US/GR BR/

NATIONAL RADIO ASTRONOMY OBSERVATORY
TUCSON, ARIZONA

A GUIDE TO THE 36-FOOT INSTRUMENTATION

JOHN M. PAYNE

JUNE 1976

A GUIDE TO THE 36-FOOT INSTRUMENTATION

John M. Payne

TABLE OF CONTENTS

A GUIDE TO THE 36-FOOT INSTRUMENTATION

John M. Payne

1.0 Introduction

The purpose of this short guide is to provide a general description of the electronic equipment that will be used by a visitor to the 36-foot telescope.

Simplified block diagrams of the more important pieces of equipment are given together with brief mention of the possible modes of observation. Operating instructions are not given; they are available at the telescope.

The actual mechanics of data taking are fully covered in the "36-Foot Telescope Computer System Manual" by Mike Hollis.

2.0 Summary of 36-Foot Receivers

2.1 Introduction

The receivers that are available at the 36-foot are shown in Table 1. Broadly speaking, the receivers fall into two categories — continuum and spectral line — although some receivers fulfill dual functions.

The most frequently used receiver, at present, is the 80-120 GHz cooled mixer Cassegrain receiver. It is anticipated that this type of receiver will be extended to the 33-50 GHz band and the 127-174 GHz band within the next year, so the description of receivers in this guide will emphasize the 80-120 GHz receiver.

2.2 Continuum Receivers

2.21 The 1 mm Receiver. This receiver uses a scandium-germanium bolometer cooled to liquid helium temperatures. The bandwidth at the present time is approximately 100 GHz, although this may be restricted in the future. The sensitivity of the receiver is such as to reach approximately 4 Jansky RMS in one hour, and the mode of operation is restricted to beam switching.

2.22 The 9 mm Prime Focus Receiver. The 9 mm receiver uses a room temperature mixer giving a DSB receiver temperature of 700°K and a BW of 500 MHz. Either beam switching or load switching is available.

2.23 The 3.5 mm Cassegrain Continuum Receiver. This receiver is the 80-120 GHz cooled mixer receiver mentioned previously. Two independent, orthogonally-polarized channels are available, each channel having a DSB noise temperature of approximately 200°K and a BW of 500 MHz. Beam switching up to 7 arc minutes at a 5 Hz rate is available by moving the subreflector. Calibration is by means of a noise tube in the subreflector and a fairly typical calibration value is 15°K.

2.23 Continued --

For some continuum measurements, on extended sources for example, the 7 arc minute beam deviation of the subreflector is insufficient. To permit such measurements we have developed a dielectric wedge switching system. With the wedge in position over the receiver feed horn, the beam is deflected from the subreflector to a region of cold sky. Such a system has the advantage of being largely self-balancing with changes in elevation angle. The main disadvantage is increased noise owing to the low switching rate (1 Hz).

2.24 The 9 mm Cassegrain Receiver. This receiver has two feed systems, each with two orthogonally-polarized channels with a DSB temperature of 550°K and a BW of 1 GHz per channel. The subreflector switching angle is so arranged that one feed is always on source. In this way an improvement in sensitivity of 5.5 (a factor of 30 in integration time) is obtained over the 9 mm prime focus receiver.

2.25 The 47 GHz Cassegrain Receiver. This receiver uses two cooled, degenerate parametric amplifiers in two orthogonally-polarized channels. The effective BW is 150 MHz, and the best noise temperature is approximately 100°K.

2.3 Spectral Line Receivers

All spectral line receivers use the local oscillator system described later in this guide.

2.31 The Prime Focus Receivers. These receivers are summarized in Table 1. Excepting the 22 GHz receiver, all are room temperature mixer receivers. These receivers are being phased out with the introduction of the cooled mixer system.

