USER'S MANUAL

For The NRAO 12m Millimeter-Wave Telescope

KITT PEAK, ARIZONA

AUGUST 1990 EDITION

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FOR THE NRAO 12 m MILLIMETER-WAVE TELESCOPE

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PREFACE

Our intent with this manual is to provide a general reference book for use of the NRAO 12 m millimeter-wave telescope. We have included basic material required for first-time use of the telescope, as well as more detailed information of possible interest to all observers. We recommend that first-time users read Chapter 1 (*Introduction*), Chapter 2 (*Getting Started*), and the *Visitor Information* Guide before coming to the telescope. You may consult other chapters as needed.

We are sure that there is room for improvement in this manual, and ask users to bring to our attention any errors, omissions, or unclear passages. So that we can provide updates when available, we want to keep record of the people who have copies of the manual. If you take a manual from the distribution box at the 12-m telescope or at other NRAO sites, please copy and fill out the address sheet on the next page and mail it to us in Tucson.

Many people have contributed to this manual, and it is a pleasure to acknowledge them: Dave Hogg and Bob Brown wrote parts of Chapter 1 (*Introduction*), Chris Biemesderfer wrote a section of Chapter 5 (*Source Catalogs*), Chris Salter wrote an early draft of Chapter 6 (*Continuum Observing*), and Al Wootten contributed material to Chapter 7 (*Spectral Line Observing*). Much of the information on the FORTH system was taken from the *36 Foot Telescope Computer System Manual (Computer Division Internal Report No. 18)* by J. M. Hollis. James Lamb, John Payne, and Antonio Perfetto contributed engineering drawings; George Kessler and Greg Morris drafted some of the figures. Darrel Emerson and Mark Gordon have provided numerous helpful comments. The 12 m telescope operators and observers made many suggestions and corrections to early drafts. Jennifer Neighbours has suffered cheerfully through the editor's stylistic whims and through several versions of word processors while performing a most commendable typesetting job; her efforts are much appreciated.

On the following pages you will find a *User's Manual Registration Form*, *Observing Application Cover Sheet*, a *Data Tape Request Form*, and an *Observer's Comment Sheet*. Please photocopy and use these as required.

Philip R. Jewell
Editor
August 1990

NRAO 12 m TELESCOPE USERS MANUAL
REGISTRATION SHEET

(Please print or type)

Name:_____

Institution:_____

Address:_____

_____

_____

City:_____

State:_____   Zip: _____

Country:_____

Please mail to:

National Radio Astronomy Observatory
Campus Building 65
949 N. Cherry Ave.
Tucson, AZ   85721-0655
USA

PLEASE RETURN THIS FORM TO ENSURE THAT YOU RECEIVE UPDATES TO THE MANUAL

National Radio Astronomy Observatory
12-Meter Telescope/Arizona Operations
Observing Application
Cover Sheet

SEND TO: Director, NRAO, Edgemont Road, Charlottesville, VA. 22903-2475
DEADLINES: 1st of Jan, July, Oct for the Spring, Fall, and Winter Periods, respectively.

1 Date:

2 Title of Proposal:

3 Authors	Institution	Who Will Observe?	Grad Student?	Observations for PhD Thesis?	Anticipated PhD Year

4 Contact Author for Scheduling

Name/Address

5 Telephones:

Office:

Home:

6 Scientific Category: ☐ atmospheric, ☐ planetary, ☐ solar, ☐ stellar, ☐ galactic, ☐ extragalactic

7 Mode: ☐ spectra, ☐ continuum, ☐ other (specify):

8 Receiver:

9 Ancillary Equipment:

10 Filters: ☐ Expander, ☐ 30-kHz, ☐ 100-kHz, ☐ 250-kHz, ☐ 500-kHz, Units ☐☐ 1-MHz 1 2, Units ☐☐ 2-MHz 1 2

11 Frequencies (include test lines):

12 Special Software? (describe on separate sheet)

13 Special Hardware? (describe on separate sheet)

14 Sessions/Days Requested:

15 LST Range:

16 Possible conflict with Sun? (time of year to avoid)

17 Abstract (do not write outside this space):

Please attach a summary (of less than 1000 words) which contains the following information:
   1) Scientific justification;   2) Observing strategy;   3) Source list with coordinates

After your proposal is scheduled, the contents of this cover sheet become public information (supporting documents are for referees only).

For Internal Use Only:

REVISED 86 11 31

NRAO 12-METER TELESCOPE

DATA TAPE REQUEST FORM

A copy of your raw data from the Analysis Computer will be archived on tape at NRAO Tucson for two (2) years. The archive tape will contain whole scans, individual records, keep data, and edited data.

Effective 1 April 1985, there will be a charge of $11.00 plus $2.00 for shipping, if applicable, for each tape supplied to you by NRAO. The charges will be added to your meals and lodging invoice or billed separately. PLEASE COMPLETE THIS FORM BEFORE LEAVING THE TELESCOPE. The form should be left with Jennifer or Max at the Tucson office if you will be stopping by during business hours; if not, please leave the form with the telescope operator.

The FORTH binary tape is the only tape that is immediately available at the end of your observing run. Analysis system (VAX) tapes require processing time; they will be mailed to you later at the tape charge plus $2.00 for shipping by least cost surface method. More than one file can be written on a tape depending on the size and BPI requested. All tapes will be FITS format unless otherwise requested. Please indicate below which tapes you want:

FORTH binary tape ☐ (hand carried)   Observing Initials _____

Analysis System Tapes	1600 BPI	800 BPI
Raw Data	☐	☐
Keep File	☐	☐
Edited Scan File	☐	☐
Individual Record File	☐	☐

SHIP TO: BILL TO: Same ☐ OR

_____   _____

_____   _____

_____   _____

_____   _____

      Ship Surface ☐   Extra Cost Method _____

SPECIAL REQUESTS:

_____

_____

_____

                    Signature _____

                    Date _____

Revised 4/30/87 (Webb2)

OBSERVER'S COMMENT SHEET

Program: _____   Receiver: _____   Date of Run: _____

Your Name: _____   Phone: (___) _____

E-mail: _____

In an attempt to assess whether observers on NRAO telescopes are experiencing any problems or difficulties connected with their visits to the site, the Observatory is encouraging each observing team to complete this form and turn it in to the Site Director's Office. You may wish to comment on our policies or procedures, and it will be especially valuable for us in our continuing concern for how we are handling the observing programs. The site director will send copies of this report to the Director's Office and to any other individual(s) whom you may name, below. We will do our best to improve the operation, based on your suggestions. Thank you.

How clear and complete did you find our user and data analysis manuals?

How well did the equipment (*including software*) operate?

How effective were the support services?

Did you accomplish your scientific objectives?

Observer: Please send the original of this sheet to the site Director who will then distribute it to the Director's Office and to any other individuals whom you may name below.

Others (by name): _____

CHAPTER 2

GETTING STARTED

CHAPTER 3

INSTRUMENTATION

CHAPTER 4

TRACKING, POINTING, AND FOCUS

CHAPTER 5

SOURCE CATALOGS

CHAPTER 6

CONTINUUM OBSERVING

CHAPTER 7

SPECTRAL LINE OBSERVING

CHAPTER 1

INTRODUCTION

1.1 THE OBSERVATORY

The National Radio Astronomy Observatory 12-meter telescope is a general purpose millimeter-wave observatory that supports spectral line and continuum observations in the atmospheric windows at 3 mm, 1.2 mm, and 0.9 mm wavelengths. The facility is located on Kitt Peak, Arizona, about 50 miles southwest of Tucson. The Observatory was constructed in 1967 with an original surface diameter of 36-feet (11-m). In 1982, the surface and backup structure were replaced with a 12 m diameter reflector.

The NRAO operates the telescope as a visitor facility, open to use by competent observers without regard to affiliation or nationality. Proposals are accepted before three deadlines each year and are evaluated by a panel of anonymous referees (see Section 1.5 for more information on proposal submission). The telescope is open for visitor use from approximately September 15th to July 15th each year. From late July through the middle of September the prevailing weather pattern precludes observations at millimeter wavelengths and the telescope operation is shut down. Extensive overhauls, telescope upgrades and major maintenance are done during the summer shutdown period.

The 12 m telescope is one of five observatory units operated by the NRAO. The NRAO is administered by Associated Universities, Inc. (AUI), under cooperative agreement with the National Science Foundation. Operations of the 12 m telescope are managed by the Site Director who, with the Deputy Director, also handles the scheduling of the instrument. The Site Director should be contacted with regard to general matters of operations policy and scheduling. In addition, more general questions or comments pertaining to Observatory-wide activities (scheduling procedures, scientific or instrumentation priorities, inter-site relations) or specific criticisms of, or suggestions for, the Tucson operation may be addressed to the Director of the NRAO located at the Charlottesville, Virginia office.

Table 1.1

Telescope and Site Statistics

Site:

East Longitude:	$-111° 36' 51.12'' = -7^h 26^m 27.41^s$
North Latitude:	$31° 57' 14''$
Elevation:	1914 m (6280 ft)

Telescope:

Primary Reflector Diameter:	12.0 m
Focal Ratio (f/D) Prime Focus:	0.42
Cassegrain Focus:	13.8
Surface Accuracy (rms):	75 μm rms
Mount:	Elevation over Azimuth
Slew Rates Azimuth:	68°/minute
Elevation:	68°/minute
Pointing Accuracy (rms):	6''
Elevation Limit:	15°
Enclosure:	astrodome with movable door and automatic tracking.

Additional visitor information, including maps, lodging fees, travel reimbursement policies, and names of specific staff members responsible for operation

of the telescope are described in the appended document, *Visitor Information for the NRAO 12 m Telescope.*

1.2 AN OVERVIEW OF THE OBSERVATORY

This section provides an introduction to 12 m capabilities and supplies the basic information needed to prepare an observing proposal. Chapter 3 contains more detailed information on equipment and Chapters 4-7 describe observing techniques in detail.

1.2.1 THE SITE AND TELESCOPE

Table 1.1 lists basic information on the observatory site and the telescope. Table 1.2 lists basic telescope efficiencies measured by the 12 m staff. More details on telescope calibration are given in the appended document, *The NRAO 12 m Telescope Equipment and Calibration Status.*

1.2.2 THE OPTICS

The 12 m uses "bent Cassegrain" optics. Following reflection by the primary, the beam is focused on a secondary hyperboloid mirror at the prime focus. From there, the beam is directed to a rotatable tertiary mirror at the vertex of the primary. This tertiary mirror directs the beam to one of four receiver bays. The position of the tertiary mirror can be commanded from the control room. Use of two or more receivers during a single observing run is possible.

Table 1.2

12-meter Efficiency Factors

Frequency GHz	Beamwidth (arc sec)	η_A	η_l	η_{fss}	η_M^*
90	69	0.47	0.87	0.73	0.90
230	32	0.26	0.85	0.75	0.48
345	$\simeq 20$	0.14	0.85	0.75	0.20

Notes:

η_A =   aperture efficiency,

η_l =   rear spillover and scattering, blockage and ohmic loss efficiency,

η_{fss} =   forward spillover and scattering efficiency, and

η_M^* =   corrected main beam efficiency (percent power in the main diffraction beam relative to the outlying error beam).

1.2.3 THE RECEIVERS

Table 1.3 lists the Cassegrain receivers available at the 12-meter telescope. A more complete description is given in the document *Equipment and Calibration Status* and in Chapter 3.

1.2.4 LOCAL OSCILLATORS, THE I.F. SECTION, AND RECEIVER SELECTION

All receivers at the 12 m use phase-locked Gunn oscillators as the local oscillator source. For the high frequency receivers, the Gunn oscillator output is multiplied by solid state triplers or quadruplers. The tuning and phase-locking of the Gunn oscillators is remotely controlled from the control room. A single Gunn oscillator will typically tune over a 10 to 30 GHz range.

Table 1.3

Receiver Statistics

Receiver Designation	Tuning Range	Approximate System Noise SSB	Note
3 mm SIS	88-115 GHz	100-200 K	a
1 mm SIS	200-250 GHz	150 K	b
1 mm Schottky	200-240 GHz 240-270 GHz 270-310 GHz 330-365 GHz	500-700 K 900-1100 K 1100-1500 K 1600-2000 K	c
1.3 mm 8-beam Schottky	215-240 GHz	500-700 K	d

Receiver Notes:

(a) The 3 mm SIS receiver is a dual linear polarization receiver, consisting of two superconducting mixers. The receiver is tunable between 88 and 116 GHz. For spectral line work the receiver is tuned so as to be inherently single sideband; for continuum work it may be tuned double sideband. The LO source is a Gunn oscillator. The liquid helium dewar must be filled every third day, a process that requires about one hour.

(b) The 1 mm SIS receiver consists of dual polarization mixers in a 4 K, closed-cycle cryostat.

(c) The 1 mm Schottky receiver consists of four pairs of dual polarization Schottky mixers covering the 200-365 GHz range. A change between mixer-pairs involves rotating a LO diplexer and may require replacing the LO multiplier; the changeover requires about 0.5 to 1 hour. The LO sources for this receiver are Gunn oscillators. Normally, not all of the four mixer pairs are available at the same time; consult the staff for availability.

(d) The 8-beam receiver is configured as a 2 x 4 array of beams, with a beam separation of 85" between beams. The array can be rotated to an arbitrary orientation and can track parallactic angle in real time.

The intermediate frequency of all 12 m mixer receivers is 1.500 GHz. The receivers in all four bays use a common, two channel I.F. processor module. The base-band output of this module is at 342 MHz.

Observers can select receivers in any of the four available bays automatically from the control room. The automatic selection process includes the routing of the LO reference signal, the I.F. signal, and the positioning of the central mirror. You can switch from one receiver to the other in as little as ten minutes, although more time is required if the receiver must be tuned. This capability makes it possible to observe with more than one receiver in a single observing run. (If you desire this capability, please state it clearly in your observing proposals, since not all receivers may be available at a given time.)

1.2.5 BACKEND SIGNAL PROCESSORS

1.2.5.1 SPECTROMETERS

The spectrometers in routine use at the 12 m are filter banks. A new generation Hybrid Spectrometer, which is a combination of analog filtering and digital autocorrelation techniques, is now available for use. Table 1.4 lists the filter banks available.

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 frequency resolutions are useful. *Chapter 3* contains a more detailed discussion of filter bank configurations.

Table 1.4

Filter Spectrometers Available

Bandwidth of Individual Filters	Number of Channels (filters) per Filter 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 kHz[1]	128	1
Spectrum Expander[2]	256	1

[1]Series operation only. (See explanation in text.)

[2]Uses the 100 kHz filter bank. Available resolutions are 25 kHz, 12.5 kHz, and 6.125 kHz.

1.2.5.2 CONTINUUM BACKENDS

Continuum data at the 12 m is acquired by a two channel, four phase digital backend. A two channel analog backend continues to drive the on-line chart recorders. The digital backend 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. The start and duration of signal blanking (during subreflector chopping) can be controlled from the front panel of the digital backend. The data output of the digital backend is in the form of 32 bit words. The maximum number of digital backend data points that the control computer can record in a single scan is 54 ON/OFF REPEATS (216 samples) or 192 mapping points for a one or two channel receiver.

The analog backends consist of phase-sensitive detectors that produce switched power and total power samples. The switched power and total power outputs are

recorded on a two-pen chart recorder (separate recorders exist for two-channel receivers). By convention, the switched power trace is recorded with a red pen and the total power trace with a blue pen.

1.2.6 COMPUTER SYSTEMS

The 12-meter telescope uses two computers, a DEC PDP 11/44 for telescope control and data acquisition (written in the FORTH language) and a DEC VAX 11/750 for data reduction. A one-way data link carries the data acquired by the PDP-11/44 to the VAX where it is copied on the VAX's RA81 "analysis" disk. An IBM PC is available to observers to enter and transmit source catalogs to the control computer (see Chapter 5). The PC also serves as a terminal to the control computer; however, the need to interact with the control computer is very minimal and is confined to viewing or editing source catalogs. The *telescope operator* enters the observing parameters (frequency, integration time, and so forth) in the PDP-11/44 prior to each observation according to your instructions.

You may examine and reduce the data (line and continuum) as it is accumulated in the VAX. The data are entered into a set of personal data files whose file name extensions typically will be the observer's initials. The major files in this area are the PDFL file, containing the scan-averaged data; the IRFL file, containing individual spectral line samples, taken normally at 30 second intervals; the GZFL file, containing results for spectral line calibration scans; and the PKFL file, containing processed data, such as the average of all similar scans for a source, and the PAFL file which contains processed mapping data. Note that because of limited disk capacity the IRFL will hold perhaps 3 days' data, and special action will be required to save a larger amount of individual record data.

When you have finished your observations, the operator will make an archive tape of the observers' files, and send it to the Tucson office. Using the town VAX 11/750, the staff will create an export tape of the type you requested (see the Data Tape Request Form in the *Preface*) and will mail it to your home institution. We

offer two types of export tapes: an ASCII tape following the FITS standard or a straight VAX BACKUP if you are using a VAX computer running the VMS operating system.

During your observations, the FORTH control computer continuously writes a backup tape, known as the "FORTH tape." The FORTH tape and the VAX archive tapes are not the same for the following reason. For spectral line data the control computer transmits *double precision* (4 byte) integer quotients scaled by 20000 to the analysis system. Scaled *single precision* (2 byte) integer quotients are written on the control computer disk and binary tape. Furthermore, continuum data from the digital backend are not recorded at all. Thus, you are encouraged to use for your final analysis those tapes written from the analysis (VAX) system.

1.3 OBSERVING CAPABILITIES

1.3.1 SPECTRAL LINE

The following spectral line observing techniques are supported at the 12 m (see Chapter 7 for more detailed descriptions):

a) Position Switching --

The telescope moves between an offset position (in relative or absolute coordinates). The spectrum is recorded as a ratio of (ON - OFF)/OFF.

b) Total Power scans --

ON and OFF total power spectra are recorded separately for later processing into final spectra. The observer may take several ON scans for each OFF.

c) Frequency Switching -- The local oscillator is shifted by a few MHz at a rate of 5 Hz. The spectrum is recorded as a ratio of (SIG -REF)/REF.

d) Beam Switching +
Position Switching -- The subreflector is chopped at a rate of 1.25 to 5.0 Hz, and the telescope is repositioned at a prescribed rate (typically every 30-90 seconds). The spectrum is recorded as (ON - OFF).

e) Mapping -- Total power or absolute position or frequency switched data are acquired while the telescope moves to automatically specified spatial positions.

1.3.2 CONTINUUM

The following continuum observing procedures are supported at the 12 m; for more detailed information, see Chapter 6.

a) ON/OFF's -- With the subreflector chopping, the telescope moves first to one beam position and then the other. Appropriate for point source observations.

b) Mapping -- The telescope steps through a rectangular azimuth/elevation grid. Can be performed in switched or total power. "Dual-beam restoration" is available in the analysis stage.

1.4 SYSTEM SENSITIVITIES

The sensitivity of the telescope and receiver systems can be computed from the formulas in this section and the numbers in Section 1.2.

1.4.1 SPECTRAL LINE SENSITIVITIES

The spectral line calibration technique generally used at the 12 m is the chopper wheel or vane method. The effective system temperature given by this technique includes corrections for atmospheric attenuation and antenna spillover, blockage, and ohmic losses. The method does not include a correction for error pattern losses as the error beam will couple differently to different sources. The effective system temperature, T_{sys}^*, on the scale defined above, is given by

$$T_{sys}^* = \frac{(1 + G_i/G_s)[T_{Rx} + T_A(sky)]}{\eta_l \eta_{fss} \exp(-\tau_o A)} \tag{1.1}$$

where G_i is the image sideband gain;

G_s is the signal sideband gain;

T_{Rx} is the receiver DSB noise temperature;

T_{sky} is the temperature of the sky (definition given below);

η_l is the rear spillover, blockage, scattering, and ohmic efficiency;

η_{fss} is the forward spillover efficiency;

τ_o is the atmospheric optical depth at 1 airmass (the zenith); and,

A   is the number of airmasses, generally given by 1/sin(elevation).

T_{sky} is given by the equation

$$T_{sky} = \eta_\ell T_M[1 - \exp(-\tau_o A)] + (1 - \eta_\ell)T_{spill} + \eta_\ell T_{bg}\exp(-\tau_o A) \qquad (1.2)$$

where T_M is the mean atmospheric temperature,

          T_{spill} is the spillover temperature, and

          T_{bg} is the cosmic background temperature.

The rms noise level for a given integration time, assuming equal integration time on the ON source and OFF source reference positions, is given by the radiometer equation

$$T_{rms} = \frac{2\, T_{sys}^*}{\sqrt{B_{fil}\, t}} \qquad (1.3)$$

where B_{fil} is the bandwidth of an individual channel in the spectrometer (in Hz), and

         t   is the total integration time, including ON and OFF source time (in seconds).

For observations of unpolarized signals with receivers that have two polarization channels, the two channels can be averaged to reduce the effective system temperature by

$$T_{sys}^* = \left[T_{sys}^*[1]^{-2} + T_{sys}^*[2]^{-2}\right]^{-1/2}, \qquad (1.4)$$

where $T_{sys}^*[1]$ is the effective system temperature of polarization channel 1, and

          $T_{sys}^*[2]$ is the effective system temperature of polarization channel 2.

1.4.2 CONTINUUM SENSITIVITY

Continuum observations at the 12 m are usually calibrated by a direct conversion of the measured antenna temperature into flux density (janskys). The scaling requires that the observer determine the atmospheric zenith optical depth, usually done with a tipping measurement. For a point source, the conversion is given by the standard equation

$$S_\nu - \frac{2kT_A}{\eta_A A_p} \exp(\tau_o A) \qquad (1.5)$$

where   k   is Boltzmann's constant (1.380662×10^{-23} J K^{-1}),

T_A is the measured antenna temperature with no efficiency or atmospheric corrections applied,

η_A is the aperture efficiency,

A_p is the physical aperture (113.10 m^2 for the 12 m),

τ_o is the zenith optical depth, and

A   is the number of airmasses.

The quantity $2k/A_p$ = 24.4155 Jy K^{-1} for the 12 m.

A convenient measure of sensitivity for continuum observations is the rms flux density per root integration time outside the earth's atmosphere, S_o. The sensitivity achieved in a given integration time t and under an atmosphere with zenith optical depth τ_o, is given by

$$S - S_o t^{-1/2} \exp(\tau_o A). \qquad (1.6)$$

A table of S_o values for key frequencies is given below.

Table 1.5

Continuum Sensitivities per Root Time

Frequency (GHz)	S_o (per channel) $(Jy\ s^{-1/2})$	S_o (both channels averaged) $(Jy\ s^{-1/2})$
90	1.5	1.0
230	6.0	4.0
345	48 (estimated)	34

1.5 PROPOSAL PREPARATION AND SUBMISSION

1.5.1 PROPOSAL REFEREEING

Twelve meter telescope scheduling operates on a trimester system, with proposal submission deadlines and their corresponding observing periods listed in Table 1.6. The intention of the 12 m proposal system is to insure that the projects granted telescope time are of current interest and that all proposals receive a prompt scheduling decision.

Table 1.6

Proposal Submission Deadlines

Deadline	Observing Period	Receivers Available
January 1	April to mid-July	3 mm, 1.2 mm
July 1	mid-September to December 31	3 mm, 1.2 mm
October 1	January 1 to March 31	3 mm, 870 μm, 1-1.4 mm

Proposals should be sent to the Director of the NRAO in Charlottesville, Virginia. After receipt by the Director's office, the proposals are assigned a reference number and are sent to a panel of five referees who are anonymous to the proposer and to each other. The referees rank the proposal as to scientific merit and possibility of achieving the scientific goal, recommend what percentage of the requested observing time should be granted, and make any comments they feel are pertinent. On the basis of the referees' rankings and comments, the 12 m Scheduling Committee selects the proposals to be scheduled. A report of referees' comments and the disposition of the proposal is sent to the proposal's contact authors, usually within 6 - 8 weeks after the deadline.

Proposals for the 3 mm and 1.2 mm bands are considered for two consecutive trimester periods. On a proposal's second consideration, it will be in competition with new proposals received for that period. If a proposal is not selected on its second consideration, it will be declared inactive and generally will not receive any further consideration for telescope time.

Proposals for the 870 μm (330-365 GHz) band are handled in a special way as described in Section 1.5.1.1.

The 12 m Scheduling Committee will notify proposers as to the disposition of their active proposals after each selection process. After any evaluation of a proposal, the authors may submit an amended version of the proposal to address referees' remarks or to otherwise strengthen the proposal. The proposal will be re-refereed for the next available period. Investigators are also free to withdraw a proposal and resubmit it as a different proposal.

1.5.1.1 SPECIAL POLICY FOR OBSERVATIONS BETWEEN 330-360 GHz

Observations in the 330-360 GHz band are especially susceptible to weather effects. Since the programs can be scheduled only during the winter months each

year, observers often have difficulty completing their programs and then must wait an entire year to try again. To help alleviate this problem, we have adopted the following policy:

1. Observations in the 330–360 GHz band will be scheduled only during the first quarter (January to April) of the year. If a high frequency proposal cannot be scheduled during this period, it will be dropped from the proposal queue, i.e., high frequency proposals receive only one consideration for scheduling. If a high frequency proposal is received at a deadline other than October 1 (for the January to April period), the proposal will be refereed at that time but will not be in competition for time before the January to April period.

2. Each high frequency observing group will be required to submit, in writing, the details of a lower frequency (3 mm or 1.3 mm) backup program to be run in the case that the weather is not good enough for high frequency observations. The backup plan will be checked for conflicts with other observing programs in the proposal queue, but will not otherwise be refereed. These backup plans should be sent to the Tucson Site Director as soon as possible after the observers receive notification that their high frequency program is to be scheduled.

3. If a high-frequency program is adversely affected by weather, the observers can apply to the Site Director for partial reimbursement of observing time, to be scheduled in the same quarter. *It is the observers' responsibility to petition the Site Director, at the conclusion of the initial observing run, for additional time.* If we do not receive any notification, we will assume that the goals of the observing run were accomplished and we will not allocate any makeup time.

    A block of time will be reserved at the end of the high frequency observing season for rescheduling the high frequency observations. Up to 50% of the original time allocation could be rescheduled. If the high frequency backup time is not needed in its entirety, refereed, lower frequency proposals in the

queue will be scheduled during the block. We will attempt to arrange the scheduling so that repeat high frequency observers or the low frequency backup observers will have at least 3 weeks' notice of their observing time.

4.   The reimbursement of observing time for weather problems applies to observations in the 330-360 GHz band only!

1.5.2 PROPOSAL PREPARATION

All proposals should include a completed 12 m Observing Application Cover Sheet, an example of which is included as Figure 1.1. A blank copy of this cover sheet is in the *Preface* of the manual. The body of the proposal *must* include:

a) A concise scientific justification for the project; (Do not exceed 1000 words.)
b) An estimate of the observing time required;
c) Frequencies and source coordinates to be observed.

As a proposer, you should insure that the project is within the capabilities of the telescope, both in terms of available equipment and the sensitivities and integration times required. The telescope and receiver parameters given in Section 1.2 and the system sensitivities in Section 1.4 will be of use in estimating the required integration times. The most up-to-date information on these parameters is in the *Equipment and Calibration Status* document.

The 12 m management imposes no hard rules as to the maximum or minimum lengths of observing programs. A typical 12 m observing run lasts 3 or 4 days of either partial or around-the-clock time. Requests for more than 5 days of time usually receive close scrutiny by the referees and scheduling committee. If only a specific LST range is required, you should request only that range. An observing session of less than a few hours may be unproductive because of the one-half to one hour of setup time typically required at the beginning of a run.

National Radio Astronomy Observatory
12-Meter Telescope/Arizona Operations
Observing Application
Cover Sheet

SEND TO: Director, NRAO, Edgemont Road, Charlottesville, VA. 22903-2475
DEADLINES: 1st of Jan, July, Oct for the Spring, Fall, and Winter Periods, respectively.

1 Date: July 5, 1990

2 Title of Proposal: A Search for Deuterated Molecules in the Bipolar Outflow sources of Starburst Galaxies

3 Authors	Institution	Who Will Observe?	Grad Student?	Observations for PhD Thesis?	Anticipated PhD Year
Jeremiah Peabody	Cactus State University	X			
Hooty Saffeticker	"	X	X	X	2010

4 Contact Author for Scheduling

Name/Address
Dr. Jeremiah Peabody
Department of Astronomy & Applied Survival
Cactus State University
Dry Gulch, Arizona 86002

5 Telephones:

Office: 602-555-4897

Home: 602-555-6203

Secretary: 602-555-4814

6 Scientific Category: ☐ atmospheric, ☐ planetary, ☐ solar, ☐ stellar, ☐ galactic, ☒ extragalactic

7 Mode: ☒ spectra, ☐ continuum, ☐ other (specify):

8 Receiver: 200-250 GHz SIS Receiver

9 Ancillary Equipment: None

10 Filters: ☐ Expander, ☐ 30-kHz, ☐ 100-kHz, ☐ 250-kHz, ☐ 500-kHz ☒☒ 1-MHz ☒☒ 2-MHz
Units 1 2 ; Units 1 2

11 Frequencies (include test lines): 216.113, 230.538 GHz

12 Special Software? (describe on separate sheet) None

13 Special Hardware? (describe on separate sheet) Hybrid Spectrometer

14 Sessions/Days Requested: 4

15 LST Range: 0 - 24

16 Possible conflict with Sun? (time of year to avoid) Late November to late January

17 Abstract (do not write outside this space):

We propose a program of seminal research into one of Nature's most perplexing problems, that of the creation of deuterium-substituted species in the bipolar outflow sources of starburst galaxies. We expect this project to keep us busy for years.

Please attach a summary (of less than 1000 words) which contains the following information:

1) Scientific justification; 2) Observing strategy; 3) Source list with coordinates

After your proposal is scheduled, the contents of this cover sheet become public information (supporting documents are for referees only).

For Internal Use Only:

REVISED 86 11 31

FIGURE 1.1 SAMPLE PROPOSAL COVER SHEET

For any proposal period, the Scheduling Committee almost always receives more proposals than can be scheduled; the requested time often exceeds the available time by factors of 2 - 4. For this reason, you should prepare proposals with care.

1.5.3 PROPOSAL AND OBSERVING PROPRIETY

You are expected to confine your observations to those described in their refereed proposal. It is absolutely essential that observers consult with the Site Director or Deputy Director and obtain his approval before altering scheduled observing programs. Approval for changes can be granted under those circumstances that do not lead to an infringement on work proposed by others, and when the changes are in keeping with the spirit of the original, refereed proposal. These rules are fundamental to the integrity of the observing system at NRAO and are taken very seriously by the management.

1.6 OBSERVATORY POLICY

1.6.1 STAFF RESPONSIBILITIES

The following is the responsibility of the NRAO staff:

- To insure that the equipment needed for your observations is available and installed at the telescope.

- To tune the receiver to the desired frequency.

- To provide sound telescope pointing.

- To provide you with fundamental telescope calibration parameters -- efficiencies, beamwidths, gain curves -- at standard observing frequencies.

- To provide advice on observing strategies, if requested.

1.6.2 OBSERVER'S RESPONSIBILITIES

As a visiting observer, you have the responsibility for proper supervision of all aspects of the observing program. This includes:

- Providing to the NRAO staff, well in advance of the time scheduled, a full description of the equipment needed for the observations as well as a complete list of frequencies to be observed. Usually this information is included on the proposal cover sheet.

- To verify the telescope pointing and fine-tune it as needed.

- To obtain all calibration and other receiver/telescope parameters necessary for data reduction. This can be done either by adopting or scaling the NRAO-provided information from standard frequencies, and/or by making the appropriate measurements. In either case, proper data calibration is your responsibility, not the NRAO's.

- To inform the NRAO staff, before the observing period has ended, about the types of data to be written on an export tape for him, and the format of the export tape.

In addition, you are requested to provide feedback on the observing run via the "Observer's Comment Sheet," available at the telescope, and in the *Preface*.

1.6.3 MAINTENANCE AND REPAIRS

One period each week is assigned to preventive maintenance and routine system tests. This period normally runs from 0900 MST to 1600 MST, and is most frequently taken on Wednesday.

If during a scheduled observing period a catastrophic failure of the instrument occurs which results in a loss of data, observations will be stopped and the NRAO technical staff will attempt to repair the equipment. In less serious cases where data-taking continues but where the quality of the data is not optimal, it is your responsibility to decide whether or not you wish to give up telescope time so that repairs can be made.

Only the Tucson Site Director or, in his absence, the Deputy Director can make the decision to interrupt scheduled operations to make non-essential repairs.

1.6.4 SHARING TELESCOPE FACILITIES WITH OTHER OBSERVING TEAMS

Since living quarters and work spaces at the telescope are limited, you should leave the mountain as soon as possible at the end of your run, allowing, of course, for a reasonable period of rest. If you wish to continue the reduction of your data sets, you should do so at the NRAO Tucson office, where a VAX 11/750 computer system identical to the analysis computer at the telescope is maintained.

When two or more observing teams are sharing observing time, the team currently observing has priority to all telescope facilities, including computer usage. The other observing teams should endeavor to stay out of the control room and not interfere in any way with the ongoing observations. Unless one group of observers is declared the "prime observer" on the telescope schedule, equipment changes needed for a program will be done at the beginning of that program's time.

1.6.5 OBSERVATIONS UNDER POOR WEATHER CONDITIONS

1.6.5.1 GENERAL

The operator on duty has the primary responsibility for the safety of the telescope, the dome, and the personnel in the dome.

1.6.5.2 HIGH WINDS

If the wind exceeds 15 mph, observations will be restricted to those quadrants where the telescope drive motor currents are not excessive.

If the steady wind, or the average of gusty wind, exceeds 35 mph the dome door must be closed. Observations can be continued through the side of the dome.

For winds above 45 mph, the dome door must be positioned 180° from the direction of the wind and held fixed. Observations can continue through the side of the dome, but the dome cannot be moved.

If the wind exceeds 55 mph operations must cease and the telescope must be placed in the service position with the stow pins in place.

1.6.5.3 MOISTURE CONDENSING ON ANTENNA; FOG IN DOME

If there is fog in the dome, or if moisture is condensing on the antenna or equipment, the dome door will be closed. Observations can continue through the side of the dome.

1.6.5.4 BUILD-UP OF SNOW OR ICE ON THE DOME

If there is a build-up of snow/ice on the dome, the accumulated snow/ice must be cleared from the dome door before observations can resume.

1.6.5.5 SUN ON THE DISH

The pointing and focus of the dish can be seriously affected if the sun is allowed on the surface of the dish or the feed support legs. If accurate pointing is desired, care must be taken to keep the sun off the dish.

To avoid excessive heating of the feed legs, the prime focus regions, and the cables to the prime focus, the dish will not be pointed to within one hour in right ascension or 15 degrees in declination of the sun.

1.6.6 OBSERVATIONS USING EMERGENCY POWER GENERATORS

The telescope and dome have three sources of electric power - the commercial source and two power generators. Observations can continue as long as at least two of the sources are operational. If only one source of power is available, the dome door must be closed.

1.6.7 SAFETY RULES

The following safety rules obtain at the 12 m telescope site. We expect all observers and visitors to the site to read and abide by these rules.

1.   To drive a GSA car, you must possess a valid driver's license.

2. The Telescope Operator on duty is the only person allowed to operate the telescope.

3. Observers are not to be on the telescope unless the duty operator has specifically authorized them to be there.

4. Safety chains and rails have been installed at the entrance to the observing rooms. They are there to prevent you from walking into any possible pinch points or dangerous areas.

5. Do not stand in the *red* areas because parts of the telescope and dome that move in those areas could injure you severely.

6. Do not touch the yellow curtains around the inside wall of the dome. Behind them are *exposed* 480-volt lines.

7. Please abide by all printed and posted safety rules such as "No Smoking" and "Do Not Enter This Area" posters, etc.

8. Only the telescope operator or other qualified Arizona employees are allowed to operate the 'cherry picker'. Observers may ride in the cherry picker if authorized to do so by the duty operator.

9. Hard hats are required for all persons in the dome area if someone is working above or in the cherry picker. The hats are located on the wall just outside of the observing room door.

10. When walking outside to the dormitories or the lab at night, please be sure to carry a flashlight. You may encounter steps, drop-offs, or snakes.

11. The consumption of alcoholic beverages or illegal drugs is absolutely forbidden in the lab and telescope/control room areas.

12.   All employees and observers are required to wear seat belts while riding in government vehicles.

13.   Ice, rocks, and rock slides are frequently a hazard on the roads and walkways. Cattle and horses cross Highway 386 and several have been hit. Please drive and walk carefully.

14.   Please drive *very slowly* and carefully in all NOAO and NRAO parking or road areas. Pedestrians, including small children seem to leap out at cars on a regular basis.

15.   A more complete list of safety rules and recommendations is available in the observers' lounge and from the telescope operator. You might find it interesting reading, although not required.

CHAPTER 2
GETTING STARTED

2.1 WHAT TO BRING TO THE TELESCOPE

Your observations will be more efficient and you will achieve better results if you have thoroughly prepared for the run before arriving at the telescope. Most of this work should be done at the time the proposal is written (see Chapter 1).

2.1.1 SPECTRAL LINE OBSERVATIONS

For spectral line observations, you should prepare the following before coming to the telescope:

A)   A *source list* with 1950 RA and Dec or (ℓ_{II}, b_{II}) Galactic coordinates, and the *LSR velocities* for each spectral line source. Keep in mind that the beam sizes for the 12 m can be quite small (20") at some frequencies so the positions should be appropriately accurate. If the source list is lengthy (say >30 objects), the observer can save time by typing the list prior to the run. This can be done in DOS text format and brought on 5.25" floppy diskette or typed into the VAX and transferred to the IBM PC. Otherwise, the positions can be typed into the PC at the start of the run (see Chapter 5 for the format of source entries).

B)   The *line rest frequencies* to an accuracy of 10 kHz. If emission lines are weak, *test line* frequencies should be included.

C)   The *sideband* choice, if the observations are being made with a double sideband receiver. The considerations for this choice include receiver tuning restrictions, the presence and location of lines in the image sideband, and the presence of atmospheric absorption lines.

D) The *observing mode.* Options are i) position switching, ii) absolute position switching, iii) frequency switching, iv) beam switching, v) position switched mapping, and vi) total power mapping. The reference offset position, in angle or frequency, should also be considered.

E) The *filter banks* and *hybrid spectrometer,* including the resolution and the mode of operation (series or parallel for filter banks). This decision hinges on the resolution and total bandwidth required. No firm rules exist, but the minimum resolution acceptable should probably give 3 - 5 channels across the line and the minimum bandwidth should have 10 - 20 % of the band on each side of the line.

2.1.2 CONTINUUM OBSERVATIONS

For continuum observations, you should prepare the following before coming to the telescope:

A) The *source list* in 1950 RA and Dec or (ℓ_{II}, b_{II}) Galactic coordinates. If the list is long (say >30 sources), time can be saved by punching the list onto IBM cards prior to the run. Otherwise, the list can be entered into the control computer at the start of the run. The format for source entry is given in Chapter 5.

