Chapter 3

Instrumentation

3.1 Telescope Site Layout

The 12m is located on the southwest ridge of Kitt Peak, about two miles below the top of the mountain. Other telescopes on the southwest ridge are the NRAO 25m VLBA antenna and the McGraw-Hill Observatory 1.2m and 2.4m optical telescopes. A drawing of the 12m site layout is given in the *Visitor's Guide to the ARO 12m Telescope* and can be found on the ARO Home Page here.

Three rooms are available in the dome for observer use. During scheduled observing time, you will normally want to sit in the control room at the observer's console so that you can communicate with the operator. An adjacent “breezeway” room has an additional workstation and work area. A third room, called the “observer lounge”, is available for work and private phone calls. This room has a couch that can be used for naps. If two observing teams are sharing time on the telescope, the data reduction station in the observer lounge is reserved for the team not currently observing. The team not currently observing should stay out of the control room if at all possible. If more than two observing teams are sharing time at the telescope, they should negotiate the use of the observer lounge

3.2 Telescope Optics

The 12m employs “bent Cassegrain” optics for all of the receivers used by visiting observers. A few test and special purpose receivers including the holography receiver are mounted at the prime focus. A diagram of the optics is given in Figure 3.1. The primary mirror is a 12.0 meter paraboloid of 72 aluminum panels. The position of each panel can be adjusted by stand-off bolts. The sub-reflector (secondary mirror) is mounted at the prime focus and is supported by a quadrapod feed leg structure. The sub-reflector mounting box contains the nutation (beam switching) electronics and the solenoid drivers for the switching. The box also contains a gas discharge noise source and associated electronics, ***which are no longer in use***. The feed horn of the noise source protrudes from a hole in the center of the machined-aluminum hyperboloid Sub-reflector. Under normal operation, the noise tube is covered with a cone reflector (called the “Cone of Silence”) to minimize standing waves in the IF passband.

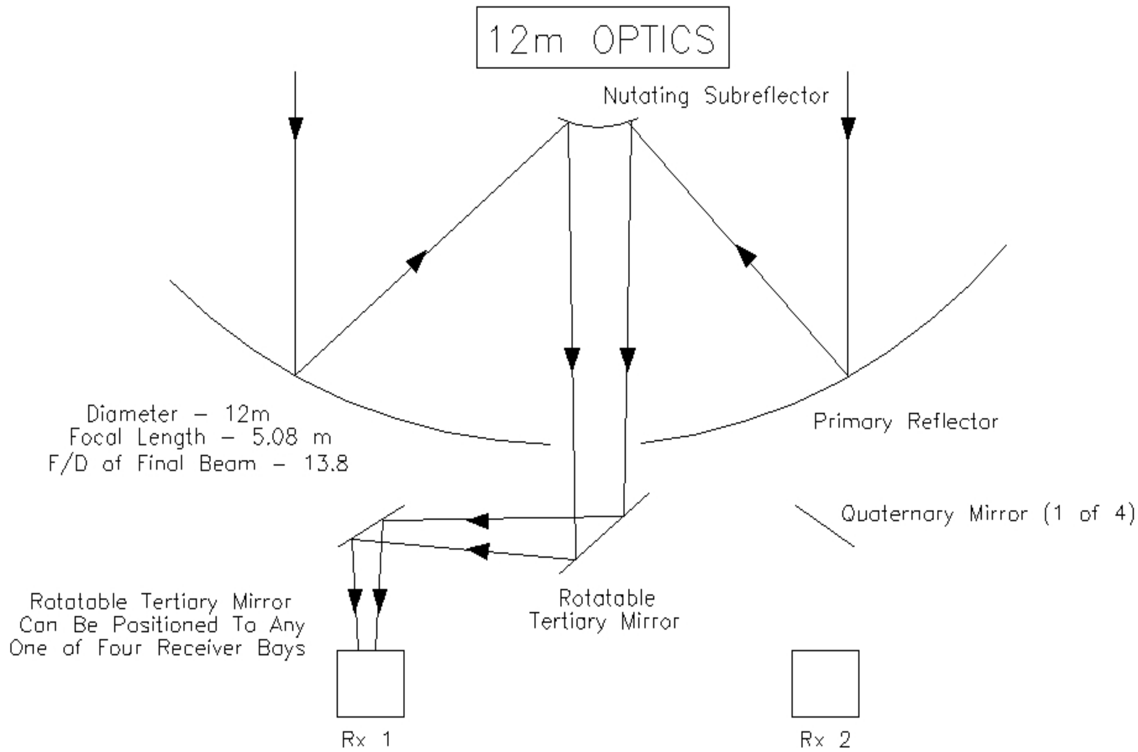

Figure 3.1: 12m Telescope Optics

The sub-reflector box is located in a focus-translation mount with three degrees of freedom of movement. The sub-reflector can be moved in and out along the radio axis to adjust for axial focus changes, it can be moved in an “up-down” (or “north-south”) direction to compensate for north-south focus changes, or east-west to adjust for optimum azimuth position.