2.32 The 80-120 GHz Receiver. Two channels are available with noise temperatures varying from 430°K-1500°K SSB. The second channel of the receiver may be offset ± 250 MHz with respect to the first channel by changing the 2nd LO frequency. An image rejection filter is available which can be tuned from the control room; calibration may be performed either by means of a noise tube at the center of the subreflector or by an ambient absorber switching over the feed.

3.0 The Continuum System

The continuum system is outlined well in the "Computer Systems Manual". A conventional square wave synchronous detector is used, and its output is converted to a 14-bit plus sign digital word every 100 ms. The switching rate is 50 Hz for the prime focus 9 mm receiver, 20 Hz for the 1 mm receiver, and 5 Hz for all other receivers. Calibration is via a coupled noise tube for the 9 mm prime focus receiver; no calibration system is used on the 1 mm system, and all Cassegrain systems use a noise tube in the center of the subreflector modulated at the switching rate. Analog strip chart records of both switched power and total power are available.

4.0 The Spectral Line System

4.1 General Description

A simplified block diagram of the spectral line back-end is shown in Figure 1. The dual channel configuration is shown as this is common with the recently developed Cassegrain receiver. For prime focus receivers only one channel is available. The data acquisition system is limited to 512 channels which may be selected in 256 channel blocks from the four 256-channel filter banks. The data is sampled by the computer every 100 ms; typically, 92 ms is spent on integration and 8 ms on the sequential readout of the 512 channels in 14-bit binary form. Different modes of operation are possible, the most common being frequency switching the receiver or position switching the telescope. Sometimes a combination of these two modes is used. A full description of the calibration procedures and data reduction routines is given in the computer manual.

4.2 The Filter Banks

Four 256-channel filter banks are available having individual channel bandwidths of 0.1, 0.2, 0.5, and 1.0 MHz. Each system has an input center frequency of 150 MHz and may be operated as two parallel, independent, overlapping 128-channel systems or as a single series 256-channel system. The band edges or adjacent channel crossover points are defined as 3 dB down.

A fifth filter bank of 128 channels and 30 kHz BW per channel is available but requires separate connection into the system.

A switching network allows any of the 256 channel banks of filters to be connnected into either the first or the second 256 channel banks of the 512 channel integrator/multiplier.

An IF switching network routes the two IF channels from the front-end into the required filter banks and also sets these filter banks to the series or parallel mode as required.

To calibrate the DC offsets associated with the detector amplifiers in the filter banks, it is usual to perform a zero check at regular intervals through the observations. A computer controlled coaxial switch in each IF line permits this.

Further details on the filter banks may be obtained from the NRAO Electronics Division Internal Report No. 146.

4.3 The Integrator/Multiplexer

This piece of equipment takes the detected output from each of the 512 filter bank channels connected to it and integrates each output in an ideal integrator for an exact period of time (usually 92 ms). At the end of this time every integrator goes into a "hold" mode and the data from each integrator is sequentially converted to a 14-bit number and fed into the PDP 11 computer.

4.3 Continued --

A full description of the multiplexer is given in Electronics Division Internal Report No. 134.

4.4 The Local Oscillator System

A block diagram of the local oscillator system is given in Figure 2.

The purpose of the LO system is to lock the receiver local oscillator (invariably a reflex klystron) to an exactly determined frequency.

A 5 MHz quartz oscillator is multiplied by twenty 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 eighteenth or the nineteenth (1.8 or 1.9 GHz) is usually selected; a frequency between 50 MHz 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 (f_1 in Figure 2).

This nominal 2 GHz signal is then fed up to the receiver and used to drive a harmonic mixer. The n^{th} 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 (f_2 in Figure 2). This is a nominal 400 MHz signal, and phase lock of the klystron is completed by phase detecting this with the loop offset frequency as a reference. The resulting DC voltage is amplified in a floating DC amplifier and applied to the reflector of the klystron in order to electronically time its output frequency.

The loop offset frequency is derived from a tunable signal generator in the control room. (It may be tuned from 300 MHz to 500 MHz.) Frequency switching is performed by switching between two such oscillators, designated "signal" and "comparison" at a 5 Hz rate.

