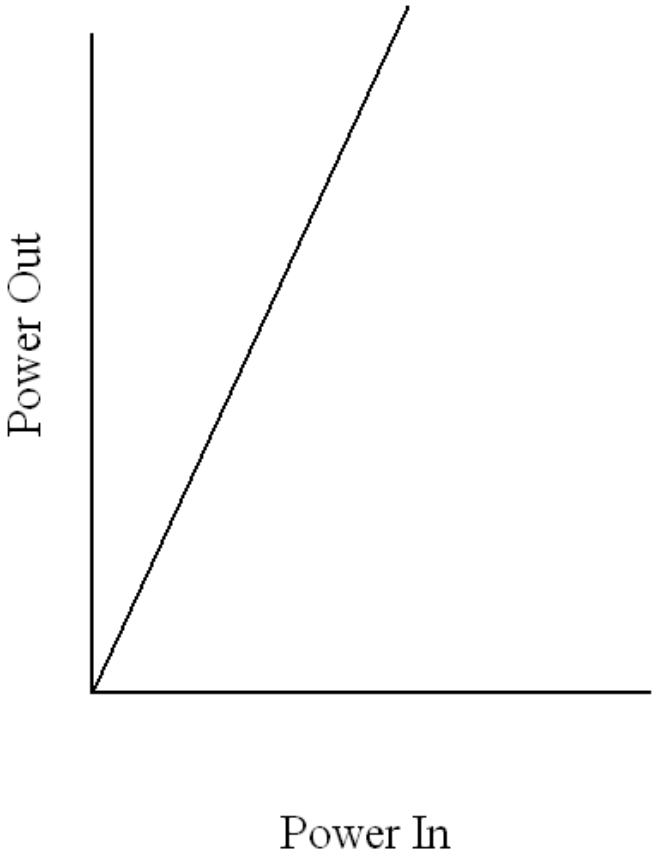


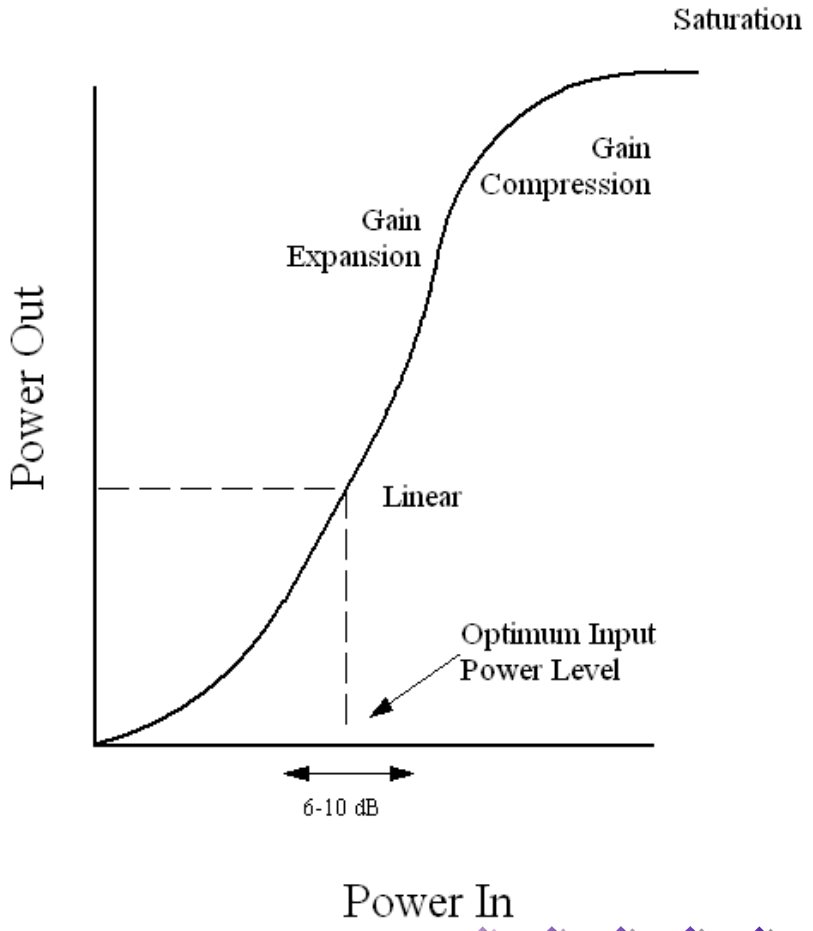

1000 - 10,000 MHz
LO1
IF Rack
Optical Fiber
2000 - 8000 MHz
BPF 1
BPF 2
1150 - 1750 MHz
2600 - 3400 MHz
Receiver
BPF 2
BPF 2
8 Units

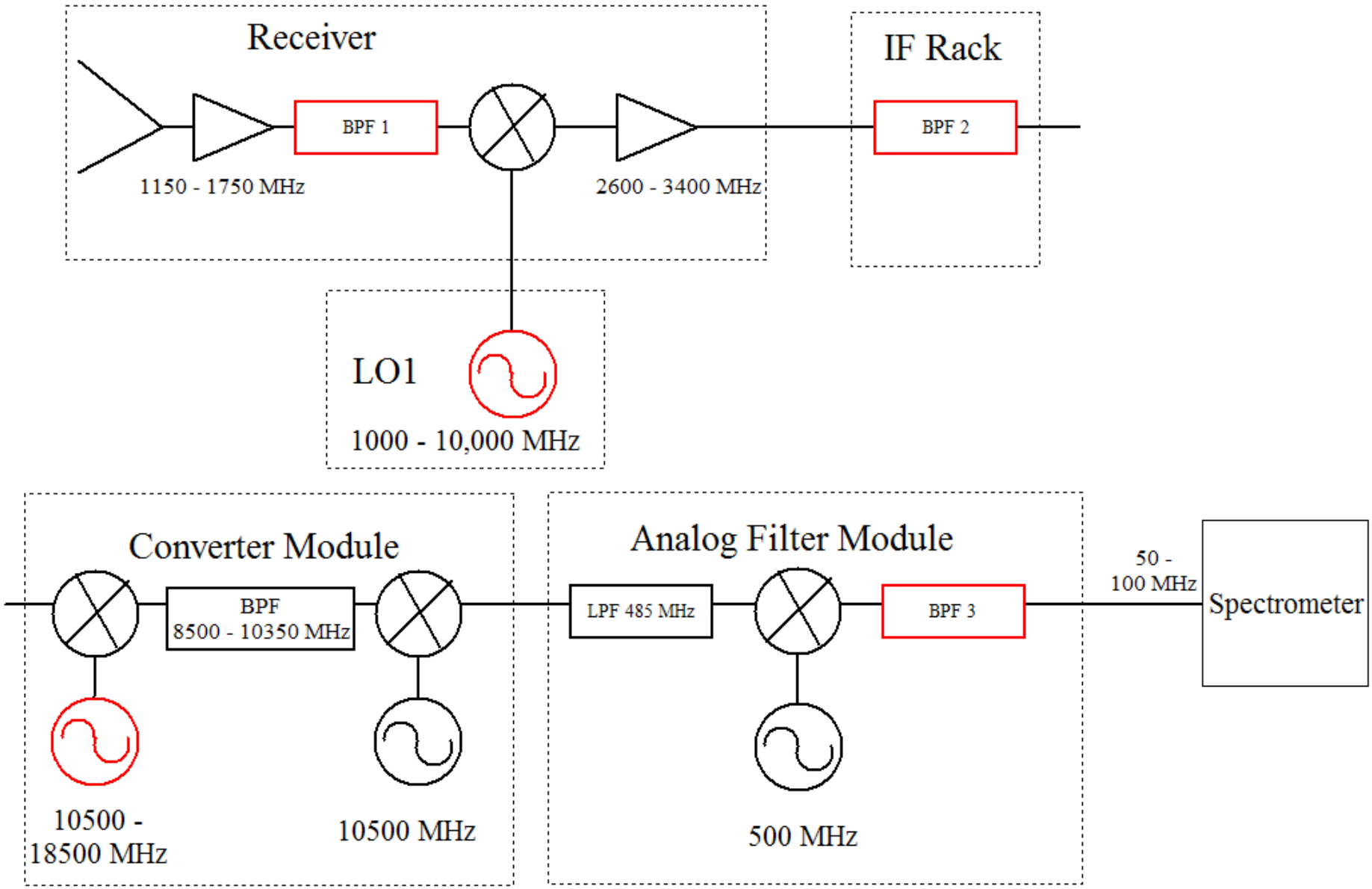
IF Rack – Input switching Matrix, IF Filters, Power Balancing Attenuators, and Drivers for 8 Optical Fibers