The tertiary or central mirror is a rectangular at mirror with azimuth and elevation position adjustments. The elevation position of the mirror is periodically measured and then clamped down. The azimuth position can be rotated to direct the radio beam to any of the four receiver bays, located behind the main reflector. The central mirror positioning is motorized and under servo control from the control room, making it possible to use more than one receiver during a single observing run, though not simultaneously.

The central mirror directs the beam to one of the four quaternary mirrors over each receiver box. The quaternary mirrors are oval flats and have one degree of freedom for position adjustment. The optics following the quaternary mirrors are contained within the receiver boxes and are usually different for each receiver.

The alignment of the mirrors is done optically. Small optical mirrors are fixed to the tertiary and quaternary mirrors. A laser is mounted in the sub-reflector position and the mirrors are adjusted so that the laser beam spot is centered on the receiver lens. The beam also may be auto collimated at the sub-reflector to achieve the most precise alignment.

3.3 Receivers

All of the receivers in use at the 12m employ heterodyne mixers (sometimes called "coherent detectors") which use superconducting-insulating-superconducting (SIS) junctions. The SIS junctions are housed in a dewar which is part of a closed-cycle cryostat with temperature stages at 20 K and 4 K. The 20 K stage is cooled by a conventional compressed helium refrigerator system; the 4 K stage is cooled by a separate Joule-Thomson unit. The two receivers are mounted in upright structures, variously known as "rockets" or "inserts". The inserts are wholly self-contained receiver units, and may be removed independently, albeit by warming the mother Dewar. A local oscillator (LO) signal, provided by a Gunn oscillator, is injected into the mixer or diplexed with the incoming radio frequency (RF) signal. The output of the mixer is an intermediate frequency that is the difference between the LO and RF signal frequencies. The SIS junctions in the 3 and 2mm receivers have tunable backshorts, which can be adjusted to resonantly cancel the unwanted sideband, and are essentially single sideband (SSB) mixers. A harmonic generator is switched into the optical path of the receiver to allow precise measurement of the sideband rejection in the 2 and 3mm receivers. At most frequencies the image sideband can be rejected to ≥20 dB.

Table 3.1 lists the current tuning ranges and typical system temperatures for all of the facility 12m receivers, while Table 3.2 lists representative telescope efficiencies.

Table 3.1: 12m Receiver Characteristics

Receiver	Tuning Range (GHz)	Approximate T_{sys}(SSB) (K)
3mmlo	68-90	170-225
3mmhi	90-116	160-350
2mm	130-170	180-400

Table 3.2: 12m Telescope Efficiencies

Frequency (GHz)	Beamwidth (arcsec)	η_A [a]	η_l [b]	η_{fss} [c]	η^*_m [d]
70	90	0.52	0.94	0.68	0.98
90	70	0.51	0.94	0.68	0.95
115	55	0.48	0.94	0.68	0.85
145	43	0.45	0.94	0.68	0.8

[a] η_A = aperture efficiency

[b] η_l = rear spillover and scattering, blockage, and ohmic loss efficiency

[c] η_{fss} = forward scattering and spillover efficiency

[d] η_m = corrected main beam efficiency (percent of power in the main diffraction beam relative to the outlying error beam)

3.4 The Local Oscillator System

Mixer receivers require a local oscillator signal. For spectral line work, the LO signal must be phase and frequency stable to an accuracy of at least 1 part in 10^5. The purpose of the LO system is to phase lock the LO source, which is otherwise a free-running oscillator. LO sources used at the 12m are solid state Gunn oscillators. The power required of the LO source by present generation millimeter-wave mixers precludes the direct use of a harmonic of a low frequency synthesizer. At the 12m, a precise synthesizer harmonic is used as a comparison frequency for the phase lock loop.

A 5 MHz rubidium oscillator is multiplied by 20 to give a frequency of 100 MHz. This 100 MHz drives a comb generator, thus enabling any multiple of the 100 MHz in the range 1-2 GHz to be selected by a filter. Either the 18th or the 19th (1.8 or 1.9 GHz) is usually selected; a frequency between 50 and 150 MHz is then added and an oscillator is phase locked to the result. In this way a spectrally pure signal in the range 1.85 to 2.05 GHz is generated.