B) *Observing Frequency.* For double-sideband observations, this is usually the local-oscillator frequency. If there is any possibility of spectral line contamination of the observations, choose an L.O. frequency such that no strong spectral lines lie in either receiver sideband.

C) *Observing Mode.* Modes supported are switched or total power ON/OFF's, five-point mapping, azimuth mapping scans, or drift scans. Consider carefully the optimum beam separation for beam-switched observations. The default values are 4' at 3 mm wavelengths, and 2' at higher frequencies.

2.2 START-UP CHECKLIST

Start-up checklists are given below for both spectral line and continuum observations. Although the Observatory staff tries to provide a fully functional system and advice about calibration constants and procedures, the responsibility for the integrity of the data rests with the observer. These checklists help insure that the system is configured properly and that variable quantities such as pointing and focus are properly set. Completion of these checklists may take an hour or more, but the time will be well-spent.

2.2.1 GENERAL START-UP

The following checks should be performed first, whether the program is spectral line or continuum observing.

1. Prepare a source list on the IBM PC and transfer the catalog to the PDP 11/44 control computer. (See Chapter 5 for details.)

2. Have the operator tune the receiver to the desired frequency, including sideband and harmonic checks. This operation can often be done in parallel with item (1).

3. Ask the operator to load the continuum observing task (DBE) in the control computer. Select a strong continuum source from the list of standard sources (see Chapter 4). A bright planet (i.e., Venus, Mars, Saturn, or Jupiter) is preferable. Pick one whose position is near the first program source, if possible.

2-3

4.   Ask the operator to perform a Five-Point Map of the source to check for pointing offsets. Records of recent pointing offsets are kept on graphs near the observer's console and can be used to estimate an initial value for the pointing. The operator will need to know the map grid spacing (called HP and usually set to 1/2 the beam FWHM) and the integration time per point. A detailed discussion of telescope pointing characteristics is given in Chapter 4. Data reduction commands for Five-Point analysis are given in Section 6.7.1 If the fit to the Five-Point is poor, repeat the map with updated pointing.

5.   Ask the operator to perform a "FOCALIZE" on the source. This checks for the best value of the radial focus. The FOCALIZE requires that you specify a first guess for the focus position (called F0) and the spacing between the focus settings (called WL). The operator or the "Friend of the Telescope" can tell you a reasonable first choice for F0 (usually around 42.0 mm). WL is usually chosen to be 1/2 the observing wavelength. (See Chapter 4 for more focus information and Section 6.7.2 for data reduction commands.) If the fit to the FOCALIZE is poor, repeat the observation with an updated value of F0.

6.   Check the pointing offsets at another elevation. Pointing offsets depend strongly on elevation angle. If possible, check pointing on a low and high elevation source and enter the results on the pointing charts.

     Note Bene: Pointing and focus may change as the temperature of the dish (or parts of the dish) changes. Pointing and focus should be checked (at least) after nightfall and daybreak and more frequently if the dish is illuminated by the sun.

2.2.2 SPECTRAL LINE OBSERVATIONS

The following checks are to insure that the receiver is tuned correctly, the spectrometer is properly configured, and the calibration scale is correct.

1. If the program line is weak and no other strong lines are in the bandpass, tune first to a strong test line that is as close by in frequency as possible. "Strong" means any line that will produce a good signal-to-noise spectrum in a 5 - 10 minute integration, for example. Standard sources are listed in the NRAO Standard Catalog #1. (1 NRAO) If possible, use the same observing setup (same sideband, spectrometer mode, and observing mode) as will be used for the program observations. If the observations are of a common species, such as CO, there is no need to tune to another line.

2. Perform a calibration scan and check for bad channels in the filter banks (see Section 2.3.3, notes 3 and 4). Report the bad channels to the operator, who will zero those channels in the control system software.

3. Observe a test line in a strong source. Observers may wish to verify the sense of the velocity/frequency scale by shifting the rest frequency or center velocity by a small amount and seeing if the line moves in the correct direction for the sideband choice. If the observing setup is complicated, for example involving offset oscillators, take special care.

4. Check that the temperature calibration is correct. This can be done by observing a standard source, presuming that the test line has known strength.

2.2.3 CONTINUUM CHECKLIST

The continuum checklist is mostly completed in the General Start-up Checklist, particularly if the observations are to be ON/OFF's of point sources. If you will be making maps, observe a calibration source first, both to check the mapping algorithms and to establish beam-switching geometry and the calibration scale.

2.3 BASIC DATA REDUCTION COMMANDS

Two other manuals, one for spectral line and one for continuum, describe the data reduction systems at use at the 12 m. These are available upon request. The discussion below is intended only as a quick reference list to help the observer get started.

2.3.1 STARTING THE REDUCTION PROGRAMS

Before observations begin, the operator will set up a VAX disk subdirectory containing data files. This subdirectory is private to each observing team, and is denoted by [OBS.ini], where ini are the 3 letter initials of the lead observer. The data files in this subdirectory are also labeled with the same initials.

If, when first sitting in front of the terminal, you find the > prompt symbol displayed, one of the reduction programs is currently running, probably left over from the last observer. Terminate execution of the program by typing EXIT. The screen will then display the $ prompt, indicating that the terminal is awaiting a VAX command. Log out of the VAX by typing LOG. To log in to your own subdirectory, hit the ENTER key (carriage return), and respond to the prompt *Username:* by typing OBS. You will then be prompted for your initials, discussed above. If you are uncertain as to what subdirectory you are in, type SHOW DEF and the VAX will respond with the name of the area in the format [DIRECTORY.SUBDIRECTORY].

The reduction program for spectral line data is called *LINE* and the continuum reduction program is called *CONDAR*. The *LINE* program can perform several basic continuum data reduction functions, such as a Five-Point Map display, Focus check display, and an ON/OFF sequence display. Hence, spectral line observers will probably not need to use *CONDAR*.

In the command lines below, a carriage return at the end of the line is implicit.

To start the continuum program from the $ prompt, type

    CONDAR

You will be prompted to enter your initials.
To start the spectral line program from the $ prompt, type

    LINE

Again, you will be prompted to enter your initials.

2.3.2 CONTINUUM (CONDAR) COMMANDS

You can execute some of the *CONDAR* functions listed below from the *LINE* program. When you can execute the functions from either program, they are identified by "*CONDAR*" or "*LINE*"; otherwise, the functions execute only from *CONDAR*. The *LINE* commands are often slightly different from the *CONDAR* commands because of pre-existing commands of the same name. For data with two receiver channels, the scan number will increment by two each time a scan is taken. The first number (usually even) refers to Channel 1 and the second (odd) to Channel 2.

2-7

1. Five-Point Map Display

Get the center scan number from the operator (it will be the final scan number minus 4 for two-channel data. Type

       `center_scan_number F`   *(CONDAR)*

       `center_scan_number CF`   *(LINE)*

> EXAMPLE 2.1 --   Display a continuum Five-Point map with center scan 5306 from the spectral line program:
>
>   5306 CF

2. Focus Check Display

Type

    `scan_number FOCALIZE`

FOCALIZE can be abbreviated FOCA.

> EXAMPLE 2.2 --   Display the focus fit for FOCALIZE scan 4812:
>
>   4812 FOCA

3. Display of ON/OFF Sequence

Type

    `scan_number S` *(CONDAR)*

    `scan_number CS1` *(LINE)*

> EXAMPLE 2.3 --   Display an ON/OFF sequence for the second
> channel of scan 2662/2663 from the continuum
> program CONDAR:
>
>   2663 S

4. Stacking (averaging) Scans

a) First load the STACK array with the scan numbers to be averaged. Do this
by typing

     EMPTY

to clear the array of any previous entries. Then type

     `scan_number A`

to add a single scan number to the stack, or

     `beginning_scan   ending_scan   ADD`

to add a range of scan numbers to the stack.

b) To average and display the scans, type

     C1   (*CONDAR* only)

for Channel 1 data,

     C2   (*CONDAR* only)

for Channel 2 data, or

CB   (*CONDAR* only)

for an average of Channel 1 and Channel 2 data. Both channels should be on the same calibration scale to use CB.

EXAMPLE 2.4 --   Stack scans 1208 to 1236 and display the first channel:

1208 1236 ADD

C1

2.3.3 SPECTRAL LINE (LINE) COMMANDS

The spectral line system always records data from two 256 channel filter banks. For each observation, the scan number will increment by two. The first number scan number (usually even) labels the first filter bank and the second scan number the second bank.

1. To display a spectrum from the first filter bank, type

scan_number   F

2. To display a spectrum from the second filter bank, type

scan_number   S

2-10

> EXAMPLE 2.5 --   The scan number displayed on the on-line status monitor is 2604. To display the first filter bank, type
>
> 2604   F
>
> To display the second filter bank, type
>
> 2604   S

Note that the procedures F and S use the same scan number. If the scan is still in progress, the data transferred to that moment will be displayed. Note that in some observing modes such as frequency switching, no data are transferred until the end of the scan.

3.   To display the chopper wheel calibration array, called the "GAINS," type

      G1

for the most recent calibration scan in filter bank 1, or

      scan_number GGET XX

for an earlier calibration scan. Similarly, to display a calibration scan for the second filter bank, type

      G2

or

      scan_number GGET XX

where this time, the scan number is that associated with the second filter bank (= first filter bank scan number + 1).

4. To eliminate a bad channel from a GAINS or spectrum, display the spectrum then type

    BADCH

    You will be prompted to enter the number of bad channels to be eliminated. Enter this, then move the vertical cross hair to each bad channel and strike any key but RETURN. At the end, this procedure will print out the channel number of each bad channel. The observer should report these to the operator, who will zero them in the control system software.

5. To stack (average) scans, first load the stack array. Do this by first typing

    EMPTY

    to clear the array of previous entries. Then type

    scan_number A

    to add a single scan number to the stack, or

    beginning_scan   ending_scan   ADD

    to load a range of scan numbers. To display an average of all data for the first filter bank, type

    C1

    For the second bank, type

    C2

For an average of both banks, type

      CB

Use **CB** only when the two filter banks are of the same resolution.

6.   To look at a scan in progress, type

        scan_number Q1   for the first filter bank, or

        scan_number Q2   for the second filter bank.

These commands display the data transferred to disk up to that moment.

CHAPTER 3
INSTRUMENTATION

3.1 SITE PLAN

The 12 m 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 25 m VLBA antenna and the McGraw-Hill Observatory 1.2 m and 2.4 m optical telescopes. A drawing of the 12 m site layout is given in the *Visitor's Guide*.

3.2 DOME FLOOR PLAN

Three rooms are available in the dome for observer use. During a 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 computer terminal and a light table. A third room is available for work, data reduction, 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 workroom 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 data reduction area in the lounge.

3.3 TELESCOPE OPTICS

The 12 m employs "bent Cassegrain" optics for virtually all 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 m paraboloid of 72 aluminum panels. The position of each panel can be adjusted by stand-off bolts. The subreflector (secondary mirror) is mounted at the prime focus and is supported by a quadrupod feed leg structure.

3-1
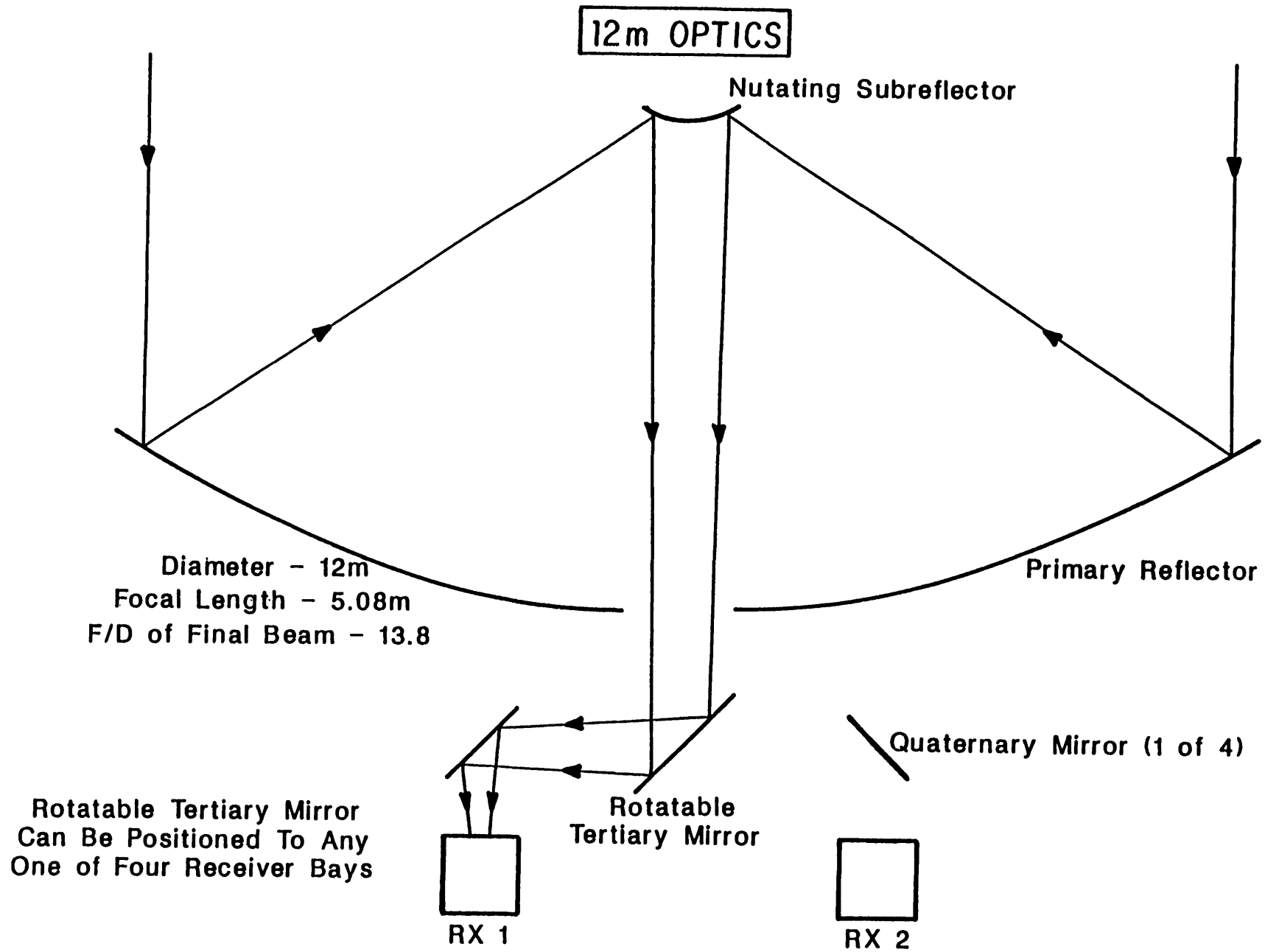
FIGURE 3.1   12-M TELESCOPE OPTICS

The subreflector 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. The feed horn of the noise source protrudes from a hole in the center of the subreflector. The subreflector is a machined aluminum hyperboloid, which has been shaped to compensate for aberrations and setting errors in the primary.

The subreflector box is located in a Focus-Translation Mount with three degrees of freedom of movement. The subreflector can be moved in and out along the radio axis to adjust for radial 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 flat 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. Position readouts are available on the telescope or in the control room.

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 subreflector position and the mirrors are adjusted so that the laser beam spot is centered on the receiver lens. The beam also may be autocollimated at the subreflector to achieve the most precise alignment.

3-3

3.4 SYSTEM ELECTRONICS

A block diagram of system electronics for the 12 m is given in Figure 3.2.

3.5 RECEIVER ELECTRONICS

All of the receivers in use at the 12 m are heterodyne mixers (sometimes called "coherent detectors"). Two types of mixers are used, Schottky barrier diodes and superconducting (SIS) junctions. A local oscillator (LO) signal 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 Schottky mixers generally operate in a double sideband (DSB) mode, meaning that the IF signal corresponds to sky frequencies both above and below the LO frequency. The lower sideband (LSB) frequency $\nu_{LSB} = \nu_{LO} - \nu_{IF}$. The upper sideband (USB) frequency is given by $\nu_{USB} = \nu_{LO} + \nu_{IF}$. For continuum work, the sensitivity of the mixer is usually best in the double sideband mode. For most spectral line work only one sideband is of interest (exceptions to this do exist, particularly for detection work). Some of the SIS junctions used at the 12 m have tunable backshorts, which can be adjusted to resonantly cancel the unwanted sideband, and are essentially single sideband (SSB) mixers.

A more detailed description of individual receivers is given in the following.

3.5.1 90 - 116 GHz SIS MIXER RECEIVER

The 90-116 GHz SIS receiver is a superconducting junction receiver with two orthogonal linear polarization channels. The junctions are housed in a hybrid cryostat consisting of an inner, liquid helium dewar surrounded by a standard cooled, gaseous helium cavity. The junctions are attached to the exterior of the liquid helium dewar by copper heat straps or "fingers." The inner dewar is filled with liquid helium and

3-4

ANTENNA

342 MHz BASEBAND

I.F. DISTRIBUTION CHASSIS

DIAL-UP MODEM

TUCSON VAX, NRAO DECNET

AZIMUTH SHAFT ANGLE RESOLVER (INDUCTOSYN)

ELEVATION SHAFT ANGLE RESOLVER (INDUCTOSYN)

RECEIVER

IF PROC.

MOUNT

DETECTED TOTAL POWER

FILTER BANKS

TERMINALS (5)

LASER PRINTERS (2)

LINE PRINTER

I.F. SYNTH.

FLUKE DRIVER LO SYNTH.

ANALOG CONTINUUM BACKEND

512 CHANNEL MULTIPLEXER

MODGRAPH TERMINAL

SUBREFLECTOR DRIVE, RADIAL FOCUS, NORTH-SOUTH TRANSLATION STAGE, POLZ. ROTATION, TEMP. SENSORS

ANTENNA DRIVE CONTROL AND AMPLIFIERS

RUBIDIUM FREQUENCY STANDARD

CHART RECORDER

OBSERVER'S CONVERSATION

AZ INDUCTOSYN DIGITAL READOUT

EL INDUCTOSYN DIGITAL READOUT

AZ CORR.

EL CORR.

DIGITAL CONTINUUM BACKEND

PDP 11/44 CONTROL COMPUTER

DATA LINK

VAX 11/750 ANALYSIS COMPUTER

DIGITAL MULTIPLEXER (DMUX I)

DAC DAC OMNIVERTER

DIGITAL MULTIPLEXER (DMUX II)

STATUS

VT05 CRT

FROM DIGITAL BACKEND

RL02 DISKS (2)

OPERATOR'S CONVERSATION

STATUS MONITORS (3)

800, 1600 BPI TAPES

TO PDP 11/44

POSITION THUMBWHEELS

VT102 TERMINAL

DIGITAL UT CLOCK

ALARM PANEL

800 BPI TAPE

LA 120 TERMINAL (HARDCOPY)

RA81, RA60 DISKS

FIGURE 3.2   NRAO 12M SYSTEM BLOCK DIAGRAM (FEB. 1988)

then pumped to low pressure by a vacuum pump to achieve temperatures as low as 2.8 K. The liquid helium "hold-time" is about 3 days. About 30-45 minutes are needed to replenish the helium.

The SIS junctions in use are niobium (Nb) based, and can be tuned to be single or double sideband. These mixers have tunable backshorts in the mixing cavity that can be set to reject the image sideband to ≥ 20 dB. A harmonic generator can be switched into the optical path for precise measurement of sideband rejection. The noise temperature is about 100 K (SSB). Gunn oscillators are used as the LO source. A block diagram of the optics for the 90-116 GHz SIS receiver is given in Figure 3.3. A block diagram of the electronics for the SIS receiver is given in Figure 3.4.

Beam From
Secondary

Low-Loss Foam Window

Polarization Diplexing
Wire Grid

Polarization Rotating
Roof Top Reflector

Teflon Lens

Teflon Vacuum
Window

Corrugated Feed Horn
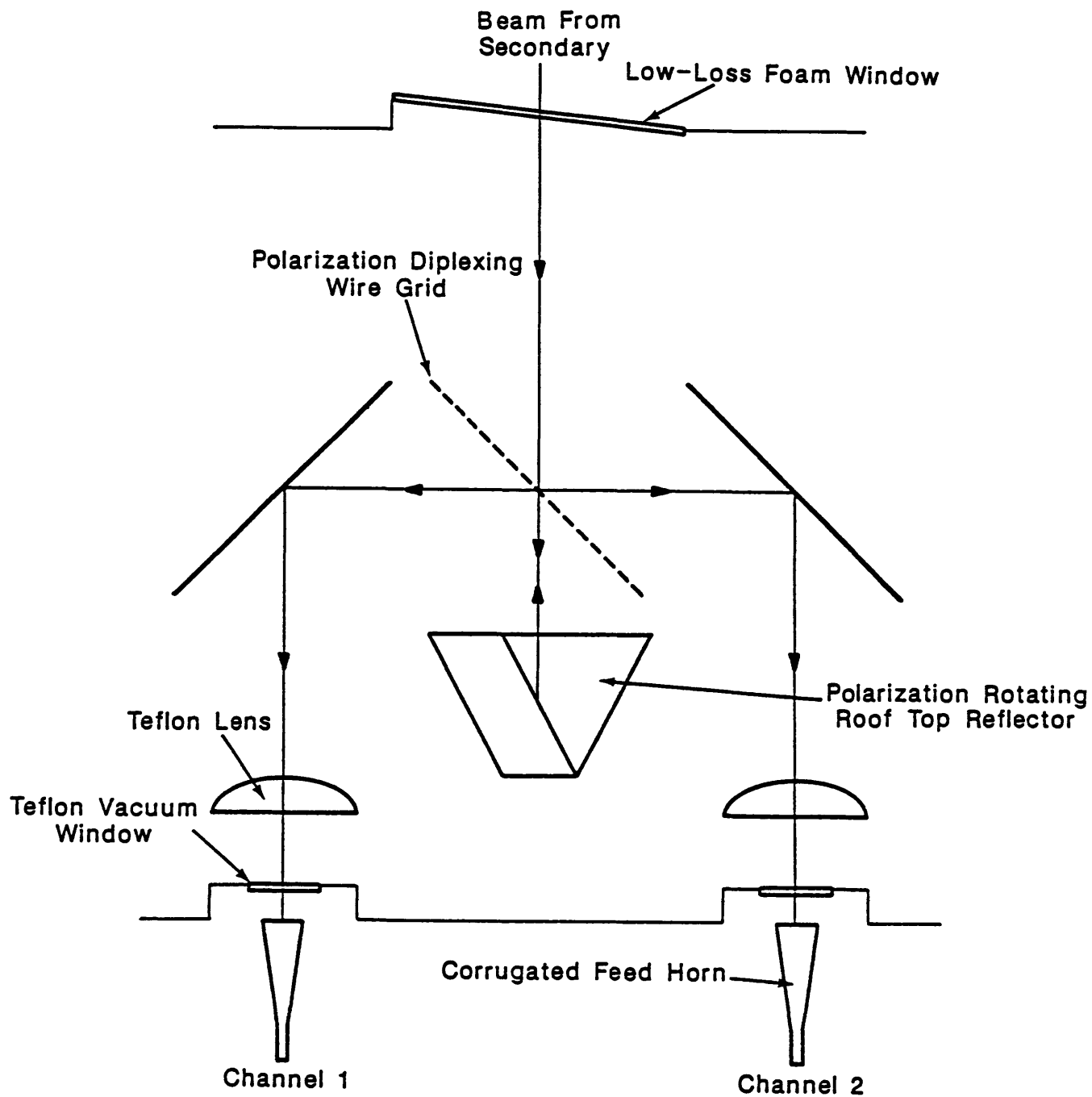
Channel 1

Channel 2

SIS 90 – 115 GHz RECEIVER OPTICS
(not to scale)

FIGURE 3.3

TO OTHER CHANNEL

REMOTELY CONTROLLED
ATTENUATOR

3 dB
SPLITTER

PHASED
LOCKED
GaAs GUNN
(90–115 GHz)

70K STAGE
20K STAGE
4K STAGE

SIS
MIXER

AUXILLARY BACKSHORT

SERVO
DRIVES

MAIN BACKSHORT

TO IF
PROCESSOR

WINDOW

WAVEGUIDE
GAP

16 dB
COUPLER

BIAS
T

1.2–1.8 GHz
HEMT / GaAs FET
IF AMPLIFIER

GaAs FET
POST AMPLIFIERS

DC BIAS
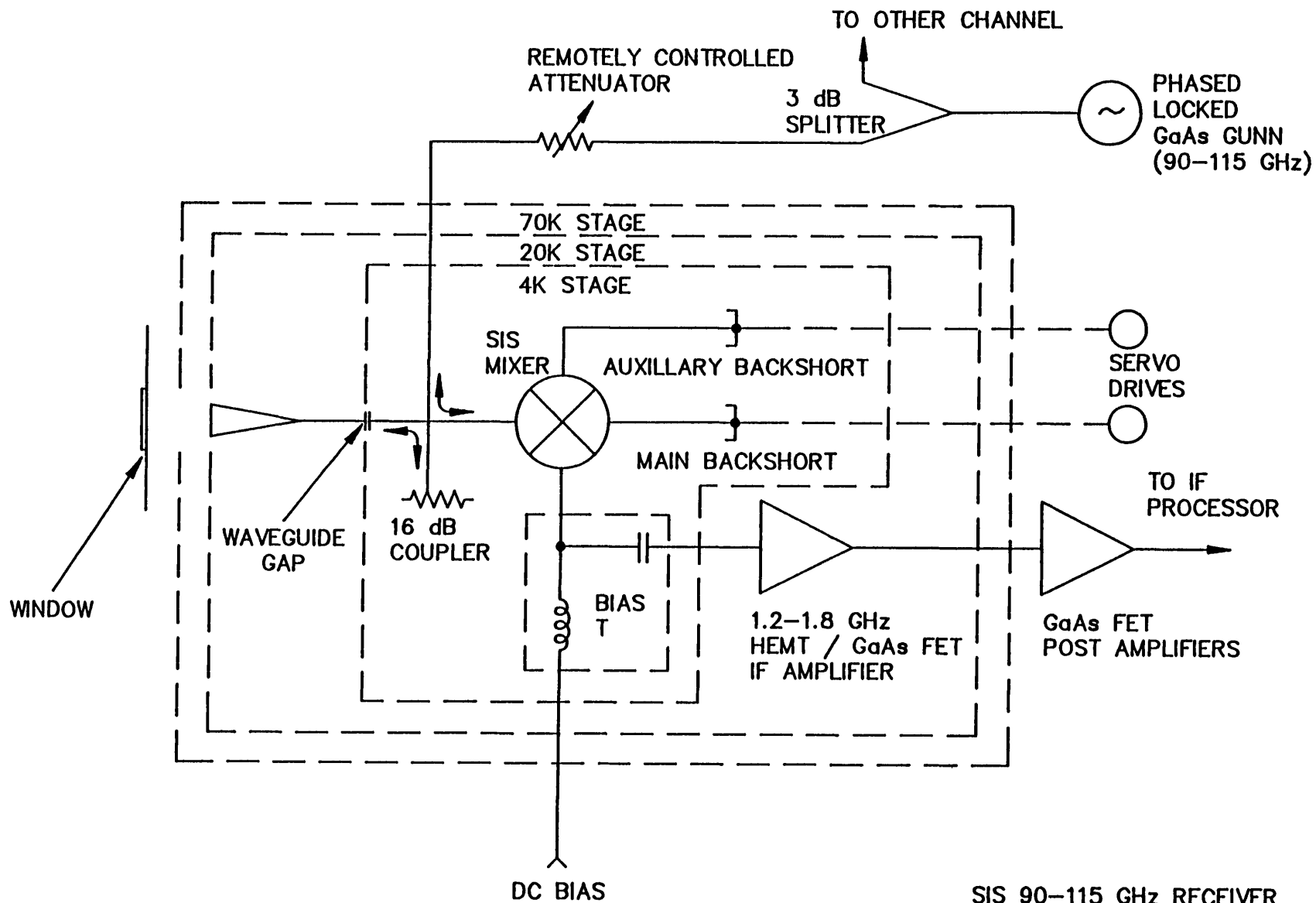
SIS 90–115 GHz RECEIVER
BLOCK DIAGRAM
1 OF 2 IDENTICAL CHANNELS

FIGURE 3.4

3.5.2 200 - 250 GHz SIS RECEIVER

The 200-250 GHz SIS receiver, new at this writing (Summer 1990), is a dual polarization receiver with a single sideband noise temperature of ~150 K in each channel. The two orthogonally-polarized receiver sections are housed in a single, 8-port dewar. The dewar is part of a closed cycle cryostat with temperature stages of ~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. This receiver has double-sideband response. Receiver tuning is done via a computer. Ask the 12 m staff for the latest information about this receiver.

3.5.3 200 - 360 GHz SCHOTTKY MIXER RECEIVER

The 200-360 GHz Schottky receiver utilizes four pairs of independent mixers. The first pair covers 200-240 GHz, the second 240-270 GHz, the third 270-310 GHz, and the last 330-360 GHz. Each band has dual orthogonal linear polarization channels. The cryostat housing these mixers has 8 mini-dewars, intended to provide four dual-polarization mixer pairs. Because of cryogenic limitations, it is usually not possible to have all four mixer pairs cooled at the same time. The local oscillator signal is injected via a quasi-optical diplexer assembly above the dewars. The injected LO signal is first tripled in frequency from its fundamental in the 3 mm band by a waveguide tripler. The diplexer assembly can be rotated to inject the RF and LO signals into the appropriate mini-dewars. This procedure takes about 30 minutes, not including time to retune the receiver from the control room. Gunn oscillators are used as the LO source. The mixers operate in a double sideband mode. Noise temperatures range from 250 K (DSB) in the low frequency band to 800 K (DSB) in the high frequency band (in each polarization channel). A block diagram of the dewar and optics arrangement for the 200-360 GHz receiver is given in Figure 3.5, and a diagram of the receiver electronics is given in Figure 3.6.

Dual Polarization
Martin–Puplett Diplexer

RF Input

Rotary Table

30" Long

Main Dewar

1 of 8 Sub–Dewars

18" Diameter
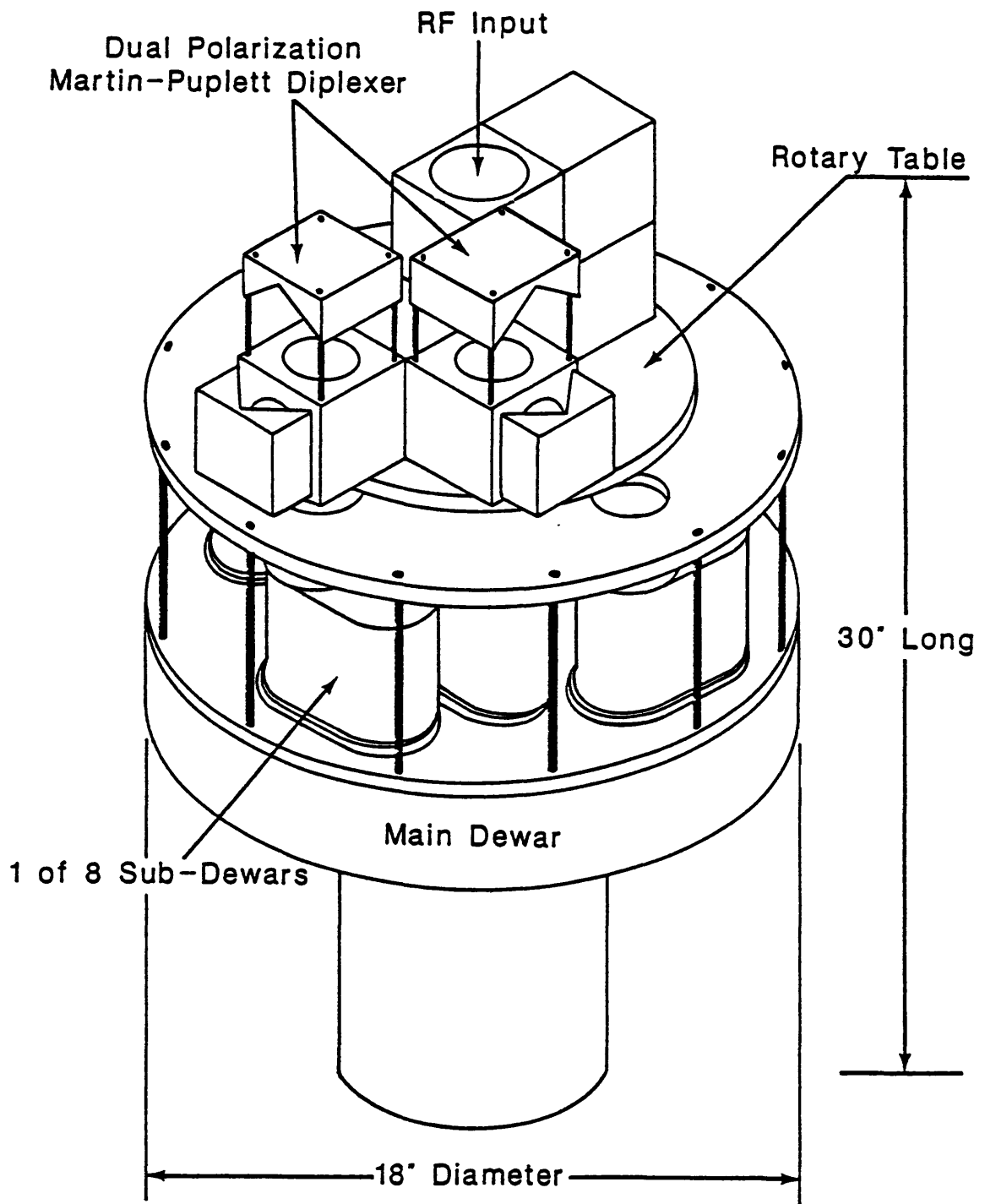
200 – 360 GHz Receiver Optics Assembly

4 Pairs of Sub–Dewars Cover:
200 – 240 GHz
240 – 270 GHz
270 – 310 GHz
330 – 360 GHz

FIGURE 3.5 — BLOCK DIAGRAM OF DEWAR AND OPTICS
FOR THE 200 – 360 GHz SCHOTTKY RECEIVER

INPUT SIGNAL FROM
QUATERNARY

OPTICS ROTATE TO
SELECT ONE OF FOUR
PAIRS OF SUB-DEWARS

POLARIZATION
1

POLARIZATION
2

TUNE CONTROL → MARTIN–PUPLETT INTERFEROMETER

LO SPLITTER
AND
POLARIZATION
SPLITTER

MARTIN–PUPLETT INTERFEROMETER ← TUNE CONTROL

TEFLON LENS

LO INPUT

SUB-DEWAR

X3 FOR 200–270 GHz

MIXER

X4 FOR 330–360 GHz

HEMT AMPLIFIER

PHASE LOCKED GUNN

COAXIAL SWITCH
TO SELECT SUB-DEWAR

INPUTS
FROM THREE
OTHER SUB-DEWARS

IF AMPLIFIER

POL 1 IF OUTPUT

POL 2 IF OUTPUT

SIMPLIFIED BLOCK DIAGRAM
OF 200–360 GHz RECEIVER

FIGURE 3.6 -- BLOCK DIAGRAM OF THE ELECTRONICS FOR THE 200 - 360 GHz SCHOTTKY RECEIVER

3.5.4 EIGHT-BEAM, 1.3 MM SCHOTTKY RECEIVER

The Eight-beam, 1.3 mm Receiver is designed for rapid mapping of spectral lines in the 215 - 240 GHz range (notably J=2→1 CO and its isotopes). The receiver places 8 independent beams on the sky in a 2 x 4 array; each beam is separated from its nearest neighbor by 87" (see Figure 3.7). The FWHM of each beam at 230 GHz is ~30", hence the telescope must be stepped in position to fill in the beams if Nyquist sampling is desired.

The receiver is made up of two independent cryostats, each housing four Schottky mixers. The LO is supplied by a single Gunn oscillator, but with separate triplers for each cryostat. Figures 3.8 and 3.9 show additional depictions of the receiver hardware.