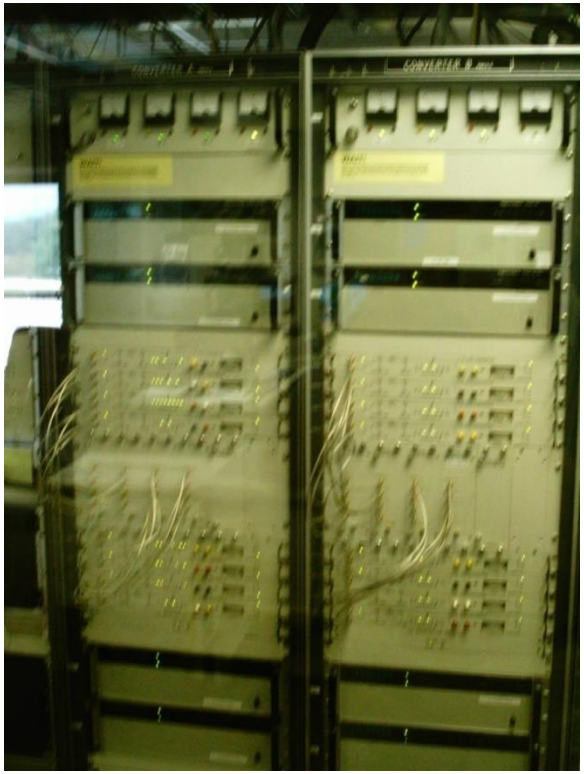
Power Balancing/Leveling and Non-Linearity

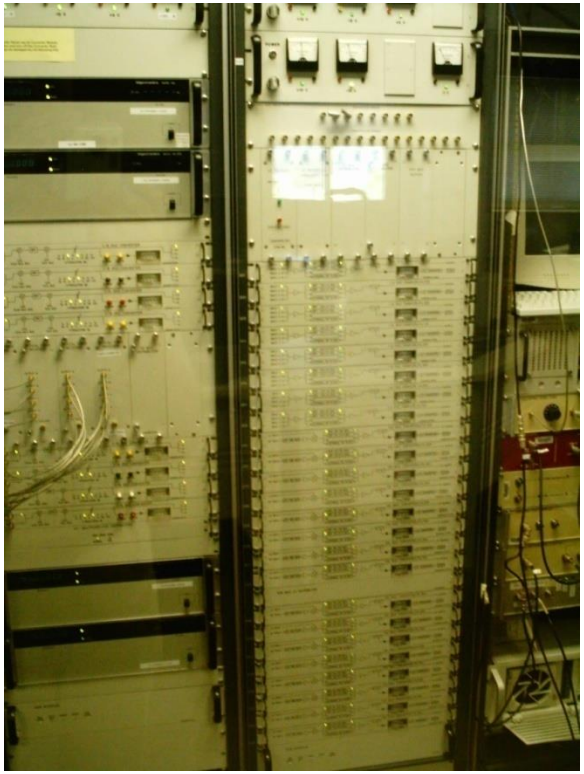




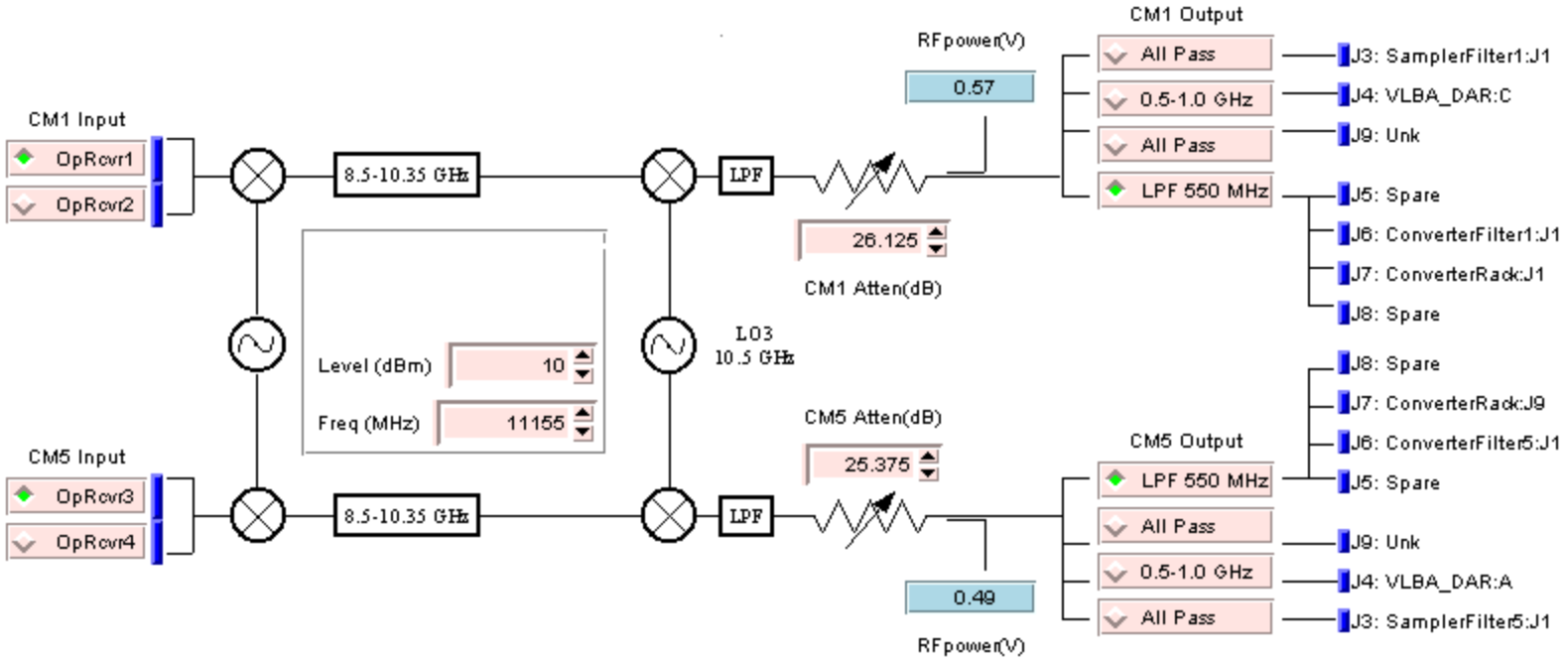

Receiver
BPF 1
1150 - 1750 MHz
2600 - 3400 MHz
IF Rack
BPF 2
LO1
1000 - 10,000 MHz
Converter Module
BPF
8500 - 10350 MHz
10500 -
18500 MHz
10500 MHz
Analog Filter Module
LPF 485 MHz
BPF 3
500 MHz
50 -
100 MHz
Spectrometer