It will be noted that the loop will lock when the klystron frequency differs from the n^{th} harmonic of the 2 GHz source by the loop offset frequency. This means, of course, two lock points, one with the klystron above the n^{th} harmonic and the other with the klystron below. These two points will be separated by twice the loop offset frequency (around 800 MHz). Which condition prevails is indicated by the two lock lights on the front of the phase lock chassis. The computer tests the loop for lock while taking data and if, for any reason, the loop becomes unlocked the data taking will be halted.

For convenience of operation the computer will calculate synthesizer settings for given line frequencies and source velocities. The synthesizer setting will depend, of course, on what sideband the signal is in (i.e., is the klystron frequency above or below the signal frequency?) and whether the klystron frequency is above or below nf_1. The correct conditions are fed into the computer by means of the sideband parameter which is fully described in the computer manual on pages X.20-X.23.

4.4 Continued --

The phase lock system can sometimes be difficult to tune and the telescope operator will generally be of great assistance in achieving a stable lock.

Some common errors in tuning the phase lock system are:

a) Forgetting to tune the output filter on the 2 GHz sources.

b) Selecting the wrong lock light.

c) Punching in the wrong synthesizer setting.

Complete step-by-step instructions are available at the telescope.

A full description of the phase lock system is given in Electronics Division Internal Report No. 97.

5.0 The 80-120 GHz Receiver

A simplified block diagram of the 80-120 GHz cooled mixer receiver is shown in Figure 3.

A lens-corrected feed is used to illuminate the subreflector, the illumination pattern being -10 dB at the edge of the subreflector. (The subreflector subtends a total angle of 4.2°.) A dual-mode transducer separates the two linear, orthogonally-polarized components which feed two cooled, single-ended, Shottky-barrier gallium-arsenide mixers. The local oscillator is fed to the mixers via a tunable injection cavity. This results in low loss in the signal path and the filtering of LO noise originating in the klystron. The IF amplifier is a cooled (15°K) parametric amplifier consisting of three modules giving a total gain of 30 dB and a bandwidth of 600 MHz at a center frequency of 4750 MHz. Cold loads and coaxial switches inside the dewar permit measurements on the bandpass and noise temperature of the paramps.

The IF signal is then further amplified outside the dewar by room temperature transistor amplifiers. At this point a portion of the IF signal is coupled off and detected for the continuum output of the receiver. The continuum detectors are temperature-controlled for maximum stability, and the input power level to the detectors is adjustable from the control room.

The two IF signals are then mixed a second time. In channel 1 the local oscillator is a crystal-controlled oscillator at 6078 MHz and in channel 2 the local oscillator may be selected to be either the 6078 MHz oscillator or an offset oscillator that permits offsetting the second channel ± 250 MHz from the first.

A third mixing with a 1478 MHz oscillator produces a 10-300 MHz IF signal in each channel with a center frequency of 150 MHz. This signal is then distributed to the filter banks via the IF distribution system.

5.0 Continued --

A noise figure meter is available for optimizing the receiver noise temperature. This measures the change in the output of the receiver when a hot (ambient temperature) load is switched over the feed. This will prove useful in finding the optimum position of the mixer back short and also tuning the image rejection filter.

When using the noise tube in the subreflector for calibration it should be noted that the noise source is linearly polarized and that any rotation of the subreflector will change the calibration values.

A note of caution is appropriate concerning the pump for the parametric amplifiers. The pump frequency is 31.8 GHz; and if the third harmonic of this frequency falls in either sideband, the receiver may well be unusable.

The tuning range of the receiver is covered by three klystrons; the exact frequencies vary from time to time, so it is well to check with the Electronics Division before an observing run. At least one hour should be allowed for a klystron change.

A Fabry Perot image rejection filter is available for calibrated spectral line work. This is tunable from the control room and should be set to the required signal frequency by using the calibration curve provided. Final tuning may be accomplished with the noise figure meter.