This nominal 2 GHz signal is then fed up to the receiver and used to drive a harmonic mixer. The nth harmonic of the 2 GHz signal (n may be any integer from ten to seventy, or higher) then mixes with a portion of the receiver LO frequency to produce the lock IF frequency. For the Gunn oscillator systems, F2=100 MHz. The phase lock of the Gunn is completed by phase detecting this beat frequency with a synthesized loop offset frequency as a reference. The loop offset frequency is generated by a tunable Fluke synthesizer.

The phase loop will lock when the LO frequency differs from the nth harmonic of the 2 GHz source by the loop offset frequency. This means, of course, two lock points, one with the LO above the nth harmonic and the other with the LO below. These two points will be separated by twice the loop offset frequency (200 MHz). The computer tests the loop for lock while taking data and stops taking data if the loop is found to be unlocked. The synthesizer frequency is computed from the following equation:

$$f_{syn} = \frac{\dfrac{\left(f_{sky} + if_{IF}\right)}{m} + kf_{lock}}{N} \qquad (3.4)$$

Where f_{syn} is the synthesizer frequency, f_{sky} is the sky frequency of the emission (the rest frequency with Doppler corrections), j=+1 for lower sideband and -1 for upper sideband, f_{IF} is the IF frequency/indexfrequency!IF, *m* is the factor by which the LO frequency is multiplied before injection into the mixer, *k*=-1 for the lower lock sideband and +1 for the upper lock sideband, f_{lock} is the phase lock loop offset frequency, and *N* is the synthesizer harmonic. The four permutations of *j* and *k* are given by a parameter "SB" (for "sideband") that is entered into the control computer.

The control computer calculates two synthesizer settings (corresponding to different harmonic numbers *N*) for a given rest frequency, source Doppler velocity, and SB value. The operator can switch between these two settings by turning a knob on the synthesizer control chassis. The computer chooses the synthesizer setting so that one is usually slightly above 1.9 GHz and the other slightly below. Both of these synthesizer settings are updated by the computer to reflect changing Doppler velocity as a result of the LSR reference frame or diurnal variations. A manual synthesizer setting can be entered from this chassis so that the receiver can be tuned without the aid of the computer if that is desired.

When tuning the receiver, the operator and observer must take care that the LO is locked to the correct harmonic and loop sideband. Two tests can be performed to assure that these conditions are met. First, if you try to lock to the wrong lock sideband, a "comb" of frequency spikes will appear on the spectrum analyzer. If this happens, turn the tune dial until the main spike moves off the edge of the screen and then returns. You must then perform a harmonic check. This is done by opening the phase lock loop (i.e. turning the phase lock circuitry off) and switching to the other synthesizer harmonic on the synthesizer control chassis. If the tuning is correct, the beat signal on the loop spectrum analyzer will appear at the same frequency for either harmonic. If these two tests are passed, the observer can be confident that he is locked to the correct frequency. A final, and conclusive, method of checking LO tuning is to look for a strong astronomical spectral line in the band, if one exists. For continuum observations, the precise frequency of phase lock is usually of little importance; observers sometimes choose to run "open loop" for simplicity of operation. Many of the receivers are more stable when phase locked, however.

3.5 The IF Section

All mixer receivers at the 12m produce an intermediate frequency of 1.5 GHz. The IF signal emerging from the receiver dewar must be further amplified and processed before detection by the spectral line and continuum backend devices. A two-channel IF system situated on the telescope performs this function. All the mixer receivers use this same processor; the switch from one receiver to another is done remotely from the control room (see §3.4).

The incoming signal first passes into an automatic leveling module. This device is used in spectral line observations to keep the input signal to the filter banks at a constant level, thus improving the performance of the filter banks. As this device will level out all continuum signals, it is turned off by computer command when continuum observations are underway. A manual switch in the control room can also turn off the device. After leaving the Leveler Module, the signal is further amplified and filtered. It is then split into two paths, one for spectral line signals and one for continuum. For continuum applications, the 1.5 GHz signal is detected and passed directly to the backend continuum signal processors.

The spectral line signal must be mixed down to the baseband frequencies at which the filter banks operate. The IF Processor Module performs this function. The incoming 1500 MHz signal is first upconverted to 2442 MHz. The mixer signal for this upconversion originates with a tunable Fluke synthesizer in the control room. The frequency of the mixing can be changed by small amounts and the two IF channels can be controlled by separate Fluke synthesizers, if desired. This affords the observer some flexibility in setting up his observations. For example, the IF might be changed to get spectral lines in opposite sidebands to fall within the bandpass. One of the channels could also be offset in frequency relative to the other. The primary restriction to these changes is that the spectral line emission must fall within the 600 MHz bandpass of the first IF amplifier. Chapter 5, Spectral Line Observing, provides a more detailed description of these options.