Converter and Analog Filter Racks, Spectrometer



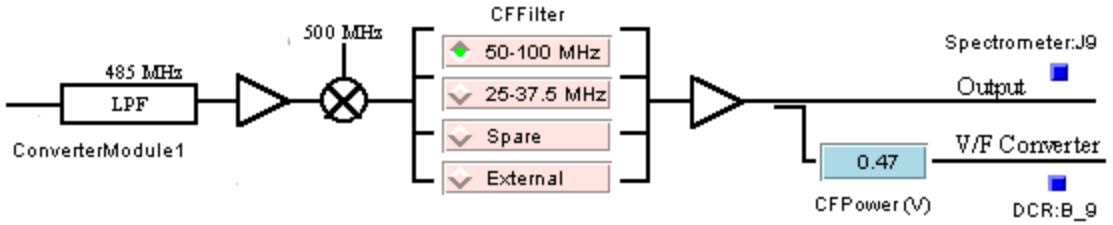


Converter Rack – Receivers for Optical Fibers, LO2 and LO3, Power Balancing Attenuators, Output Switches to Backends and AFR

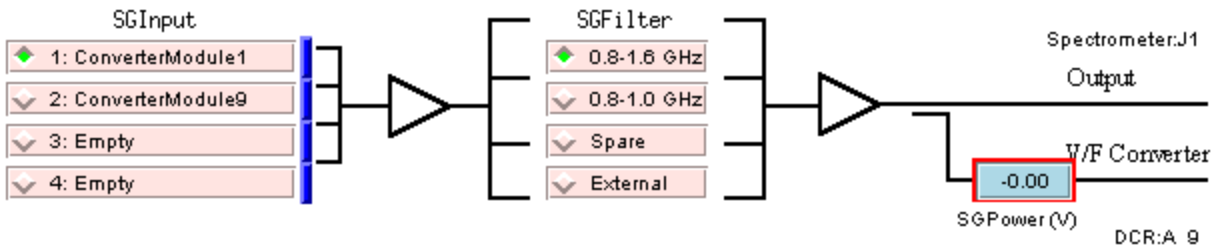


Analog Filter Rack

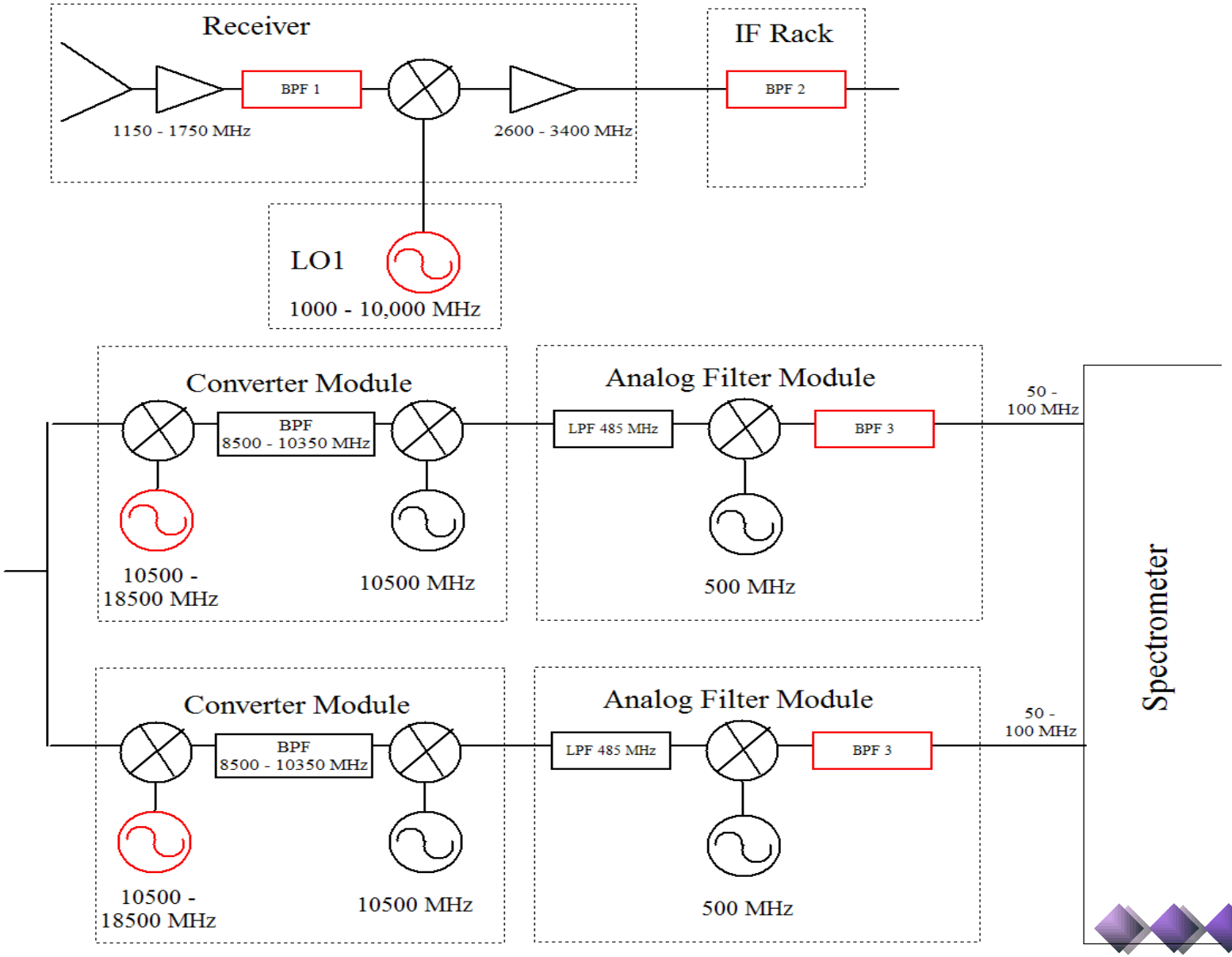
For 12.5 and 50 MHz Slow-Speed Spectrometer Samplers : LO4 and Filters



For 200 and 800 MHz High-Speed Spectrometer Samplers : Input Switches and Filters.