The Eight-beam receiver is intended for use with the Hybrid Spectrometer and Eight Channel IF processor. The Hybrid Spectrometer and IF processor can accept 8 IF channels of 300 MHz or narrower bandwidth, or 4 IF channels of 600 MHz bandwidth.
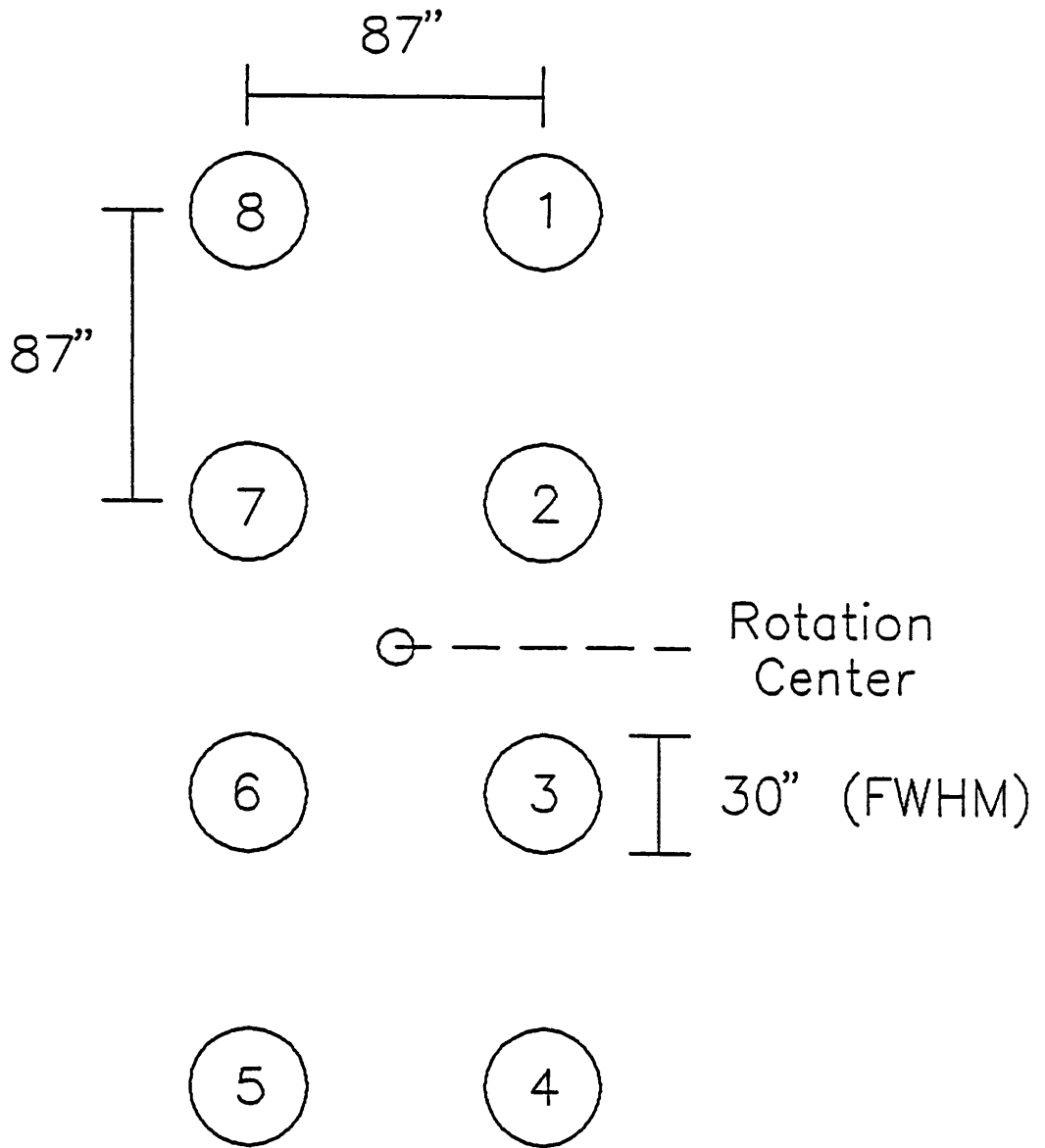
BEAM CONFIGURATION FOR
EIGHT−BEAM RECEIVER

FIGURE 3.7 — BEAM RELATIONS FOR THE 230 GHz, 8−BEAM RECEIVER

8 BEAMS FROM SUBREFLECTOR

OPTICAL POWER
DIVIDER

LO INPUT
FROM TRIPLER

DIPLEXER

BEAMS 5-8

4 BEAMS TO DEWAR
(LO + SIGNAL)

BEAMS 1-4

ROTATES FOR
BEAM ROTATION
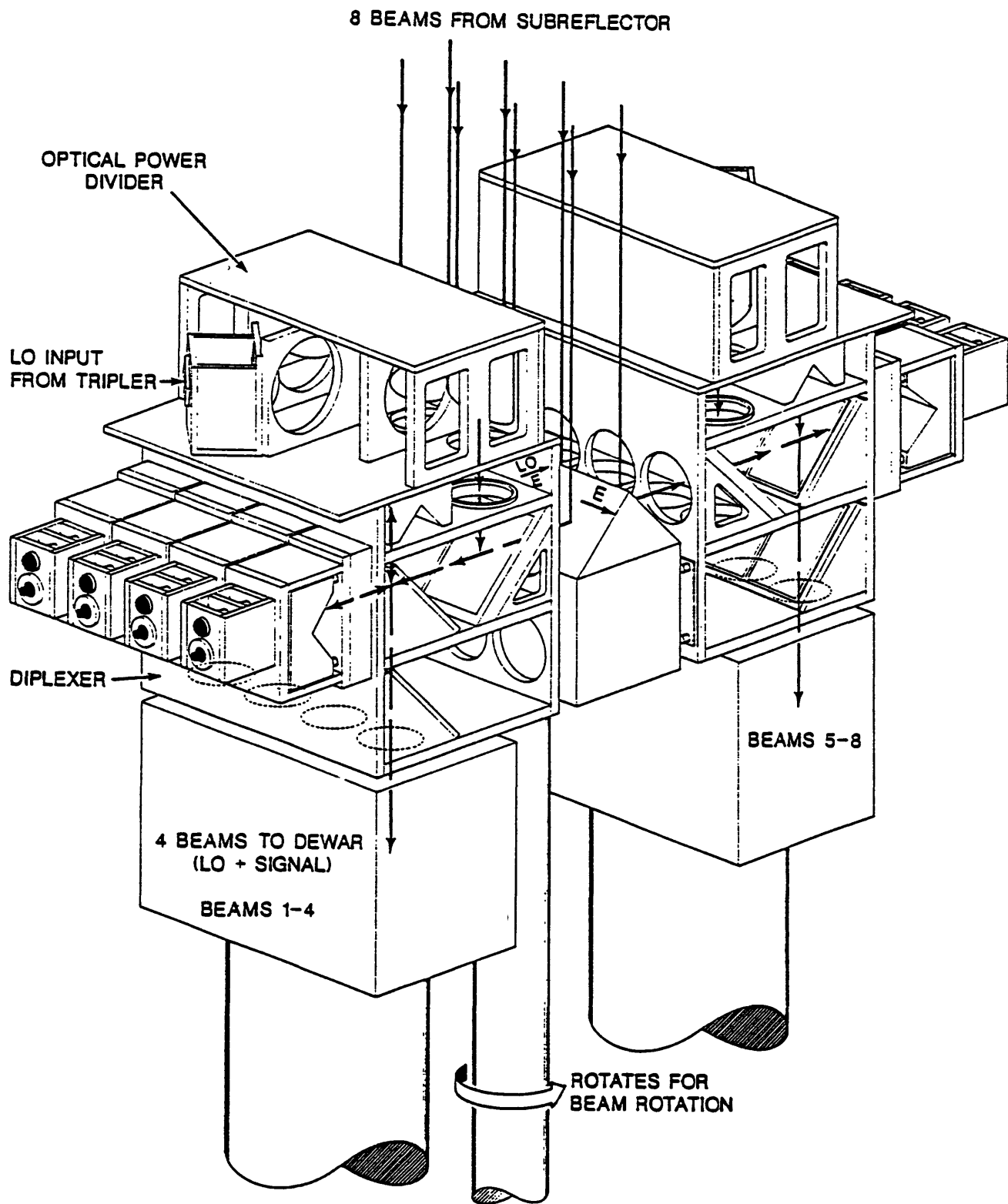
FIGURE 3.8 — EIGHT-BEAM RECEIVER (DEPICTION 1)
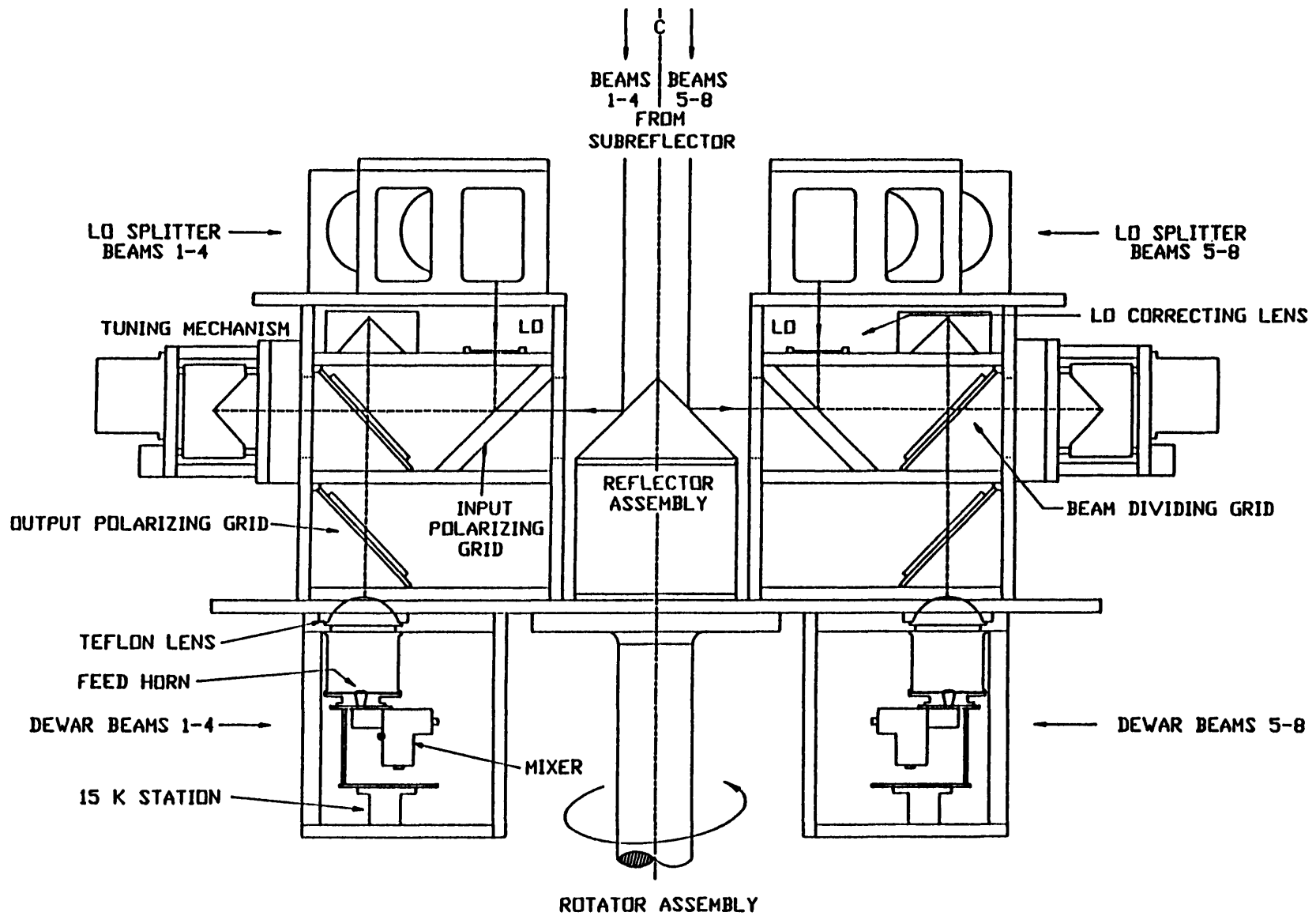
FIGURE 3.9 -- EIGHT-BEAM RECEIVER (DEPICTION 2)

3.5.4.1 EIGHT-BEAM ROTATOR AND POSITIONING CONVENTIONS

The entire eight-beam receiver cryostat and optics assembly is housed in a precision rotation mechanism which can rotate the orientation of the array of beams to an arbitrary angle on the sky. Thus, the array may be positioned to take advantage of a particular source geometry. Furthermore, the eight-beam rotator can then track parallactic angle so that as the source moves across the sky in hour angle, the orientation of the array is the same in the RA-DEC frame (because the 12 m is an AZ-EL telescope, parallactic angle rotation must be taken into account). **The rotation center of the array is defined to be its geometric center, i.e., the center of the box defined by Beams 2, 3, 6, and 7.**

Three different angles come into play in describing the positioning and movement of the rotator: (1) *the rotator control angle*, (2) *the source parallactic angle*, and (3) *the user-defined position angle*.

3.5.4.1.1 ROTATOR CONTROL ANGLE

The engineering staff has defined an angle convention describing the rotation of the 8-Beam rotator relative to its position encoders. This angle is displayed on an LED digital readout on the Rotator control chassis. The convention is stated as follows, with examples given in the Figures 3.10 - 3.12.

When the telescope is pointing due South (180° Azimuth) and the long dimension of the array is aligned along the Prime Meridian (i.e., up and down in the elevation direction), with Beams 1 and 8 at high elevation (and high declination), the array has a rotator control angle of 180°. If the Rotator is turned so that Beams 1 and 8 move toward larger azimuth, the rotator control angle *decreases*.

The Rotator has a total range of travel of ~355° and can nominally rotate between the control angles of 2.5° and 357.5°.

Rotator Control Angle Convention
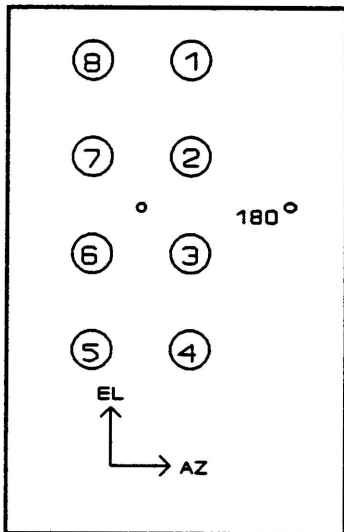
| Figure 3.10 -- Rot. Cont. Angle = 180° | Figure 3.11 -- Rot. Cont. Angle = 135° | Figure 3.12 -- Rot. Cont. Angle = 225° |
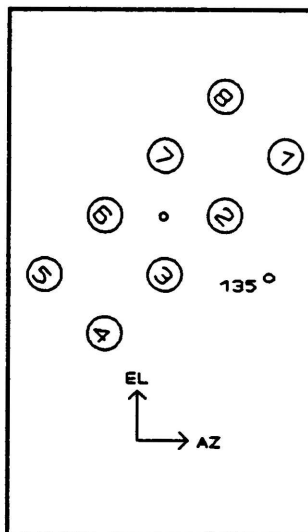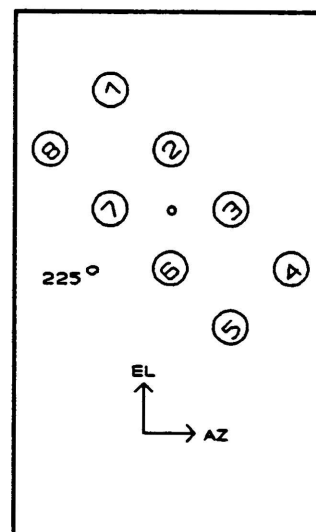
3.5.4.1.2 PARALLACTIC ANGLE

The *parallactic angle* is defined astronomically as the angle between lines of constant azimuth and lines of constant hour angle. Thus, it is a function of the Azimuth and Elevation and Hour Angle and Declination of the source. The convention employed here is defined in the box that follows:

When the source is on the Prime Meridian (0 Hour Angle) *in the south*, Parallactic Angle is defined to be 0°. While the source is above the horizon in the south, Parallactic Angle always increases with time.

When the source is on the Prime Meridian (upper culmination) *in the north*, Parallactic Angle is defined to be 180°. In the north, Parallactic Angle *decreases* with time.

When the Rotator is tracking Parallactic Angle with 0 Position Angle Offset (see below), the LED readout of the rotator control angle will read

[180° - (Parallactic Angle)].

Parallactic Angle Convention

3.5.4.1.3 USER POSITION ANGLE

The user-defined *Position Angle* is available to allow the user to position the rectangular array of beams in the RA/DEC frame to achieve optimal mapping efficiency according to the geometry of the source. The most common example of this would be to position the long dimension of the array of beams along the major axis of a galaxy. The convention for defining Position Angle is as follows:

The User-Defined Position Angle follows the usual astronomical position angle convention: Position Angle *increases* toward the east, or toward increasing Right Ascension. Note that this convention is independent of whether the source is north or south of the zenith.

As an example, the position angle of the major axis of M31 is +37.5°; to orient the 8-Beam Rotator along that axis, a User Position Angle of the same value would be entered.

User-Defined Position Angle Convention.

3.5.4.1.4 POINTING AND MAPPING OFFSETS WITH THE 8-BEAM ROTATOR

The rotation center of the array is at its geometric center, where no beam exists. During normal mapping observations, the rotation center will normally be the mapping center of the array. Thus, the observer should enter Az/El pointing offsets that correspond to the rotation center of the array. However, when checking telescope pointing, the array must be offset so that one of the beams is positioned on the pointing source. The staff has defined BEAM 2 to be the "Pointing Beam." Furthermore, the array must be returned to a Rotator Control Angle of 180° before performing
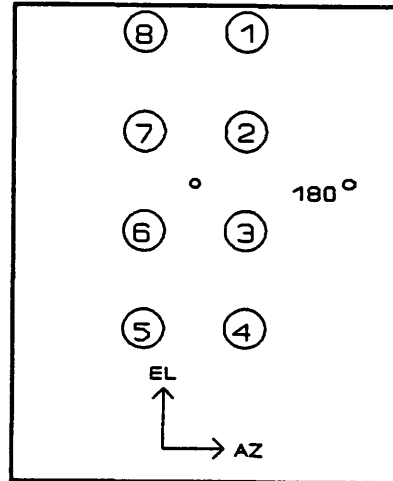
Figure 3.13

the pointing check, otherwise the results will be skewed according to the rotation angle of the array. The discussion that follows illustrates the conventions for positioning the array in the AZ/EL frame. When you are *not* tracking Parallactic Angle, the control angle of the rotator should be set to 180°. If you are tracking Parallactic Angle, the array is in the RA/DEC frame and the rotator control angle will be generally different from 180°.

With the beams configured as shown above, with a control angle of 180° and where we are not tracking Parallactic Angle, the sense of movement in the AZ/EL frame is as follows:

To move the source from Beam 2 to Beam 7, make the AZ offset more positive.
To move the source from Beam 2 to Beam 3, make the EL offset more positive.

When the array is rotated from its "null" control angle of 180°, the position of the beams are given by the equations for a Cartesian coordinate system rotation. In the AZ/EL frame the position of an individual beam is given by

$$\Delta A_i = \Delta A_0 - [A_i \cos(\theta_0 - \theta) + E_i \sin(\theta_0 - \theta)], \qquad (3.1a)$$

and

$$\Delta E_i = \Delta E_0 - [E_i \cos(\theta_0 - \theta) - A_i \sin(\theta_0 - \theta)], \qquad (3.1b)$$

where ΔA_0 and ΔE_0 are the azimuth and elevation pointing correction for the center of the array, θ_0 is the hardware control angle of the array in its null position ($\approx 180°$), θ is the rotator control angle, and A_i and E_i are the azimuth and elevation offsets of the individual beams relative to the geometric center, and are given by Table 3.1

TABLE 3.1

Array Az / El Beam Offsets Relative to Center

(at Control Angle of 180°)

Beam Number	Azimuth Offset from Center (")	Elevation Offset from Center (")
1	43.5	130.5
2	43.5	43.5
3	43.5	-43.5
4	43.5	-130.5
5	-43.5	-130.5
6	-43.5	-43.5
7	-43.5	43.5
8	-43.5	130.5

If you *are not* tracking Parallactic Angle (e.g., for a pointing check), then you will be observing in an AZ / EL frame and all positioning offsets should be in AZ and EL. If you *are* tracking Parallactic Angle, you will be observing in an RA / DEC frame and mapping and beam offsets should be given in RA and DEC.

Relations similar to Equations (3.2) exist for RA/DEC offsets when the array is rotated by a user Position Angle. The equations describing these offsets are

$$\Delta RA = -RA_i \cos(\phi) + DEC_i \sin(\phi) \qquad (3.2a)$$

and

$$\Delta DEC_i = DEC_i \cos(\phi) + RA_i \sin(\phi) \qquad (3.2b)$$

where ϕ is the Position Angle and RA_i and DEC_i are the RA and DEC offsets of each beam relative to the rotation center, when the array is at 0° Position Angle. These offsets are the same as in Table 3.1, with RA corresponding to the Azimuth column and DEC to the Elevation column. If you wish to convert arc seconds on the sky to seconds of time in RA, remember to divide by 15 $\cos(\delta)$.

3.6 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 12 m 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 12 m, a precise synthesizer harmonic is used as a comparison frequency for the phase lock loop. The LO chain is diagrammed in Figure 3.14 and explained below in detail.

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

FREQ. COUNTER

TUNE SERVO DRIVE

BACKSHORT SERVO DRIVE — GUNN OSCIL — MULTIPLIER OR Rx's 1st MIXER

RUBIDIUM STANDARD

5 MHz — FLUKE SYNTH.(6160 B) 100 MHz NOMINAL — F SIGNAL

5 Hz

HARM. MIXER

GUNN BIAS

F2 (I.F.) | F1 (1.84 TO 1.96 GHz) — BACKSHORT SERVO DRIVE

5 MHz — FLUKE SYNTH.(6160 B) 100 MHz NOMINAL — F REFERENCE

FREQ. MONIT.

(USED FOR FREQ. SWITCHING ONLY)

PHASE LOCK BOX

2 GHz PLL
REF. IN MON.

5 MHz — FLUKE SYNTH.(6160 B) 92 TO 98 MHz — F SYNTH. — PHASE-LOCKED OSCILL. (SYNT.x20=1.84 TO 1.96 GHz) F1

COMP.

∅ LOCK SWITCHES (SELECTS 1 OF 4 RECEIV.)

FLUKE DRIVE

PLL IF MONITOR (HP SPECTRUM ANALYZER)

F2

MANUAL FREQ. SET

COMP.

SELECT RECEIVER

TEL. CABLES OR DIG. DATA LINK

PHASE LOCK CONTROL
(RECEIVER CONTROL RACK)
.SET GUNN VOLTAGE
.SET LOOP GAIN
.LOCK STATUS
.TUNE ADJUST
.BACKSHORT ADJUST
.HARM. MXR BACKSH. ADJUST
.2GHz DRIVE
.MONITORS

FGUNN=NxF1±F2
N=HARMONIC NUMBER
F1=FSYNTH.x 20 (1900±60 MHz)
F2=LOCK I.F. (100 MHz) (IF RANGE=0 TO 200 MHz)

INTEGRATE DISABLE

SB=0   FSYNT.=[[(FSKY−1.5 GHz)/M+100 MHz]/N]/20
SB=1   FSYNT.=[[(FSKY+1.5 GHz)/M+100 MHz]/N]/20
SB=2   FSYNT.=[[(FSKY−1.5 GHz)/M−100 MHz]/N]/20
SB=3   FSYNT.=[[(FSKY+1.5 GHz)/M−100 MHz]/N]/20

(M —►MULTIPLIER FACTOR:1 TO 4)

CONTROL ROOM ◄— —► TELESCOPE/Rx

PHASE-LOCKED LO SYSTEM BLOCK DIAGRAM-12 METER TELESCOPE

FIGURE 3.14 — 12-M LOCAL OSCILLATOR CHAIN

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 (F_1 in Figure 3.14).

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 (F_2 in Figure 3.14). For the Gunn oscillator systems, F_2 = 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:

$$f_{syn} = \left[(f_{sky} + jf_{IF})/m + kf_{LOCK} \right] / N \qquad (3.3)$$

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, 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. Figure 3.15 shows how the various SB options are related in frequency space.
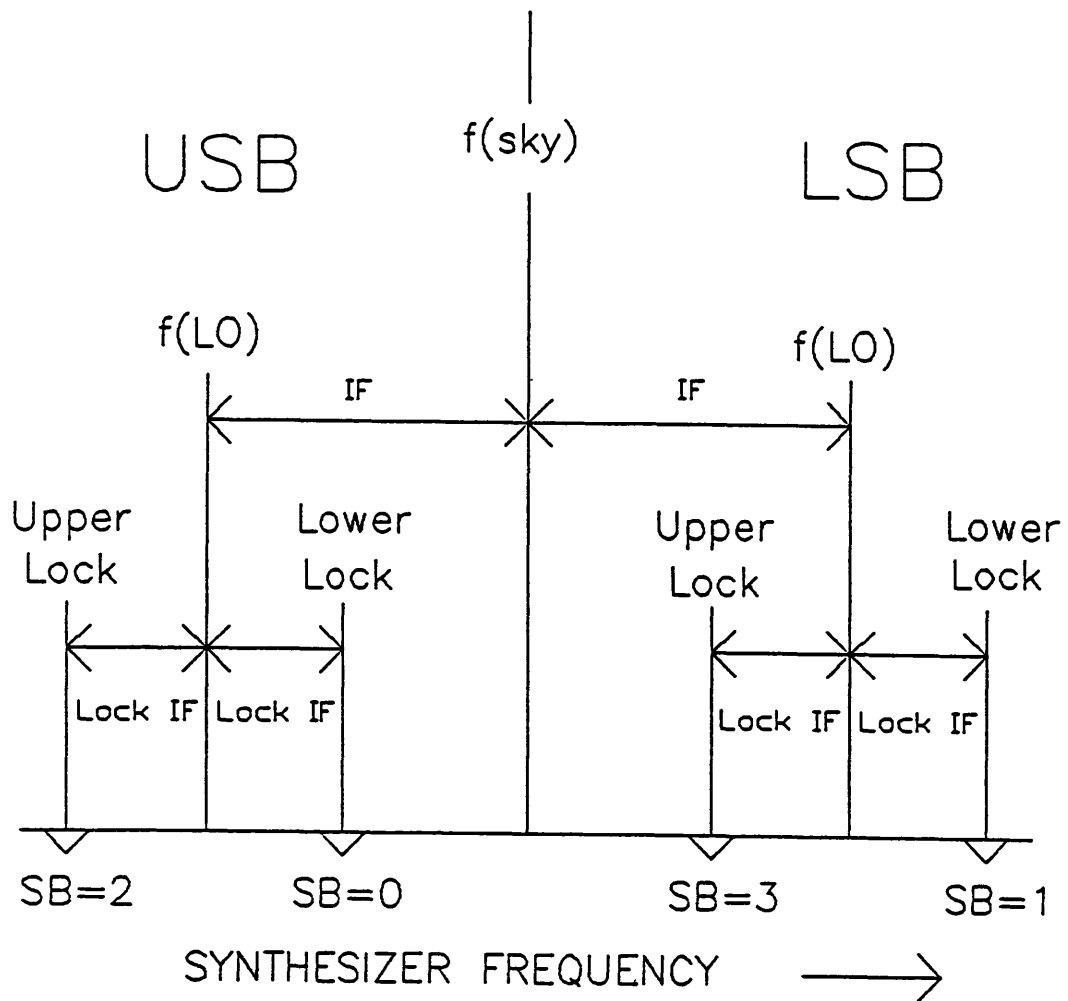
FIGURE 3.15 — MAP OF SIDEBAND (SB) OPTIONS
IN FREQUENCY SPACE

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.

3.7 THE IF SECTION

All mixer receivers at the 12 m 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, except the eight-beam system, use this same processor; the switch from one receiver to another is done remotely from the control room (see section 3.6).

Figure 3.16 shows a block diagram of the whole IF system. 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, as diagrammed in Figure 3.17. 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 7, *Spectral Line Observing*, provides a more detailed description of these options.
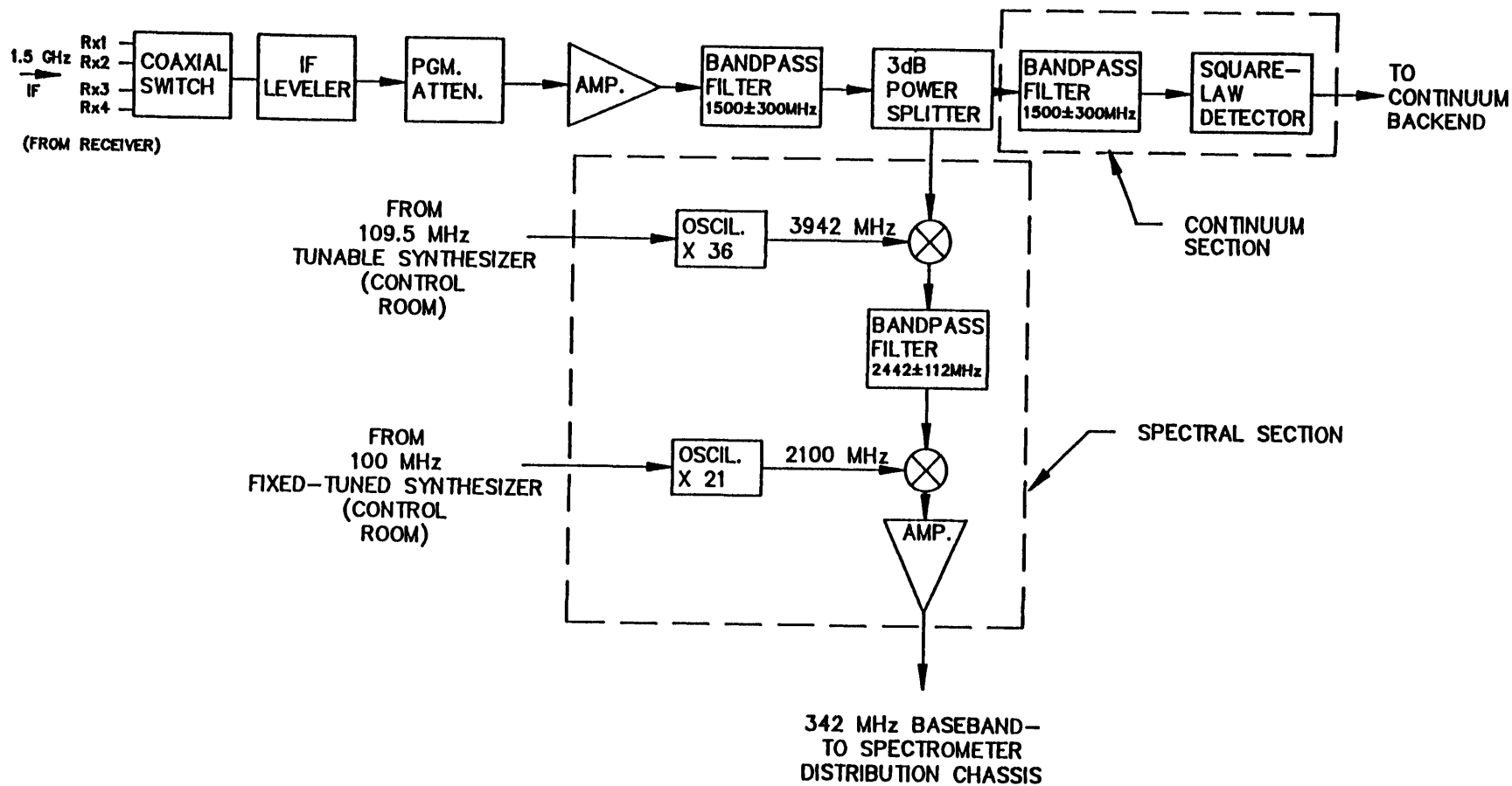
1.5 GHz I.F. PROCESSOR–SPECTRAL LINE AND CONTINUUM PATHS

FIGURE 3.16 — BLOCK DIAGRAM OF I.F. SYSTEM

CHANNEL 1

1500 MHz →■ 1500 MHz ±300 MHz B.P.F. → ⊗ → 2442 MHz ±268 MHz B.P.F. → ⊗ → L.P.F. 700 MHz → CH 1 342 MHz

OFFSET OSCIL. — 3942 MHz (X36)

FLUKE SYNT. — 109.5 MHz

FROM RECEIVER

STANDARD 5 MHz

100 MHz FLUKE SYNT.

2100 MHz OSCIL.

FLUKE SYNT. — 109.5 MHz

OFFSET OSCIL. — 3942 MHz (X36)

TO FILTER BANKS (CONTROL ROOM)

1500 MHz →■ 1500 MHz ±300 MHz B.P.F. → ⊗ → 2442 MHz ±268 MHz B.P.F. → ⊗ → L.P.F. 700 MHz → CH 2 342 MHz

CHANNEL 2
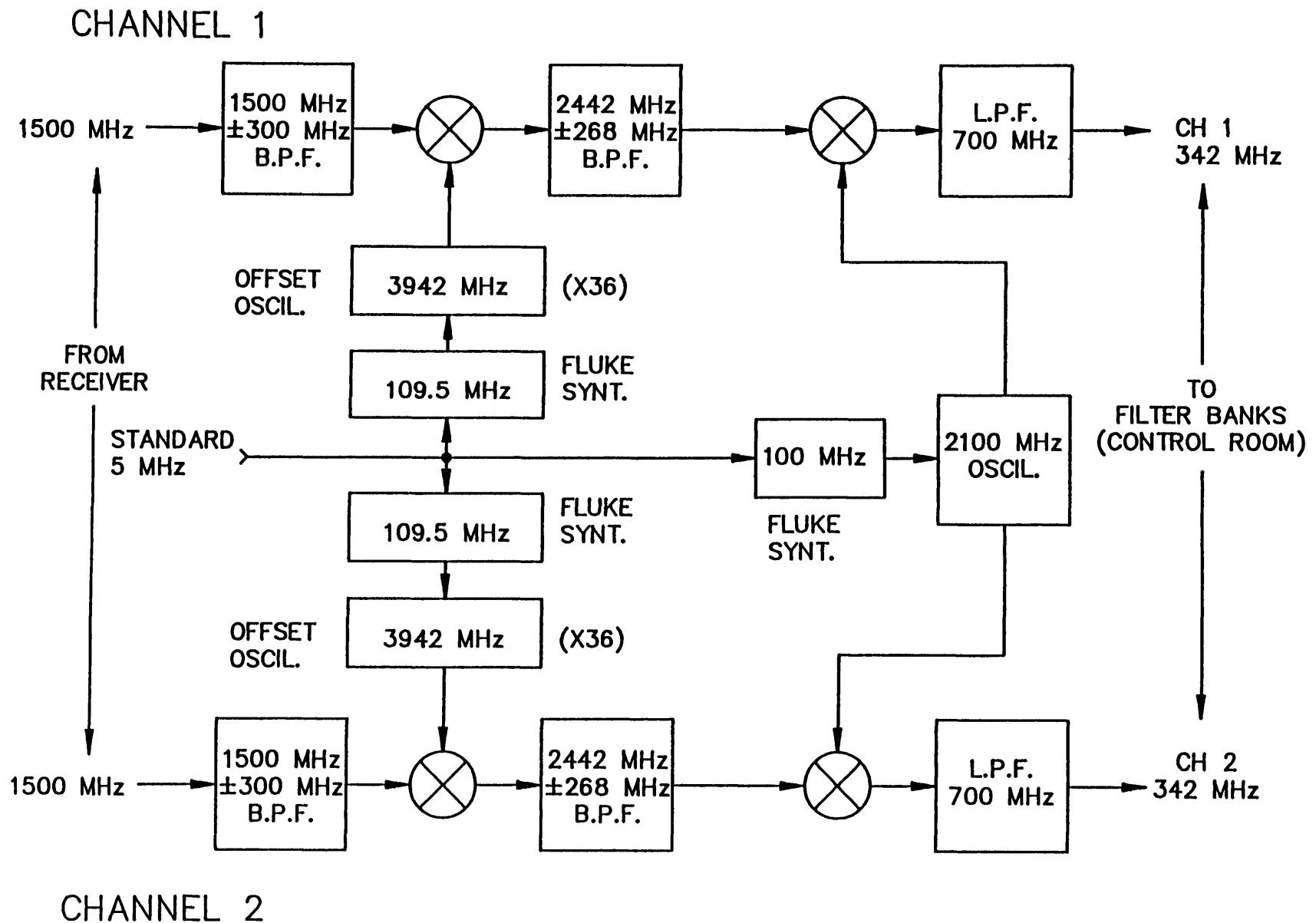
1.5 GHz IF PROCESSOR—SPECTRAL LINE SECTION

FIGURE 3.17 -- SPECTRAL LINE I.F. PROCESSOR MODULE

3.8 SPECTROMETERS

3.8.1 FILTER BANKS

The 12 m has eight filter spectrometers and a "spectrum expander" available for spectral line work. Most of these filter banks have 256 channels, and can be split into two 128 channel sections for dual polarization receivers. When the filter bank is split into two sections it is termed "parallel" mode, and when all channels are used for a single receiver output, the operation is termed "series" mode. Additional discussion on the use of the filter banks is given in Chapter 7.

Table 3.2 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.

TABLE 3.2

Filter Spectrometers Available

Bandwidth of Individual Filters	Number of 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 kHz[1]	128	1
Spectrum Expander[2]	256	1

[1]Series operation only (see explanation in text).

[2]Uses the 100 kHz filter bank. Available resolutions are 25 kHz, 12.5 kHz, and 6.125 kHz.

The Spectrum Expander works in conjunction with the 100 kHz filter bank. The Spectrum Expander samples the input signal at a given rate and then reads the sampled signal out at a faster rate. The output spectrum, S_o, is related to the input spectrum, S_i, by the relation

$$S_o(f) = \sum_{n=-\infty}^{\infty} S_i[f - n\epsilon(E - 1)] \, sinc^2 \left[\frac{f - nE\epsilon}{\epsilon} \right], \qquad (3.4)$$

where f is the frequency, E is the expansion factor R_o/R_i, with R_o and R_i the output and input resolutions, respectively, and $\epsilon = R_i/M$, where M is the memory length. The nulls in the Spectrum Expander response have been arranged to occur every 100 kHz. Thus, the Expander comes first in the signal path and its output is directed to the 100 kHz filter bank. The Expander can be used only in "series" mode. The theory of spectrum expanders is discussed by R. J. Lacasse (1980, NRAO Electronics

Division Internal Report, No. 209), and by P. S. Henry (1979, *Rev. Sci. Instr.*, 50, 185).

3.8.2 HYBRID SPECTROMETER

The Hybrid Spectrometer (HySpec) is a new spectrometer, just introduced at the telescope in the Fall of 1989. It is a combination of analog filter and digital autocorrelation technology. The I.F. signals from the receivers are pre-filtered in up to sixty-four 37.5 MHz segments, and then each segment is sampled in three levels and autocorrelated. After the FFT, the resulting filter spectra are then pieced together to form the final spectra of full bandwidth. The information available for match-up of the filter spectra include the output of total power square-law detectors, the zero-lag term of the autocorrelation, and a number of redundant, overlapping spectral channels, which reduces an initial 2048 spectral channels to 1536 quality channels.

The 1536 spectral channels of the spectrometer can be divided among up to 8 independent I.F. channels. As such, it matches well with the 230 GHz Eight-Beam Receiver, as well as with the 2-polarization channel, single beam receivers. The maximum bandwidth of the instrument is 2400 MHz, although none of our present receivers have such a large bandwidth. The typical observing mode for the Eight-Beam Receiver will be 8 x 300 MHz or 4 x 600 MHz, which will have, respectively, 192 or 384 channels per spectrum. Higher resolution modes are available. Two-channel, single beam modes will be, typically, 2 x 600 MHz, 2 x 300 MHz, 2 x 150 MHz, etc., with 768 channels per spectrum. Table 3.3 summarizes the currently available observing modes.

TABLE 3.3

Hybrid Spectrometer Modes

No. of I.F.'s	Bandwidth (MHz)	No. of Channels per I.F.	Channel Resl. (kHz)
Multi-beam Mode:			
8	300	192	1562
8	150	192	781
8	75	192	391
8	37.5	192	195
4	600	384	1562
One or Two Channel, Single Beam			
2	600	768	781
2	300	768	391
2	150	768	195
2	75	768	98
2	37.5	768	49
1	37.5	1536	24

3.9 ANALOG CONTINUUM BACKEND

Two continuum detectors exist at the 12 m, a two-channel analog, phase-sensitive detector and a two-channel, four-phase digital backend. The analog backend has been phased out in favor of the digital backend for standard continuum observations. The analog backend continues to drive the on-line chart recorders, however.

The analog detector, called the "standard backend" (SBE), produces both switched power and total power signals. The SBE can route or can generate a signal/reference signal for the subreflector and then synchronously detect the receiver output. Internal and manually adjustable external blanking circuits exist. The "Full Scale Temperature" and the gain of the SBE can be set from the front panels (each channel is independent). These controls are set to standard values and rarely need adjustment. The most important setting is the Full Scale Temperature. This setting must be high enough to keep the SBE from saturating but low enough to provide sufficient precision, free from digitation effects, for weak signals. Red warning lights on the front panels of the SBE's indicate saturation. The voltage readout on the on-line status monitor can also indicate low accuracy.

Ordinarily, the only time the SBE will require adjustment is when switching from a coherent receiver to the bolometer (no longer in standard use). You must increase the Full Scale Temperature when using the bolometer (usually from 30 to 1000). The bolometer contains its own attenuation circuits for use with the absorbing chopper wheel, which generates a very large signal.

3.10 DIGITAL BACKEND

The digital backend (DBE) performs all standard continuum observations. It has a number of advantages over the analog backend, including giving more accurate data (32 bits), a better treatment of blanking during subreflector movement, simultaneous measurement of up to four phases instead of two, and the inclusion of a calibration signal as one of the phases. The number of data points that can be stored in a single scan for a one or two channel receiver is limited to 54 ON/OFF repeats or 192 mapping points. For continuum ON/OFF observations, you can circumvent any possible limitations simply by taking more scans of a smaller number of points and summing the data in the *CONDAR* program.