Table 3.4: 12m Filter Spectrometer Characteristics

Filter Bandwidth[a]	Channels (Filters) per Bank	Filter Banks Available
2 MHz	256	2
1 MHz	256	2
500 kHz	256	1
250 kHz	256	1
100 kHz	256	1
30 kHzb	128	1

[a]NOTE: This is the FWHM channel width. See Appendix D for further details.
[b]Series option only.

3.6 Spectrometers

3.6.1 Filter Banks

The 12m has eight filter spectrometers available for spectral line work. The multiplexer will provide two spectra with a total number of spectral channels not in excess of 512. Thus, it is always possible to record simultaneously the output of two filter banks. Except for the 30 kHz bank, all of the filter banks have two independent 128 channel sections. You can configure these banks in one of two ways. In the "series" option, the two sections are placed end to end in frequency space, *i.e.*, the 256 channels are sequential in frequency. In the "parallel" mode, the two sections are used independently to accept different receiver (polarization) channels. The series mode is appropriate for observations requiring a large bandwidth. The parallel mode is useful for narrow band observations in which two different spectral resolutions are needed. Additional discussion on the use of the filter banks is given in Chapter 5.

Table 3.4 provides a list of the spectrometers. The resolutions listed are the filter half power widths and their separations. The 2 MHz filter banks work at a center frequency of 342 MHz and thus directly accept the output of the IF processor discussed above. The other filter banks work at a center frequency of 150 MHz and require that the 342 MHz input signal be further down-converted.

3.6.2 Millimeter Autocorrelator (MAC)

The Millimeter Autocorrelator (MAC) (MAC) is a correlation spectrometer with a digital section similar in design to that used at the Green Bank Telescope (GBT). The full bandwidth for any given observation is pre-filtered through a set of anti-aliasing filters, and then each IF is sampled in three levels and autocorrelated.

The 65536 spectral channels of the spectrometer can be divided among up to 8 independent IF channels. The maximum useable bandwidth of the instrument is 1200 MHz. Table 3.5 summarizes the currently available Millimeter Autocorrelator (MAC) observing modes.

3.6.3 Continuum Backend

Continuum data at the 12m is acquired by a two channel, four phase digital backend (DBE). The DBE can record two switch phases and two calibration phases. The calibration phases can be generated by the synchronous emission of a noise diode, which is available at 3 mm wavelengths only (***No longer in use***). The DBE also generates a signal/reference pulse to move the sub-reflector at a default switching rate of 4.0 Hz, so that each phase of a four phase switching cycle lasts 125 ms. The DBE blanks the input signal (*i.e.* stops taking data) while the sub-reflector is in transition from one position to another. The blanking properties are regularly adjusted by the 12m staff.

3.7 Computer Equipment

The 12 Meter Telescope computer system is composed of a network of Linux workstations. The telescope control and primary data analysis functions are controlled by a quad-processor Intel Xeon PC's. The control program is a C-language-based interface package called RAMBO. The RAMBO interface handles all of the functions of data acquisition, including communication with the VxWorks device drivers which run the spectrometers, receivers, and other devices associated with a particular measurement. Most major analysis packages are available on the observer's workstations

Table 3.5: Millimeter Autocorrelator (MAC) Configurations

Bandwidth and Channels		Useable Bandwidth and Channels[1]		$\Delta\nu$[2]	Resolution
(MHz)	Channels	(MHz)	Channels	(kHz)	(kHz)
2 IF Modes					
800	2048	600*	1536	390.6	781.2
800	4096	600	3072	195.3	390.6
400	4096	300*	3072	97.6	195.3
400	8192	300	6144	48.8	97.6
200	8192	150*	6144	24.4	48.8
200	16384	150	12288	12.2	24.4
100	16384	75*	12288	6.1	12.2
100	32768	75	24576	3	6.1
4 IF Modes					
800	1024	600*	768	781.2	1562
800	2048	600	1536	390.6	781.2
400	2048	300*	1536	195.3	390.6
400	4096	300	3072	97.6	195.3
200	4096	150*	3072	48.8	97.6
200	8192	150	6144	24.4	48.8
100	8192	75*	6144	12.2	24.4
100	16384	75	12288	6.1	12.2

[1] The useable bandwidth takes account of the 75% efficiency of the analog filters.
[2] NOTE: This is the frequency sampling interval, not the FWHM channel width, for a given channel. The FWHM channel width is 2.0 times this value.
See Appendix D for details.

All values in this table refer to each IF.
Modes tagged with a * are produced by dropping the last half of the lags