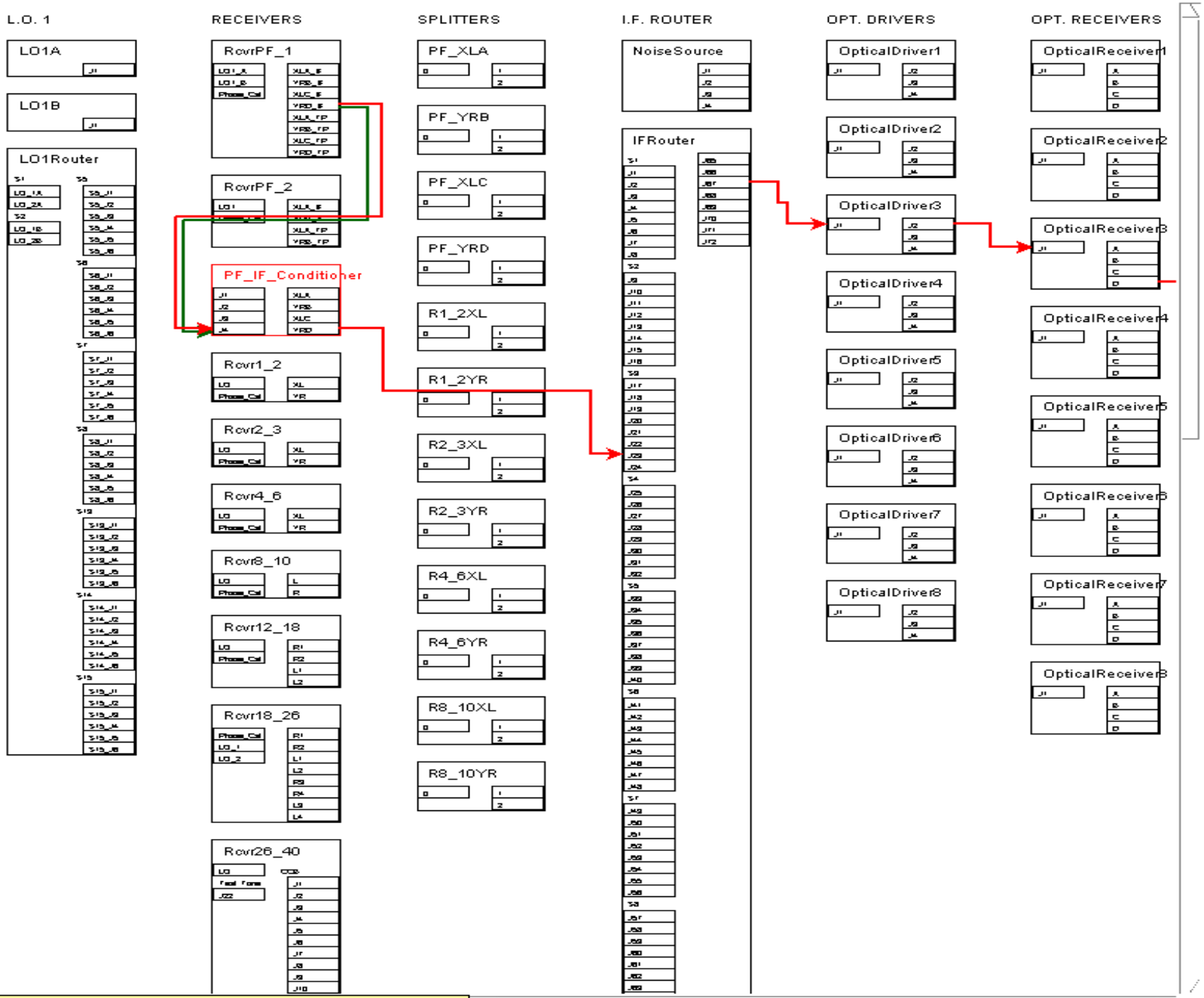


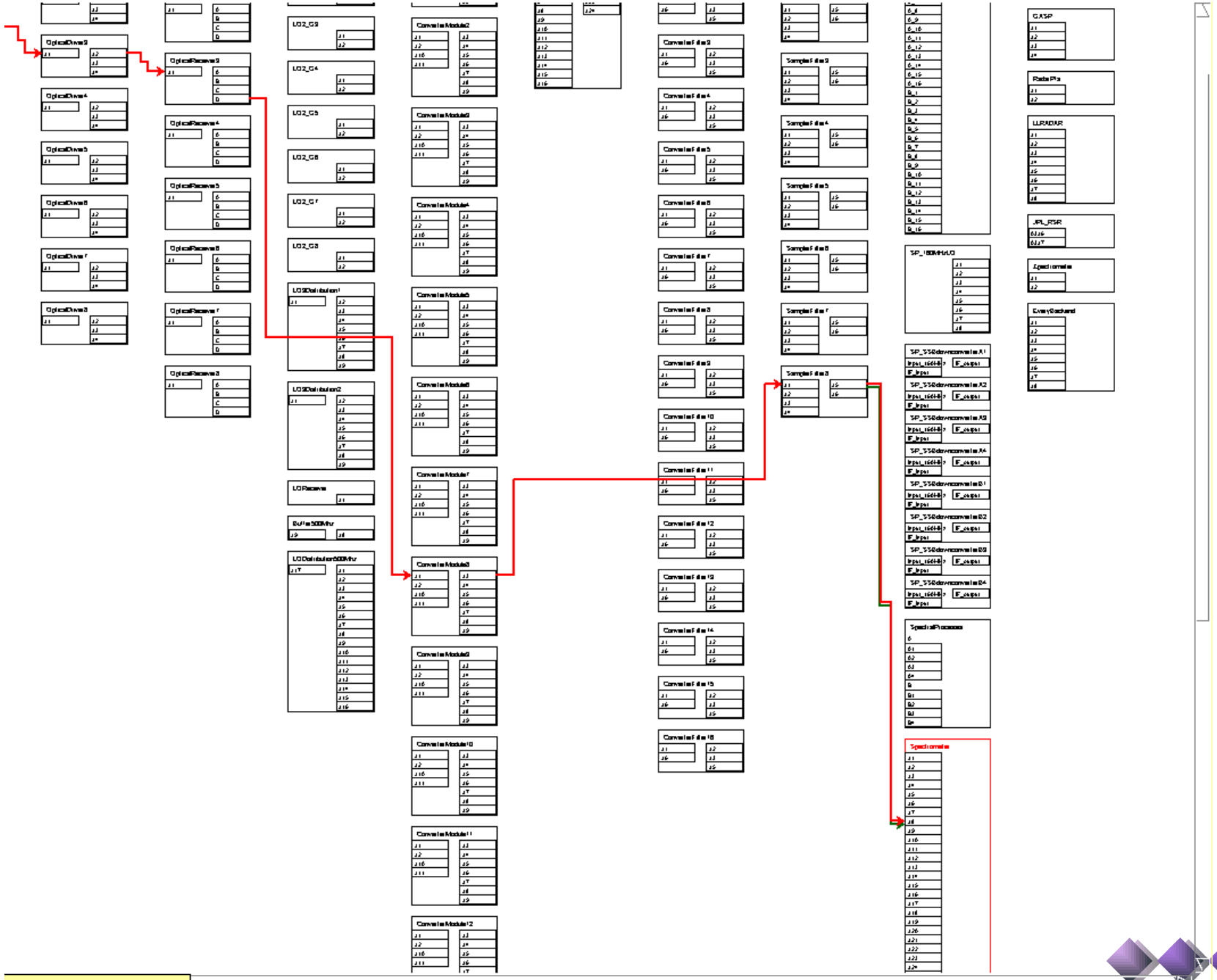
Quiz 2: Determine values for red components



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.