The DBE generates a signal/reference pulse to move the subreflector. The switching rate is 4.0 Hz, so that each phase of a four phase switching cycle lasts

125 ms. The DBE can blank the input signal (*i.e.*, stop taking data) while the subreflector is in transition from one position to another. The length of the blanking time can be set with a digi-switch (Delay 1) on the front panel of the DBE. After the subreflector receives a pulse to move, it takes a few milliseconds to begin moving because of the L-C time constant in the subreflector solenoids. The start of the blanking interval can be delayed from the time the signal/reference pulse is issued by setting another digi-switch (Delay 2) on the front of the DBE chassis. The staff can provide the best numbers for Delay 1 and Delay 2, but are typically 28 ms for Delay 1 and 9 ms for Delay 2. The criterion for determining these values is to find the setting that produces the maximum source intensity for a point source with no azimuth elongation of the beam as produced by a cross-scan through the source. Figure 3.2 showed the way in which the DBE is integrated into the telescope receiving and signal processing system.

3.11 COMPUTER EQUIPMENT

The 12 m telescope uses two computers, one for telescope control and data acquisition and the other for on-line data processing. The control computer is a Digital Equipment Corporation PDP 11/44 mini-computer. This computer runs the original version of the stand-alone FORTH computer language. The computer is a 16 bit machine and FORTH allows 28 kilobytes of program code to be loaded at a time. Communication with the machine is done through the operator's control terminal or the observer's IBM PC. The computer controls or reads analog devices via an analog-to-digital converter known as the "Omniverter." Two digital multiplexing devices are also connected to the computer. The computer has two DEC RLO2 (10 MByte) disk drives and an 800 BPI tape drive. The control programs and a backup data set are stored on disk. As each scan is taken, the system writes the data to tape in binary form.

As each data record is finished, it is transmitted to the analysis computer, a DEC VAX 11/750 running the VMS operating system. The 11/750 is a 32 bit, virtual memory machine with 5 MBytes of real memory. The system has two disk drives, a

205 MByte DEC RA60 removable disk which is used as the operating system disk, and a DEC RA81, a 456 MB Winchester which is used as the data disk. Tape drives of 800 and 1600 BPI are connected to the machine. Users can communicate with the VAX through several terminals at the site. Remote communications and electronic mail via the NRAO DECNET system (which has access to computer networks such as BITNET and INTERNET), as well as through dial-up modems are possible. NRAO policy does not allow remote access to the telescope VAX from another computer unless approved by the site manager (this does not include the transmission of small electronic mail messages). An identical system exists in the NRAO offices in Tucson and is available for post-time data reduction.

At the telescope, the observer performs most of his data reduction with one of two Modgraph terminals, which can emulate a Tektronics 4010 graphics terminal and a DEC VT100 text terminal. VT100's are also available. The observer's IBM PC can also emulate a Tektronics 4010 graphics terminal. The hardcopy devices are two QMS LaserGraphix printers. The telescope VAX has FORTRAN and C compilers and a complete set of documentation exists at the telescope.

The computing environment at the Tucson offices is very similar, and completely compatible with that at the telescope. Because of the limited facilities at the telescope and the possibility of conflict with other observers, we require that all post-observing run data reduction be done in Tucson. The Tucson computer room contains a VAX 11/750, a dual-density 800/1600 BPI tape drive, high-capacity disk drives, Modgraph graphics terminals, a line printer, and a laser printer for hardcopy. The town VAX has FORTRAN and C compilers and runs all of the telescope data reduction programs.

CHAPTER 4
TRACKING, POINTING, AND FOCUS

4.1 TRACKING CAPABILITIES

The 12 m telescope can track both stationary (sidereal) sources or fast moving sources such as the Sun, Moon, planets, comets, or satellites. The positions of stationary sources may be entered into source catalogs by the observer, directly into the on-line system through the operator's control terminal, or dialed in by the operator through thumbwheel digi-switches. Stationary source positions may be given as

     a) current equatorial positions (already precessed),

     b) Equinox 1950 equatorial positions, or

     c) Galactic coordinate positions. (ℓ_{II}, b_{II})

The only standard epoch available for precession is 1950. However, you can use the control system to precess positions for other specific dates to 1950, provided the dates are within 16,000 days (43.8 years) of 1950. You can then enter the 1950 positions into source catalogs or directly into the system. The operator has instructions for this procedure in the Operator's Reference Manual.

To track fast-moving sources, the control system requires three positions, centered upon the present time. The tracking algorithm then makes a parabolic interpolation to determine the source position at the specific time of observation. Planetary positions are stored for an entire year by the staff programmers. The interpolation is done for a one-day separation interval. The observer must prepare the positions for other objects such as comets and asteroids. The standard version of the control program accepts position intervals as small as one hour. A special version of the program is available for intervals as small as 15 minutes.

NOTE:

Chapter 5 gives instructions for entering positions into source catalogs.

4.2 TRACKING LIMITS

4.2.1 ELEVATION LIMITS

Mechanical limits constrain the movement of the telescope on both the azimuth and elevation axes. Under normal source-tracking operation, the control system software prevents the telescope from moving into these limits. The telescope is also equipped with fail-safe hardware limit switches that will turn the drive motors off and apply the brakes before the telescope can be damaged. When the telescope reaches a lower elevation of 15.0°, it begins to depress a safety spring on the elevation stop. Tracking can continue until the elevation drive motor begins drawing excessive current; this usually occurs at an elevation near 14.5°. A final limit switch is tripped at 13.8° elevation.

The control computer will allow a source to be tracked up to an elevation of 90°. The pointing equations diverge at the zenith, however, and elevations greater than 88° should be strictly avoided during observations. For routine observations, we recommend that you avoid elevations >80° if possible, since both tracking and pointing degrade in that range. For maintenance purposes only, the telescope can be driven to an elevation of 92° before tripping a final limit switch.

4.2.2 AZIMUTH LIMITS

To prevent the over-wrapping of cables, the telescope has hardware and software azimuth limits. The control system will not allow the telescope to rotate through 70.4° azimuth to acquire or track a source. As they rise, sources with declinations between

FIGURE 4.1 — 360° AZIMUTH TRANSITIONS WHILE TRACKING

25° and 31.5° will pass through 70.4° azimuth above 15° elevation. When a rising source reaches an azimuth of 70.4°, the telescope will rotate 360° to re-acquire the source. The region of the sky where azimuth transitions occur is displayed in Figure 4.1. If an integration is in progress when the transition azimuth is reached, the integration is halted while the telescope rotates around to re-acquire the source. The integration is resumed when the source is reached again. If it is undesirable for this to happen, you should cease the integration before reaching the transition azimuth.

4.3 TRACKING ERROR TOLERANCE

The 12 m telescope is vulnerable to tracking errors produced by wind gusts. The tracking software has a provision for rejecting from the integration any data sample that was taken with the telescope off source. The basic timing cycle of the 12 m control system is 100 milliseconds (0.1 sec). After each 100 ms interval, the system checks for error conditions such as tracking errors or a loss of frequency phase lock. If an error condition is detected, the data sample collected during the last 100 ms interval is not averaged with the rest of the data.

You can chose how much tracking error you are willing to accept. This number is called the "Tracking Tolerance" and is displayed on the on-line status monitor in the lower left-hand corner under the heading "TOL". The 12 m typically experiences 3-4" tracking errors under calm conditions. The tolerance is usually not set to less than 5" for this reason. Typical choices for the tolerance are 5" for 1.3 mm and shorter wavelength observations, and 10" for 3 mm observations. Figure 4.2 shows the amount of signal that is lost by a given pointing error, expressed as fractions of a FWHP beamwidth.

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Antenna Gain vs. Beam Displacement for a Point Source
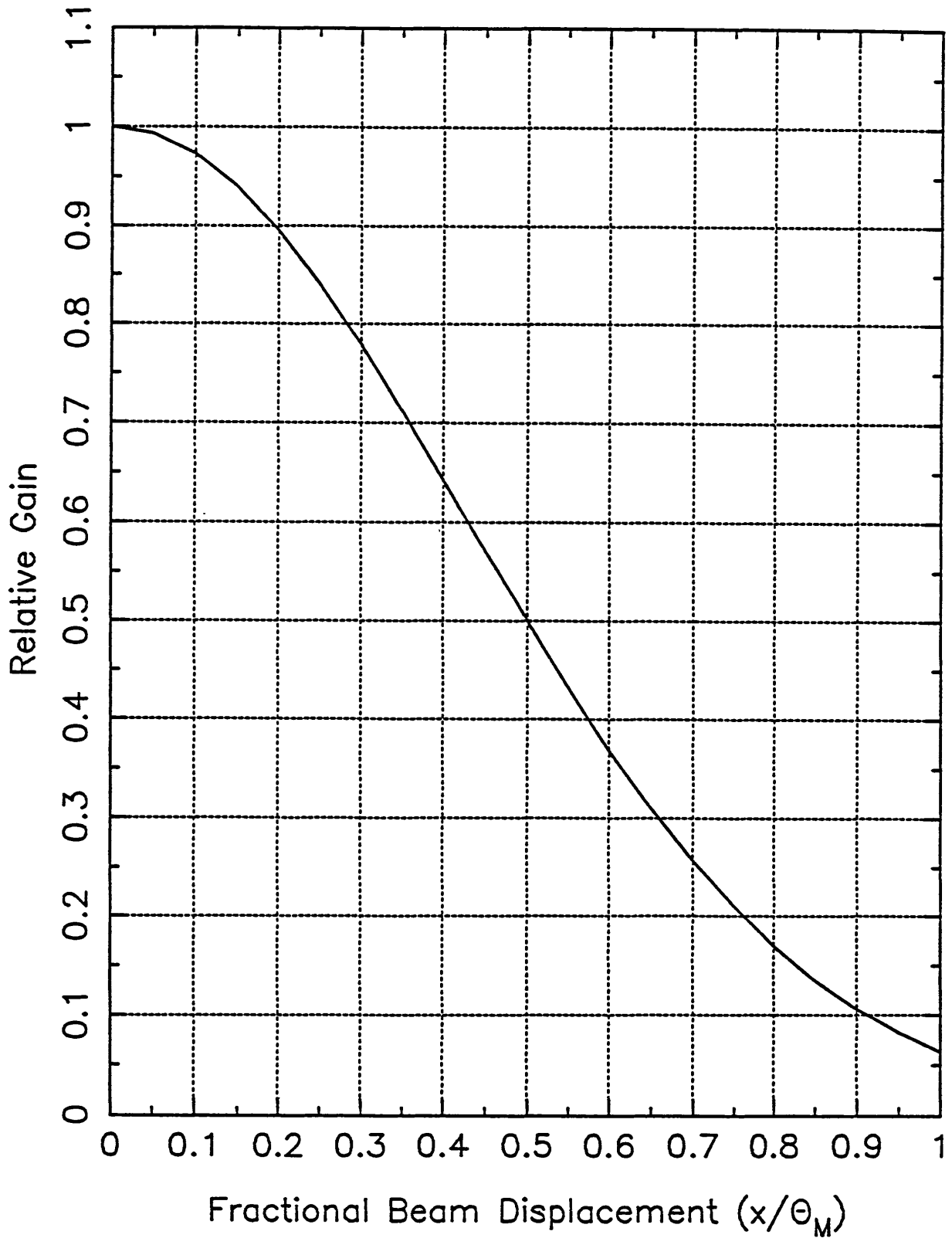
FIGURE 4.2 -- SIGNAL LOST BY POINTING ERRORS

4.4 POINTING MODEL EQUATIONS

In addition to coordinate conversions, the telescope tracking program incorporates pointing corrections. The pointing corrections take into account resolver zero offsets, differences between electrical and mechanical axes, axis tilt, etc. Two sets of pointing equations exist: a primary set whose coefficients are redetermined once or twice a year, and a secondary set (actually a subset of the primary equations) which are reset frequently. The pointing models used for the 12 m are described in detail in *Appendix A*, "12 m Pointing Equations."

4.5 SUBREFLECTOR BEAM THROW

The 12 m telescope is equipped with a nutating (chopping) subreflector that is used for beam-switched observations in both the spectral line and continuum modes. Other observing modes, such as position switching, are made with the subreflector locked in place. Obviously, the throw position of the subreflector, whether it is chopping or locked in place, affects the pointing of the telescope. The current 12 m subreflector switches only in azimuth, although mount misalignments may produce a small component in the elevation direction (usually these are less than 1-2"). The pointing equations for the 12 m are set up for 0 offset in subreflector position, *i.e.*, with the subreflector axis aligned with the electrical axis of the primary reflector. When the subreflector is offset so that the telescope must be moved in the positive azimuth direction to bring the source into be beam, the subreflector is said to be in the "+BEAM." When the telescope must be moved in the negative azimuth direction to acquire the source, at least with respect to the +BEAM, the subreflector is in the -BEAM. Figure 4.3 illustrates this convention. Both the spectral line and continuum backends are configured so that the +BEAM signal is positive and the -BEAM signal negative.

POINTING and
ELECTRICAL AXIS

+BEAM   −BEAM

AZIMUTH −−>
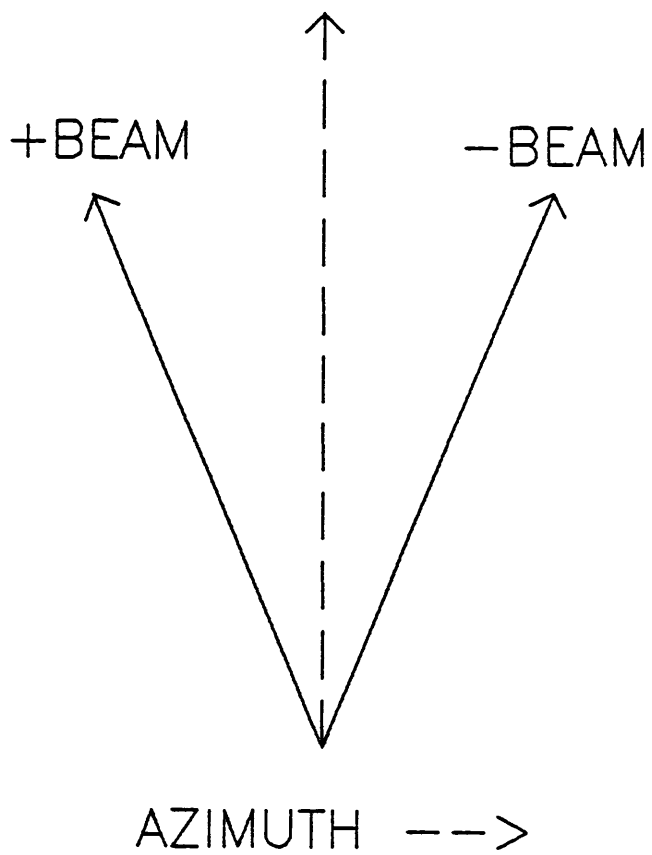
FIGURE 4.3 −−SUBREFLECTOR +BEAM/−BEAM CONVENTIONS

The control system software takes account of the subreflector throw setting when positioning the telescope. The computer does not read the subreflector setting automatically, however; it depends upon the operator to manually set the throw value. The subreflector is physically set by turning two dials on the subreflector control chassis. A calibration curve included in the document *NRAO 12 m Equipment and Calibration Status* shows how the indicated reading on the subreflector corresponds to the angular throw on the sky. Default values of subreflector throw are stored in the computer: for example, ±2' for λ3 mm and ±1' for λ1 mm and λ850 μm. The operators have available the subreflector dial settings corresponding to these throws. If you wish to change the throw from the default value, tell the operator what throw you desire and you and he can compute the corresponding dial setting. After changing the throw, we advise that you check pointing and do a continuum cross-scan on a strong source to confirm the beam throw. Continuum mapping rows are explained in detail in *Chapter 6*, but here is a quick example of how to set up a single row.

EXAMPLE 4.1 -- Checking Subreflector Throw with an Azimuth Cross Scan

Suppose we are observing at $\lambda 3$ mm and have set the subreflector for a nominal 4' beam throw (±2'). To confirm this, have the operator set in the following parameters in the FORTH control computer DBE observing task to perform an azimuth mapping row:

    30 XCELL (sets the X cell size to 30" ==> OK for a ~60" beam)
    1 SROW   (calls for 1 row to be observed)
    19 SCLM (calls for 19 column grid points to be observed, =9.5' row; this
              gives 2.25' on either side of the two beams)
    50 SEC ! (5 second integrations, OK for the major planets)
    DBMAP   (executes a dual-beam map)

After the map is finished, you may display it with the following CONDAR command in the VAX analysis computer:

    scan_number M

You should see the response of both subreflector beams; one response will be negative and the other positive. The two beam positions are the -BEAM and +BEAM. The beam throw can be measured automatically with the CONDAR procedure DBGAUSS. To use this procedure, you must first install it by typing (from within CONDAR)

    INSTALL DBGAUSS

Display the mapping row with the command given above, then type DBGAUSS. A Gauss fit of the two beams will be displayed and the beam separation will be given.

4.6 AZIMUTH AND ELEVATION POINTING OFFSETS

You are responsible for determining the residual azimuth and elevation offsets, relative to the nominal telescope pointing. These offsets are usually of the order 10" - 20" and often vary across the sky. In particular, the offsets often show an elevation dependence. The pointing of the 12 m may drift over a period of a few days by 10" or so, and you are cautioned not to assume that old pointing data are still valid. If a project requires accurate pointing, observers should budget 5 - 10 % of their total observing time to pointing checks. High frequency projects, for which the FWHP of the main beam is 30" or less, obviously require more attention to the pointing.

You may perform pointing checks in either continuum or spectral line mode. Pointing sources must have an angular brightness distribution that is compact compared to the antenna beam. In addition, they must have well-determined positions and must be strong enough to point on in a reasonable amount of time, e.g., 10 minutes or less. The best pointing sources are the major planets Venus, Mars, Jupiter, Saturn, and Uranus, observed in continuum mode. These sources have strong flux densities throughout the millimeter band, although Uranus is faint at 3 mm and longer wavelengths. To obtain complete sky coverage, particularly north of the zenith, the planets must be supplemented with other pointing sources. A tabulation of these sources and approximate flux densities at $\lambda 3$ and $\lambda 1.3$ mm is given in Table 4.1. This table includes the sources traditionally used at the 12 m together with sources found useful at the IRAM 30 m telescope (C. Thum, 1988 private communication). The sources with no listed flux density are on the order of 1 Jy in strength. It should be noted that the flux densities of many of the extragalactic sources in the table can be highly time-variable.

TABLE 4.1

GALACTIC AND EXTRAGALACTIC CONTINUUM POINTING SOURCES

Source	RA (1950)			DEC (1950)			3 mm Flux (Jy)	SEC	RPT	1 mm Flux (Jy)	SEC	RPT
0048-09	0	48	10.0	-9	45	24						
0112-017	1	12	43.9	-1	42	55						
0133+47	1	33	55.1	47	36	13						
0135-247	1	35	17.1	-24	46	9						
W3(OH)	2	23	16.5	61	38	57	3.8	10	3			
0224+671	2	24	41.2	67	7	40	0.8	10	4			
0235+164	2	35	52.6	16	24	4						
3C84	3	16	29.6	41	19	52	12	10	2	6	10	3
0336-019	3	36	59.0	-1	56	17						
NRAO150	3	55	45.3	50	49	20	2.5	10	3			
0420-014	4	20	43.5	-1	27	29	4.5	10	3			
0426-380	4	26	54.7	-38	2	52						
3C120	4	30	31.6	5	15	0	2.5	10	3			
0454-234	4	54	57.3	-23	29	29						
0458-020	4	58	41.3	-2	3	33						
TAUA	5	31	30.0	21	59	0						
0552+398	5	52	1.3	39	48	22						
0605-085	6	5	36.0	-8	34	20						
0607-157	6	7	26.0	-15	42	3						
0642+449	6	42	53.0	44	54	31						
0716+714	7	16	13.0	71	26	15						
0727-115	7	27	58.1	-11	34	53						
0735+178	7	35	14.1	17	49	9						
0736+017	7	36	42.5	1	44	0						
0805-078	8	5	49.6	-7	42	23						
0814+425	8	14	51.7	42	32	8						

TABLE 4.1 -- continued

Source	RA (1950)			DEC (1950)			3 mm Flux (Jy)	SEC	RPT	1 mm Flux (Jy)	SEC	RPT
0820+560	8	20	53.2	56	2	27						
OJ287	8	51	57.3	20	17	58	5	10	3			
0923+392	9	23	55.3	39	15	24						
1034-293	10	34	55.8	-29	18	27						
1039+811	10	39	27.8	81	10	24						
1044+719	10	44	49.8	71	59	27						
1116+128	11	16	20.8	12	51	7						
1156+295	11	56	57.8	29	31	26						
3C273	12	26	33.2	2	19	43	30	5	3	10	10	2
VIRA	12	28	17.6	12	40	2	6.5	10	3			
1244-255	12	44	6.8	-25	31	28						
3C279	12	53	35.8	-5	31	8	13	10	2			
1308+326	13	8	7.6	32	36	40						
1313-333	13	13	20.1	-33	23	10						
CENTA	13	22	31.7	-42	45	30	7	10	3			
1334-127	13	34	59.8	-12	42	10	4	10	3			
1354+195	13	54	42.1	19	33	44						
1418+546	14	18	6.2	54	36	58						
1502+106	15	2	0.2	10	41	18						
1504-167	15	4	16.4	-16	40	59						
1510-089	15	10	8.9	-8	54	48						
1514-241	15	14	45.3	-24	11	23						
1546+027	15	46	58.3	2	46	6						
1548+056	15	48	6.9	5	36	11						
1633+382	16	33	30.6	38	14	10						
1637+574	16	37	17.4	57	26	16						
1638+398	16	38	48.2	39	52	30						

TABLE 4.1 -- continued

Source	RA (1950)			DEC (1950)			3 mm Flux (Jy)	SEC	RPT	1 mm Flux (Jy)	SEC	RPT
3C345	16	41	17.6	39	54	11	3.5	10	3			
1655+077	16	55	44.0	7	45	59						
1657-261	16	57	47.7	-26	6	29						
NRAO530	17	30	13.5	-13	2	46						
1732+389	17	32	40.5	38	59	47						
1741-038	17	41	20.6	-3	48	49						
1749+096	17	49	10.4	9	39	43						
1803+784	18	3	39.2	78	27	54						
1807+698	18	7	18.5	69	48	57						
1823+568	18	23	14.9	56	49	18						
1828+48	18	28	13.5	48	42	41						
1921-293	19	21	42.2	-29	20	26	11	10	2			
1928+738	19	28	49.3	73	51	45						
1954+513	19	54	22.5	51	23	46						
CYGA	19	57	44.5	40	35	46						
1958-179	19	58	4.6	-17	57	17						
K3-50A	19	59	50.1	33	24	19						
2005+403	20	5	59.6	40	21	2						
2007+776	20	7	20.4	77	43	58						
2037+511	20	37	7.5	51	8	36						
DR21	20	37	14.3	42	9	0	14.5	10	2			
NGC7027	21	5	9.4	42	2	3	4	10	3			
2128-123	21	28	52.7	-12	20	21						
2134+004	21	34	5.2	0	28	25						
2145+067	21	45	36.1	6	43	41						
BLLAC	22	0	39.4	42	2	9						
2201+315	22	1	1.4	31	31	6						

TABLE 4.1 -- continued

Source	RA (1950)			DEC (1950)			3 mm Flux (Jy)	SEC	RPT	1 mm Flux (Jy)	SEC	RPT
2210-257	22	10	14.1	-25	44	23						
2216-038	22	16	16.4	-3	50	41						
3C 446	22	23	11.1	-5	12	18	8	10	2			
2230+114	22	30	7.8	11	28	23						
2234+282	22	34	1.7	28	13	23						
2243-123	22	43	39.8	-12	22	40						
3C454.3	22	51	29.5	15	52	54	6.5	10	3			
2255-282	22	55	22.3	-28	14	22						
NGC7538	23	11	36.7	61	11	50						
2318+049	23	18	12.1	4	57	23						
CASA	23	21	11.0	58	32	48						

The 3 mm flux densities were provided by T. J. Balonek.

The spectral line emission from a number of sources can be used for pointing purposes. Emissions from rotational transitions of CO, HCN, and SiO are often strong enough and angularly compact enough to provide good pointing results. A list of spectral line pointing sources and their strong molecular emission lines are listed in Table 4.2.

The technique used to check pointing in both the continuum and spectral line mode is the 5-point map. Instructions for making and reducing continuum 5-point maps are given in Chapter 6 and instructions for spectral line 5-point maps are given in *Chapter 7*.

TABLE 4.2

SPECTRAL LINE POINTING SOURCES

Source	α(1950)	δ(1950)	V$_{LSR}$	CO J=1→0	CO J=2→1	HCN J=1→0	SiO J=2→1
R Scl	01 24 39.9	-32 48 05	-18.0	1	?	?	N.E.
Mira	02 16 49.0	-03 12 12	47.0	1			3 (v)
IK Tau	03 50 43.7	11 15 30	35.0	0.5			5 (v)
GL 618	04 39 33.8	36 01 15	-21.0	1			N.E.
Ori IRc2	05 32 47.0	-05 24 24	4.0				
U Ori	05 52 50.9	20 10 05	-39.0				1 (v)
GL 865	06 01 17.5	07 26 03	42.0	0.5			N.E.
VY CMa	07 20 54.7	-25 40 12	24.0				
R Leo	09 44 52.2	11 39 40	1.0	0.1			8 (v)
IRC+10216	09 45 14.8	13 30 41	-26.0	8	12		N.E.
CIT 6	10 13 11.0	30 49 17	-2.0	2	2		N.E.
V Hya	10 49 11.3	-20 59 03	-18.0	0.5			N.E.
R Hya	13 26 58.4	-23 01 23	-1.0				
W Hya	13 46 21.1	-28 07 08	40.0				
U Her	16 23 34.7	19 00 16	-14.0				1 (v)
IRC+20326	17 29 42.0	17 47 36	-5.0	0.5			N.E.
VX Sgr	18 05 03.2	-22 14 06	6.0				10.0
IRC+20370	18 39 41.7	17 38 16	-1.0	0.8	1		N.E.
W Aql	19 12 41.6	-07 08 08	-25.0	1.0			N.E.

TABLE 4.2 -- continued

Source	α(1950)	δ(1950)	V_LSR	CO J=1→0	CO J=2→1	HCN J=1→0	SiO J=2→1
χ Cyg	19 48 38.5	32 47 11	10.0	0.7	1.5		5 (v)
V Cyg	20 39 41.3	47 57 44	13.0	1	1		N.E.
NML Cyg	20 44 33.8	39 55 57	0.0				

4.7 POINTING ANALYSIS PROGRAM

Each time a continuum five-point map is reduced, the fit results are written to a permanent data file on the VAX analysis computer. A program exists on the VAX for displaying, tabulating, and analyzing the recent pointing history of the telescope. You can use this program to find out the pointing characteristics of the telescope as measured by yourself and the observers preceding you.

The Pointing History Display Package is executed by typing the word "GPOINT" (after exiting from *LINE* or *CONDAR*). Figure 4.4 is a flow chart that shows the primary components of the program. The routine first sorts the data file in case any data has been entered out of chronological order and deletes any duplicate entries. You are then prompted to select from a number of options as to which data you want to select from the file. (Keep in mind that data from different receivers should not be analyzed together and that data more than about two weeks old is probably invalid.) The selection options are given in the menu shown in Table 4.3. Some of the options require additional input information -- in those cases you will be prompted for it. You may select as many options as you desire. For example, you can select date and frequency ranges and specific observer initials. Selecting 0 will stop the selection process. Selecting Option 1 (all data) will also stop the selection process and will void any selections entered before. At the conclusion of this menu you will be asked if you want to write a file of the selected data records.

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GPOINT FLOW CHART

```
        ┌──────────────┐
        │    SORT      │
        │  DATA FILE   │
        └──────────────┘
                │                        DCL
                │
  ┌ ─ ─ ─ ─ ─ ─│─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┐
  │             ▼            PROGRAM          │
  │      ┌──────────────┐    SPOINT          │
  │   ┌─▶│   SELECT     │                    │
  │   │  │  DATA TO     │                    │
  │   │  │  ANALYZE     │                    │
  │   │  │  (MENU 1)    │                    │
  │   │  └──────────────┘                    │
  │   │         │                            │
  │   │         ▼                            │
  │   │  ┌──────────────┐   ┌──────────────┐ │
  │   │  │    PLOT      │   │    PLOT      │ │
  │   └──│  SELECTION   │◀─▶│   OPTIONS    │ │
  │      │  (MENU 2)    │   │  (MENU 3)    │ │
  │      └──────────────┘   └──────────────┘ │
  │             │                            │
  └ ─ ─ ─ ─ ─ ─ │ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ─ ┘
                ▼
        ┌──────────────┐
        │    PLOT      │
        │  HARDCOPIES  │
        │  & PRINT     │
        │  DATA FILES  │
        └──────────────┘
```
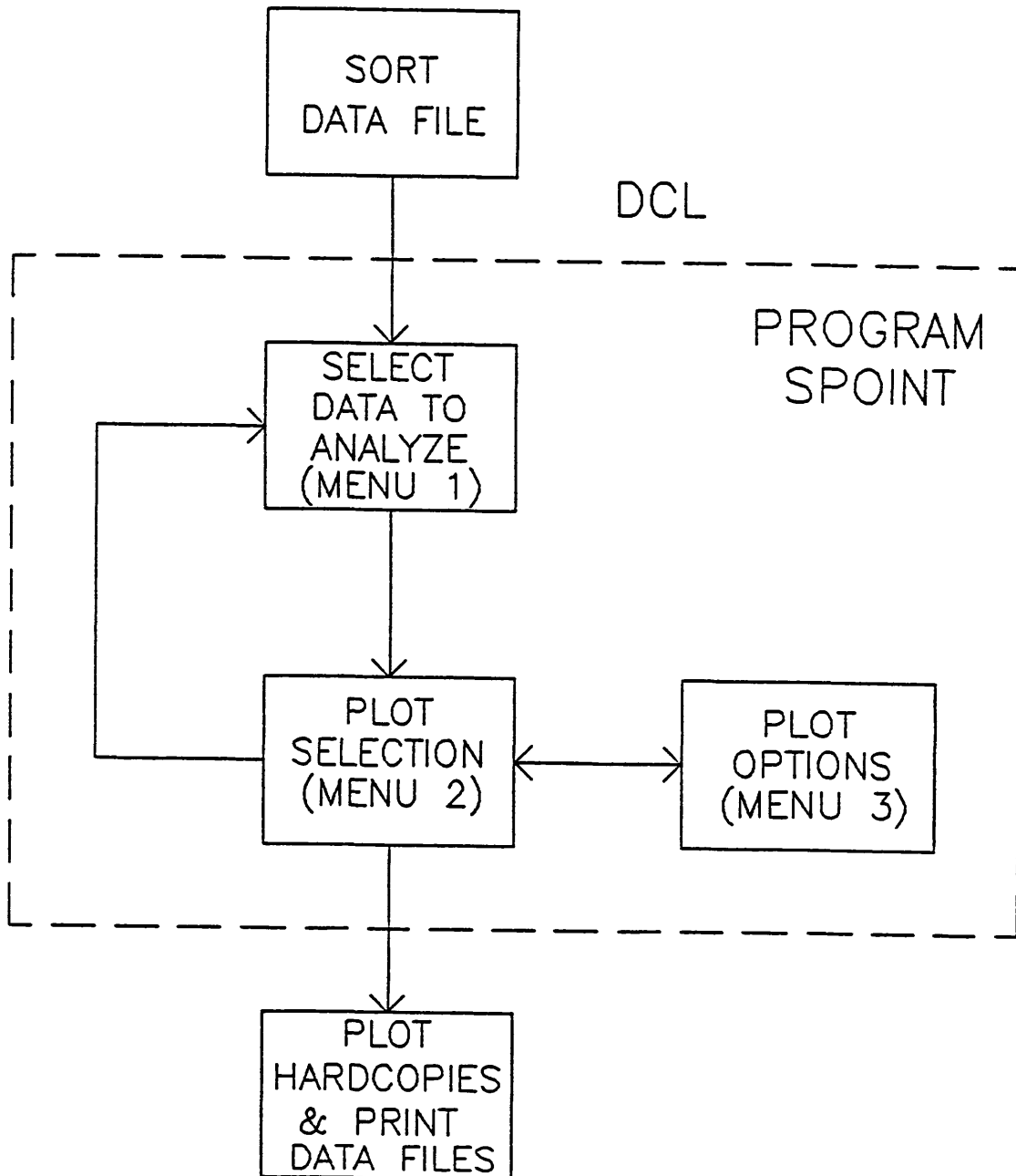
FIGURE 4.4 -- FLOW CHART OF GPOINT PROGRAM

TABLE 4.3

GPOINT MENU #1 -- DATA SELECTION

0. End selections.

1. Plot all data.

2. Plot only those points within a specified data and time range.

3. Select only those points within a daily UT interval.

4. Plot only those points within a specified frequency range.

5. Plot only those points labeled by specified observer's initials.

6. Plot only those points within a specified declination range.

7. Plot only those points within a specified hour angle range.

8. Plot one receiver channel, both channels, or an average.

9. Delete points from the display (by scan number).

The next section of the program prompts you to select what type of plot want. You can plot the azimuth and elevation pointing corrections as a function of elevation or cosine elevation. As a function of elevation, the plots are easier to use, but the pointing corrections should be approximately linear when plotted against cosine elevation. The plot options are given in the second GPOINT menu, which is listed in Table 4.4.

You may give the plots selected in the menu above a number of attributes by setting options in Menu #3, displayed in Table 4.5. If you wish to make hardcopies on the laser printer, you have two possibilities at your disposal. By selecting Option 2 in Menu #3, each plot displayed on the terminal screen will also be written to a hardcopy file. Alternatively, each time a new plot is displayed on the screen, an option will appear in Menu #2 for making hardcopies. The hardcopies will not be generated until you terminate the program. Then, you will be given the choice of printing the plots immediately, or saving them in plot files on the VAX to be plotted later. An example of a GPOINT plot is given in Figure 4.5.

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TABLE 4.4

GPOINT MENU #2 -- PLOT SELECTION

-1. Return to data selection menu.

0. No more plots -- terminate execution.

1. Go to the plot option menu (laser printer and LSQ fits).

2. Plot Delta-azimuth against elevation.

3. Plot Delta-azimuth against cosine (elevation).

4. Plot Delta-elevation against elevation.

5. Plot Delta-elevation against cosine (elevation).

6. Plot Delta-azimuth against azimuth.

7. Plot Delta-elevation against azimuth.

8. Plot Delta-Az, Delta-El pairs on an AZ/EL grid.

9. Plot Delta-Az, Delta-El vectors on an AZ/EL grid.

TABLE 4.5

GPOINT MENU #3 -- PLOT OPTIONS

0. Return to the plot selection menu.

1. Make a copy on the terminal only (default).

2. Make a copy on the terminal and the laser printer.

3. Include a least squares fit of the data.

4. Do not make a least squares fit of the data (default).

5. Plot a full grid on the Tektronics (Modgraph) display.

6. Turn off the full grid display for the Tektronics.

7. Plot each source with a different symbol.

8. Turn off Option 7.

9. Plot up-arrows for rising sources and down-arrows setting sources.

10. Turn off Option 9.

11. Plot day/night data with different symbols.

12. Turn off Option 11.

13. Subtract a DC level from AZ/EL vector plots.

14. Turn off Option 13.

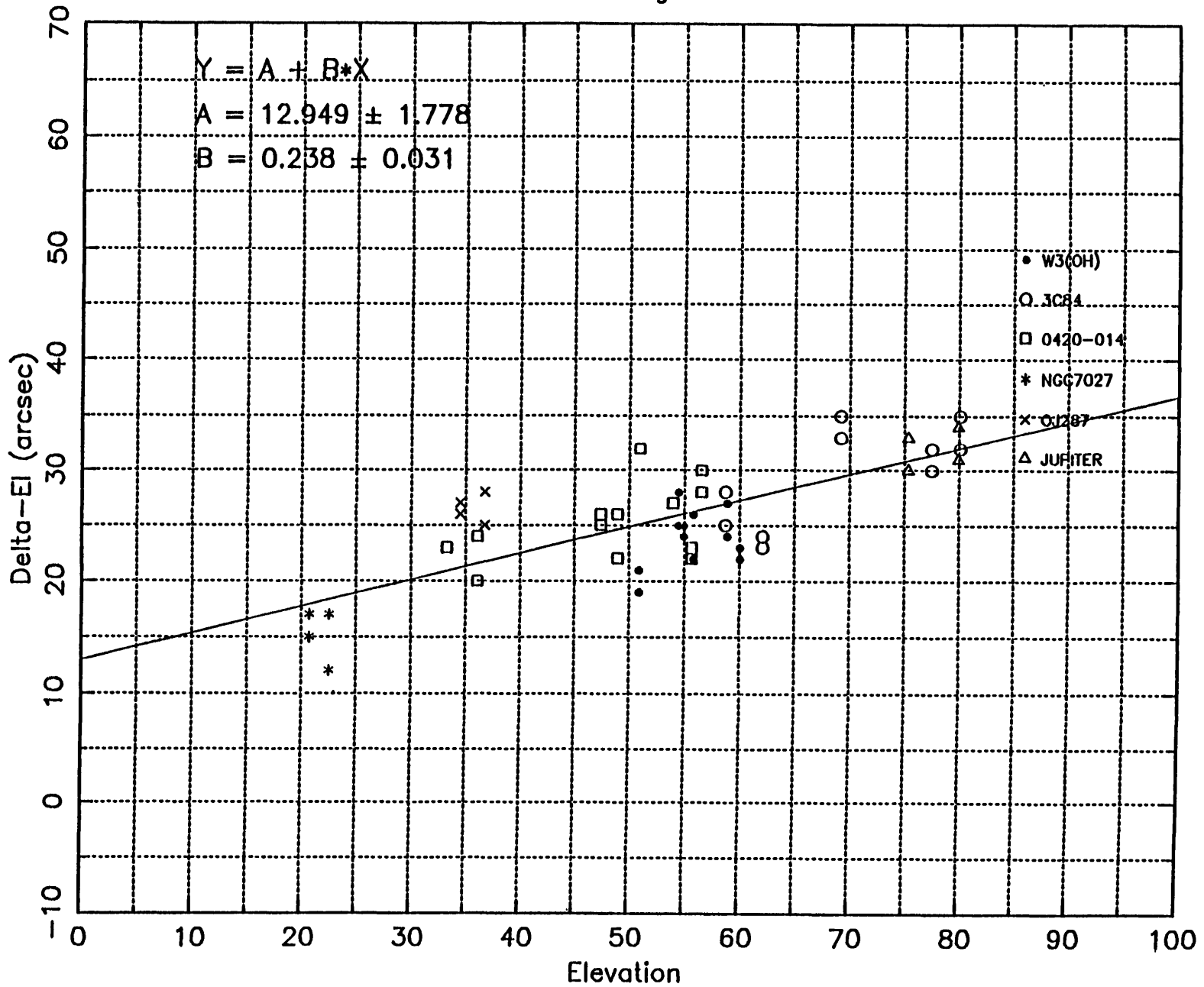# Elevation Pointing Corrections

$$Y = A + B*X$$
$$A = 12.949 \pm 1.778$$
$$B = 0.238 \pm 0.031$$

- • W3(OH)
- ○ 3C84
- □ 0420−014
- * NGC7027
- × OJ287
- △ JUPITER

Delta-El (arcsec)

Elevation

FIGURE 4.5 -- SAMPLE GPOINT POINTING ERROR PLOT

4.8 SEQUENCE OF POSITION COMPUTATION OPERATIONS

The sequence of computer operations that is executed when seeking and then tracking a source is as follows:

a) Input RA-DEC (1950 or current) or Galactic Position;

b) If 1950 position, precess to current date. A precession matrix is computed each day at 0 hours UT. This matrix is used to precess positions for the current day. The precessed position of a source is computed only when the source is first accessed.

c) If source is a planet, interpolate to current UT.

d) Do spherical coordinate conversion from RA-DEC to AZ-EL.

e) Add azimuth and elevation encoder corrections as computed from Equations (A.1), (A.2), (A.7), and (A.8) (*Appendix A*).

f) Add azimuth and elevation pointing corrections (see next section).

g) Command telescope to the correct AZ-EL position.

h) Loop to step (c) once per second. Between loops, extrapolate AZ and EL drive rates every 100 ms to compute positions.