A frequently encountered problem in spectral line observing (particularly when using the wideband filter banks) is the so-called "standing waves". These standing waves result from noise originating within the receiver being scattered off the subreflector and back into the receiver. The output of the spectrometer will then show ripples at a frequency corresponding to the round trip time from receiver to subreflector.

Cancellation of these standing waves may be achieved by means of an adjustable plate in the center of the subreflector. Such a plate is provided at the telescope together with instructions for its use.

NRAO FRONT-END BOX STATUS

Applicable Telescope	Frequency (MHz)	Amplifier Type	System Temperature (Kelvin)	3 dB Bandwidth (MHz)	Feed Type	Polarization	Calibration Value	Switching System	Remarks	Person in Charge
36-ft	22—24 GHz	Degenerate Paramp	300 DSB	100 DSB	Horn	Linear	≈ 60 K	Load, beam, or frequency.	Stabilized LO system.	Cochran
36-ft	31—50 GHz	Mixer	1500 SSB	100	Horn	Linear	150 K	Chopper wheel or frequency.	Line receiver.	Ross
36-ft	31.4 GHz	Mixer	700 DSB	400	2 Horns	Variable	13.8 K	Other beam or load.	Continuum receiver.	Freund
36-ft	31.4 GHz	Mixer	600 DSB (Each Channel)	1 GHz	Cassegrain and Horn	Dual Linear	≤ 10 K	Nutating subreflector.	Continuum receiver. Four channels with two feeds each receiving orthogonal linear polarizations. This configuration gives an improvement in signal to noise of three over a single channel. This represents an improvement of 5.5 over the existing prime focus receiver (a reduction in integration time of a factor of 29). Available 9/76.	Freund
36-ft	47.5 GHz	Degenerate Paramp	150 DSB	200 DSB	Horn	Linear	10 K	Beam, load.	Line or continuum. Two channels receive orthogonal linear polarizations. One channel tunes from 46.4 to 47.38 GHz with an IF bandwidth of 150 MHz. The other channel tunes from 45.3 to 47.2 GHz with an IF bandwidth of 75 MHz.	Ross
36-ft	67—85 GHz	Mixers	2500 SSB	100	Beam Switch	Linear	30 K	Beam or frequency.	Stabilized LO for line work. Component changes required to tune over the 67-85 GHz range.	Ross
36-ft	80—120 GHz	Cooled Mixer	500—1000 SSB per channel	500 MHz	Cassegrain Horn and Lens	Dual Linear	≤ 10 K	Nutating subreflector or frequency.	Line or continuum. Two channels receive orthogonal linear polarizations. The second LO in one channel is variable, allowing channels to be separated by up to 500 MHz. A B.T.L. image rejection filter is available for calibrated spectral line work.	Cochran
36-ft	80—120 GHz 33—50 GHz	Cooled Mixer	500—1000 SSB per channel	500 MHz	Cassegrain Horn and Lens	Dual Linear	≤ 10 K	Nutating subreflector or frequency.	Two dual channel mixer receivers in same box. Line or continuum. The two channels of each receiver are orthogonally polarized. The second LO in one channel is variable, allowing channels to be separated by up to 500 MHz. Three hours should be allowed for changes from 80-120 to 33-50 or vice versa. The 33-50 GHz receiver will use an image rejection mixer; the 80-120 GHz receiver will use an image rejection filter for line work. Available September 1976.	Payne
36-ft	250 GHz	Cooled "3-Part" Bolometer	30 000	100 GHz Limited by filters and atmosphere.	Optical Single or Dual Beam	Unpolarized	Special procedure.	Other beam or load.	Scandium-Germanium bolometer. Reaches approximately 4 Jansky RMS in 1 hour under dry weather conditions. NEP 2×10^{-13}.	Albaugh