L.O. 1
RECEIVERS
SPLITTERS
I.F. ROUTER
OPT. DRIVERS
OPT. RECEIVERS
LO1A
LO1B
LO1Router
RcvrPF_1
RcvrPF_2
PF_IF_Conditioner
Rcvr1_2
Rcvr2_3
Rcvr4_6
Rcvr8_10
Rcvr12_18
Rcvr18_26
Rcvr26_40
PF_XLA
PF_YRB
PF_XLC
PF_YRD
R1_2XL
R1_2YR
R2_3XL
R2_3YR
R4_6XL
R4_6YR
R8_10XL
R8_10YR
NoiseSource
IFRouter
OpticalDriver1
OpticalDriver2
OpticalDriver3
OpticalDriver4
OpticalDriver5
OpticalDriver6
OpticalDriver7
OpticalDriver8
OpticalReceiver1
OpticalReceiver2
OpticalReceiver3
OpticalReceiver4
OpticalReceiver5
OpticalReceiver6
OpticalReceiver7
OpticalReceiver8
Graphical representation of cabling between GBT devices. Click



ibling between GBT devices. Click

Spectrum

Sideband	lower
IF	1200
Sky	-2770
Bandwidth	0
Polarization	linear_y
Noise Diode	lowCal

Sinusoid

IF	0
At LO	0

From: SamplerFilter8:J5

Feed: RcvrPF_1:YRD_342
Freq: 270 to 420 MHz
Polarization: linear_y
Horn: 1
Tone: RcvrPF_1:C342Y
Freq: 0 MHz
Filter: RcvrPF_1:FL342_5Y
Freq: 270 to 420 MHz
Mixer: RcvrPF_1:MXYRD
LO: 1430 MHz
Component -- LO1A:synthesizer
Lower Sideband: IFo = 1430 - IFi
Filter: RcvrPF_1:FLYRD3
Freq: 1040 to 1120 MHz
Filter: RcvrPF_1:FLYRD
Freq: 960 to 1200 MHz
Attenuator: RcvrPF_1:ifChannelD
Output Port: RcvrPF_1:J4
Input Port: PF_IF_Conditioner:J4
Output Port: PF_IF_Conditioner:J8
Input Port: IFRouter:J23
Output Port: IFRouter:J67
Input Port: OpticalDriver3:J1
Attenuator: OpticalDriver3:attenuator
Output Port: OpticalDriver3:J2
Input Port: OpticalReceiver3:J1
Output Port: OpticalReceiver3:J5
Input Port: ConverterModule8:J1
Mixer: ConverterModule8:MX2
LO: 13500 MHz
Component -- LO2_G4:synthesizer
Lower Sideband: IFo = 13500 - IFi
Filter: ConverterModule8:FL1
Freq: 8500 to 10350 MHz
Mixer: ConverterModule8:MX3
LO: 10500 MHz
Component -- LO3Distribution1:synthesizer
Lower Sideband: IFo = 10500 - IFi
Filter: ConverterModule8:FL2
Freq: 0 to 2200 MHz

Spectrum

Sideband	lower
IF	1200
Sky	-2770
Bandwidth	0
Polarization	linear_y
Noise Diode	lowCal

Sinusoid

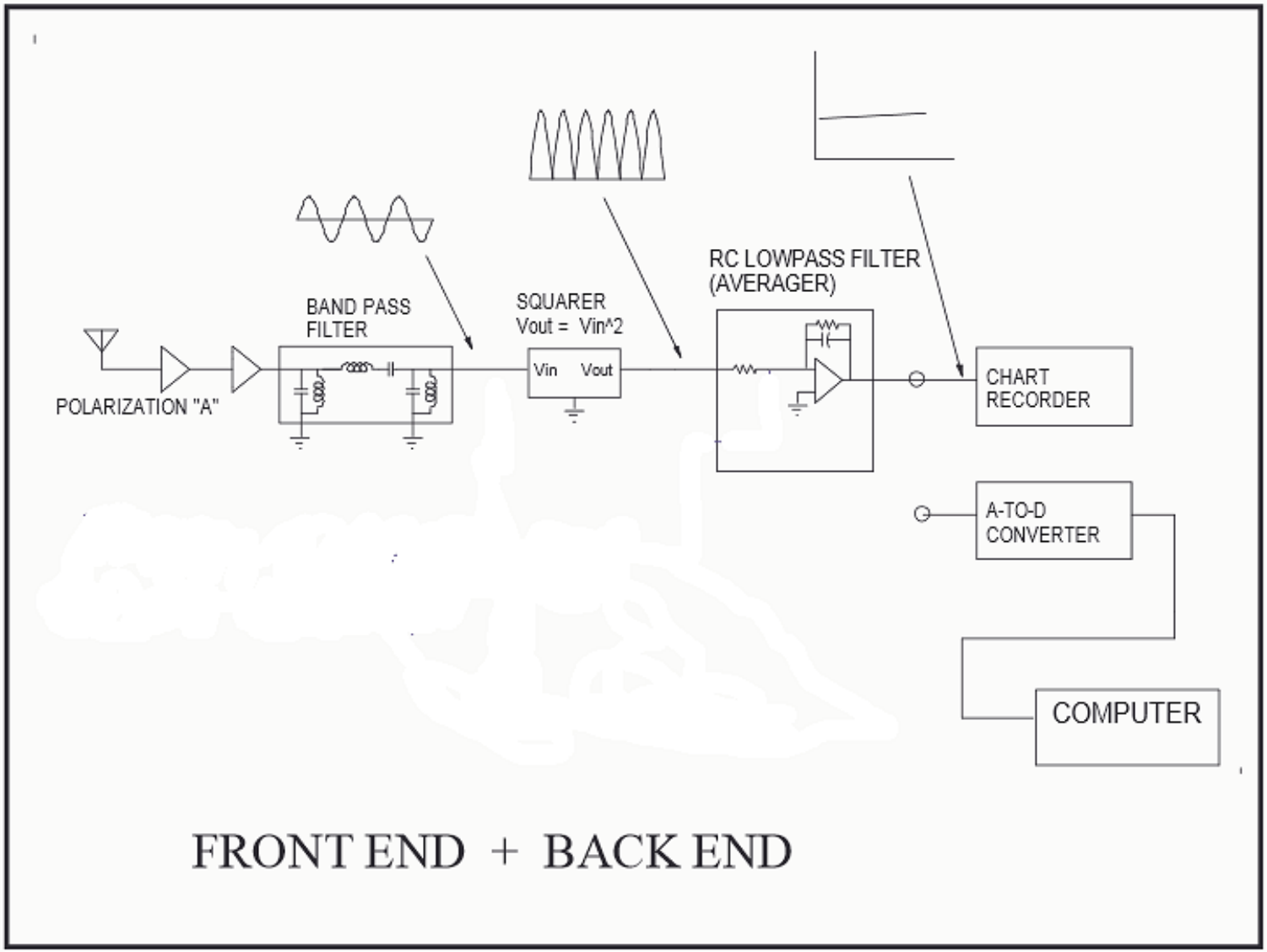
IF	0
At LO	0

From: SamplerFilter8:J5

Mixer: RcvrPF_1:MXYRD
LO: 1430 MHz
Component -- LO1A:synthesizer
Lower Sideband: IFo = 1430 - IFi
Filter: RcvrPF_1:FLYRD3
Freq: 1040 to 1120 MHz
Filter: RcvrPF_1:FLYRD
Freq: 960 to 1200 MHz
Attenuator: RcvrPF_1:ifChannelD
Output Port: RcvrPF_1:J4
Input Port: PF_IF_Conditioner:J4
Output Port: PF_IF_Conditioner:J8
Input Port: IFRouter:J23
Output Port: IFRouter:J67
Input Port: OpticalDriver3:J1
Attenuator: OpticalDriver3:attenuator
Output Port: OpticalDriver3:J2
Input Port: OpticalReceiver3:J1
Output Port: OpticalReceiver3:J5
Input Port: ConverterModule8:J1
Mixer: ConverterModule8:MX2
LO: 13500 MHz
Component -- LO2_G4:synthesizer
Lower Sideband: IFo = 13500 - IFi
Filter: ConverterModule8:FL1
Freq: 8500 to 10350 MHz
Mixer: ConverterModule8:MX3
LO: 10500 MHz
Component -- LO3Distribution1:synthesizer
Lower Sideband: IFo = 10500 - IFi
Filter: ConverterModule8:FL2
Freq: 0 to 2200 MHz
Attenuator: ConverterModule8:AT1
Output Port: ConverterModule8:J3
Input Port: SamplerFilter8:J1
Filter: SamplerFilter8:FL1
Freq: 800 to 1600 MHz
Output Port: SamplerFilter8:J5
Input Port: Spectrometer:J8