4.9 RADIAL FOCUS

To bring the incident radiation to a focus at the receiver feed horn, the subreflector (secondary mirror) of the 12 m may be moved in and out along the electrical axis of the telescope. The focus exhibits an elevation dependence which is automatically corrected by the control system computer, according to the equation

$$F(E) = F_o + 2.8 \sin(E) \tag{4.1}$$

where $F(E)$ is the focus setting in millimeters, E is the elevation, and F_o, the subreflector focus setting at 0° elevation, is to be determined by the observer. F_o is given in millimeters, and larger values of F_o represent greater distances between the dish surface and the subreflector.

An automatic procedure called a FOCALIZE (*this word really is in the dictionary!*) exists in the control computer for determining the best value for F_o. An analysis routine of the same name exists in *CONDAR* and *LINE* for displaying and fitting the results. Instructions for performing a FOCALIZE are given in *Chapter 6.*

4.10 LATERAL FOCUS

The position of the subreflector for optimum gain shifts in the elevation direction, with changing elevation angle. The change in antenna gain produced by this effect is not significant at 3 mm wavelengths but could be as much as 20 % or more at 1.3 mm and shorter wavelengths. The 12 m is equipped with a lateral, "North-South" translation stage at the prime focus to eliminate this gain loss. The computer is able to control automatically the positioning of the stage, simultaneously applying an appropriate correction to the telescope pointing in elevation. This correction to elevation pointing is 34"/mm of movement of in the North-South focus stage.

In the future, the coefficients necessary to control the movement of the North-South translation stage will be installed in the computer and applied automatically. At this time, the North-South stage is fixed in position. An automatic procedure for fitting for maximum North-South gain, called NSFOCAL is available. This routine operates analogously to the FOCALIZE procedure. Normally, only staff astronomers use this procedure; we do not recommend that observers spend time trying to optimize this further.

CHAPTER 5
SOURCE CATALOGS

5.1 INTRODUCTION

The control system supports five user-defined source catalogs of 34 entries each. In addition, the staff maintains seven in-house catalogs for standard pointing, calibration, and test sources. Visiting observers are not allowed to edit the in-house catalogs, but may edit the five user catalogs, subject to the following proviso: when two or more observing teams are sharing telescope time, each team should take care not to edit or delete the others' catalogs. Once an observing team has completed its run, its observing catalogs may be edited or deleted. As described in the following sections, you may prepare and transmit catalogs via a PC workstation or through a direct terminal session with FORTH.

5.2 USING THE IBM PC TO ENTER AND TRANSMIT SOURCE CATALOGS

To insulate 12 m users from the pain of entering source positions directly into the FORTH computer, the staff has developed or acquired programs for an IBM PC for editing, parsing, and transmitting ASCII source catalogs to FORTH. The PC is situated at the Observer's Console in the 12 m control room and can be used for catalog preparation, as a direct terminal to FORTH, as a terminal to the VAX, or in its native PC-DOS mode.

The programs for parsing and transmitting source catalogs to FORTH have many capabilities and can handle a number of data entry formats. A complete description of these capabilities is given in *NRAO 12-m Computing Report #16* (10 Feb 1989) by C. Biemesderfer. Much of the material in this section (5.2) is taken directly from that report, although not all the information in that report is repeated here.

5.2.1 MAKING A SUBDIRECTORY ON THE PC

Before using the PC to create a source catalog, receive one from the VAX, or transmit one to the FORTH computer, you must first create a subdirectory on the PC to hold your files. Presuming that the PC is powered up and booted, make your subdirectory as follows:

Type

NCD   This is the NORTON Change Directory utility; it will display a tree structure of directories.

Now use the arrow keys to toggle to a directory called USER.

Type

M   This will allow you to make a subdirectory under USER

Type in your observer initials (preferably the same used to set up your run on the FORTH computer and the VAX). Strike the ENTER key and you will be placed in your subdirectory and will be ready to enter or copy source catalogs. The staff requests that you use this PC subdirectory for all your PC work while at the telescope, whether related to source catalogs or not.

5.2.2 SOURCE CATALOG TRANSPORT MEDIA

You can create your source catalog at the telescope or bring it with you from your home institution on one of several transport media including:

1.   5.25", 360k floppy diskette (DOS format)

2.   1600 BPI magnetic tape to be read on the VAX and transferred to the PC.

3. Electronic transfer to the VAX over one of the standard networks. (If you desire this option, *you must check that the transfer is possible before coming to the telescope!*)

5.2.3 SOURCE CATALOG DATA FORMATS

The parsing programs on the PC will accept a variety of source catalog input formats, then translate them into the rigid format required by the FORTH system. Here are the rules for the PC system:

1. The program can identify 5 fields: source name, horizontal coordinate, vertical coordinate, LSR velocity, and an optional coordinate system identifier. The coordinate systems allowed are equatorial or galactic.

2. The fields can be in any order, although within a given file the order must be the same. The default field order is source name, right ascension, declination, and LSR velocity.

3. Numeric fields may be integer, floating point, or sexagesimal (for α and δ). Sexagesimal coordinates must contain colons (:) to delimit hours (or degrees), minutes, and seconds.

4. A coordinate system flag may be specified in a file where the coordinate systems are mixed between equatorial and galactic. This flag is an integer field, where

    1   indicates equatorial coordinates (the default), and

    2   indicates galactic coordinates.

5. The fields (source name, coordinates, velocities) may be delimited by any character; blanks or tabs (any number) are the default. *The source name field must never contain blanks, and (once again) sexagesimal coordinates must be separated by colons (:).*

6. Blank (null) records and comment records are allowed. The comment character may be specified; # is the default.

```
EXAMPLE 5.1 EQUATORIAL COORDINATES IN SOURCE CATALOGS

#  CATALOG.TXT -- 12-meter observer catalog (sample)
#
#  Name            RA              DEC             LSR Velocity

   IRC+10216       09:45:14.8      13:30:40.0          -26.0
   M17SW           18:17:26.5     -16:14:54.0           19.4
```

5.2.4 CREATING A SOURCE CATALOG ON THE PC

Several text editors are available on the PC for use in entering source catalogs. These include EDLIN, PCWRITE, vi, and the Norton Editor (NE). You may use which, if any, you are the most familiar with. All can be started from your user subdirectory. If you are not familiar with any of these, we recommend that you use the Norton Editor. This is a very simple, full-screen editor. A manual for this editor exists at the telescope, but you probably won't need to consult it. To start the Norton Editor, type

         NE   filename.ext (we recommend that you use **.TXT** as the file extension since **.CAT** is reserved for the ultimate, parsed file that is to transmitted to FORTH.

The program will display a banner screen as it starts and will ask you to strike any key to begin entering source information. You can begin typing information at this point. When you are finished typing in your source catalog, strike the key

    F3

then   **E**   (for exit and save)

If you need more information while editing, strike the **F1** key. That displays the first help screen. Subsequent strikes of the **F1** key will display additional help screens. These help screens will probably provide all the information you need, but if all else fails, you can read the manual (which is short).

5.2.5 TRANSFERRING A SOURCE CATALOG FROM THE VAX

If your source catalogs are on the VAX, you will need to transfer them to the PC. To do this, create a subdirectory as described above, then type

    VTERM   This starts the VTERM terminal emulation and file transfer program.

Hit the **ENTER** key and you will get the VAX login prompt. Log into the OBS area and your subdirectory (designated by your observing initials). Your source catalogs should be in this subdirectory. Now type

    VTRANS   This starts the file transfer system. The VAX prompt that appears will be **VTRANS>**

To transfer a file from the VAX to the PC, type at the **VTRANS>** prompt

    PUT filename.ext

The transfer will commence; when it is finished the PC will beep. Note that the file will be transferred into the current subdirectory on the PC, so you must be sure that you are in the correct PC subdirectory before beginning the transfer. VTRANS has many other capabilities. You probably won't need these, but if you want more information, type

HELP

at the VTRANS prompt, or

HELP VTRANS

at the regular VMS $ prompt. When the transfer is finished, type

EXIT

to stop VTRANS. If you are finished with your VAX session, log off. At any time during your VAX session, or after you have logged off, you can toggle between the VAX and the PC by hitting the "hot key" sequence

LEFT SHIFT - RIGHT SHIFT *i.e.*, hit the two **SHIFT** keys simultaneously.

5.2.6 TRANSLATING THE PC FILE INTO FORTH FORMAT

After you have created a source catalog in your PC subdirectory, you must then translate it into the FORTH "source card" format. This format is explained in detail in following sections for special case needs, but generally, you can let the PC do the work for you. If your source catalog is already in FORTH format (e.g., from a previous observing run), you can skip to the next section.

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The process of translating the arbitrary input file into FORTH format is called *parsing*, and the program that does this is called `catparse`. The format for `catparse` is

```
catparse [-switch] [arguments] [| filter] [>output_filename]
```

where all the quantities in [] are optional. The possible switches are

- **-f** specify the input file name (default CATALOG.TXT)
- **-r** specify the order of the catalog fields (default nrdv)
- **-d** specify field delimiter (change from the default blanks)
- **-c** specify comment delimiter (change from the default #)

The switches and arguments are explained in detail in *Computing Report #16*. The case that arises most often at the telescope is:

```
catparse -f input_file >output_file
```

EXAMPLE 5.2 TRANSLATING A SOURCE CATALOG TO FORTH FORMAT

```
catparse -f myfile.txt >myfile.cat
```

---

where `myfile.txt` is the input file in arbitrary format and `myfile.cat` is the output file in FORTH format.

5.2.6.1 SPECIFY CATALOG FILE NAME: -f

The default file name (catalog.txt) may be changed with the -f switch. An alternate filename can be specified by typing

> catparse -f *filename*

For example, if one wanted to parse the file ircmap.dat, the command line would look like

> catparse -f ircmap.dat

Note:

The parsed output will be directed to the terminal screen unless you specify the > output redirection flag.

5.2.6.2 SPECIFY FIELD ORDER: -r

The order of the fields or columns in the catalog file may be altered with the -r switch. By default, the fields are expected to be source name, right ascension, declination, and velocity. The field order is specified as a string of characters where each character represents a field.

> catparse -r *string*

The single character abbreviations for the various kinds of column are

r   right ascension
d   declination
l   galactic longitude
b   galactic latitude
n   source name

v   source velocity

w   world coordinate system (WCS) flag

x   *placeholder*

where nrdv is the default.

For most catalogs, the WCS is assumed to be the same throughout the file and whether it is equatorial or galactic is determined by the appearance of the characters 'rd' or 'lb' in the record format string. For example, a catalog with columns in the order α, δ, source name, and velocity could be used by typing

> catparse -r rdnv

All the coordinates in the file are assumed to be α, δ pairs.

Occasionally, one will have a catalog with coordinates mixed between equatorial and galactic systems. In order for such a catalog to be properly interpreted, each record must contain a tag field that indicates which WCS applies for the source position. The WCS flag is just an integer, where 1 signifies equatorial coordinates and 2 means galactic. The existence of this WCS flag field as well as its location in the record is indicated by a 'w' format specifier, as in the following examples:

> catparse -r nrdwv   or
> catparse -r nlbwv

Notice that is irrelevant whether the coordinates are specified as α, δ or ℓ, b as long as their relative positions on the record are correct.

Often, catalog files will contain extraneous information. (Well, extraneous as far as catparse is concerned.) Fields that should be skipped over in order to get to other valid data can be marked with the 'x' format specifier. For instance, a catalog

that contains records giving source name, I magnitude, velocity, α,δ, and α and δ components of proper motion could be parsed by typing

```
> catparse -r nxvrd
```

Note that it is not necessary to indicate the presence of data farther to the right on the record than the fields of interest (the proper motions in this example).

5.2.6.3 SPECIFY FIELD DELIMITER: -d

The default field or column delimiter(s) may be changed with the -d switch. The default delimiter is *white space*, which means any number of blanks and/or tabs separate the fields. Several delimiters may be specified (as a single string), if necessary, but be wary of parsing consequences before getting too fancy. For best results, enclose the overriding delimiter(s) in double quotes.

```
> catparse -d "delimiter(s)"
```

For instance, if the fields in the catalog file were delimited by commas rather than white space, that would be indicated by typing

```
> catparse -d ","
```

5.2.6.4 SPECIFY COMMENT IDENTIFIER: -c

Comment records may appear in the catalog file. These records are identified by a special character in the first column of the record; by default, the # character signifies that a record is a comment and should be ignored by the parser. The identifying character can be changed with the -c switch. Only *one* comment character may be specified; for best results, enclose the character in double quotes.

> catparse -c "*comment_identifier*"

If comment records beginning with '!' were present in the catalog file, one would type

> catparse -c "!"

5.2.6.5 SPECIFY OUTPUT FILE

The output from the catparse program will be written to the terminal screen by default. Most of the time, you will desire that the results of the parsing run be placed in another file that can be transmitted to the FORTH system. Such an output file is created by taking advantage of the *output redirection* feature of the operating system. A greater-than sign or right angle bracket followed by a file name will redirect any information normally written to the terminal into the named file. Typing

> catparse -f sources.dat >sources.cat

will parse the catalog sources.dat into the file sources.cat.

The FORTH system will be slightly happier if your catalog entries are sorted, and a sorted output file can be created by using another feature of the PC's command interpreter, namely, that of *piping* output through a *filter*. The filter we are interested in is SORT. The pipe character is '|' and is used similarly to the redirection character. If one types

> catparse -f sources.dat | sort >sources.cat

one will wind up with a sorted catalog in the file sources.cat. If the output redirections were left off the above command, the sorted catalog would be displayed on the terminal.

5.2.7 TRANSMITTING A SOURCE CATALOG FROM THE PC TO FORTH

> Note:
>
> You must get permission from the operator before transmitting catalog files to FORTH. If the system is busy tracking and taking data, catalog information can be dropped forcing a retransmission, or worse, FORTH can be hung up requiring a system reboot.

Before transmitting a catalog to FORTH, be sure that it has been translated into the proper FORTH format. Once done, type at the PC

catxmit *filename*

This will start a terminal session with the FORTH computer and loads the FORTH CATALOG program. Before doing the transfer, you will need to perform some setup operations including selecting a catalog, checking its current contents, and possibly emptying it. Follow these steps:

1. FORTH has 5 user catalogs, each of which can contain 34 source entries. These catalogs are common to all observers, so if you are sharing time on telescope with another team, you must coordinate the use of these catalogs.

2. The catalogs are addressed (i.e., pointed to) by typing

    n CAT

    where n can be 1, 2, 3, 4, or 5.

3. List the contents of the catalog by typing

    INDEX

4. You may delete the contents of a catalog by typing

    CLEAR

    BUT PLEASE MAKE SURE YOU ARE NOT DELETING SOMEONE ELSE'S CATALOG WHO IS STILL AT THE TELESCOPE. After an observing program is completely over, the catalogs for that program may be deleted. If you do not **CLEAR** the catalog, the transferred entries will be appended. If the catalog is already your own, this may be what you desire.

5. Begin the transfer by typing

    CTRL/T   i.e., pressing the **CTRL** and **T** keys simultaneously.

    You will see the contents of the catalog listed out.

6. You can list your catalog again by typing

    INDEX

    Please proof them carefully, as transmission errors have been known to occur.

7. To end your **catxmit** session, hit the **ESCAPE** key

    ESC

5.3   GAINING ACCESS TO THE CONTROL SYSTEM FROM THE OBSERVER'S PC

The observer's PC provides access to the FORTH system regardless of whether you are using the parsing and transmittal programs described above. There are two ways to gain access to FORTH from the PC. The first is through catxmit described above. catxmit automatically loads the FORTH CATALOG module and expects to transmit a catalog. If you wish to start a simple terminal session with FORTH without transferring a catalog, you may do so by typing at the PC

FORTH

This starts a terminal emulation program similar to the VTERM sessions on the VAX. Please note that the only reason you would ever want to interact with the FORTH system is for catalog manipulation. The FORTH system is fragile and it is quite possible for the observer to crash the system by typing in the wrong thing.

If you start a direct terminal session with FORTH, there are a few things you should know. The FORTH control system functions by loading specific modules into memory. The module that provides access to the source catalogs is called CATALOG. Anytime the system is rebooted or the spectral line or continuum tasks are loaded, the catalog module must be reloaded. Do this by typing

CATALOG

The loading process requires about 10 - 20 seconds. When (and only when!) the loading is complete, you are ready to enter or edit his catalogs using the commands given below.

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5.4 FORMAT OF THE SOURCE CATALOG ENTRIES

FORTH catalog entries must conform to one of the following three formats. Once again, you can save yourself the pain of this rigid format by using the PC parsing program described above. Still, you may need to know this format for entering single positions or for editing catalogs.

Equinox 1950.0 Right Ascension and Declination:

```
hh:mm:ss.s  Sdd:mm:ss.  EPOCH     name   Skk.k   KM/S
```

Current Right Ascension and Declination:

```
hh:mm:ss.s  Sdd:mm:ss.  CURRENT   name   Skk.k   KM/S
```

Galactic (lII, bII) coordinates:

```
ddd.dddd    Sdd.dddd    GALACTIC  name   Skk.k   KM/S
```

In the above formats, "S" signifies a sign digit (±); however, note Rule 5 below.

5.4.1 EXPLANATION AND RULES

1. The format of the source cards is rigid. The order and number of colons and decimal points, and the number of places after the decimal point is definite and may not be varied. In particular, *do not forget the final decimal point on the declination specification.* Failure to follow the format will result in incorrect source positions. Also, FORTH expects all commands to be in UPPER CASE letters.

2. Any number of spaces between words in permissible.

3. The words EPOCH, CURRENT, GALACTIC, KM/S, etc., must appear literally (i.e., don't type '1950' instead of EPOCH; EPOCH tells the computer that the positions are 1950.0).

4. The source name is limited to 11 characters with no embedded blanks. All alphanumeric characters and other standard ASCII characters such as '+', '-', etc., are allowed.

5. Plus signs must not be used in the coordinates to indicate positive declinations or latitudes.

6. Leave no blank spaces between a minus sign and its number: -10.0 not - 10.0

7. Leading zeroes may be included if desired. Equivalent entries are:

```
1:23:45.0    -2:34:56.
01:23:45.0   -02:34:56.
```

8. The source velocity is optional. If the velocity and the KM/S word are not given, a velocity of 0.0 will be set by the program. For spectral line observing, the velocity should be specified in the source card, in general. Velocities are always given in units of kilometers/second.

Velocity entries are interpreted in two different ways, depending upon the control system flag LOWVEL/HIGHVEL that is entered by the operator. LOWVEL is the default mode. In this mode, velocities can be entered to an accuracy of 0.1 km/s and can range between the values -3267.8 and 3267.8 km/s. In the HIGHVEL mode, velocities ranging between -32678 and 32678 km/s can be entered to an accuracy of 1 km/s. In the HIGHVEL mode, the velocity format on the source card should include a decimal point but no trailing digit. Example: 15973. KM/S. Low and high

velocity entries can be mixed in the same source catalog. They are not interpreted until the source is called up by the operator. *If the source is to be interpreted with a high velocity, the operator must specify* HIGHVEL *before calling up the source. This flag will stay set until the system is booted or reloaded or the operator types* LOWVEL. The observer should give clear instructions to the operator in this regard and should make sure that the velocities are properly interpreted.

EXAMPLE 5.3 FORTH SOURCE CARD ENTRIES

```
02:21:57.0    61:52:45.    EPOCH   W3            -39.0  KM/S
09:45:14.8    13:30:41.    EPOCH   IRC+10216     -26.0  KM/S
19:21:42.2   -29:20:26.    EPOCH   1921-293
359.6296      -0.9357      GALACTIC  SGR-1A        60.2  KM/S
```

5.5 TYPING A SOURCE CATALOG DIRECTLY INTO FORTH

To enter a source catalog by directly typing on the terminal, follow the instructions given below. You can use the same process to make additional entries into an existing catalog.

1. Start the terminal session from the PC by typing

    FORTH

    The OK prompt should appear. Then type

    CATALOG

to load the CATALOG module. After 15-20 seconds, the OK prompt will reappear. Do not type anything before the OK prompt appears.

2. Select a catalog in which to load the source list. To see which catalogs are empty, type

    PAGE

to clear the screen, and

    n CAT INDEX

where n can be 1 through 5. If your observing team is the only one using the telescope, you may empty any of the user catalogs by typing

    CLEAR

after selecting a catalog with the 'n CAT' command. *If you are sharing time with another observing team, do not empty a catalog without finding out which catalogs they are using.* Leave the system pointing to the catalog you wish to use. You may also use catxmit to load additional sources into an existing catalog, i.e., without clearing it. In this case, the additional sources will be appended to the previous list.

Note: <u>Never CLEAR an NRAO or PLANETS catalog.</u>

3. Enter the sources according to the format given in Section 5.4.

4. When finished, type

    PAGE INDEX

to get a listing of the catalog. Proof the entries and if they are correct, type

FLUSH

This writes the catalog to disk. If this command is not issued, the catalog will be lost the next time the system is booted.

5.6 DELETING ENTRIES FROM A CATALOG

The FORTH CATALOG program does not have any facility for editing errors in the source specification other than deleting the entire line and retyping it correctly. To do this, type

FIND *source_name* DELETE

where *source_name* is the source name of the entry. After any change to the catalog, remember to FLUSH it to disk.

5.7 PLANETS CATALOG

The Observatory maintains a catalog of planetary positions for the observer's convenience. Planetary positions at 0^h UT for each day of the year are stored in the control computer. The position of the planet at a given instance is computed from a three point parabolic interpolation of the positions at 0^h UT for the current day, the day before, and the day after. At 0^h UT each day, the telescope operator must load the planetary positions for that day.

To get a listing of the planetary positions, start the terminal session with FORTH by typing at the PC

FORTH

Then type

CATALOG

if the FORTH catalog module is not already active, and after the 'OK' prompt appears, type

PLANETS INDEX DATE

A listing of the positions will appear followed by the date of the positions.

A sample listing is given in Figure 5.1. The three positions for each object are the "yesterday," "today," and "tomorrow" right ascensions and declinations, with respect to the current epoch, in that order (the position on the same line with the source name is the position for the current day). The right-most column gives, from top to bottom, the horizontal parallax correction in arcseconds, the UTC for which the center position applies (always 0 for the planets), and the UNIT setting which told the FORTH system the appropriate data precision for the analog backend (this is no longer needed for the digital backend). The FORTH system uses integer arithmetic, and UNIT corresponds to the number of digits past the decimal place. The system cannot record more than four significant digits.

5.8 ENTERING POSITIONS FOR THE MOON, COMETS, OR SATELLITES

Positions for fast moving objects such as the Moon, comets, or satellites go into the PLANETS catalog and are handled in the same way as for the planets, i.e., the system makes a three point interpolation of positions at specific epochs. However, since these objects may change their positions very rapidly, the interval between epochs usually must be less than one day if the interpolation is to be sufficiently accurate. Intervals of 24, 12, 8, 6, 4, 3, 2, and 1 hours are supported. A special version of the program is available that will allow intervals as small as 15 minutes. You must also specify the data precision at the time the entries are made.

MERCURY

VENUS

SUN

MOON

MARS

JUPITER

SATURN

URANUS

NEPTUNE

PLUTO

COMET

SATELLITE

OK _

```
12:10:25.9    0:52:11.        8  ←  Horizontal Par. (")
12:15:18.5   00:26:12.        0  ←  U.T. epoch of coords.
12:20:12.0   00:04:36.        3  ←  "UNIT" scaling factor
16:09:32.4  -23:38:38.       10
16:14:16.2  -23:53:54.        0
16:19:00.3  -24:08:37.        0
13:12:29.0   -7:40:57.        0
13:16:12.0   -8:03:21.        0
13:19:54.6   -8:25:37.        0
23:31:34.1   06:33:03.      358
 0:25:13.8   06:35:06.        0
-1:21:04.3   13:15:42.        1
12:57:14.   -05:26:11.        0
12:59:40.5  -05:37:46.        3
13:02:06.5  -05:53:20.        2
06:45:23.3  -22:46:10.        0
06:45:36.3  -22:46:00.        2
06:45:49.2  -22:45:50.        2
18:35:13.0  -22:46:31.        1
18:35:26.3  -22:46:26.        0
18:35:40.0  -22:46:22.        3
18:07:50.6  -23:41:56.        0
18:07:57.0  -23:41:54.        4
18:08:05.4  -23:41:52.        0
18:42:06.1  -22:12:16.        0
18:42:09.3  -22:12:15.        4
18:42:12.6  -22:12:14.        0
15:04:26.6   -1:32:10.        0
15:04:34.6   -1:33:09.        4
15:04:42.7   -1:34:00.        4
14:05:41.3  -31:40:44.       18
14:06:12.4  -31:45:48.        3
14:06:43.6  -31:50:52.        0
 0:00:00.0   00:00:00.        0
 0:00:00.0   00:00:00.        4    14 OCT
```

FIGURE 5.1 — SAMPLE PLANETS CATALOG

5.8.1 MOON POSITIONS

Follow this prescription for entering positions of the Moon.

1. Start the terminal session from the PC by typing

   FORTH

   Once the OK prompt appears, type

   CATALOG

   if the catalog task is not already active. When the 'OK' prompt appears, type

   PLANETS

   to enter the planets catalog.

2. Ask the operator for the notebook containing the Moon ephemeris. Positions for each hour of the day (in Universal Time) and each day of the year are contained in this notebook.

3. Set the interval between positions to 1 hour by typing

   1 DH !

   (This command is essential; don't forget it!)

4. Set the data precision factor (UNIT) to 1 by typing

          1 BELONG MOON

5.   The format for Moon position entries is

      hh:mm:ss.s Sdd:mm:ss. mm:ss hh HOURS MOON

where	hh:mm:ss.s	is the current RA,
	Sdd:mm:ss.	is the current DEC,
	mm:ss	is the horizontal parallax (minutes and seconds of arc),
	hh	is the UT hour of the position.

The words HOURS MOON must appear as such. Do not include an explicit + sign if the declination is positive. Three entries are required, the positions for "last hour," "this hour," and "next hour."

6.   If the Moon is observed through 0^h UT, the HOURS entry of the source specification must be handled in a special way. As 0^h is approached, enter

      24 HOURS instead of 0 HOURS, and
      25 HOURS instead of 1 HOURS.

When the current hour is 1^h UT, the three hours will be entered as 0, 1, and 2 HOURS.

7.   To obtain a listing of the entries, type

      PAGE PLANETS INDEX

If the entries are correct, type

      FLUSH

to write the entries to disk. If an error exists, start over!

9. When the Universal Time moves from one hour to the next, enter the next Moon position. Note that it is not necessary to type in all three positions, only the new one. FLUSH the positions to disk to avoid loss in case of a system crash.

5.8.2 COMET AND SATELLITE POSITIONS

Comet and satellite positions are handled in the same way as Moon positions except that the observer is responsible for providing his own ephemeris with a position interval that will produce accurate results in a three-point interpolation. The positions should be computed with respect to the current epoch (*i.e.*, apparent coordinates of date) and should include horizontal parallax corrections. Take particular care that the positions and radial velocities are based on up-to-date orbital elements and are corrected for light travel time.

To load comet or satellite positions into the PLANETS catalog, follow the procedure for Moon positions with these exceptions:

1. Set the time interval between positions to that generated by your ephemeris by typing

    hh DH !

    where hh is the interval in hours. It is your responsibility to insure that the interval is small enough to produce sufficient pointing accuracy.

2. Since comet signals are usually weak, set the data precision to the maximum accuracy (UNIT = 4) by typing

4 BELONG COMET

3. The format for the source cards is

     hh:mm:ss.s   Sdd:mm:ss.   mm:ss   hh   HOURS   COMET

where

hh:mm:ss.s Sdd:mm:ss.	is the <u>CURRENT</u> right ascension and declination,
mm:ss	is the horizontal parallax,
hh	is the UT epoch of the position, and HOURS COMET must appear as such.

4. The instructions given in Section 5.9.1, items 5 through 9, apply to comet positions as well.

5. To make an entry into the SATELLITE slot, replace the word COMET with SATELLITE and follow the format of item 3 above.

5.8.3 USING THE PLANET, COMET, AND SATELLITE SLOTS FOR OTHER SOURCES

Other solar system objects such as asteroids can be loaded into the PLANET, COMET, or SATELLITE catalog slots. You must retain the original name, *i.e.*, you must not change the names MERCURY, PLUTO, etc., but you may alter the positions to contain the position of the desired source. You can then keep a correspondence table to keep track of which source is represented by which alias. Each time the operator resets the PLANETS catalog (usually at 0 hours UT each day), any substitute planets positions will be destroyed and replaced with the true planetary position. Hence, we recommend that you use COMET or SATELLITE for substitute positions. If you need more slots

```
EXAMPLE 5.4 MOON AND COMET CATALOG ENTRIES

    Example 1. Typical Moon entry

        05:27:47.9  22:09:26.  60:51  02  HOURS  MOON
        05:30:28.4  22:14:47.  60:50  03  HOURS  MOON
        05:33:09.1  22:19:58.  60:49  04  HOURS  MOON

    Example 2. Moon entry through 0ʰ UT

        12:50:23.7  -08:05:08.  59:36  23  HOURS  MOON
        12:47:58.0  -07:53:08.  59:34  24  HOURS  MOON
        12:45:32.4  -07:41:07.  59:33  25  HOURS  MOON

    Example 3. Comet entry with 6-hour separation between positions.

        21:30:03.8  -09:04:37.  01:15  01  HOURS  COMET
        21:33:33.2  -09:57:59.  01:15  07  HOURS  COMET
        21:36:51.9  -10:51:36.  01:15  13  HOURS  COMET
```

than that, use planets not usually observed for pointing and focussing, such as Mercury, Neptune, and Pluto.

5.9 VELOCITIES OF PLANETS AND COMETS

Observers sometimes observe the spectral line absorption or emission from planetary atmospheres or cometary envelopes. In either case, the control computer will adjust the local oscillator frequency synthesizer so as to keep the spectral lines on a geocentric velocity scale. The planetary positions stored in the computer (but not displayed in the PLANETS catalog) contain the geocentric velocity for each day of the year. In the case of comet observations, you must supply the geocentric velocity from the ephemeris. The operator can input the cometary velocity manually from his console. In either the planetary or cometary cases, the computer will, in addition, correct for the Earth's diurnal motion. For this reason, you should not specify cometary velocities in the topocentric frame, as the system would then make topocentric corrections twice.

5.10 SUMMARY OF CONTROL SYSTEM COMMANDS FOR CATALOG ENTRY

n CAT

Calls up (but does not display) a user catalog, where n is its number (1 - 5).

n NRAO

Calls up (but does not display) an in-house catalog, where n is its number (1 - 7). Currently, only catalogs 1 - 3 have unique entries.

PLANETS

Calls up (but does not display) the catalog containing planetary, solar, lunar, cometary, and satellite positions.

INDEX

Displays the catalog called up by CAT, NRAO, or PLANETS.

CLEAR

Empties the catalog called up by CAT or NRAO. This is an irreversible command; once given, the catalog is gone forever. *Under no circumstances should you* CLEAR *an* NRAO *or* PLANETS *catalog.* If an NRAO catalog is CLEARed, it must be reloaded from tape; if a PLANETS catalog is CLEARed, the systems programmer must restore it.

FIND *source_name* DELETE

Deletes the source entry, where source_name is the name of the source.

FLUSH

Writes the catalog to disk. This command should always be issued after all the sources have been typed in and checked. For safety's sake, it can be typed after a number of sources have been entered. If the control system crashes, the catalog will be preserved if FLUSH has been issued.

n BELONG MOON
n BELONG COMET

n BELONG SATELLITE

> Sets the value of UNIT (data precision factor, *not needed for the digital backend*) for the Moon, comet, or satellite observations.

hh DH !

> Sets the time interval between catalog positions in hours (applicable to PLANETS catalog entries for the planets, Moon, a comet, or a satellite.

CHAPTER 6
CONTINUUM OBSERVING

6.1 INTRODUCTION

This chapter describes the continuum observing capabilities of the 12 m telescope and provides prescriptions for setting up a continuum observation. The contents of the chapter include

- A start-up checklist
- Considerations in selecting an observing frequency
- Continuum observing basics
- A description of the digital backend (signal processor)
- Observing modes,
    ON/OFFs
    Grid Mapping and Dual Beam Restoration
    Drift Scans
- Utility routines,
    Five point maps
    Focus checks
    Sky tips
- Calibration techniques

6.2 START-UP CHECKLIST

Once the scientific goals of the observing program are in mind, you must make the following decisions:

a) *Precise Observing Frequency.* When choosing a precise frequency, consider both the absorption spectrum of the atmosphere and the possibility of contamination by galactic spectral line emission.

6-1

b) *Observing Mode.* Select the appropriate observing mode from those available, and decide upon the setup parameters. Observing modes supported are ON/OFF's, single beam and dual beam GRID MAPPING, and utility programs such as FIVE POINT MAPS, SKY TIPS, and FOCUS checks.

c) *Beam Throw.* A particularly important setup parameter for beam-switched observations is the beam throw. The throw can be varied from 0 to 6' (a 6' throw may be inefficient in terms of the blanking necessary).

d) *Observing Time Budget.* As with all observations, you should carefully plan the observing program to include time not only for observations of the program sources, but for pointing, focussing, and calibration.

When beginning a continuum observing run, we recommend that you follow these steps:

1) Have the operator tune the receiver to the frequency of your program observations and make any other necessary changes.

2) Perform a hot/cold load observation to measure the receiver noise temperature and to set calibration scale factors.

3) Check the telescope pointing and focus on a standard source, preferably in the same part of the sky as your first program source.

4) Make a short ON/OFF observation of a strong standard source such as a planet to see that the telescope and receiver systems are functional, at least in gross terms.

5) Observe a standard source using the system configuration and observing techniques you intend to use for program observations.

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6) Commence the program. Remember to check pointing and focus and to observe flux density standards frequently.

We strongly recommend that you invest the time to perform these checks. Remember: *The responsibility for the integrity of the data rests with the observer.*

6.3 SELECTING AN OBSERVING FREQUENCY

You should take some care in the precise choice of a continuum observing frequency. In addition to the scientific goals that determine the approximate frequency, you should also consider two other factors: what frequency gives the best atmospheric transmission, and will the observations be affected by contamination from spectral lines in the bandpass. In the 3 mm band, maximum transmission occurs near 90 GHz; in the 1.3 mm band, maximum transmission occurs near 230 GHz; and in the 0.9 mm band, maximum transmission occurs near 345 GHz.

If the observations are near molecular clouds, spectral line contamination can seriously affect continuum measurements. This is particularly true if the continuum bandpass contains strong molecular lines, such as those from CO, HCN, or HCO^+, but even a series of weak lines, when integrated over the band, can be a problem. As receiver sensitivities have improved, observers have discovered that some molecular line sources contain what is nearly a continuum of spectral lines -- the so-called "spectral line forest." We advise continuum observers to research the sources they wish to observe to find if any of these molecular line sources are either associated with the program source or along the line of sight. You should then consult a molecular line listing such as the F. J. Lovas Catalog (1986, *J. Phys. Chem. Ref. Data*, 15, 251) to pick the optimum observing frequency. Most of the 12 m continuum receivers are double sidebanded, with 600 MHz bandwidths in each sideband, and a sideband separation of 3.0 GHz.

6.4 OBSERVING BASICS

You can perform several types of continuum observations at the 12 m. The most common types are 1) point source flux density measurements, and 2) maps of emission in extended sources. This section describes the basic considerations, terminology, and techniques for making these observations. Detailed descriptions of the observing procedures are given in Section 6.6.

6.4.1 SWITCHING MODES

In contrast to spectral line signals, continuum signals are fundamentally indistinguishable from other broadband noise sources, such as atmospheric emission, spillover radiation from the ground and surrounding buildings, and receiver gain fluctuations. Such noise sources (particularly atmospheric emission) are, in fact, usually stronger than the celestial signal. Furthermore, atmospheric emission may change over very short time scales (<< 1 s) and may vary significantly at sky positions separated by as little as a few arc minutes.

To distinguish the celestial signal from other broadband signals, the 12 m systems provide various switching and subtraction techniques. Most of the techniques employ *beam switching* of one type or another. Beam switching is accomplished by a nutating subreflector (also known as a chopping secondary). At present, the subreflector switch rate is 4.0 Hz and the subreflector throw can be varied from 0 to about 6 arc minutes. Between 4' and 6', the subreflector switching efficiency diminishes; hence, we discourage use of the maximum throw.

At the 12 m, the two subreflector positions are termed the +BEAM and the -BEAM. With the analog phase-sensitive detectors, the source produces a positive deflection on the chart recorder when it is in the +BEAM and a negative deflection when in the -BEAM.

Two types of beam switching are employed: *single beam* and *dual beam*. For point source ON/OFF scans, a dual beam observations means that during the course of the scan, the telescope is positioned so that the source is alternately in the +BEAM and the -BEAM. For grid mapping observations, the dual beam mode means that source emission is expected in each of the subreflector beam positions and that the dual beam restoration algorithm (described below) will be applied. A single beam observation, for either point source or mapping observations, means that source is observed in only one of the subreflector beam positions.

The other switching mode is total power position switching for which the subreflector locked to a single position (the +BEAM, by convention). Observers occasionally use this mode to make accurate aperture efficiency measurements so as to avoid any efficiency losses incurred during subreflector switching. These observations usually use a planet whose strength is large compared to the emission differences of the atmosphere at the two sky positions of a position switched observation. In the rare circumstance in which a source is so extended that the dual beam restoration mapping technique is inapplicable, total power observations may be required. *For most standard observing procedures, observers prefer beam switching over total power position switching, as it provides much better cancellation of the atmosphere.*

Most of the continuum observing procedures available at the 12 m function for either beam switched or total power modes. The operator controls whether the observation is in beam switched or total power mode simply by turning a switch on the subreflector control chassis to make the subreflector nutate or to lock it in a single position. The signal processor (digital backend) always integrates four phases, even if the subreflector is locked to a single position. In the fixed beam case, all four switch phases produce the same data, apart from random noise and noise tube emission.