TABLE 1

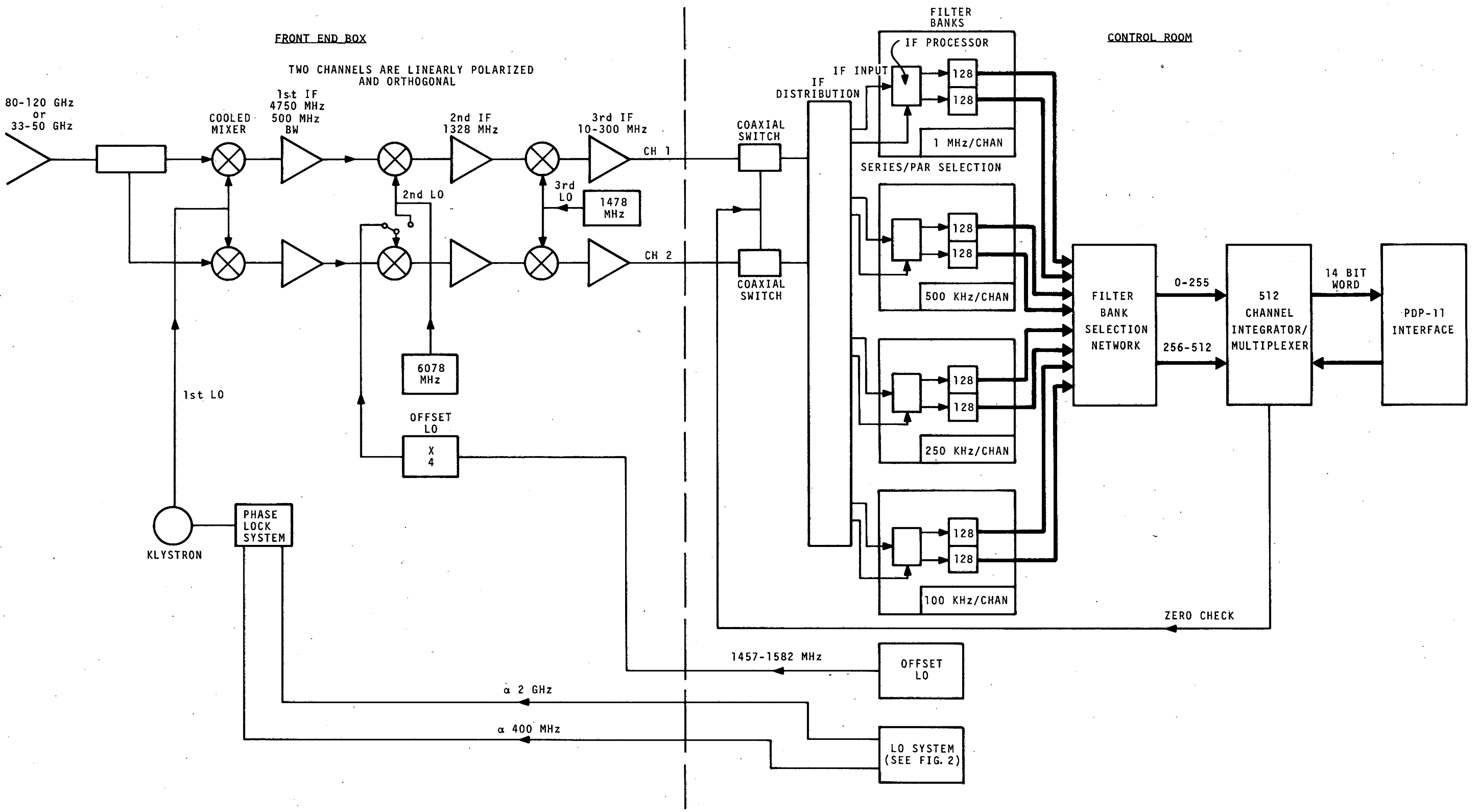

FIGURE 1: BLOCK DIAGRAM OF SPECTRAL LINE SYSTEM.