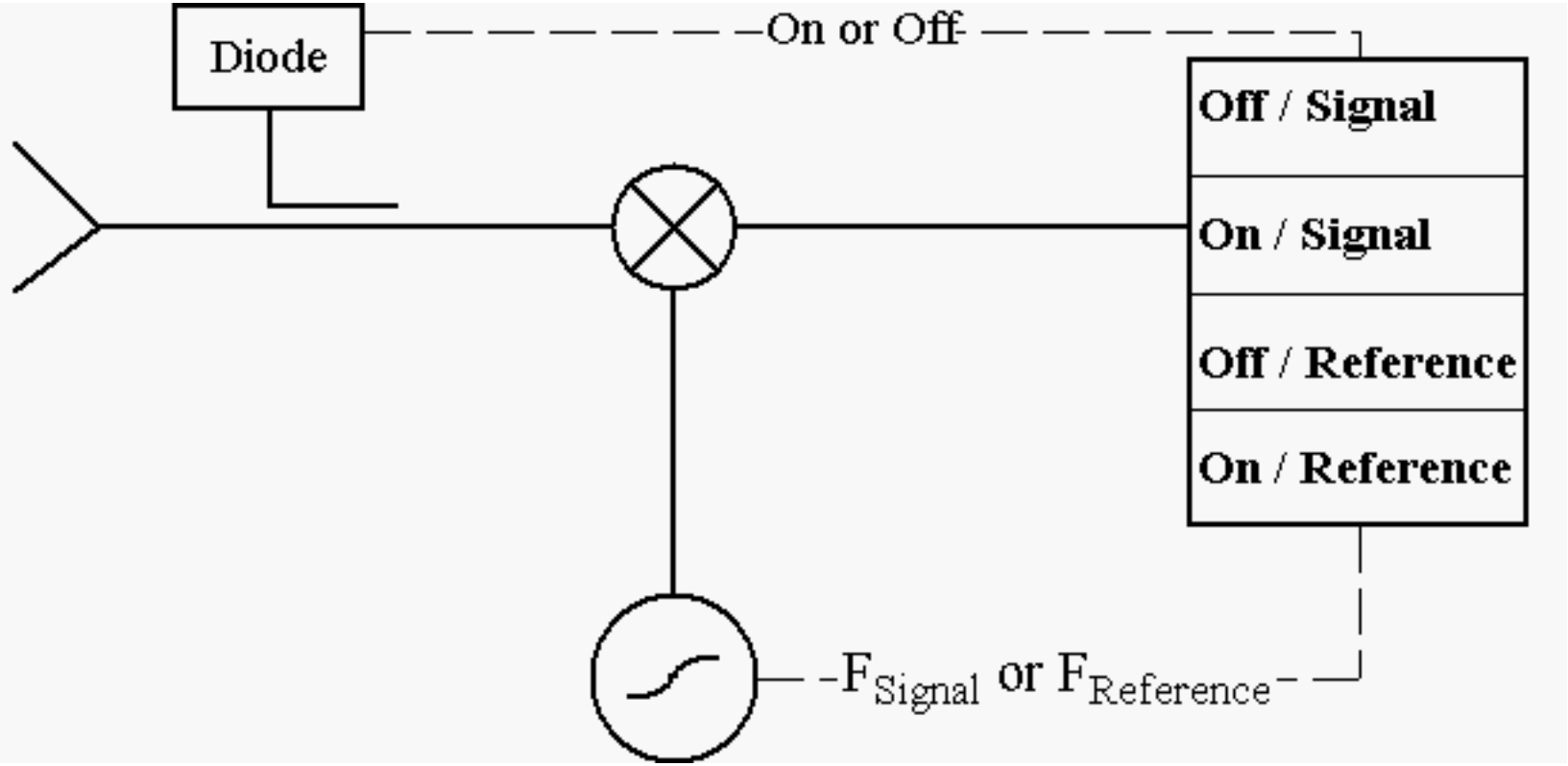
GBT – Astrid does all the hard work for you…..

```
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
vlow      = 0
vhigh     = 0
vframe    = "lsrk"
vdef      = "Radio"
noisecal  =  "lo"
pol       = "Linear"
nchan  =  "low"
spect.levels = 3
"""
```