6.5 THE DIGITAL BACKEND

The data from all standard continuum observations are processed through the digital backend (DBE). An analog backend is used to display switched power and total power traces on the on-line chart recorders, but is not used for data processing and recording.

6.5.1 DIGITAL BACKEND HARDWARE CONFIGURATION

In Chapter 3 we gave a description of the hardware configuration of the DBE. In brief, it processes two independent channels and accumulates the signals from four switching phases. The integrators are 32 bit devices.

The four switch phases of the DBE are defined as

$$\Phi_1 = \text{SIG} + \text{CAL} , \qquad (6.1)$$

$$\Phi_2 = \text{REF} + \text{CAL} , \qquad (6.2)$$

$$\Phi_3 = \text{SIG} , \qquad (6.3)$$

$$\Phi_4 = \text{REF} , \qquad (6.4)$$

where SIG and REF refer, respectively, to the signal and reference positions (+BEAM and -BEAM) of the nutating subreflector. CAL refers to the signal generated by the synchronous noise tube, which is available for 3 mm observations. If the subreflector is fixed, as in a single-beam, total power measurement, the SIG and REF phases are the same (apart from random noise).

The operator can control three hardware setup parameters on the DBE: S/R, the switch period; DELAY 1, the blanking interval; and, DELAY 2, the interval between the start pulse of a switch cycle and the onset of blanking: DELAY 2 is used to compensate for the mechanical inertia of the subreflector.

The switch period S/R currently *must be set to 0.25 sec* (a 4 Hz switch rate), so that the control computer can acquire DBE data in synchronism with its basic timing cycle. The mechanical inertia of the subreflector imposes a limit of about 6 Hz on the maximum switch rate. DELAY 1 is typically set to 28.0 ms (out of a 125 ms phase period). The value to enter into DELAY 2 is given by the formula

$$DELAY\ 2 = [S/R]/2 - [\text{desired delay in start of blanking}]. \qquad (6.5)$$

The subreflector requires about 9 ms to respond after it is commanded to move, so for [S/R] = 250 ms, DELAY 2 = 116 ms. The values of DELAY 1 and DELAY 2 should be set to give maximum signal strength for a point source, and to minimize contamination by emission between the signal and reference beams when mapping an extended source.

When the operator initiates a continuum scan, the control computer issues a signal to the DBE to begin a cycle of four phases. Each time a cycle is completed, the control computer reads the contents of the four phase registers of the DBE. Ideally, this occurs every 500 ms of elapsed time. The presence of error conditions (loss of phase lock or pointing out-of-tolerance) may cause the elapsed time to exceed the specified integration time. If the control computer detects an error condition during Phases 1 or 2, it sends a restart signal to the subreflector and the phases are retaken. If the error condition occurs during Phases 3 or 4, the computer rejects the entire 500 ms of data. The control system time counter counts down monotonically in 100 ms steps (the monitor updates only every second). If the cycle must be restarted because of an error condition, the scan counter on the status monitor will indicate that the integration has proceeded farther than it really has (the computer cannot reset the counter backwards in time). This can lead to the peculiar situation of the time counter running to negative values at the end of the scan. The computer always records the correct amount of data as specified by the input integration time, however.

6.5.2 SOFTWARE SIGNAL PROCESSING OF DIGITAL BACKEND DATA

The data sent from the control computer and recorded on the VAX analysis computer contain the four phases, integrated over the number of dumps, for each sample or sky position. Thus, the raw data scan contains four times as many points as there were samples. If the sample number is denoted by S_i and phases in that sample as Φ_i, the data are recorded in the order

$$S_1,\Phi_1 \quad S_1,\Phi_2 \quad S_1,\Phi_3 \quad S_1,\Phi_4 \quad \quad S_2,\Phi_1 \quad S_2,\Phi_2 \quad S_2,\Phi_3 \quad S_2,\Phi_4 \ldots$$

and so on. *No calibration factors have been applied to the data as it is recorded*; the data are completely raw counts from the DBE.

To obtain a table of these data, enter the *CONDAR* command

scan# GET TABLE

Do not try to display these data with the PAGE SHOW command as the magnitude of the data are of the order 10^5 and will cause overflows on the display.

The raw data are converted into meaningful signals by the analysis program *CONDAR*. The signals that can be computed from the phases are

switched power	$SP = (\Phi_1 - \Phi_2 + \Phi_3 - \Phi_4)/2$,	(6.6)
total power	$TP = (\Phi_1 + \Phi_2 + \Phi_3 + \Phi_4)/4$,	(6.7)
cal signal	$C = (\Phi_1 + \Phi_2 - \Phi_3 - \Phi_4)/2$,	(6.8)
zero level	$Z = \Phi_1 - \Phi_2 - \Phi_3 + \Phi_4$.	(6.9)

Since the data stored in the analysis system are completely raw, *CONDAR* requires that several calibration parameters be stored in the scan headers so that the data can be displayed on proper temperature and flux density scales. These parameters must be set into the control system computer by the operator and are as follows:

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NT   If a noise tube calibration signal is part of the switch cycle, this parameter is set to 1; if not, it is set to 0.

DSF   If NT - 0 (no noise tube), this parameter is used to scale the data (see Eqn. 6.11). The default value for DSF is 10,000. If NT - 1, DSF is not used.

TC   This is the calibration scale temperature. If the calibration is based on a noise tube, TC should be the temperature of the noise tube emission. If there is no noise tube, TC is set to the value that gives the proper antenna temperature difference between hot and cold loads.

TAU0   This is the optical depth of the atmosphere at the zenith (in nepers).

%EFF   This is the aperture efficiency and is used to convert antenna temperature to flux density (janskys).

The *CONDAR* verbs that manipulate and calibrate DBE data are

FIXDBE   (calibrates the data and reorders it from sequential phases to sequential switched power, total power, calibration values, and zeroes);

SWITCHED   (reorders the data array to contain only calibrated switched power data);

TOTALPWR   (reorders the data array to contain only calibrated total power data);

CALDBE   (reorders the data array to contain only calibrated calibration values);

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ZERO   (calculates the calibrated rms of the "zero" values and stores the rms in the *CONDAR* array VRMS(1));

AVGD   (computes the mean temperature and standard error of the mean of an ON/OFF sequence).

The verbs SWITCHED, TOTALPWR, CALDBE, and ZERO call the verb FIXDBE implicitly, *i.e.*, do not use FIXDBE before using these other verbs. In general, you will not need to use these verbs explicitly as resident POPS procedures (see below) are available for standard displays of switched and total power data.

The way in which FIXDBE calibrates depends on the value of the control system flag "NT" as described above. If NT=1, indicating the presence of a calibration signal phase, the data are scaled by the factor

$$F_{CAL} - (TC/C) * \exp(A * TAU0) , \tag{6.10}$$

where C is the average calibration signal from each sample, A is the airmass, and TAU0 the zenith optical depth. If NT=0, indicating no calibration signal, the data are scaled by the factor

$$F_{NO\_CAL} - (TC/DSF) * \exp(A * TAU0) , \tag{6.11}$$

where DSF was described above. The conversion from antenna temperature to flux density is by the usual equation

$$S - \frac{2kT_A}{\%EFF*A_p} \tag{6.12}$$

where A_p is the physical aperture of the telescope.

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The basic *CONDAR* data reduction commands are as follows:

scan#	S	displays a switched power ON/OFF sequence;
scan#	T	displays total power sequence;
scan#	CAL	displays the calibration signals;
scan#	Z	displays the zero signals;
scan#	M	displays a mapping row;
scan#	F	displays a five-point map;
scan#	SPTIP	displays vane-switched tipping scan;
scan#	FOCALIZE	displays a focus-check scan;
scan#	C1, C2, CB	stacks scans with specified weighting -- see below.

The procedure T, which displays a total power sequence, presumes that source emission is present in only one of the telescope positions.

When NT = 1 (noise tube present), the verbs SWITCHED and TOTALPWR compute a system temperature and store the result in the header under the label TSYS. The computation of TSYS is by way of the equation

$$TSYS = \frac{\Phi_4}{\Phi_2 - \Phi_4} \, TC = \frac{REF}{(REF + CAL) - REF} \, TC. \qquad (6.13)$$

The verbs SWITCHED and TOTALPWR also calculate a signal-to-noise figure of merit called TPSN, which is stored in the adverb VRMS(2). TPSN is the switched power signal divided by the total power signal and is given by

$$TPSN = \frac{\Phi_1 - \Phi_2 + \Phi_3 - \Phi_4}{\Phi_3 + \Phi_4} (0.5) = \frac{SIG - REF}{SIG + REF} \qquad (6.14)$$

6.6 OBSERVING PROCEDURES

6.6.1 POINT SOURCE ON/OFF OBSERVING PROCEDURES

The 12 m has available several observing procedures for making ON/OFF measurements, i.e., measurements of the difference between the output powers at a defined point (ON) and a nearby reference position (OFF). These procedures work with the subreflector nutating or not. The ON/OFF procedures are often used for measuring the flux density of weak point sources.

6.6.1.1 THE ON/OFF "SEQUENCE"

The standard point source ON/OFF observing procedure is called a SEQUENCE in the control system terminology. Using this procedure, the telescope moves between the ON and OFF source positions in the pattern OFF-ON-ON-OFF. A sequence is made up of one or more REPEATS of this basic cycle. This order of samples eliminates the effects on the measurements of linear drifts in atmospheric noise or receiver gain. You can specify integration time per position. (Procedures that are simply ONs, OFFs, or an ON-OFF pattern are described below.)

The standard set-up for an ON-OFF sequence in beam switched mode is double beam switching (DBS), i.e., with the ON and OFF positions separated by the subreflector throw. In this way the radio source to be studied can be cycled between the positive and negative beams by the movement of the telescope. Figure 6.1 displays the positional relationships between the OFF and ON samples. For the DBS mode, the output power difference between the ON and OFF phases is proportional to twice the source flux density. The advantage of the ON-OFF approach is that, to first order, it cancels imbalances between the two beams.

One can, of course, select the OFF position to be different from the position of the -BEAM (or the ON position different from the +BEAM). This is a single beam (SBS) observation. The most frequent use of the SBS mode is to determine the
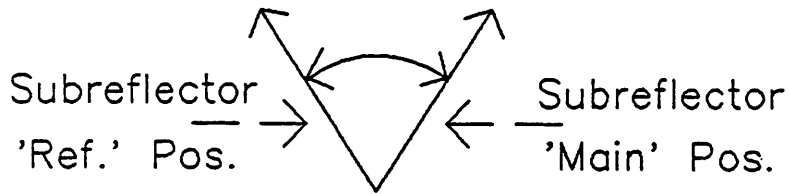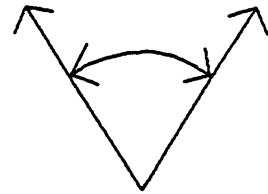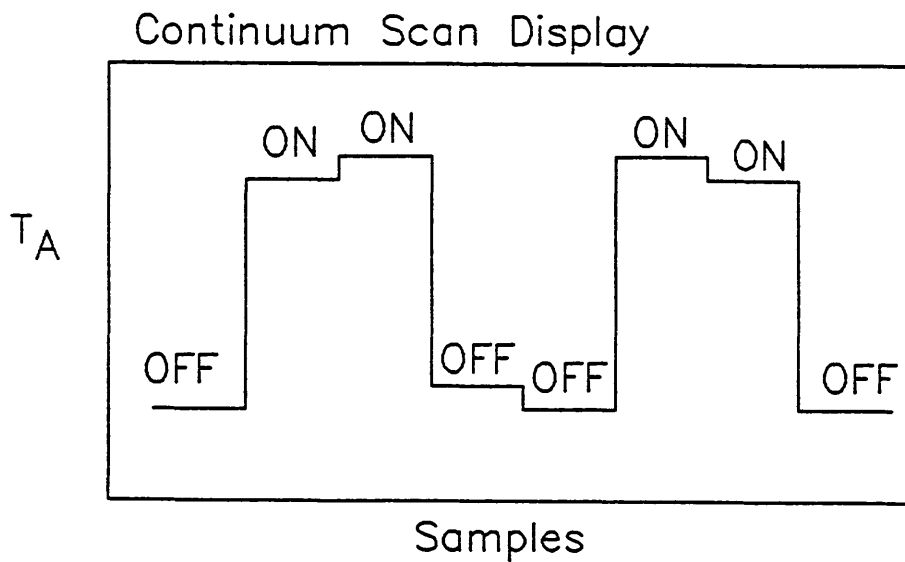
FIGURE 6.1 -- POSITION RELATIONSHIP OF CONTINUUM
ON-OFF SAMPLES

position of the +BEAM and the -BEAM independently, and thereby determine the subreflector throw and orientation.

To perform an ON-OFF sequence, you must give the operator the following setup parameters:

a) The length of time to be spent on each ON or OFF sample and the number of REPEATS of the OFF-ON-ON-OFF cycle. The sample length is usually chosen to be 5 or 10 seconds. This length is usually a good compromise between maximum switching efficiency of the telescope and the best compensation for atmospheric drifts (the switching pattern corrects for linear drifts and will approximate higher order drifts if the sample time is sufficiently short). The total integration time of a SEQUENCE is (4 * SECONDS * REPEATS). Thus, if you request 5 SECONDS per sample and 6 REPEATS, the sequence takes 120 sec.

b) Whether the sequence will be made in beam switched mode or position switched (PS) mode. If the observations are in the beam switched mode, indicate whether the Dual Beam (DBS) or Single Beam (SBS) option is in effect (the DBS mode is the normal case).

c) The required telescope tracking tolerance (TOL), and the optimum pointing positions of the ON and OFF beams (consult the pointing charts at the observer's console).

When you are satisfied that all is in order, ask the operator to begin the scan.

Individual sequences are analyzed in *CONDAR* by the resident procedure S. A number of sequences can be stacked and analyzed with the resident procedures C1, C2 and CB (see *CONDAR* reference manual). If you are observing with a two- channel receiver, you would look at the individual sequences by typing, successively

                Scan#   S   (Channel 1)
                Scan#+1 S   (Channel 2)

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An example of the data display for a sequence is given in Figure 6.2.

EXAMPLE 6.1 A CONTINUUM SEQUENCE

You are attempting to detect a weak continuum point source at 230 GHz. You select the following options for each scan:

DBS mode (dual beam switching)

2' beam throw

10 second samples

10 repeats

The integration will last 400 seconds ($6^m 40^s$).

6.6.1.2 DON-OFF, DON, AND DOFF

The DON-OFF observing routine is very similar to the SEQUENCE, except that the basic observing pattern is simply OFF-ON, rather that OFF-ON-ON-OFF. As with the SEQUENCE, you may set the integration time of the ON and OFF samples and set the number of repeats of the OFF-ON pattern. The observation can be performed as a beam switched (dual or single beam) or a fixed beam position switched scan. An example of the data display for a DON-OFF scan, produced with the *CONDAR* procedure M, is given in Figure 6.3.

The DON observing routine takes an integration at the ON (usually +BEAM) position. The integration consists of a specified number of repeats of ON samples. You can set the integration time per sample. The DOFF routine is identical to DON except that the telescope tracks the OFF (usually -BEAM) position instead of the ON.

SCAN	SOURCE		#CH	DATE	LST	SEC	TS	AZ	EL
6602	SATURN		1	10-16	20:32:58	5.0	200	210.9	28.5
TA=	3.6470	0.0500	JY=	197.827	2.710	S/N=	72.99	ASF=1.19	

MEAN VALUE (K)
OF ON-OFF

ON ON

MEAN ON-OFF IN JY

RMS OF MEAN
(in JY)

$\dfrac{\langle T_A \rangle}{RMS}$

ATMOSPHERIC SCALE FACTOR
$(e^{\tau \cdot A})$

2.

OFF

0.

OFF

-2.

-4.

-6.

2   4   6   8   10   12   14   16   18   20
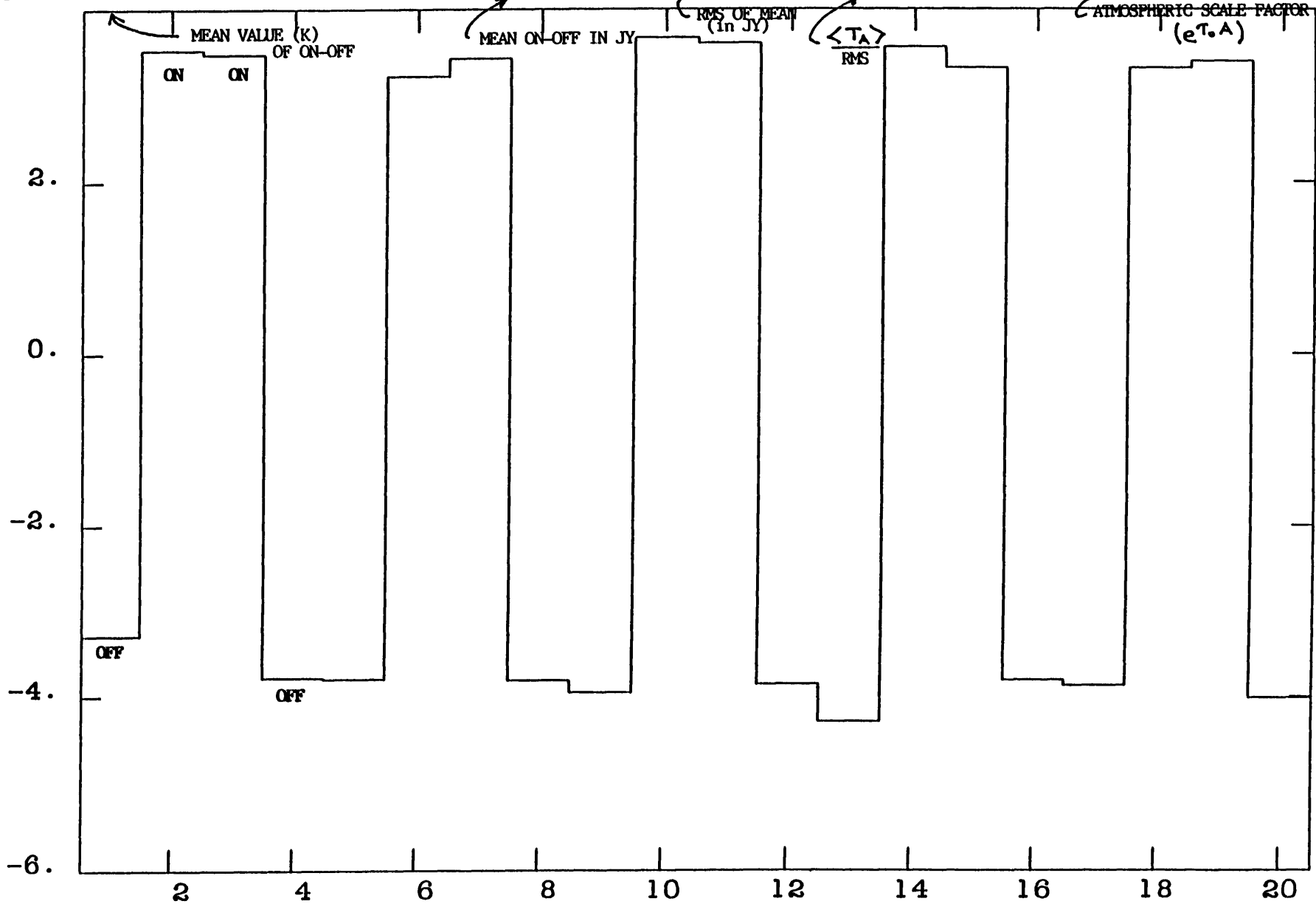
FIGURE 6.2 -- CONTINUUM ON-OFF SEQUENCE
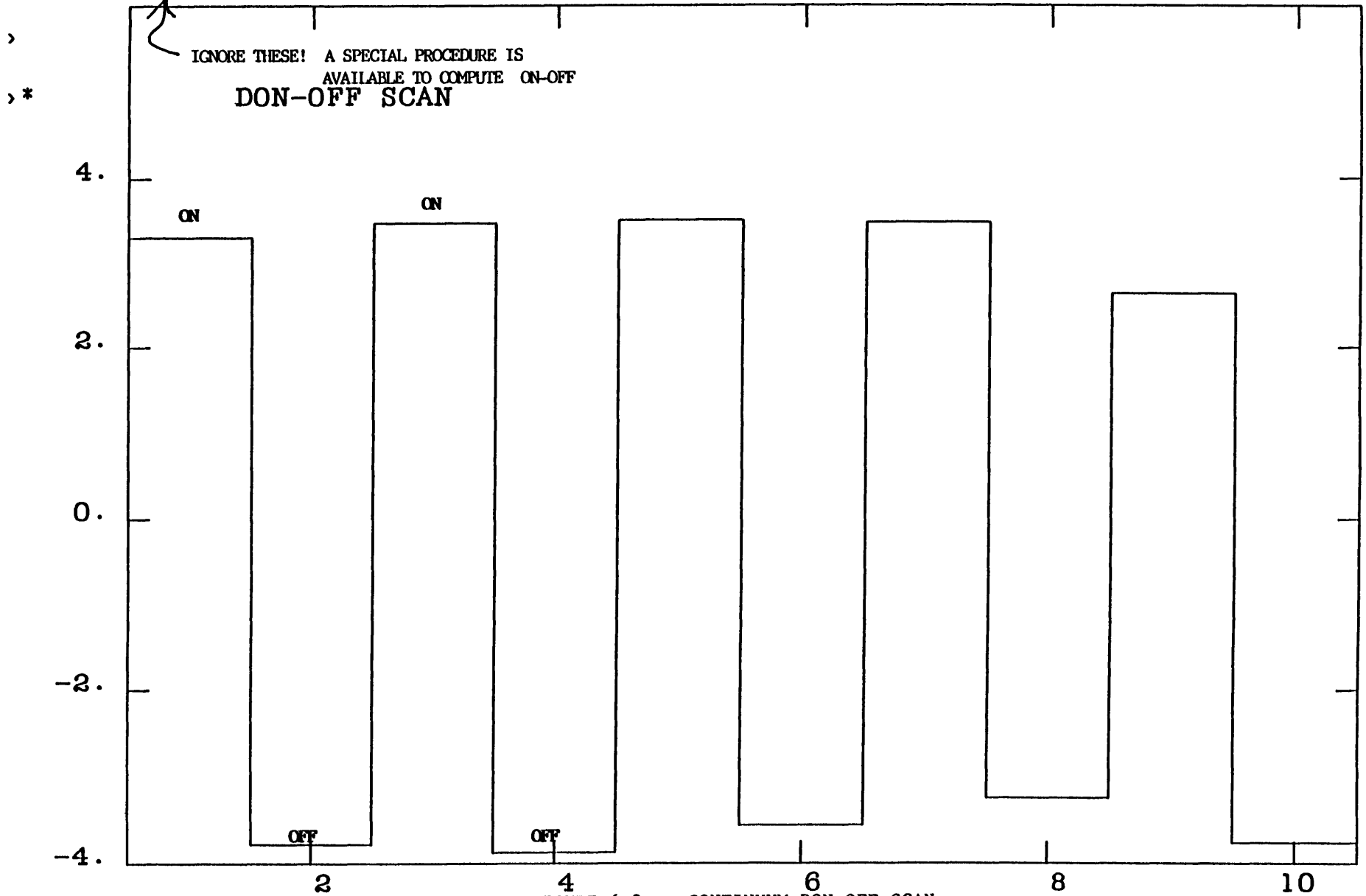
FIGURE 6.3 -- CONTINUUM DON-OFF SCAN

The DON-OFF routine, together with the DON and DOFF routines described below, may be of use in canceling systematic errors arising from rear spillover. Some observers have found that in long integrations on very weak sources, they have detected residual, but false emission that is apparently the result of different spillover signals from the two subreflector beam positions. This is possibly caused by buildings and other structures inside 12 m astrodome. A technique that has met with some success in canceling these residual offsets is to cover the same sky track (and the same background), as nearly as possible, for both the OFF and ON portions of the scan.

The DON-OFF, DON, and DOFF routines give observers more control over the movement of the telescope and make it easier to cover the same sky track. The general technique is to chose the sample integration time (for an DON-OFF) or the total integration time (for an DON or DOFF) so that the arc covered by sidereal motion is the same as the beam throw. Since the beam throw is in azimuth and the source arc is in hour angle, the ON and OFF arcs will be slightly offset.

6.6.2 MAPPING EXTENDED SOURCES

Two options are available for mapping extended continuum sources: (1) a grid-mapping procedure in which the telescope steps through a rectangular grid in the azimuth/elevation frame; and (2) a drift scan procedure in which the telescope maintains a fixed position in azimuth and elevation and the source moves through its beam on an hour angle track via its celestial motion.

6.6.2.1 GRID MAPPING

This routine covers a field by mapping a rectangular grid in azimuth and elevation, relative to the field center. This observing procedure has been developed for use with the dual-beam reconstruction algorithm of Emerson et al. (1979 *Astr. Ap.*, 76, 92). It will, however, work satisfactorily for either fixed beam (total-power)

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mapping or the mapping of fields that are smaller than the subreflector throw via the +BEAM.

The telescope builds a two-dimensional grid of observations by scanning rows at constant elevation relative to the source position. The telescope moves along a row in discrete steps, performing an integration at each position. The grid points are separated in azimuth by real angle. If a map has M columns and N rows the requested field center will lie at the central grid point INT[(M+1)/2], INT[(N+1)/2)] if N and M are odd numbers, where INT denotes an integer truncation. If N and M are even, the requested field center will fall at grid point [(M/2)+1, (N/2)+1]. A scan represents a row of the map in this observing mode. The mean sidereal time of each point is stored in the scan array. Analysis programs have been prepared to combine the scans into two-dimensional maps. You can process these maps using the dual beam restoration algorithm, then transform them into celestial coordinates and stack them. These operations, and subsequent post-processing, are performed by the *NOD2* package running under the control of *CONDAR*.

To observe such a map, proceed as follows (to facilitate communication with the operator, the control system commands are included):

a) Tell the operator whether the data will be taken in total power, fixed beam (total power) or beam switched mode.

b) Tell the operator the following:

   i) The azimuth cell size (XCELL) in mm:ss format. For dual beam maps we recommend a cell size of $\theta_B/2.5$, where θ_B is the FWHM of the main beam.

   ii) The elevation cell size (YCELL) in mm:ss format.

   iii) The number of rows (SROW).

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iv) The number of columns (SCLM).

v) Whether the map is to be in dual-beam mode (DBMAP) or single beam-mode (SBMAP). In a dual beam map, the telescope is positioned so that the azimuth of the center of the map is at the mid-point of the two beams. In a single-beam map, the map is referenced to the +BEAM in azimuth rather than the mid-point between the +BEAM and -BEAM.

vi) You may specify a subset of the map with the commands
    BROW, EROW (beginning and ending rows)
    and BCLM, ECLM (beginning and ending columns)

c) When you are satisfied that all is in order, the operator will start the map with the DBMAP or SBMAP command. The map will be scanned in the azimuth direction starting from the low elevation extreme and working to higher elevations.

You can display a single mapping row with the *CONDAR* command
    scan#   M   (Channel 1)
    scan#+1   M   (Channel 2)

Figure 6.4 gives an example of the data display for a single mapping row with a dual-beam response and a Gaussian fit. Mapping rows can be combined and displayed as contour maps using the *CONDAR/NOD2* data reduction package. The document *Mapping with the 12m Telescope* by C. J. Salter describes the full data reduction procedure for continuum mapping.

The local sidereal time (LST) of each mapping point is stored in the PDFL data scan directly after the regular data. For example, a mapping scan of 51 points will contain 204 data points (51 sky positions times 4 switch phases per point). The next 51 numbers in the data array (i.e., 205 to 255) will contain the LST (in decimal hours) at which each mapping point was taken.

EXAMPLE 6.2 AZ/EL GRID MAPPING

Example (a):

　　　You wish to map a source at an LO frequency of 230.1 GHz. The dimensions of the source are about 4' in azimuth by 3' in elevation. The FWHM beam size is 30". You chose to integrate for 4 sec per point.

　　　An appropriate beam throw for this frequency and a field of this size is 2' (it is best if the azimuth dimension of the map is not more than about 3 times the beam throw). Set the grid spacing (XCELL, YCELL) to 30"/2.5 = 12". We chose to allow about 1.5' on each side of the map to establish the zero levels. Thus, the map will be 7' x 6' (az x el), or 31 rows by 35 columns (we chose an odd number for the rows and columns so that one grid point will fall on the center position of the source). The operator should enter the commands

```
12 XCELL
12 YCELL
31 SROW
35 SCLM
40 SEC !
DBMAP
```

Example (b):

You wish to make a calibration map on Saturn at 230.1 GHz in dual beam mode. The beam throw is 2' and the beam FWHM is 30" and the planetary disk diameter is smaller than the beam. We wish to map 2' on each side of the planet to look for near-in sidelobes. An integration time of 3 sec is deemed sufficient.

The beam throw is 2' in azimuth and we want 2' on either side of the +BEAM and -BEAM responses to source. The azimuth scan distance is then 6'. The elevation scan distance is 4'. For a cell size of 12" (see Example #1), we need 21 rows by 31 columns. Ask the operator to enter the commands

```
12 XCELL
12 YCELL
21 SROW
31 SCLM
30 SEC !
DBMAP
```

```
        -0.468        2.5           8.9
         0.500        2.4          16.8
                0.01800

CENTERS(")  =        266.802032         505.162689
FWHMS(")    =        74.9862518         71.4911118
PEAK TEMPS  =       -0.468169630        0.499698132
BEAM SEP    =        238.360657     ARCSEC
            =        3.97267771     ARCMIN
```

SIGNAL BEAM

GAUSSIAN FIT

REFERENCE BEAM
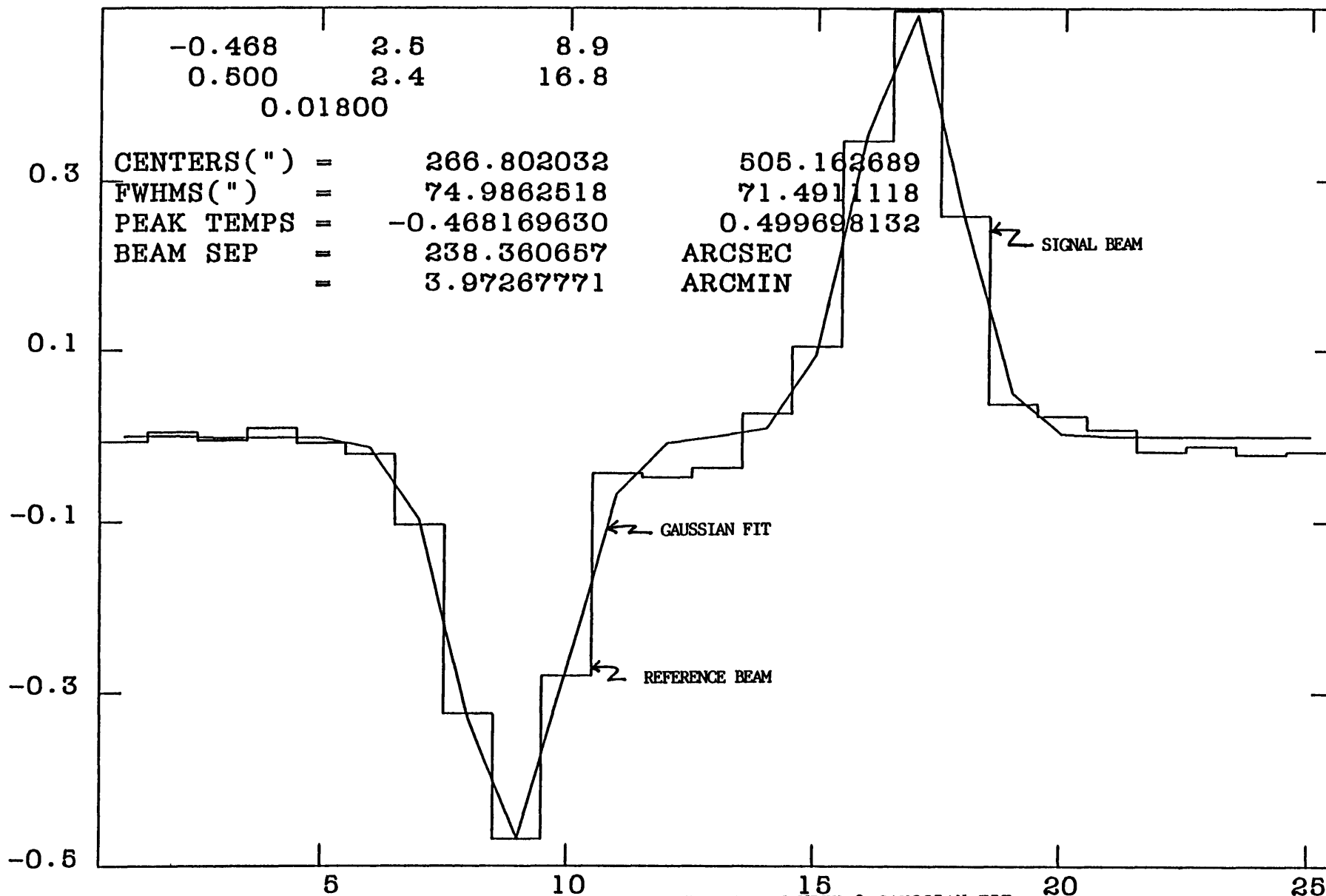
FIGURE 6.4 -- CONTINUUM MAPPING ROW WITH 2-GAUSSIAN FIT

6.6.2.2 DRIFT SCANS

In this procedure, called DRF in the control system, the telescope maintains a fixed azimuth and elevation while the source drifts through the beam. By entering right ascension and declination offsets, you can build up a set of hour angle and declination "rows."

To make a sequence of identical drift scans on a source, proceed as follows:

a) Inform the operator as to whether the data will be taken in fixed beam (total power) or beam switched mode.

b) Tell the operator the following:

i) The integration time per sample;

ii) The number of points to be recorded in the scan (number of REPEATS);

iii) The tracking tolerance in arcsec.

iv) The negative R.A. offset to be entered by the operator as an RA MAIN offset (see below).

c) Using available pointing information, set up the azimuth-elevation pointing corrections.

d) Tell the operator how many drift scans you wish to make, and he will then commence the scan with the DRF command.

The data acquisition computer requires about 0.2 sec of overhead between points of a row, *e.g.*, a 1 sec integration takes 1.2 sec of real time. This serves to shift

the center of the field in the −RA direction, if the calculated field center was based on real time. The overhead will also cause the beam to appear narrowed.

Drift scans are analyzed in *CONDAR* using the resident procedure, **M**. If observing with a two-channel receiver, you can look at the results for the two channels separately by typing

> Scan#   **M**   (Channel 1)
>
> Scan#+1 **M**   (Channel 2)

EXAMPLE 6.3 DRIFT SCAN OBSERVATION

In a typical drift scan observation, you may wish to make scans of length N times the HPBW, sampling M times per HPBW. If the source has declination δ, and if the HPBW is H arcsec, then

Negative R.A. offset (in arc sec) = $-N \cdot H / (2 \cdot \cos \delta)$;
Required number of points = $(N \cdot M) + 1$;
Integration time per sample = $H / (M \cdot 15 \cdot \cos \delta)$ sec of time ;

(Remember that the integration time per sample has to be rounded to the nearest 0.5 sec).

Suppose that you wish to map a planet at 90 GHz, where the beam size is about 70″. You choose to sample at half-beam spacings (35″), want the scan to be 20 beamwidths in length, and want to integrate for 1 sec per point. Thus, the scan will be 40 points long. The nominal center of the field, not accounting for the time lost to overhead, will be −20^s in right ascension from the source position. The operator would enter these commands:

> 10 SEC !   (=> 1 sec integrations)
> 40 RPT !   (=> 40 points in the scan)
> −300 MRAO   (RA offset, equivalent of 20^s in arc measure)
> 1 DRF   (perform 1 drift scan)

6.7 UTILITY OBSERVING ROUTINES

6.7.1 THE FIVE-POINT MAP

The FIVE-POINT mapping option is the standard observing technique for determining the antenna pointing of the 12-m telescope. It can also be used to measure the flux density of a strong source with the highest precision, or the flux density of a source whose position is not exactly known.

The FIVE-POINT map consists of five successive ON/OFF SEQUENCES (each with a separate scan number), positioned as in azimuth and elevation relative to the nominal source position, as shown in Figure 6.5. The numbers identifying the positions give the time order in which the sequences are taken. The azimuth-elevation offsets of the five positions, relative to the nominal source position, are the following

(1) (0, HP)   – the high elevation point
(2) (0, -HP)   – the low elevation point
(3) (0, 0) – the Central point
(4) (-HP, 0)   – the -Azimuth point
(5) (HP, 0)   – the +Azimuth point

HP is a selected offset (in arcsec) that is usually chosen to be close to the half the HPBW of the telescope at the observing frequency. HP should be somewhat larger if the source is extended; for a planet that is resolved by the beam, chose HP to be approximately the semi-diameter of the source.

To make a five-point map proceed as follows:

a) Set up as if for an ON-OFF SEQUENCE, i.e., specify the integration time per sample and the number of repeats of the OFF-ON-ON-OFF cycle.