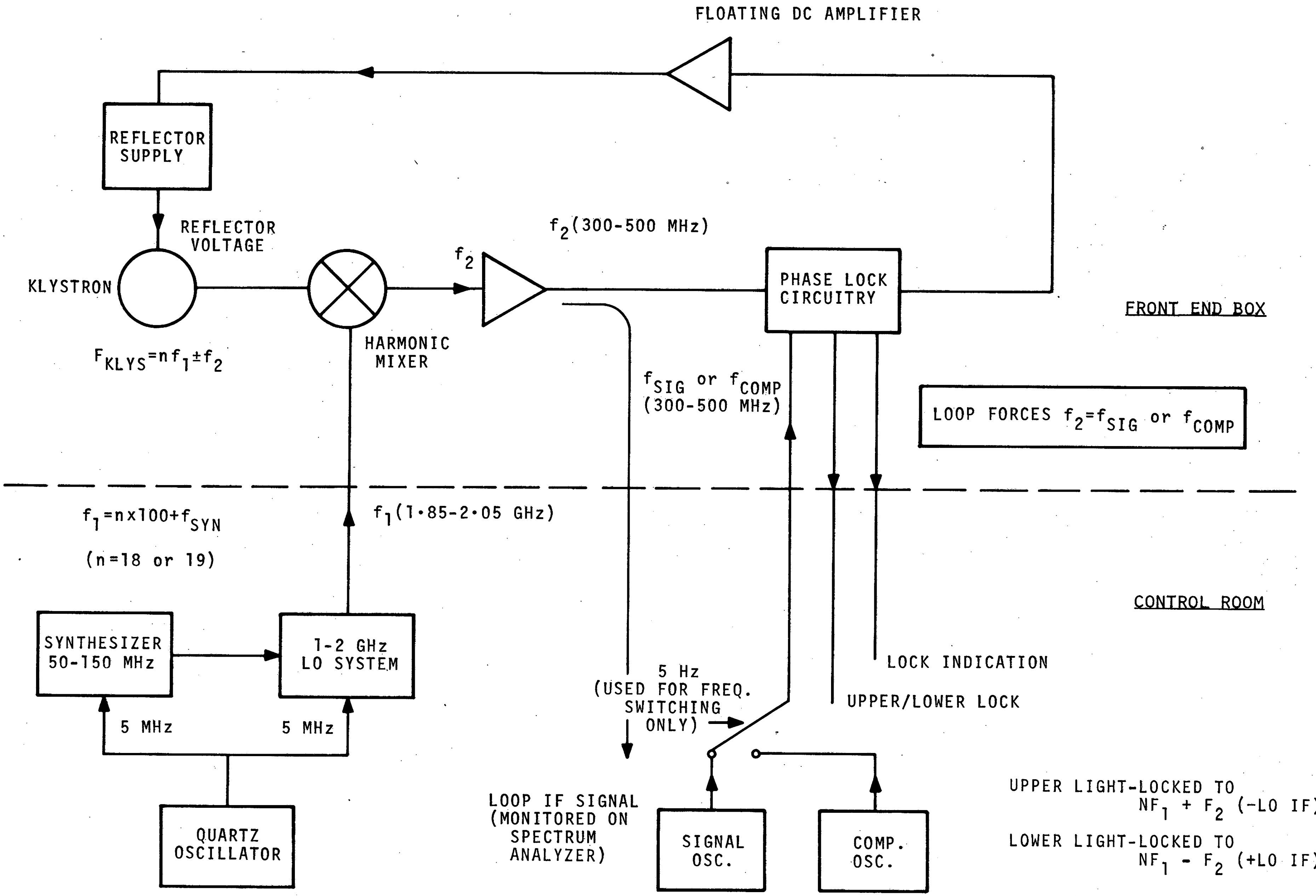

FIGURE 2: SIMPLIFIED BLOCK DIAGRAM OF 36-FT LO SYSTEM