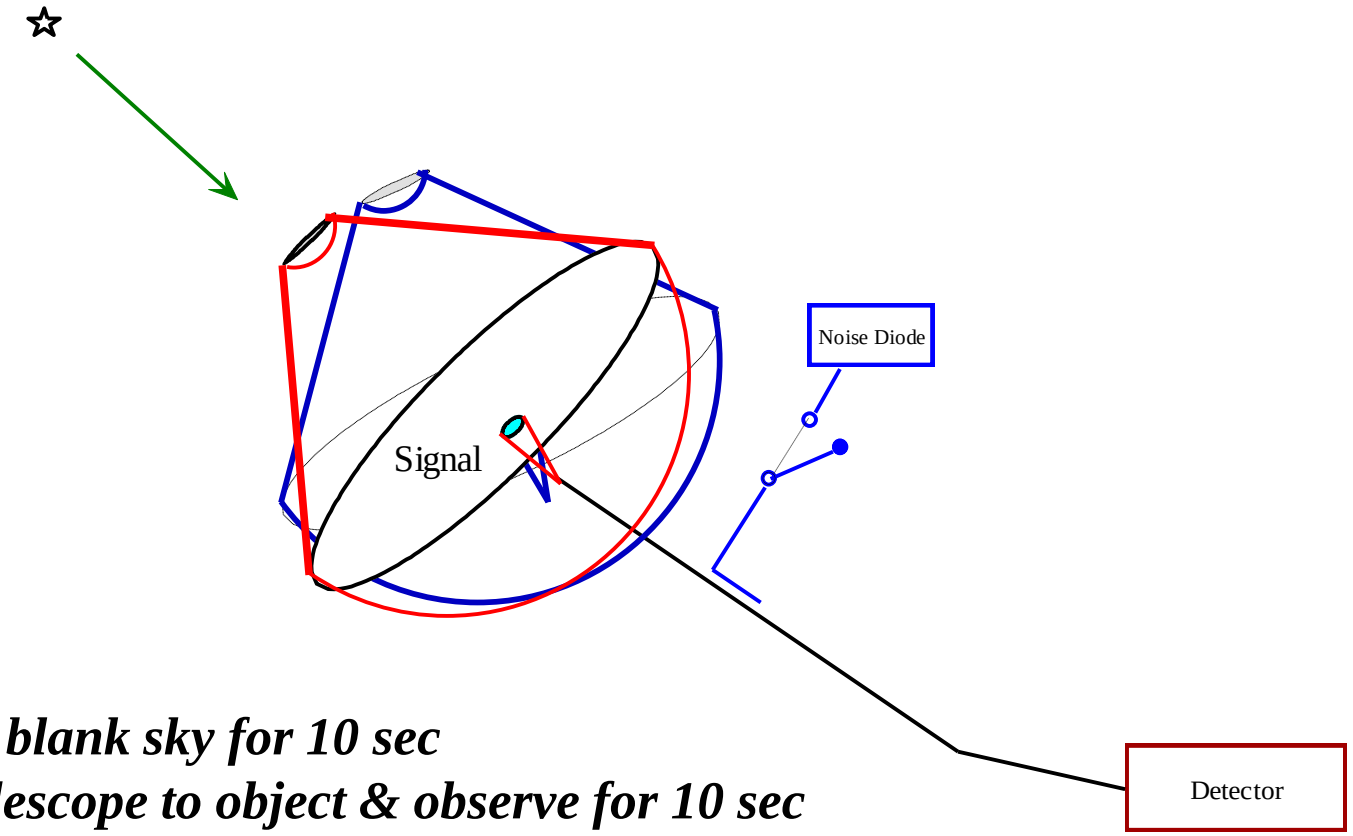
FRONT END + BACK END

Model Receiver



Continuum - Point Sources

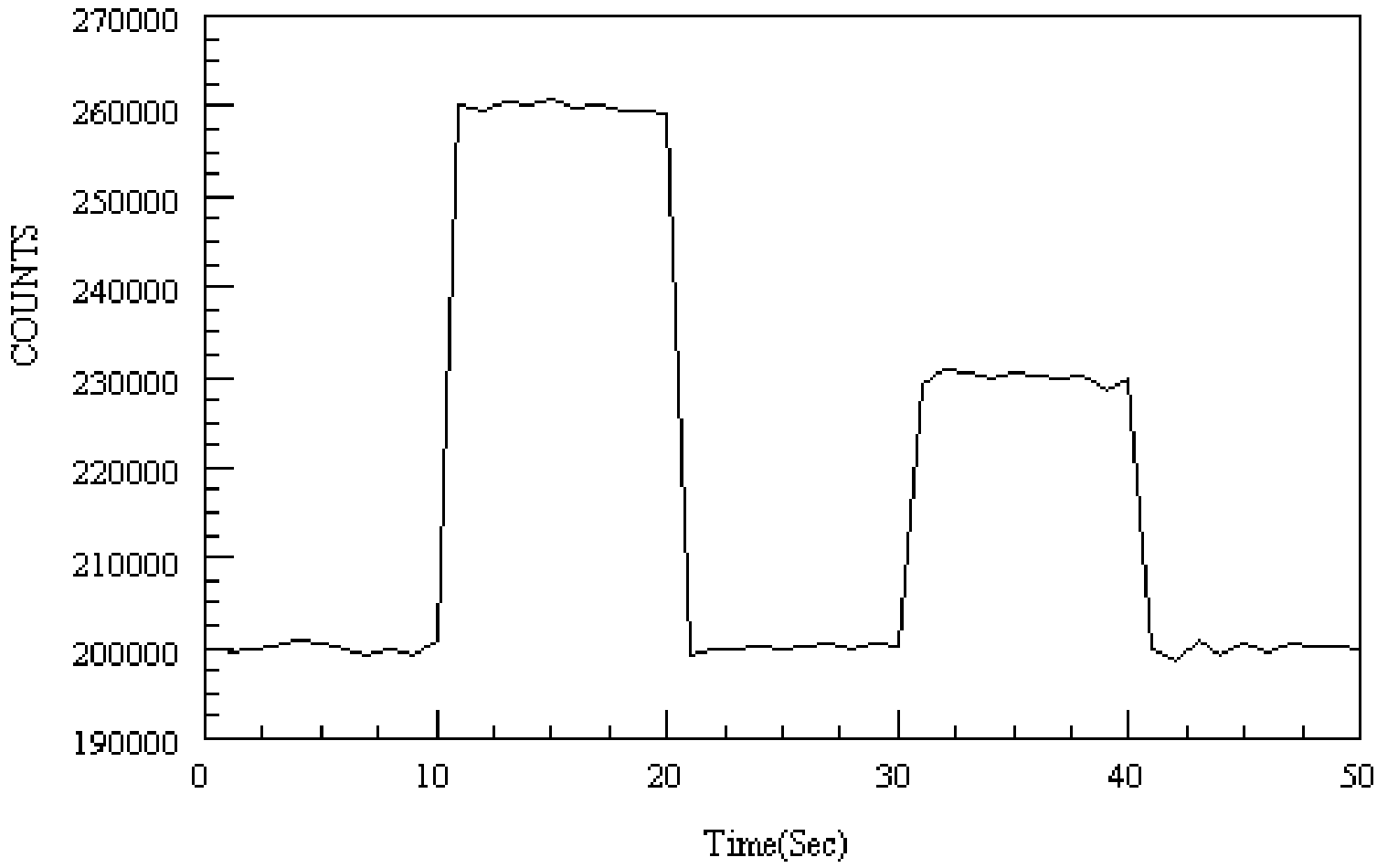
On-Off Observing



- ***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

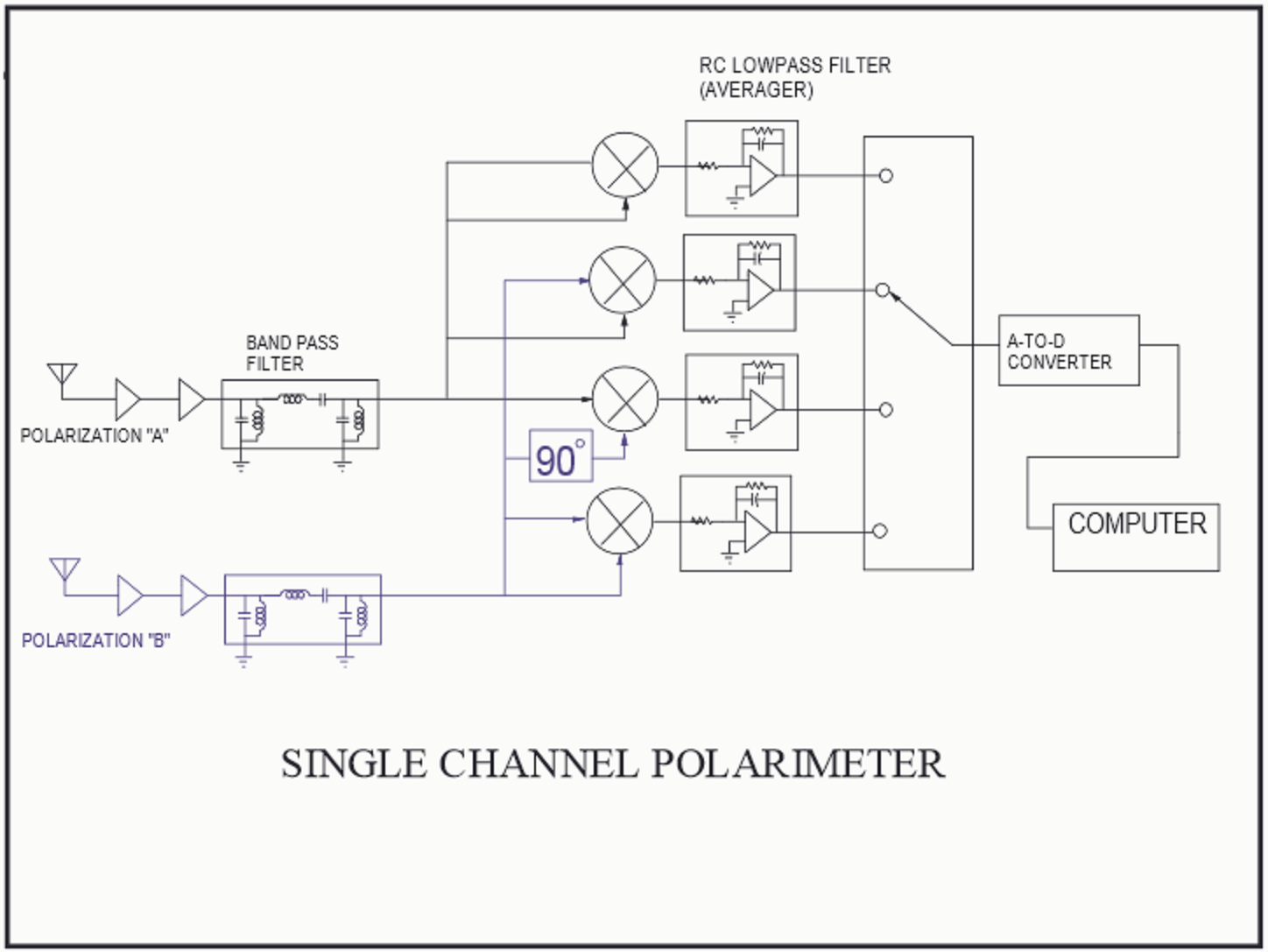
On-Off Observing



Continuum - Point Sources
On-Off Observing

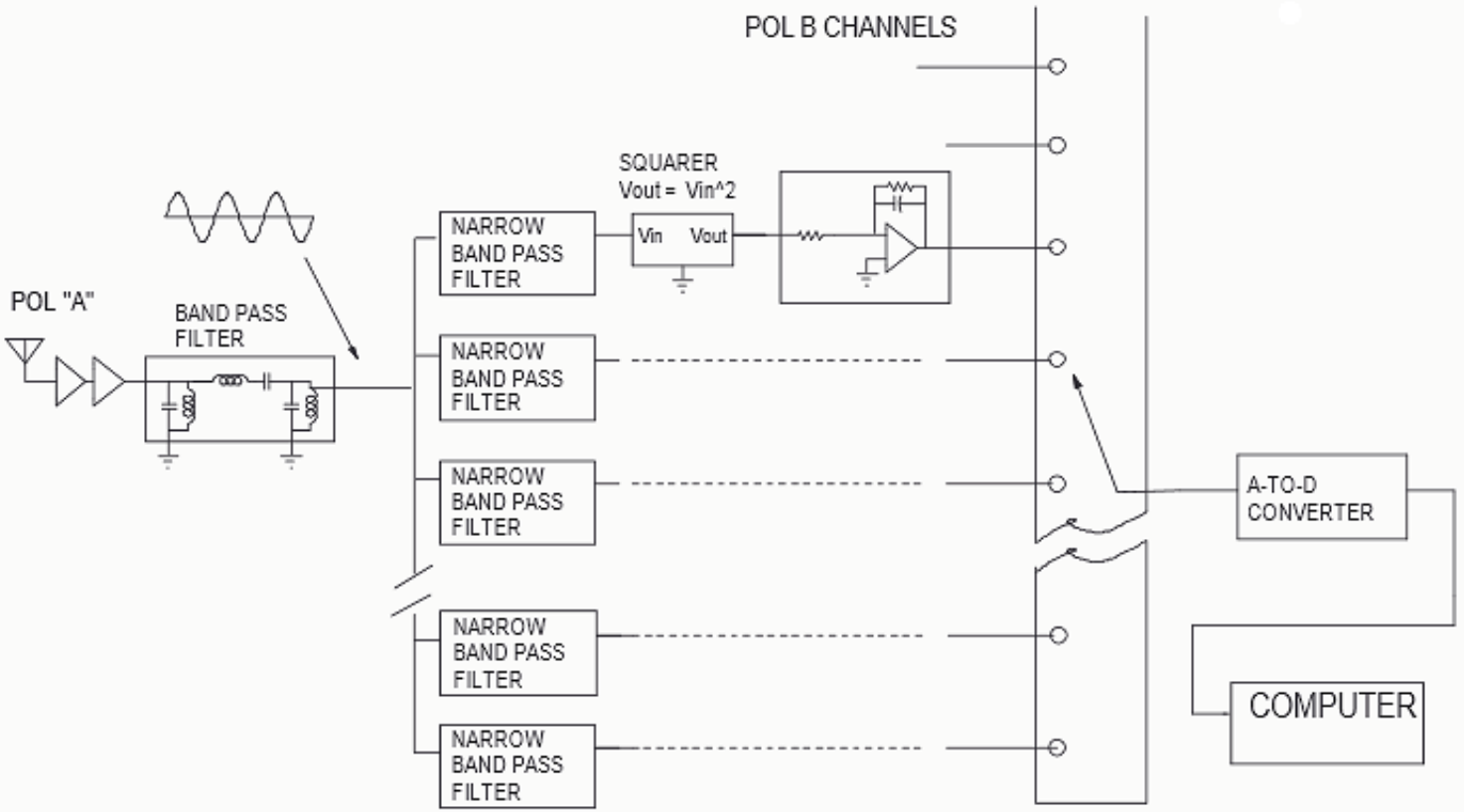
- Known:
- Equivalent temperature of noise diode or calibrator (T_{cal}) = 3 K
- Bandwidth ($\Delta\nu$) = 10 MHz
- Gain = 2 K / Jy