+ELEV. ('NORTH')
POINT

①

GRID SIZE ('HP')

-AZ ('EAST')   ④   ③   ⑤   +AZ ('WEST')
POINT   POINT

CENTER
POINT

②

-ELEV. ('SOUTH')   EL.
POINT

AZ.
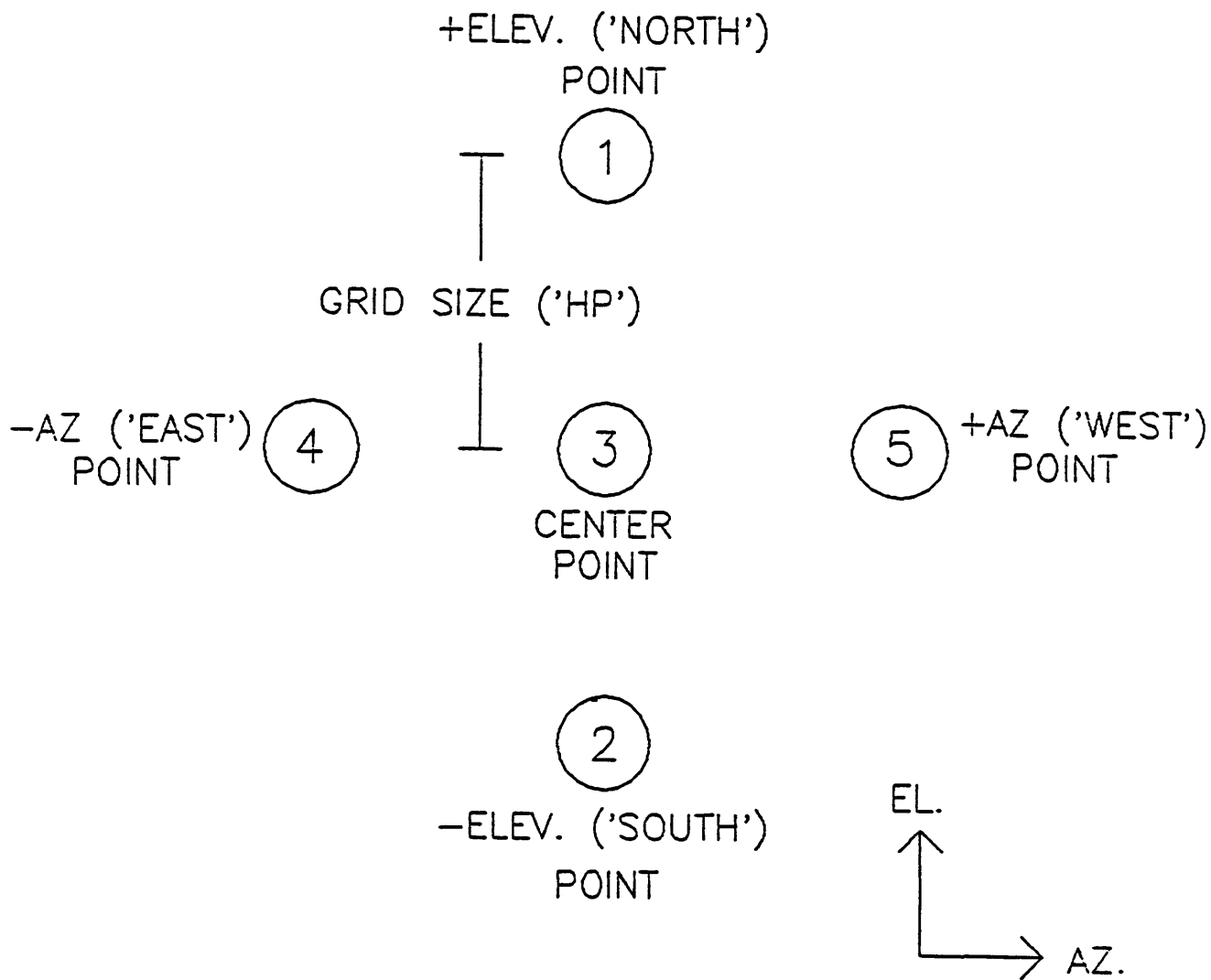
FIVE−POINT MAPPING SCAN −−
LAYOUT and ORDER

FIGURE 6.5 −− FIVE POINT MAP POSITIONS

b) Give a value for HP to the operator. Typical values would be 15"-20" at 230 GHz and 35"-40" at 90 GHz, for a point source. For an extended planet, HP should be no less than the radius of the planet.

c) If all seems in order, ask the operator to start the observation.

d) The FIVE-POINT map is analyzed in *CONDAR* with the resident procedure, F. If observing with a two channel receiver you can look at the results for the two channels separately by typing

```
Central-scan#     F        (Channel 1)
Central-scan#+1   F        (Channel 2)
```

The display (Figure 6.6) provides the observer with the best-fit positional offsets in az-el, and the estimated peak flux density of the source, both for a constrained fit of Gaussian half-width 2·HP and an unconstrained solution. The optimum pointing offsets (labelled CORRECTED OFFSETS) are also printed, assuming the given position of the source to be correct.

EXAMPLE 6.4 FIVE-POINT MAP

You wish to perform a pointing check on Saturn at 230 GHz. A typical setup would be 5 second samples and 2 repeats of the OFF-ON-ON-OFF cycle.

SCAN	#CH	DATE	LST	SOURCE	SEC	TIME	TS	TAMB	HP
6546	1	10-16-89	19:32: 1	SATURN	6.0	2:40	0.	8.4	36.

	AZ	EL		(AZ)	(EL)
TELESCOPE COMMANDED:	196:37:21	33:39:04	+BEAM:	02:00	00:00
POINTING OFF:	-0:08	-0:02	-BEAM:	-2:00	00:00

INPUT AZ POINTING CORRECTION

INPUT EL POINTING CORRECTION

SUBREFLECTOR BEAM THROW

118.17
7.18

(+EL)

(-AZ)

BEST FIT LOCATION
OF POINTING SOURCE

+
86.54
0.28

+N
194.23
0.70

(CENTER)

+
104.06 ← AZ FLUX
2.03 ← RMS OF FLUX MEAS.

(-EL)
+
84.18
2.34

FIT WITH AZBW=ELBW= 70   (SYMBOL=F)
DAZ=   2.4   PEAK(JY)= 194.26
DEL=   4.4   PEAK(JY)= 199.61
FIT WITH NO RESTRICTIONS   (SYMBOL=N)
DAZ=   2.4   PEAK(JY)= 196.99   BW= 68.6
DEL=   4.6   PEAK(JY)= 196.99   BW= 71.4

FITTED FWHP BEAM
WIDTHS (AZ, EL)

CORRECTED OFFSETS
AZ   EL
-00:06 +00:02

GIVE THESE NUMBERS TO THE OPERATOR
AS THE NEW (TOTAL) POINTING CORRECTIONS.

FIGURE 6.6 -- SAMPLE FIVE POINT MAPPING FIT

6.7.2 THE FOCALIZE

On taking over the telescope, you should make a check of telescope focussing and repeat this occasionally during the run particularly after nightfall and daybreak. Focussing is performed via the FOCALIZE procedure. This steps the radial distance of the subreflector from the telescope vertex through seven positions centered on the nominal best setting (FO). Larger values of FO represent greater distances between the dish surface and the subreflector. The incremental movement between positions (WL) is chosen by the observer.

Perform a FOCALIZE as follows,

a) Choose as bright a continuum source as possible. The planets Jupiter, Venus and Saturn are ideal. If the source is extended relative to the telescope main beam, the accuracy of the FOCALIZE will be diminished, however.

b) Make a five-point map of the source to optimize the antenna pointing (see Section 6.7.1).

c) If necessary, give the operator a nominal value for the axial subreflector position (FO). If in doubt, consult the operator or "Friend of the Telescope".

d) Choose the increment (WL) by which to step the subreflector. A reasonable choice for WL is about half the wavelength (*i.e.*, 0.5 mm at λ1 mm and 1.5 mm at λ3 mm). If the source to be used is weak, or the atmospheric conditions are poor, it may be better to make WL somewhat larger.

e) Tell the operator the integration time per sample focus position (5 seconds is usually sufficient for a strong planet, but weaker sources may require 10 to 15 seconds.

f) When ready, ask the operator to commence the scan.

To reduce the FOCALIZE in *CONDAR* use the commands,

      Scan#   FOCALIZE   (Channel 1)

      Scan#+1   FOCALIZE   (Channel 2)

The focus curves displayed (Figure 6.7) should be smooth and "quasi-Gaussian". (If not, repeat the FOCALIZE. Increase the value of WL if this is felt necessary.) The display will give a best-fit value for FO. Where appropriate, you should average the values for the two channels.

After performing the fit, pass the improved value of FO to the operator and he will enter it into the system.

EXAMPLE 6.5 A FOCALIZE

You wish to check the focus against Mars at 115 GHz. Since Mars is weaker than several of the other planets, chose an integration time of 10 sec. An appropriate value of WL at this frequency is 1.5 mm.

6.7.3 SKY TIP PROCEDURES

To properly calibrate continuum data, you must correct for the attenuation of the signal as it traverses the atmosphere. We usually determine the atmospheric attenuation from the optical depth at the zenith, τ_o. The total power antenna temperature at a given airmass (elevation) is a function of τ_o and is given by the equation

$$T_A(sky) = T_{Rx} + \eta_t J_M [1 - \exp(-\tau_o \cdot A)] + (1 - \eta_t) J_{spill}$$
$$+ \eta_t J_{bg} \exp(-\tau_o \cdot A), \qquad (6.15)$$

where T_{Rx} is the receiver double sideband noise temperature, η_t is the "warm spillover" efficiency (rear spillover, scattering, blockage, and ohmic loss efficiency), J_M is the Raleigh-Jeans equivalent (R-J-E) mean atmospheric temperature, τ_o is the atmospheric optical depth at the zenith, A is the airmass, J_{spill} is R-J-E temperature of the warm spillover, and J_{bg} is the R-J-E temperature of the cosmic background radiation. The R-J-E temperatures are related to kinetic temperatures through the equation

$$J(\nu, T) = \frac{h\nu/k}{\exp(h\nu/kT) - 1} \qquad (6.16)$$

where ν is the observing frequency, T is the kinetic temperature, and h and k are the Planck and Boltzmann constants, respectively. The opacity of the atmosphere at the zenith, τ_o, is usually determined by measuring the $T_A(sky)$ at several elevations and fitting the results with some form of Eqn. (6.15) for τ_o. The mean atmospheric temperature and the spillover temperature are usually ~ 0.95 - 0.97 of the ambient temperature.

The basic observing procedure for measuring τ_o is called an SPTIP. This procedure steps the telescope through a series of elevation angles, moving from low to high elevation, and then back to low. The precise elevations, in steps of 0.3 airmasses, are listed in Table 6.2.
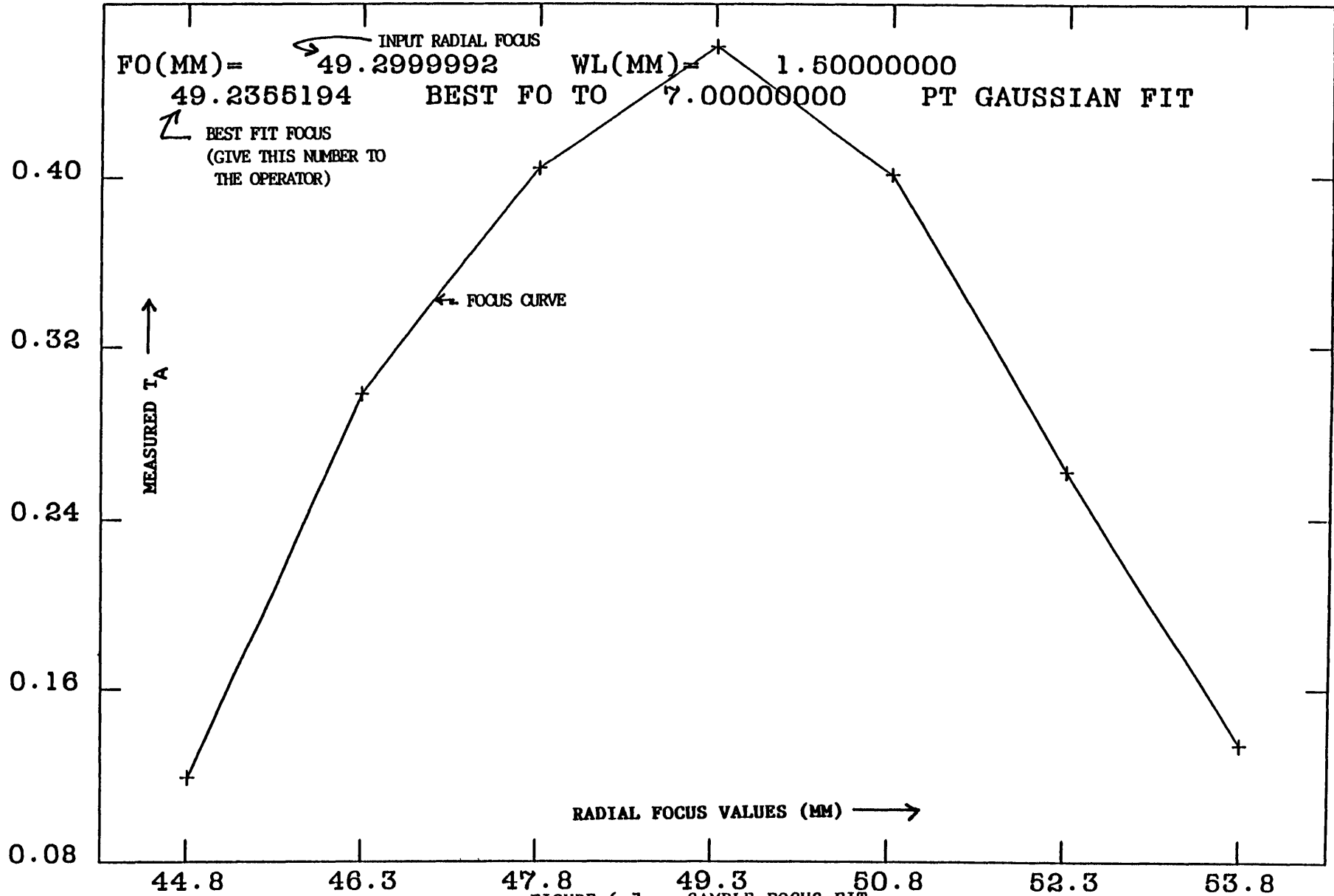
FIGURE 6.7 -- SAMPLE FOCUS FIT

Table 6.1

Sky Tip Antenna Positions

Step	Elevation(°)	Airmass
1	22.62	2.6
2	25.77	2.3
3	30.00	2.0
4	36.03	1.7
5	45.58	1.4
6	65.38	1.1
7	45.58	1.4
8	36.03	1.7
9	30.00	2.0
10	25.77	2.3
11	22.62	2.6

In an SPTIP, the system makes total power observations of both the sky and the ambient temperature absorbing vane at each position in Table 6.2. Both sky and vane temperatures are recorded for analysis. The *CONDAR* data analysis package contains three methods of analyzing an SPTIP. These reduction routines are described below.

To perform an SPTIP observation, proceed as follows:

a) Tell the operator the integration time in seconds for each measurement of the tip. Both vane and sky integrations will be of this length (5 sec is a typical value).

b) In most cases, you should make the observation at the azimuth angle of the program source (an exception is when the telescope will point near the sun during the tipping scan). Have the operator drive the telescope to this azimuth and commence the scan.

c) Analyze the SPTIP using one of the three methods discussed below to arrive at a value of the zenith optical depth, TAU0. If you wish on-line atmospheric corrections to be applied to continuum data displays, ask the operator to enter the new value of TAU0. Remember that the atmospheric absorption changes with time, and if the highest accuracy is required, a small correction should be applied off-line using all the opacity data for the run to interpolate the most-probable value for each scan.

6.7.3.1 THE SPTIP ANALYSIS PROCEDURE

The SPTIP data reduction procedure uses the difference between vane and sky temperatures. This is the simplest of all the tip analysis routines: it requires no input parameters, does not require accurate calibration of the temperature scale, nearly always produces at least a first order approximation to the optical depth, but makes a number of simplifying assumptions that may diminish its accuracy.

The antenna temperature of the sky is given in Eqn. (6.15); the antenna temperature of the vane is given by

$$T_A(vane) - T_{Rx} + J_{vane} , \qquad (6.17)$$

where J_{vane} is the R-J-E temperature of the vane (generally the ambient temperature). The difference between vane and sky temperatures is thus

The SPTIP analysis procedure makes the following assumptions:

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$$T_{v-s} - J_{vane} - \eta_l J_M [1 - \exp(-\tau_o \cdot A)] - (1 - \eta_l) J_{spill}$$
$$- \eta_l J_{bg} \cdot \exp(-\tau_o \cdot A). \tag{6.18}$$

$$J_{vane} - J_{amb} , \tag{6.19a}$$

$$J_M - J_{amb} , \tag{6.19b}$$

$$J_{spill} - J_{amb} , \tag{6.19c}$$

$$\eta_l - 1 , \text{ and} \tag{6.19d}$$

$$T_{bg} - 0 \tag{6.19e}$$

where J_{amb} is the R-J-E ambient temperature. Under these assumptions, one then finds that

$$\ell n (T_{v-s}) - \ell n (J_{amb}) - \tau_o \cdot A . \tag{6.20}$$

From the measured array of T_{v-s} as a function of A, the SPTIP procedure fits for τ_o by linear least squares. Among the assumptions 6.19a to 6.19e, 6.19b and 6.19d are the most inaccurate. In addition, because the calibration scale is not always in calibrated kelvins, the term $\ell n(J_{amb})$ in Eqn. (6.20) is fit as a free parameter. This gives τ_o more freedom than it ought to have.

Experience with the SPTIP routine has shown that although it is the easiest of the available routines to use, it suffers from two deficiencies: (1) it tends to underestimate τ_o, especially for large values of τ_o, and (2) it often appears to give a misleadingly good fit, i.e., it may indicate that the atmosphere is more stable than it really is. Nevertheless, under moderately low τ_o's (say <0.3), the SPTIP usually gives an acceptably good measure of the atmospheric optical depth.

To perform an SPTIP, follow the instructions in Section 6.6.1. When the SPTIP is completed, analyze the data in *CONDAR* by typing

scan# SPTIP   (Channel 1)

scan#+1 SPTIP   (Channel 2)

The data and fit are displayed in Figure 6.8, together with the fitted value of r_o.

6.7.3.2 THE DIFTIP REDUCTION PROCEDURE

The DIFTIP routine performs a fit of the natural logarithm of the differences T_{v-s} at adjacent airmass positions. From Eqn. 6.18, the difference between T_{v-s} at adjacent airmass positions A_i and A_{i+1} is

$$(T_{DIFF})_i - \eta_l(T_M - T_{bg})[\exp(-r_o A_{i+1}) - \exp(-r_o A_i)]. \qquad (6.21)$$

In the SPTIP observation, adjacent observing positions are separated by an equal airmass ΔA (≈ 0.3), so that $A_{i+1} = A_i - \Delta A$, on the ascending portion of the tip. Thus, Eqn. 6.21 can be written as

where $(T_{DIFF})_i$ is the difference between T_{v-s} at the ith and $(i+1)^{th}$ positions. After taking the natural logarithms, this equation may be written

The DIFTIP analysis procedure averages repeating airmass positions of the ascending and descending portions of the SPTIP observations to produce 6 independent observations. These 6 points give 5 T_{DIFF} points. These 5 points are fitted with Eqn. 6.23 by linear least squares. The slope of the line gives r_o.

FIGURE 6.8 -- SAMPLE SPTIP TIPPING SCAN

To use the DIFTIP procedure, first perform an SPTIP observation. When the observation is completed, type

scan#   DIFTIP

to display the fit. An example of a DIFTIP display is shown in Figure 6.9.

Under stable skies, the DIFTIP procedure is more accurate than the SPTIP reduction procedure because it does not neglect the spillover temperature (which is, in fact, subtracted out). Unfortunately, DIFTIP is very sensitive to a "lumpy" sky because of its differential nature of the fit. The data (and the fit values) will be noisy under lumpy sky conditions, but this is something that you should know about. We recommend that you run DIFTIP each time you run SPTIP and compare the results.

6.7.3.3 THE STIP REDUCTION PROCEDURE

The STIP reduction procedure fits Eqn. (6.18) to the data from an SPTIP observation by way of nonlinear least squares. This procedure is the most direct of all the tipping analysis options: it makes no assumptions other than the accuracy of the basic model [Eqn. (6.15)]. To give an accurate measure of r_o, it does have several stringent requirements:

    i)   The temperature scale must be accurately calibrated;

    ii) You must supply several input parameters, including

        η_l --called ETA in *CONDAR*-- or allow it to be a free parameter of the fit);

        FTM, the ratio T_M/T_{amb} ;

        FTSBR, the ratio T_{spill}/T_{amb}

STIP is a powerful procedure that can also be used to fit for η_l, a basic efficiency factor. Because it is a nonlinear (hence iterative) fitting routine, it may not converge if the data are of poor quality or, conversely, it may converge to a nonsensical result. *Use STIP with caution.*

SCAN	SOURCE		#CH	DATE	LST	SEC	TS	AZ	EL
1389	SPTIP		2	9-17	20:44:39	5.0	0	212.9	27.5

TYPE:DIFTIP FREQ= 91.50000

TAU=   0.194868237

BEST FIT FOR ZENITH ATMOSPHERIC OPTICAL DEPTH

MEASURED VALUES
(SEE TEXT FOR DESCRIPTION)

BEST FIT
LINE

2.40

2.32

2.24

2.16

2.08

2

4
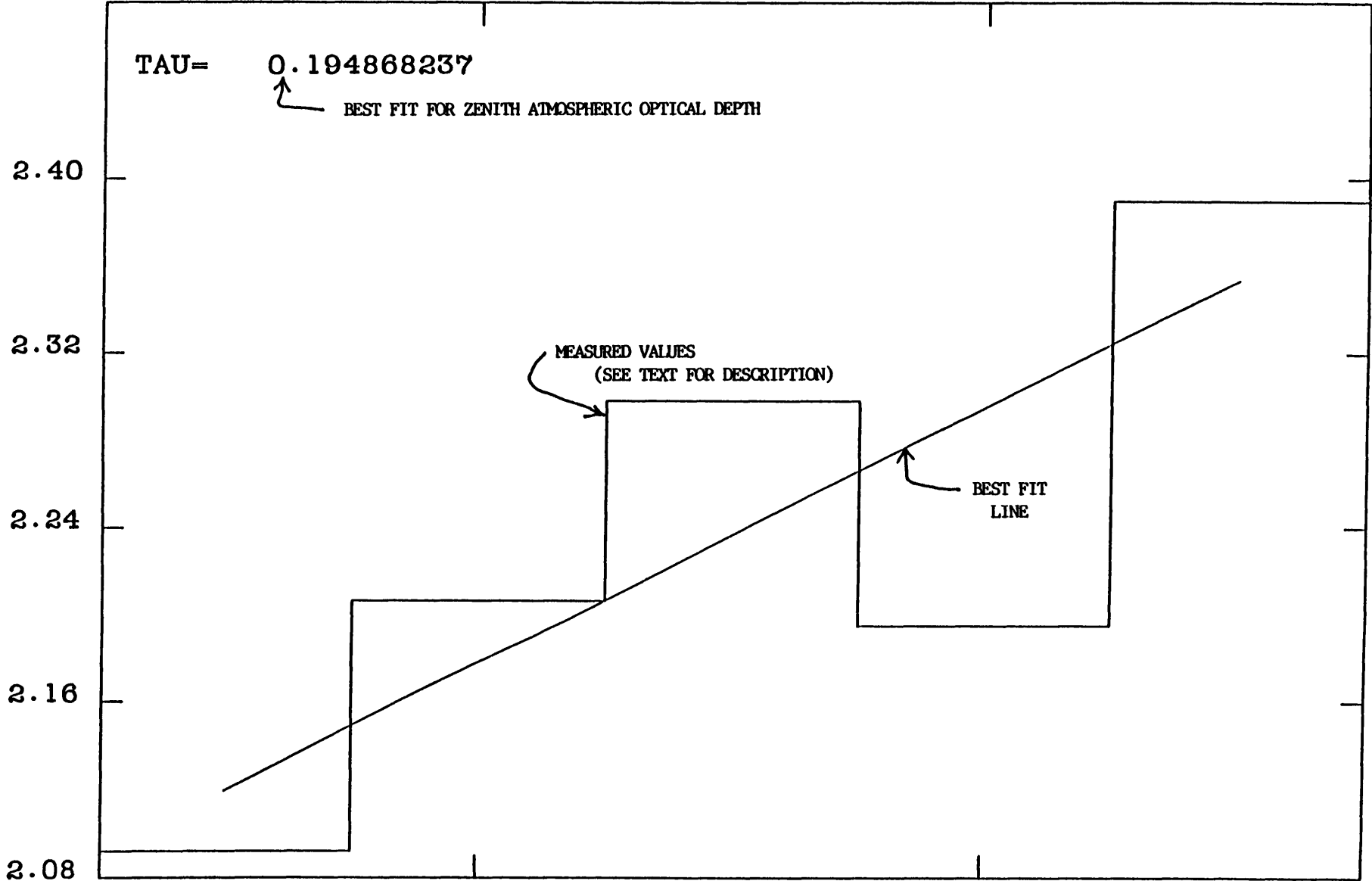
FIGURE 6.9 -- SAMPLE DIFTIP TIPPING SCAN

To use the STIP routine, proceed as follows:

a) Perform an SPTIP observation following the instructions of Section 6.7.3.

b) In *CONDAR*, set these adverbs, with the format adverb_name=value, *e.g.*, ETA = 0.85:

ETAFREE   Set ETAFREE = 0, if η_t is to be held fixed (the default), or ETAFREE = 1, if η_t is to be a free parameter of the fit;

ETA   this is the value of η_t that is either held fixed or serves as the starting value of the fit (it is typically about 0.85 (See the document *Equipment and Calibration Status*);

FTM   defined above; and

FTSBR   also defined above.

c) When the adverbs are set as desired, type

scan# STIP   to perform the fit and generate a display. The display (Figure 6.10) shows the fit and lists the fitted value of r_o with standard error, and η_t with standard error, if η_t was a free parameter of the fit.

FIGURE 6.10 -- SAMPLE STIP TIPPING SCAN REDUCTION

6.7.3.4 STACKING MULTIPLE SPTIPS

When the atmospheric conditions are poor, the SPTIP fits are often somewhat noisy. One way of improving matters is to make a number of consecutive tips and average them. This can be done with non-resident procedure SPSTACK, which must be INSTALLed. The scan numbers of the tips are entered into the STACK in the usual way (see the CONDAR manual) and then one types,

SPSTACK

The procedures currently assume the data to be one channel and the STACK should be filled separately for each channel.

6.8 CALIBRATION

To accurately calibrate continuum data, you must set the temperature scale and/or the flux density scale, correct for atmospheric attenuation, and correct for telescope systematics such as the gain-elevation effect. The method currently used to calibrate 12 m continuum data is called "direct calibration".

6.8.1 DIRECT CALIBRATION

Absolute calibration entails an accurate determination of the antenna temperature scale, a measurement of the sky opacity via a tipping scan, a measurement of the aperture efficiency or a factor for converting from antenna temperature to flux density, and finally, correction for the gain-elevation effect if it is important at the particular observing frequency. To use this calibration method, follow the steps outlined below.

1) Perform a hot/cold load calibration to determine the receiver noise temperature and to calibrate the temperature scale and the intensity of the noise tube, if one is in use (only the 3 mm system is equipped with a noise tube). The procedure for making a hot/cold measurement is described in detail in Section 6.8.2.

This measurement will produce a value for T_C, the calibration scale factor, which is required by the data analysis routines to scale the data. If T_C is the noise tube temperature and the noise tube is recorded as a switching phase throughout the run, the temperature scale should remain fairly accurate so long as the receiver is not tuned to another frequency. If no noise tube is available, the temperature scale may vary because of receiver gain drifts.

2) Perform a tipping calibration to estimate the opacity of the atmosphere at the zenith, TAU0. The data reduction procedures can use this parameter to correct the data for atmospheric attenuation. (The hot/cold load procedure will also produce a measure of TAU0.)

3) Observe discrete astronomical sources to calibrate the telescope pointing and set a flux density scale for the data. The measurement can be used to enter a value of the aperture efficiency (called %EFF in the control system). The aperture efficiency is used by the data reduction routines to convert antenna temperature to flux density. The observations of calibration sources should be repeated frequently during the course of the observing run. A calibration curve, plotted as a function of time, can be used for the most accurate adjustment of the flux density scale in the final analysis.

4) If you are observing at a frequency where the gain-elevation properties of the telescope are ill-defined, these can be determined via observations of a strong compact source over the relevant elevation range. Copies of

the presently measured gain-elevation curves at standard frequencies are presented in the document *Equipment and Calibration Status.*

Many observers choose to skip the measurement of the temperature scale by hot/cold loads and calibrate their data strictly by comparisons with standard sources. In this relative calibration method, one merely observes a succession of standard sources, forms a calibration curve of flux density conversion factors, and through interpolation, corrects the data after the run is over. It is still necessary to measure the atmospheric optical depth frequently and to correct for gain-elevation effects, since the measurements of the standard sources generally will be at different elevations than the program sources.

Since we recommend that with the absolute calibration method, you also measure standard sources frequently to fine-tune the flux density scale, it would seem that calibration of the temperature scale by hot/cold loads is an unnecessary step. Nevertheless, we believe that it is worth the time to perform a hot/cold load and set the temperature scale to an accurate value at for these reasons: (1) the hot/cold load measures the noise temperature of the receiver and thus indicates if the receiver is tuned and functioning well; (2) by setting the temperature scale and the aperture efficiency to reasonable values, the data displays will always be accurate and will make it easier to monitor the performance of the system and to interpret the signal strengths and noise levels of the data.

6.8.2 HOT/COLD-LOAD CALIBRATION

A hot/cold load calibration can be used to set the continuum temperature scale, to measure the receiver noise temperature, the noise tube temperature, the sky temperature, and the atmospheric optical depth. At present, we perform hot/cold loads by manually inserting hot and cold loads into the beam and measuring the deflections through the computer, on digital voltmeters, and sometimes on the analog chart recorders. The cold load usually consists of a styrofoam box holding a square of microwave absorber immersed in liquid nitrogen. The vaporization temperature

of liquid nitrogen at the elevation of 12 m telescope is 80 K. For frequencies below about 230 GHz, we recommend that you use this temperature. For higher frequencies, the styrofoam may begin to absorb the radiation and will add to the temperature of the load. At these high frequencies, we recommend that you use another type of cold load known as a "dipper." The dipper consists of a funnel-shaped box lined with absorber on the end of a wooden handle. The dipper is dipped into liquid nitrogen and held over the receiver feed during cold load cycles. A hot/cold measurement requires the active participation of the operator and at least one observer. To perform a hot/cold load calibration with a coherent receiver, proceed as follows:

a)   The operator must drive the telescope to the zenith position. If you intend to measure the noise tube temperature and atmospheric parameters, ask the operator to open the dome door to 90°.

b)   The operator must make these preparations in the control room:

i)   Lock the subreflector to the +BEAM position;

ii)   If the noise tube is being used

•   turn the calibrate control switch on the back of the subreflector control chassis from DBEND to SUB;

•   turn the cal modulate switch on the front of the subreflector control chassis to OFF.

iii)   Enter these setup parameters into the FORTH system:

0 NT   (whether or not the noise tube is being used)
10000 DSF
0 TAU0 !
EXPEDITE
20 SEC !
40 RPT !
1 SEQUENCE   (but no carriage return until you are ready to start the scan)

c) The operator should then fill the cold load box with liquid nitrogen and carry it to the receiver bay. The ambient temperature vane can be used as the hot load, in general.

d) On the continuum receiver control rack, switch the left-most thumbwheels on the I.F. attenuators of both channels to 1, giving >100 dB of attenuation. This will provide the zero point measurement.

e) Start the scan by hitting a carriage return on the operator's control system terminal (actuating the SEQUENCE command). The scan will last 320 sec (5^m20^s) which is adequate time for all measurements. If you do not want to measure sky or noise tube values, you can make the scan shorter by entering a smaller number of RPTs.

f) Measure the zero point levels for about 10 sec. Then, by speaking over the intercom to the telescope, have the operator insert the cold load, and leave it in place for about 20 sec. Note the voltages on the digital voltmeters on the continuum I.F. chassis. Ask the operator to remove the cold load and switch the ambient vane in for about 20 sec, and note the voltages. The vane is controlled from a chassis in the control room with a switch labeled "COMPUTER-VANE-SKY-SWITCH". Perform 3 cycles of COLD/HOT measurements.

g) After the HOT/COLD measurements, ask the operator to move away from the beam and measure the sky voltage. If the noise tube is not in use, let the scan run out with the telescope looking at blank sky. If there is a noise tube, switch the tube ON using the modulate switch on the subreflector control chassis, and note the voltages. You may wish to make several SKY/CAL measurements before the scan ends.

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h) When the scan ends, you may examine the scan on the computer by typing
   (in *CONDAR*)

    scan#   T (for the first channel), and
    scan#+1   T (for the second channel).

An example of the output is shown in Figure 6.11 (produced by the
procedure HC which is explained below). If the scan looks good, tell the
operator that he may come down from the telescope.

i) Before proceeding further, reset any hardware switches or software
   settings that were changed for the measurement, including

   • Subreflector cal switch to DBEND
   • Subreflector modulate control switch to COMPUTER
   • Vane control switch to COMPUTER
   • Computer setting 1 NT if a noise tube is in use.

If you wish to reduce the data by hand, you can get a table of the numbers in
the scans by typing

    scan#   T   TABLE (for Channel 1) and
    scan#+1   T   TABLE (for Channel 2).

The formulae for various quantities are given below.

We have defined a *CONDAR* procedure called HC which will calculate these
parameters automatically. To use this procedure, first type

    INSTALL HC

HOT LOAD LEVEL

FREQ   =   91.5000000
T_HOT   =   293.649994
TR_HOT   =   291.460938
T_COLD   =   80.0000000
TR_COLD   =   77.8243942

TA_HOT   =   79.4985275
TA_COLD   =   34.5809631
TA_DIFF   =   44.9175644
OLD TC   =   6.00000000
HC SCALE =   4.75619173
TC(H/C)   =   28.5371513 ← NEW TC VALUE

TA_SKY   =   34.9508972
T_SKY   =   79.5838699
FTM   =   0.949999988
FTSBR   =   0.949999988
ETA   =   0.839999974
TAUO   =   0.164513513
T_RX   =   86.6464639 ← RECEIVER NOISE TEMPERATURE

COLD LOAD LEVEL

ZERO LEVEL

80.

60.

40.

20.

0.

20   40   60   80   100   120   14

0
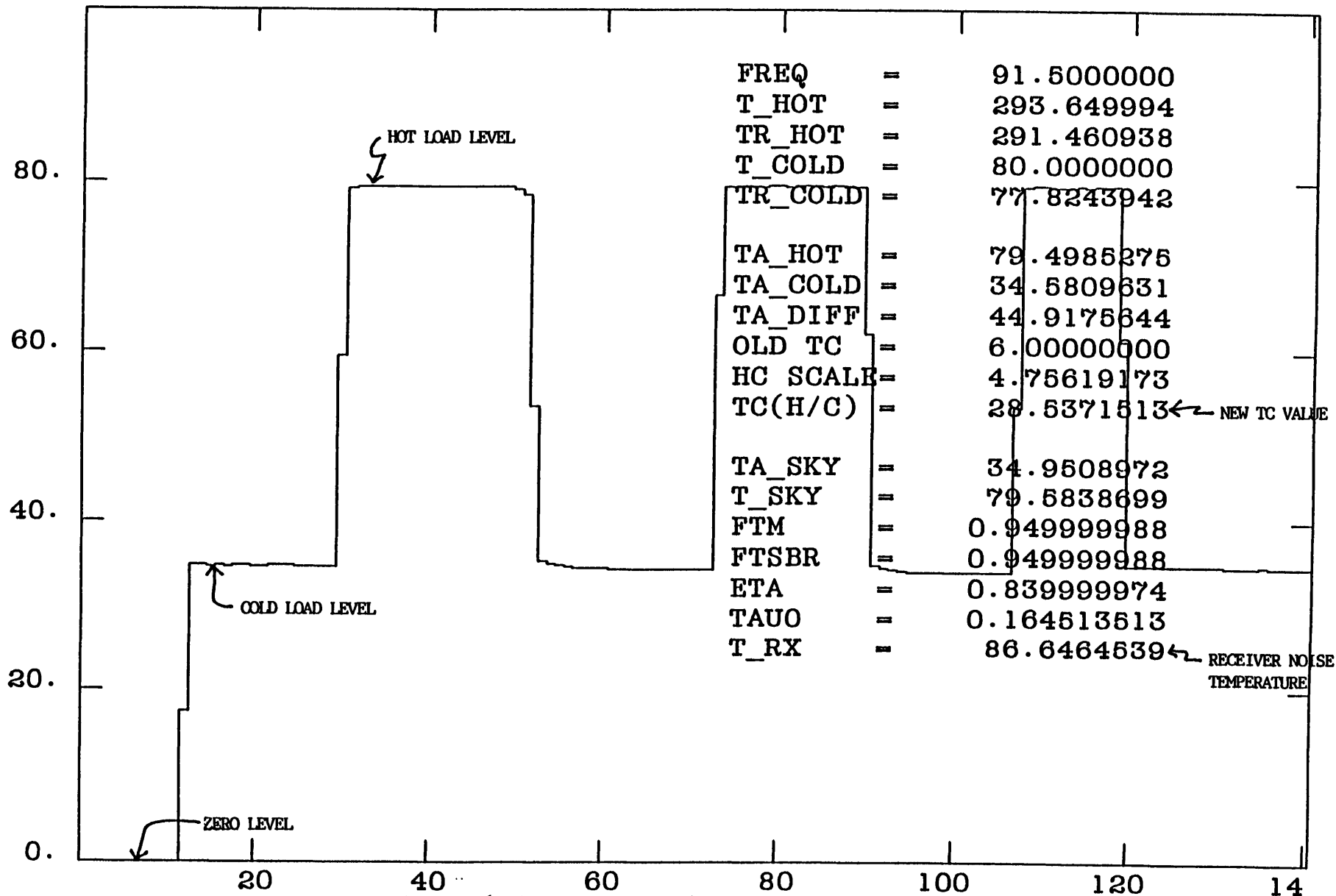
FIGURE 6.11 -- SAMPLE HOT/COLD LOAD MEASUREMENT

and the procedure will be loaded from a disk file into *CONDAR* memory. To run the procedure, type

        scan#   HC

The procedure will prompt you for the following information: (1) the observing frequency in GHz; (2) the hot load temperature in Celsius; and (3) the cold load temperature in kelvins. If the observation was made in double sideband mode, give the frequency of the local oscillator. The hot load temperature should be the temperature of the vane; the vane temperature is displayed on the "CHOPPER CONTROL" chassis in the control room.

After entering these data, the cross hairs will appear on the graphics screen and you will be prompted to mark the zero offset, the cold load, and hot load samples. The procedure will then prompt you to enter any sky and noise tube samples that may exist. If you are using a noise tube for data calibration, the quantity labeled TC(NT) should be given to the operator as the new TC value. TC(NT) is the temperature of the noise tube deflection relative to the hot/cold load scale. If you are not using a noise tube, the value labeled TC(H/C) is the appropriate TC value.

In addition to the computer scan, you should reduce the data obtained from the voltmeters (or chart recorders) for comparison. The formulae for the quantities of interest are given below.

The receiver noise temperature is a function of the "Y-factor," defined by

$$Y = \frac{V_{HOT}}{V_{COLD}} ,$$
(6.24)

where V_{HOT} is the measured hot load voltage *less the zero offset voltage*, and V_{COLD} is the measured cold load voltage *less the zero offset voltage*. The receiver noise temperature T_{Rx} is then given by

$$T_{Rx} = \frac{J_{HOT} - Y \cdot J_{COLD}}{Y - 1} , \qquad (6.25)$$

where J_{HOT} is the Rayleigh-Jeans effective (R-J-E) temperature of the hot load and J_{COLD} is the R-J-E temperature of the cold load. The expression relating R-J-E temperatures to kinetic temperatures was given in Eqn. (6.16).