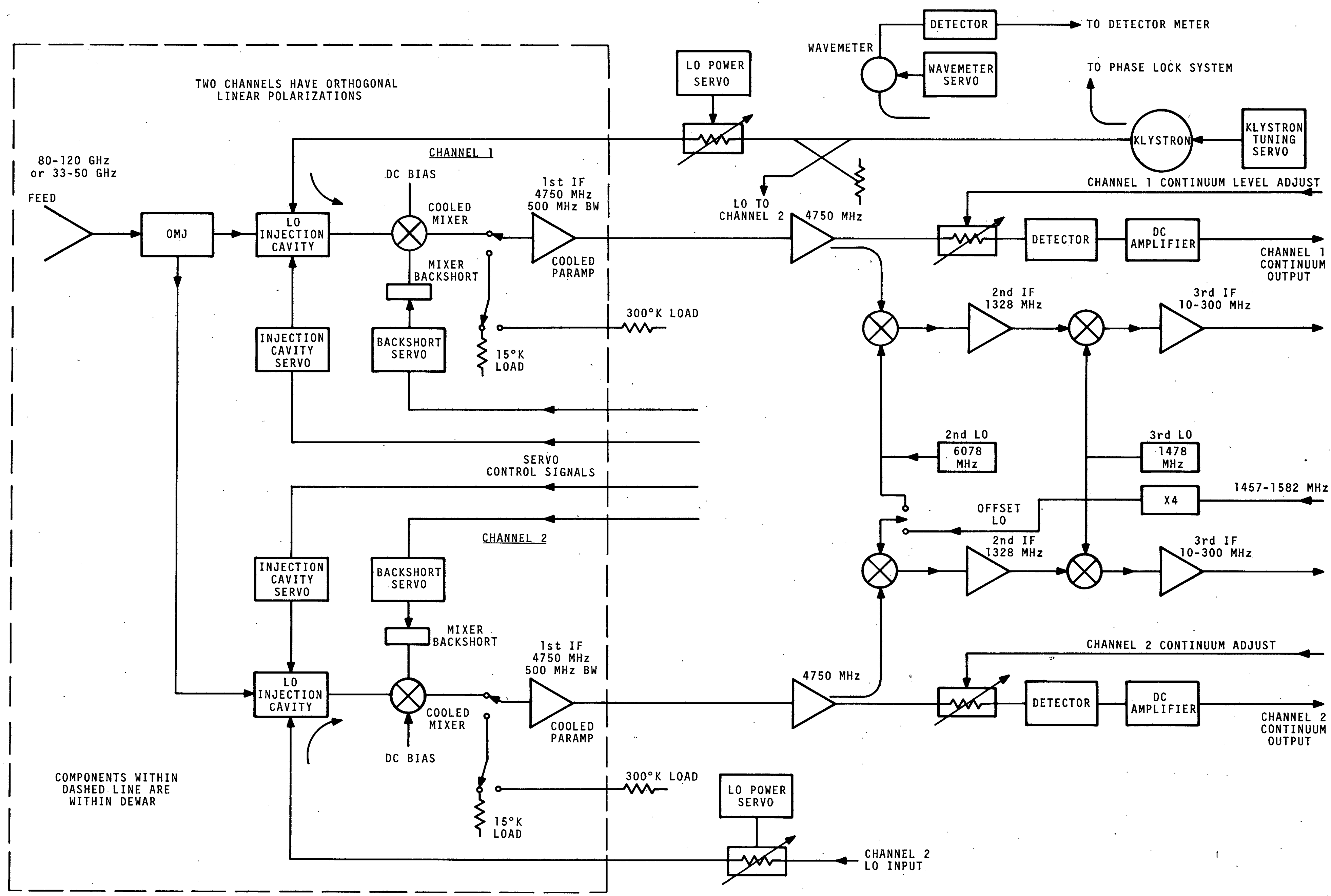

FIGURE 3: COOLED MIXER CASSEGRAIN RECEIVER - BLOCK DIAGRAM