- Desired:
- Antenna temperature of the source (T_A)
- Flux density (S) of the source.
- System Temperature(T_s) when OFF the source
- Accuracy of antenna temperature (σ_{TA})

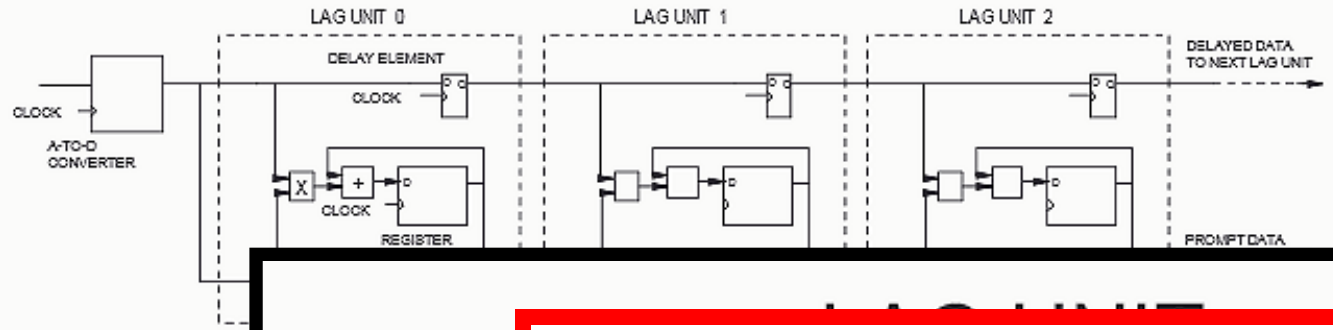


SINGLE CHANNEL POLARIMETER

FILTER BANK SPECTROMETER



AUTOCORRELATOR



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

$$S(Frequency) = DFT(R(t))$$

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

$$\text{Resolution} = \frac{\text{Bandwidth}}{\text{Number of lags}}$$