The kelvins per volt, KPV, of the continuum system is given by

$$KPV = \frac{J_{HOT} - J_{COLD}}{V_{HOT} - V_{COLD}} . \qquad (6.26)$$

The R-J-E sky temperature is given by

$$J_{SKY} = (V_{SKY} - V_{COLD}) \cdot KPV + J_{COLD} . \qquad (6.27)$$

If a noise tube was measured, its R-J-E temperature is given by

$$J_{NT} = (V_{NT} - V_{SKY}) \cdot KPV , \qquad (6.28)$$

where J_{NT} is the R-J-E temperature of the noise tube and V_{NT} is the measured voltage of the noise tube. The optical depth of the atmosphere at the zenith is, from Eqn. (6.15)

$$\tau_o = - \frac{1}{A} \ln \left[\frac{T_A(sky) - T_{Rx} - \eta_\ell J_M - (1 - \eta_\ell) J_{spill}}{\eta_\ell (J_{bg} - J_M)} \right], \qquad (6.29)$$

where A = 1 if the observation is at the zenith.

Equations (6.24) - (6.29) are used in *CONDAR* procedure HC and can be used to reduce the computer data manually if you so choose. If you are using a noise tube, use the value of J_{NT} given by Eqn. (6.28) for the calibration scale factor, T_C, entered into the control computer. If you are not using a noise tube, the value to T_C to use is given by

$$T_C = \frac{J_{HOT} - J_{COLD}}{T_A(HOT) - T_A(COLD)} \cdot T_C(OLD\_VALUE) , \qquad (6.30)$$

where $T_A(HOT)$ and $T_A(COLD)$ are the apparent antenna temperatures of the hot and cold loads, respectively, and $T_C(OLD\_VALUE)$ is the old value of T_C that was in the computer during the hot/cold measurement. For each channel, there should be good consistency between the values computed via the computer and the voltmeter.

If you are using a noise tube to calibrate the data, the calibration scale should stay fairly accurate even if the gain of the receiver changes slightly. If you are not using a noise tube, the T_C's and noise temperatures are accurate only at moment they are measured: receiver gain and tuning drifts will change these parameters. Depending on your choice of calibration methods, you may need to repeat the hot/cold measurements frequently.

6.8.3 CALIBRATION OF THE FLUX DENSITY SCALE

For most continuum observations, the flux density scale is calibrated by observations of standard radio sources. In doing this, it should be remembered that, in addition to corrections for receiver and atmospheric effects, you should allow for the gain-elevation properties of the telescope if the observations cover a significant range of elevations. Current gain-elevation curves are given in the *Equipment and Calibration Status* document.

At millimeter wavelengths, the flux densities of most extragalactic sources are variable and we recommend the use of the planets or compact HII regions for calibration. At least at 1 mm, the brightest planets are usually significantly resolved. The peak flux densities of the planets should be computed using the PLANETS utility program available on the VAX. This program needs to know

- Effective observing frequency (GHz).

- The telescope HPBW (arcsec).

- The planetary unit semi-diameter (arcsec), *i.e.*, the semi-diameter of the planet as seen from a distance of 1 AU, available from the *Astronomical Almanac* or Table 6.3.

- The geocentric distance of the planet (A.U.), available from the *Astronomical Almanac*.

- The brightness temperature of the planet at this frequency.

The result is given in Jy/beam.

Table 6.3 gives the recommended brightness temperatures of the planets at 90 and 227 GHz. Most of these are taken from the work of Ulich and collaborators made with the 36 ft or 12 m telescopes. The 227 GHz temperature of Venus is interpolated from the measurements of a number of observers (Ulich et al., 1981; Werner et al., 1978; Whitcomb et al., 1980; Rowan Robinson et al., 1978), scaled to be consistent with the brightness temperature of Jupiter. Mars is not recommended as a flux density calibrator because its effective temperature probably depends on solar distance.

Table 6.2

Planetary Flux Density Standards

Planet	T_B(90 GHz)	T_B(227 GHz)	Unit Semidiameter (arcsec)
Venus	367 ± 10 K	317 ± 30 K	8.34
Mars*	207 ± 6 K	207 ± 7 K	4.68
Jupiter	179 ± 5 K	165 ± 18 K	95.20
Saturn	149 ± 4 K	140 ± 14 K	78.15
Uranus	134 ± 4 K	101 ± 11 K	35.02
Neptune	127 ± 4 K	104 ± 11 K	33.50

* See note below.

At 90 GHz, Ulich (1981, *A. J.*, **86**, 1619) suggests an effective temperature for Mars of

$$T_B \ (90 GHz) = 206.8 \left[\frac{1.524}{R_o} \right]^{1/2} K \, , \qquad (6.31)$$

where, R_o is the Mars-Sun distance in A.U.

Some other radio sources are expected to be non-variable, and in the case of HII regions, unpolarized. Three sources that make suitable flux density calibrators at 90 GHz are given in Table 6.3.

Table 6.3

Flux Density Calibrators

Source	S(90 GHz)
DR21	14.5 ± 0.7 Jy
W3(OH)	3.8 ± 0.3 Jy
3C274(Virgo A)	6.5 ± 0.3 Jy

The flux densities of Table 6.2 are peak flux densities measured with the 12 m telescope. They are on the flux scale of Table 6.3.

6.9 CONTINUUM STATUS MONITOR

A sample continuum status monitor display is shown in Figure 6.12. The key to the display, line by line, is as follows:

Lines 1 and 2

SCAN	:	Current scan number
SOURCE	:	Source name
HORIZON	:	Time to 15° elevation (rise or set)
LST	:	Current local sidereal time
UTC	:	Current coordinated universal time
DUT1	:	UT1-UTC time correction
YEAR	:	(top) year, (bottom) date
OBS	:	Observer's initials
OPR	:	Operator's initials

OK

```
 1  SCAN          SOURCE    HORIZON      LST       UTC      DUT1                   1989   OBS  OPR
 2   5078          OJ287        2:03    12:28:56  18:22:18         -513   14 OCT  SYS  CDC
 3                                                                   RCVR: 3.0MMSIS
 4                   R. A.        DECLINATION                       AZIMUTH  ELEVATION
 5  CURRENT       8:54:14.1   20:08:55.       COMMAND   269:58            40:55
 6  1950.0        8:51:57.3   20:17:58.       ACTUAL    269:52:51.    40:53:44.
 7  GALACTIC      206.8124     35.8209        ERROR      -0:01:19.    -0:00:01.
 8  OFFSET           0:00.0        0:00       OFFSET        -2:14          0:37
 9
10  FREQUENCY   IF'S  LO  SB   NT    DSF               POINT.    -0:14          0:02
11   91.50000       100   1   2     1        0         +BEAM      2:00          0:00
12   1.91273634    1500              1        0         -BEAM     -2:00          0:00
13   1.87288766
14  ATM   REFRT   T(AMB)   POLZ   HP          F0    TAU0     TC    %EFF
15   1.52   52.0    15.85     0:00   0:35    50.6   0.086    6.0     45
16                                                                  6.0
17           TDL   FOCUS   SP(V)   TP(V)   MODE  SCANS   SAMPLES          SEC   TIME
18  INPUT   0:10    52.4    -0.01  0.3033         BS     4       8       10.0    1:20
19  ACTUAL  0:04    51.6     0.01  0.3142                                9.3
```

FIGURE 6.12 -- CONTINUUM MONITOR SCREEN

Line 3:

(Far right) Receiver identification code

Line 4-8:

(Left side)

CURRENT	:	Apparent right ascension and declination of date
1950.0	:	RA and DEC at Equinox 1950
ECLIPTIC	:	Source ecliptic coordinates
OFFSET	:	RA and DEC offsets (RA in time units, DEC in angle units)

(Right side)

COMMAND	:	Source azimuth and elevation (spherical coordinate conversion plus pointing corrections)
ACTUAL	:	Actual AZ/EL encoder readings
ERROR	:	Difference between COMMAND and ACTUAL
OFFSET	:	Total AZ/EL offsets (sum of pointing offsets plus subreflector beam throw)

Line 9

(will contain mapping offsets when a map)

Lines 10-13

FREQUENCY	:	(top) Rest frequency, in GHz; (middle) First of 2 possible ~ 2 GHz synthesizer frequencies; (bottom) Second of 2 possible 2 GHz synthesizer frequencies
I.F.'s	:	(top) Phase-lock loop IF (MHz); (bottom) First local oscillator frequency (MHz)
LO	:	Multiplier factor for the LO source
SB	:	Sideband code (0, 1, 2, or 3)
NT	:	Noise tube in use (1 = in use, 0 = not in use)
DSF	:	Data scale factor (top - Ch. 1, bottom - Ch. 2)

POINT	:	AZ and EL pointing model corrections, mm:ss
+BEAM	:	Subreflector +BEAM position (AZ and EL, mm:ss)
-BEAM	:	Subreflector -BEAM position (AZ and EL, mm:ss)

Lines 14-16

ATM	:	Number of airmasses (1/sin(EL)) at current elevation
REFRT	:	Refraction coefficient for elevation refraction pointing correction (")
T(AMB)	:	Ambient temperature (Celsius)
POLZ	:	Orientation angle of prime focus box (always 0)
HP	:	Beam half-width and half-maximum (used for 5-point mapping grids)
F0	:	Radial focus zero position (in mm)
TAU0	:	Zenith optical depth (nepers)
TC	:	Calibration scale factors (K) - (top - Ch. 1, bottom - Ch. 2)
%EFF:	:	Aperture efficiency (in percent)

Lines 17-19

TOL	:	Pointing tolerance mm:ss (top - input, bottom - actual pointing error, sum of AZ and EL)
FOCUS	:	Actual radial focus at the current elevation (top - input, bottom - actual)
SP(V)	:	Switched power voltage from analog backend (top - Ch. 1, bottom, Ch. 2)
TP(V)	:	Total power voltage from analog backend (top - Ch. 1, bottom - Ch. 2)
MODE	:	Observing mode (e.g., BS = beam-switching)
SCANS	:	Number of scans requested
SAMPLES	:	Number of continuum ON/OFF samples requested
SEC	:	(top - total sample time requested; bottom - sample time remaining
TIME	:	(top - total integration time requested for this scan; bottom - integration time remaining)

CHAPTER 7
SPECTRAL LINE OBSERVING

7.1 INTRODUCTION

This chapter supplies basic information for setting up and executing a spectral line observation. Specific topics covered are

- A start-up checklist;
- Choosing the observing sideband;
- Choosing and configuring the filter and Hybrid spectrometers;
- Observing mode options;
- Calibration and signal processing options;
- Changing the effective intermediate frequency (I.F.);
- A key to the on-line status monitor display.

Other chapters provide additional material important to spectral line observations such as hardware descriptions and pointing and focusing the telescope.

7.2 SETUP CHECKLIST

Once the scientific goals of the observing session are clearly in mind, you must decide upon the equipment and observing techniques to be used. The decisions to be made and the options are listed below.

a) *Sideband Choice.* For double sideband observations, care must be taken in choosing the placement of the image sideband.

b) *Spectrometer Configuration.* Filter bank spectrometers with several different resolutions are available. The observer must choose which to use and how they should be configured (the "parallel" or "series" option).

The Hybrid Spectrometer, which has numerous resolution and bandwidth options, is also available.

c) *Observing Mode.* Choices are
  - Position Switching (with relative offsets)
  - Absolute Position Switching (fixed offsets)
  - Frequency Switching
  - Beam switching
  - Position switched mapping
  - Total power scans

d) *Observing Time "budget."* Prior to the start of observations, you should make a rough budget of observing time requirements. In addition to the integration time on the program sources, you should budget time for "overhead" items such as telescope movement, and pointing and calibration tests.

Before beginning program observations, check the telescope pointing and focus. A few observations of test sources are also advisable. These observations are discussed in Chapters 2, 4, and 6.

7.3 SIDEBAND CHOICE

Most of the Schottky mixer receivers in use at the 12 m operate in a double sideband (DSB) mode, that is, they respond to two frequency bands separated by twice the I.F. Other receivers, such as the 3 mm SIS receiver can operate in a single sideband (SSB) mode and require upper sideband operation. For the DSB receivers, you can generally opt to place the program line in either the lower sideband (signal sideband below the LO frequency) or the upper sideband (signal above the LO). Equipment constraints, such as the tuning range of the local oscillator or the receiver, may sometimes determine the sideband. Other times, the presence of telluric lines

steer the choice. When you are free to choose the sideband, make the choice with care.

The primary things to watch out for when choosing the sideband configuration is the presence of "contaminating" lines from the image sideband. Consult a good tabulation of spectral lines such as the Lovas Catalog (F. J. Lovas, *J. Phys. Chem. Ref. Data*, 15, 251, 1986) to see what spectral lines are present in both the signal and image sidebands. If an image line is too close to the program line in the signal sideband, a small local oscillator shift will usually cure the problem (the frequency axes run oppositely for the upper and lower sidebands). One can also make small adjustments in the I.F. to change the placement of lines from the two sidebands. This option is discussed in detail in Section 7.7. Sometimes, lines from the image sideband can be used to advantage for calibrations or system checks.

The sideband choices are labeled by codes which determine both the main sideband and the phase lock sideband. The choice of the phase lock sideband is strictly an equipment parameter that does not affect the sky frequency. Most of the Gunn oscillators in use at the 12 m require a certain lock sideband. The definitions of the sideband codes (SB) in terms of the resulting synthesizer frequencies are given below and in Chapter 3.

$$SB = 0 \qquad f_{syn} = [(f_{sky} - 1.5 \text{ GHz})/M + 100 \text{ MHz}] / N \qquad (7.1a)$$

$$SB = 1 \qquad f_{syn} = [(f_{sky} + 1.5 \text{ GHz})/M + 100 \text{ MHz}] / N \qquad (7.1b)$$

$$SB = 2 \qquad f_{syn} = [(f_{sky} - 1.5 \text{ GHz})/M - 100 \text{ MHz}] / N \qquad (7.1c)$$

$$SB = 3 \qquad f_{syn} = [(f_{sky} + 1.5 \text{ GHz})/M - 100 \text{ MHz}] / N \qquad (7.1d)$$

In the equations above, f_{syn} is the 2 GHz synthesizer frequency, f_{sky} is the sky frequency of the center of the signal band, M is the multiplier factor (harmonic) applied to the oscillator source to produce the LO frequency, and N is the harmonic of the 2 GHz synthesizer used to produce f_{syn}. Note that

$$f_{sky} - f_o + f(V) \tag{7.2}$$

and f_o is the rest frequency of the observed line and f(V) is the velocity correction that compensates for the motion of the source. The computation of f(V) depends upon the condition of a control computer flag set by the parameters VNONREL and VREL. VNONREL is the default and causes f(V) to be calculated as

$$f(V) - F_o * (1 - V/c) , \tag{7.3}$$

where c is the speed of light and $V = V_{LSR} + V_R$, with V_{LSR} the radial velocity of the source relative to the Local Standard of Rest, and V_R the projected velocity of the telescope relative to the LSR in the direction of the source. If VREL is in effect, then

$$f(V) - F_o * (1 - V/c + 1/2 * V^2/c^2) . \tag{7.4}$$

This latter expression is a second order expansion to the relativistic Doppler equation.

7.4 SPECTROMETERS

Two spectrometer systems are available at the 12 m. The older, and still primary system at this writing, consists of analog filter banks. The newer spectrometer is a hybrid device, which is a combination of analog filter and autocorrelation spectrometers. The filter banks and the hybrid spectrometer were discussed in Chapter 3.

7.4.1 FILTER BANKS

Most of the analog filter banks have 256 channels each. The filters are integrated, multiplexed, and recorded by the control computer every 100 milliseconds. A total of 512 channels can be recorded at a time, which means that two filter banks can be used for each scan. The filter spectrometers available and the ways

in which they can be configured are described below. Table 7.1 gives a summary of the 12 m filter banks.

Table 7.1

12 m Filter Banks

Filter Resolution[a]	Number of Channels	Number of Banks	Parallel/ Series Option	Hardware Center Chan[b] Par./Ser.
2 MHz	256	2	Yes	64.5/128.5
1 MHz	256	2	Yes	64.5/128.5
500 kHz	256	1	Yes	64.5/128.5
250 kHz	256	1	Yes	64.5/128.5
100 kHz	256	1	Yes	64.5/128.5
30 kHz	128	1	No (Series) Only)	65
Expander[c]	256	1	No (Series) Only)	128.5

[a]The resolutions listed are the FWHP of each filter and the separation of each filter in the bank.

[b]Filter bank channel numbering begins with 1.

[c]The Expander has resolutions of 25, 12.5, or 6.25 kHz, and uses 100 kHz filter bank.

7.4.1.1 THE PARALLEL/SERIES OPTION

Most of the 256 channel filter banks can be split into two 128 channels sections that can be fed with independent I.F. signals. When a filter bank is split into two sections, the bank is said to be in a "parallel" configuration. The parallel mode is used most often with dual polarization receivers (most 12 m receivers are of this

type), with the two polarization channels going into each half of the filter bank. The advantage of this mode is that the two halves of the filter bank can be averaged to produce improved signal-to-noise in the final spectrum. The disadvantage of this mode is that the total bandwidth is cut in half. Observers of narrow Galactic lines typically choose the parallel option, and use two filter banks with different resolutions.

Observations that require larger bandwidths, such as CO from other galaxies, usually choose the "series" mode. In the series mode, the two filter bank halves are used end-to-end to analyze a single input I.F. signal. A typical observing mode might be to use one of the 1 MHz filter banks for Polarization 1 and the other for Polarization 2. The two banks can be averaged in software to improve the signal-to-noise of the final spectrum. Figure 7.1 shows the parallel/series option diagrammatically.

7.4.1.2 THE SPECTRUM EXPANDER

The spectrum expander is a device which "expands" or increases the frequency resolution of the 100 kHz filter bank. The expansion factors are 4, 8, and 16, which result in resolutions of 25, 12.5, and 6.25 kHz per channel. The expansion factor can be selected by a switch on the front panel of the Spectrum Expander chassis. The Expander and the 100 kHz filter bank must be used as a unit, with the 100 kHz filter bank set to the "series" mode. The I.F. signal from the receiver passes first through the Expander and then through 100 kHz filter bank. The theory behind the Expander is explained in the N.R.A.O. Electronics Division Technical Report No. 209 by R. Lacasse. The most frequent observing configuration with the Spectrum Expander is to set the resolution to 25 kHz and use the Expander as Filter Bank 1 and the 30 kHz filters as Bank 2. In this case only 384 channels are recorded at a time.

At this writing, the Spectrum Expander suffers from a calibration deficiency: the gain of the device varies across the band, although apparently in a uniform

FIGURE 7.1 -- PARALLEL/SERIES FILTER BANK OPTIONS

SERIES Filter Bank Configuration Option
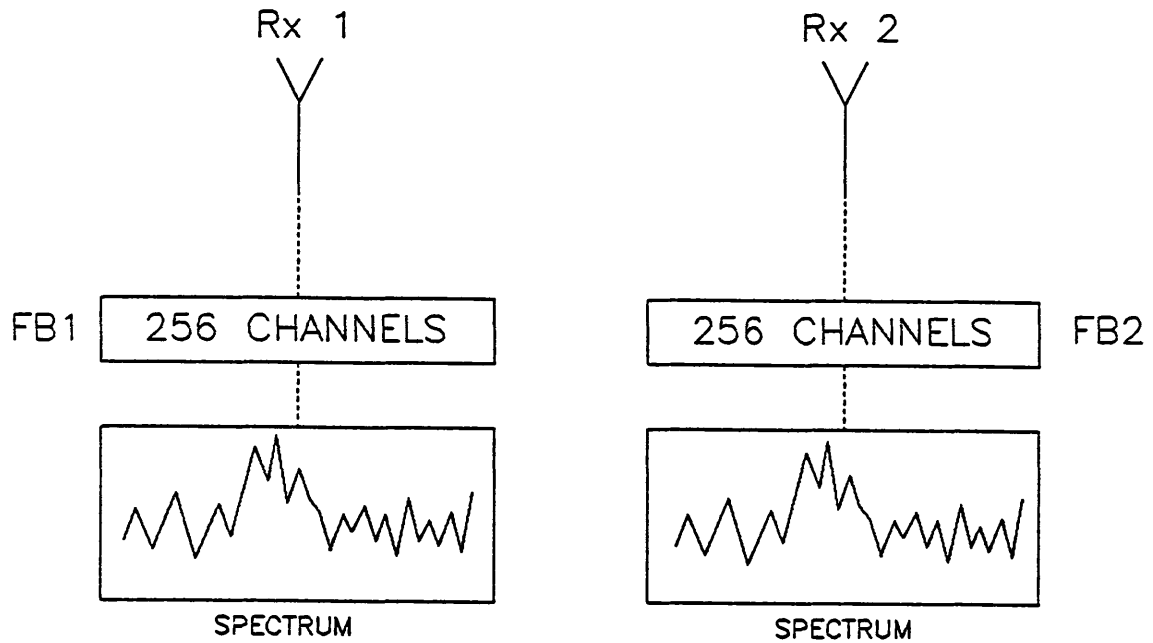
PARALLEL Filter Bank Configuration Option
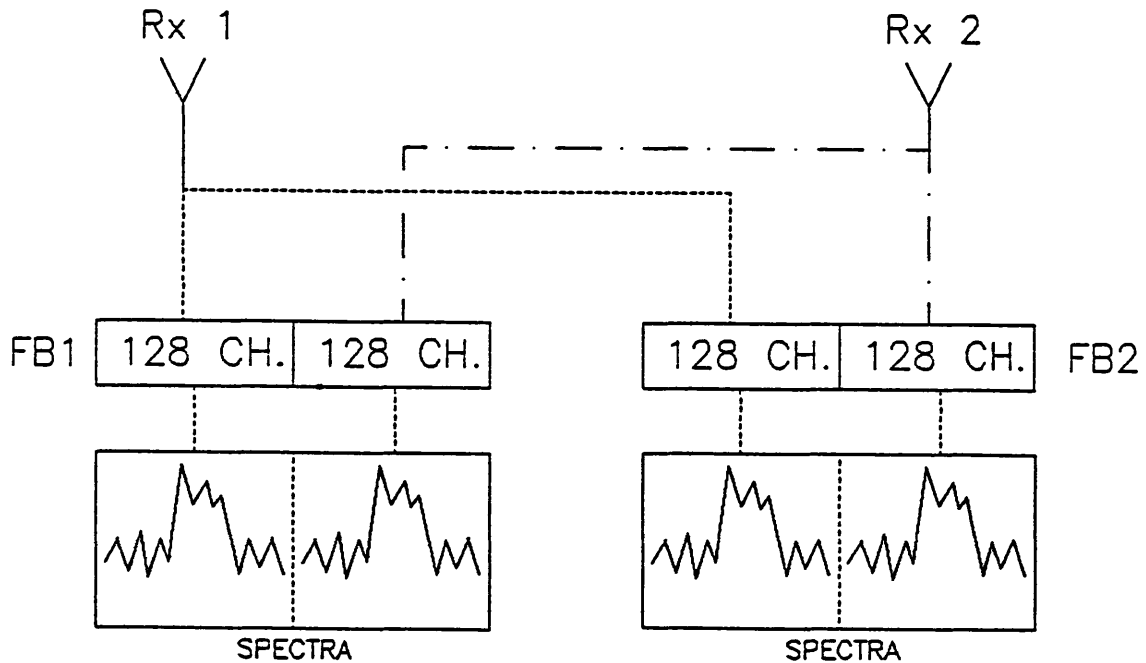
manner. The device functions well as a spectrometer, but to obtain good calibration, observers may wish to cross-calibrate with the 30 kHz filter bank.

7.4.1.3 BAD CHANNEL ELIMINATION

At times, certain channels in the filter banks are defective. You can identify these "bad" channels by examining the output of a vane calibration cycle, which is called the "GAINS." Vane calibration is described in detail in Section 7.6. Bad filter channels usually appear as spikes in the GAINS and will often cause scaling problems in the final spectrum if not eliminated. You can display the GAINS with the *LINE* data reduction program. To find the bad channels, perform a calibration scan and type G1 to display the first filter bank and G2 to display the second bank. If bad channels exist, type the command BADCH. You will be asked to enter the number of bad channels. After doing so, the cross hairs will appear on the screen. Move the vertical cross hair to each bad channel and strike any key on the main keyboard except RETURN. When all the bad channels have been entered, the program will give a report of the channel numbers. The bad channels to be eliminated are labeled by the heading "FORTH BAD CHANNELS;" tell these channel numbers to the operator. Up to 30 bad channels can be eliminated, but rarely more than 5 channels out of 512 will be bad. It is also possible to eliminate blocks of 16 channels, but this is seldom necessary. If blocks of 16 channels are bad, notify the Electronics Staff.

Once the operator has entered the bad channels, he will perform another vane calibration cycle to set the bad channels to zero. On all subsequent spectra, those channels will be at zero antenna temperature. If the spectrum is offset from zero for some reason, the eliminated channels will appear as spikes reaching to the zero level. These spikes can be eliminated in reduction software by using the REPLACE command (see the *LINE* manual).

7.4.2 HYBRID SPECTROMETER

The hybrid spectrometer offers a number of bandwidth and resolution modes, listed in Table 7.2. (See also Chapter 3.)

TABLE 7.2

Hybrid Spectrometer Modes

No. of I.F.'s	Bandwidth (MHz)	No. of Channels per I.F.	Channel Resl. (kHz)
Multi-beam Mode:			
8	300	192	1562
8	150	192	781
8	75	192	391
8	37.5	192	195
4	600	384	1562
One or Two Channel, Single Beam			
2	600	768	781
2	300	768	391
2	150	768	195
2	75	768	98
2	37.5	768	49
1	37.5	1536	24

7.5 OBSERVING MODES

Six primary spectral line observing modes are available: position switching (relative offset), absolute position switching, total power ONs and OFFs, automatic total power ON-OFF position switching, frequency switching, beam switching, total power grid mapping, automatic position switched mapping, and drift scan mapping. The attributes and applications of each is described in detail below. Signal processing and calibration for each mode is described in Section 7.6.

7.5.1 POSITION SWITCHING

Position switching, called the PS mode, is the most common and reliable observing mode at the 12 m for general spectral line observations. It involves considerable overhead in telescope movement and requires that equal time be spent in the ON and OFF source positions, but the data quality is usually good. In this mode, the telescope moves between the ON position and a relative OFF position, which may be specified in either azimuth and elevation, or hour angle and declination offsets. Usually the offset is in azimuth, so that the ON and OFF positions are taken at about the same airmass. The best rejection of the atmosphere and the best spectral baselines are achieved with small angular switches. Choose the smallest switch possible, so long as you are confident that the OFF position is free of emission.

PS data recorded on disk is a final spectrum formed from the ratio (ON-OFF)/OFF, where the ON and OFF data are total power samples. In contrast to the total power observing modes TPN and TPF, discussed below, the ON and OFF samples are not saved as separate scans for independent processing. Although the PS mode offers less flexibility in processing data than do the total power modes, it also reduces the total volume of data and makes processing easier.

To reduce telescope movement and provide the best compensation for linear drifts in atmospheric emission, choose the number of OFF-ON pairs to be a multiple

7-10

of 2. The observing cycle will then be repeats of an OFF-ON-ON-OFF pattern. Each ON or OFF is called a SAMPLE and each OFF-ON pair is called a REPEAT. The observer must tell the operator how long to integrate for each SAMPLE (the default is 30 seconds) and how many REPEATS per scan, or alternatively, the total length of the scan in minutes. A typical scan might be 6 minutes long, with 30 second SAMPLEs (meaning 6 REPEATS). You can, of course, vary the length of the scan to suit your own needs. Each ON-OFF pair can be edited individually with the *LINE* program (see Record Editing in the supplement to the *LINE* manual). The operator can issue the command to take scans one at a time, or can set the system into an automatic data-taking loop. Figure 7.2 shows an example of a spectrum produced by a PS scan.

The parameters of a PS scan that you must give to the operator are summarized as follows:

- The relative offset position, which may be specified in either (Az, El) or (RA, DEC) coordinates. The maximum offset allowable is 2°48'.

- The integration time for an individual sample (ON or OFF). 30 sec is the default.

- The number of ON/OFF pairs (REPEATS) per scan (can be specified to the operator as the total length of the scan).

- The number of scans to be performed for every calibration measurement.
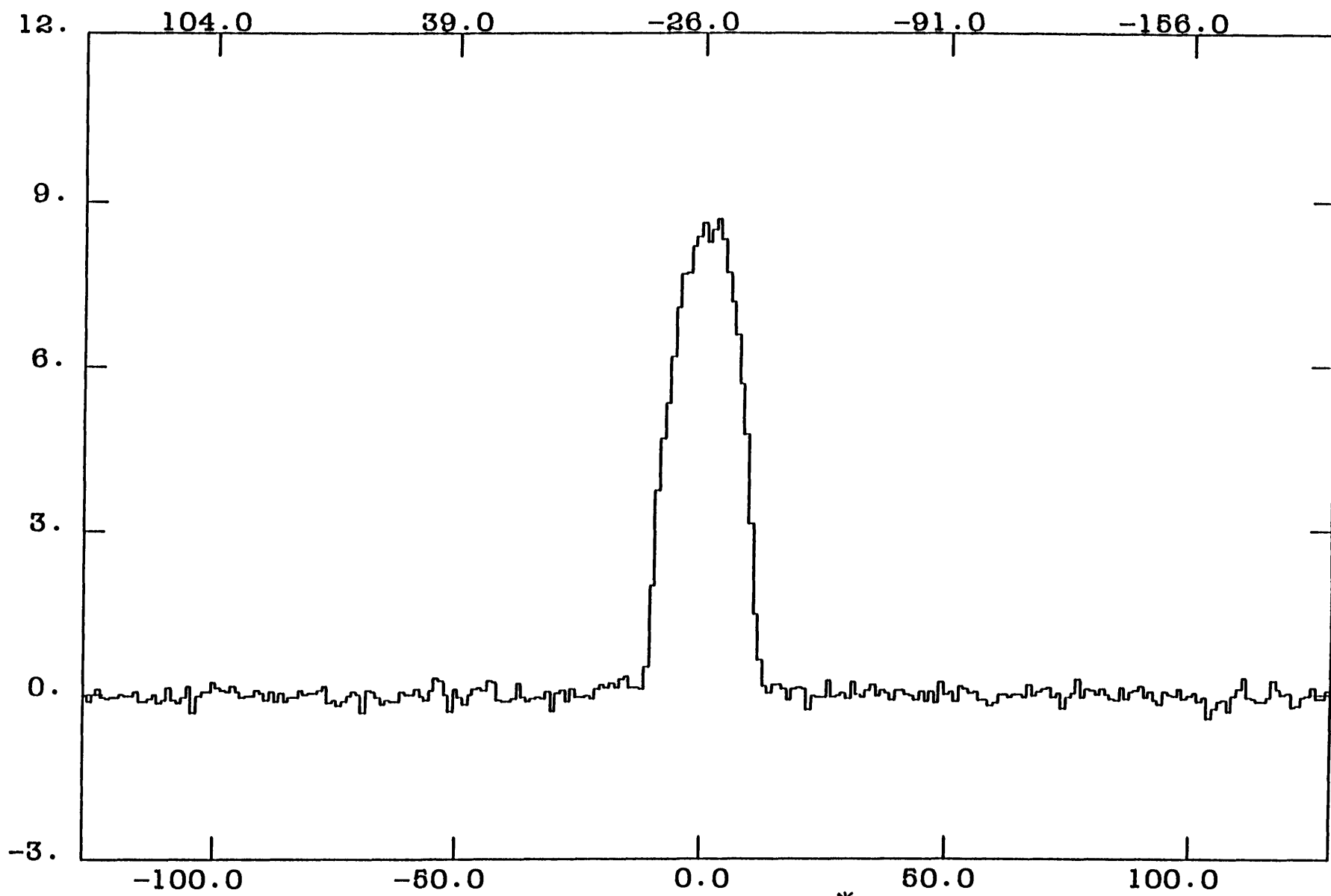
FIGURE 7.2 — POSITION–SWITCHED SPECTRAL LINE SCAN

EXAMPLE 7.1 POSITION SWITCHING

a)   We want to observe M17SW in the J = 1-0 CO line at 115.27120 GHz as a calibrator source. This source is spatially extended and the CO line is very strong. We want to calibrate and then take one scan. Use the following setup:

OFF Position:	+60' in Azimuth
Sample Time:	30 sec
ON/OFF REPEATS per scan:	2 (gives a 2 minute scan)
Scans per Cal:	not applicable

Ask the operator to perform a manual calibrate and one PS scan.

b) We wish to take a long integration on a weak line in a galactic dark cloud. The source has a spatial extent of about 10' of arc. The weather is stable and we are observing at elevations above 30 degrees. The following setup would be suitable:

OFF Position:	+20' in Azimuth
Sample Time:	30 sec
ON/OFF REPEATS per scan:	6 (gives a 6 minute scan)
Scans per Cal:	2

Ask the operator to start PS observations in the AUTO mode. Observations will continue until you ask the operator to stop.

7.5.2 ABSOLUTE POSITION SWITCHING

Absolute position switching, called the APS mode, is useful when observing in complex emission regions where it is difficult to find an emission-free reference position. In such cases, position switching with (Az,El) offsets can be dangerous because rotation of the parallactic angle as the source is tracked across the sky may cause emission to rotate into the reference beam. You will want to search for an emission-free position as close to the source position as possible, and use this as the

reference position. If you wish, you can compute the (RA,DEC) offsets to this position and use ordinary position switching. Most observers find it most convenient, particularly for future observations, to enter the absolute (RA,DEC) coordinates of the reference position and use the absolute position switching observing mode.

APS is identical to ordinary position switching except that the switching is done between two positions absolutely specified by their celestial coordinates. The reference (OFF) position should be given a different name from the signal (ON) position and is best placed in a different source catalog from the signal position. Data taking and calibration options are the same as for ordinary position switching.

The parameters of an APS scan that you must give to the operator are summarized as follows.

- The name of the source (ON) position and the number of the catalog which contains it;

- The name of the reference (OFF) position and its catalog;

- The integration time for each SAMPLE (ON or OFF). 30 sec is the default;

- The number of REPEATS of an ON-OFF pair or the total integration time of the scan;

- The number of scans between each vane calibration, if that calibration method is chosen.

EXAMPLE 7.2 ABSOLUTE POSITION SWITCHING

We are observing CO in the Galactic Center region. Our source is called G359.5-0.1. We know a nearby position which is free of emission which we call G359REF. A procedure such as the following is typical:

Put the position of the source, G359.5-0.1, in 1 CAT (for example);

Put the position of the reference, G359REF, in 2 CAT (for example);

Tell the operator the catalog of each source. Set up the other observing parameters just as if it were an ordinary position switched scan. Ask the operator to perform an APS scan.

7.5.3 TOTAL POWER ONS AND OFFS

Two observing procedures, called TPN and TPF, are available for recording total power spectral line scans. The two procedures are identical, except that TPN tracks the ON (source) position and TPF tracks the OFF (reference) position. You must execute the procedures manually, one scan at a time. As such, these procedures are mainly used for diagnostic purposes. To use TPF and TPN, follow this prescription:

1) Provide the operator with the following setup information:

- The source catalog and the source name (the ON position).

- The (Az,El) pointing corrections and the reference offset position (OFF). The offset may be specified in AZ and EL or in RA and DEC.

- The integration time of the scan in seconds (the scan will have only one SAMPLE, i.e., REPEATS does not apply to TPN or TPF scans).

2) Have the operator perform a vane CALIBRATE, a TPF (the OFF scan), and a TPN (the ON scan) in that order. The scan numbers of the CALIBRATE and TPF will be stored in the header of the TPN scan for use in data processing.

3) To look at either the TPF or TPN scans, type

> scan# F for the first filter bank, or
>
> scan# S for the second filter bank.

The displayed scan will be a total power bandpass. Unless the band contains a very strong spectral line, you will probably not be able to see any lines. To display a final spectrum, formed from the ratio (ON-OFF)/OFF * CAL, type

INSTALL TON	(Loads a procedure from a disk file. You only need to load the procedure once per session on the analysis system.)
scan# TON	for the first filter bank, or
scan#+1 TON	for the second filter bank.

The scan number should be that of the TPN (ON) scan. The TON procedure will use the last CALIBRATE and TPF scan to form the spectrum.

7.5.4 FREQUENCY SWITCHING

The frequency switching observing mode has two primary uses: to increase the on-source integration time through "in-band" switching and to alleviate the problem of finding an emission-free reference position when observing in a (spatially) complex emission region. It also entails less system overhead than most other

observing modes. In this mode, called an FS observation, a reference spectrum is obtained by shifting the center frequency of the signal spectrum. In principle, this can be done by switching the frequency of the LO or an I.F. oscillator; at the 12 m, the former is generally used. If the frequency shift is small enough, the spectral line will appear in both the signal and reference spectra. When the resultant spectrum is formed, the line will appear twice, once in emission and once in absorption. The spectrum can be "folded" to obtain a $\sqrt{2}$ improvement in signal-to-noise. With this technique, which is called "in-band" or "overlapped" frequency switching, you are effectively observing on-source all the time.

The primary drawback of frequency switching is that the spectral baselines are generally not as good (i.e., flat) as with position switching. This is because the two frequency positions each have their own spectral bandpass shapes which do not cancel in the computation of the final spectrum. If the lines are narrow and the frequency shift is small (say <10 MHz), acceptable results can often be obtained. One must also be careful of frequency switching in regions (spatial or frequency) containing many spectral lines in the bandpass.

Frequency switching is effected by switching the phase lock loop offset frequency (the Lock IF) between two nearby settings, usually generated by separate oscillators. The oscillator settings must be set manually. The frequency of switching is usually 5 Hz and is generated by the spectral line multiplexer when so instructed by the computer. The phase lock circuitry must be able to lock at both the signal and reference frequencies. This places a practical limit on the magnitude of the shift of typically < 20 MHz. Some receiver systems use the fundamental frequency of the Gunn oscillator as the LO frequency. For these systems, a shift in the loop offset frequency will produce exactly the same shift in the spectrum. Other receiver systems, particularly the high frequency receivers, use a harmonic multiple of the oscillator source as the LO frequency. The desired frequency shift must be divided by the appropriate multiple before setting the loop offset frequencies.

You will usually want to know whether the reference frequency is higher or lower than the signal frequency, or in other words, where the apparent "absorption" and "emission" features appear in the band. This is dependent upon which sideband ("SB") is being used. Figure 3.15, which shows how the SB options are related in frequency space, and Table 7.3 will be of use in making this determination.

Table 7.3

Effect on Band Center Frequency of Changing the Lock I.F.

SB	Increasing the Lock I.F. will shift the band center to a frequency that is
0	lower
1	higher
2	higher
3	lower

To reduce "in-band" frequency switched data in the *LINE* data reduction system, use the parameters FS and FR and use the FOLD command. FS is frequency offset (in MHz) of the signal line relative to band center and FR is the frequency offset (in MHz) of the reference line. FOLD is the verb which averages the signal and reference lines and displays the result.

You should understand the workings of the oscillator system and calculate your own frequency settings (the "Friend of the Telescope" can help you with this). After doing so, the operator will set the oscillators for you. If possible, test the technique on a strong line before proceeding to a long integration on a weak line. Example 7.3 shows how to make the oscillator calculations for frequency switching.

When performing frequency switched observations, you must decide upon the following parameters and give them to the operator:

1)   The magnitude, sense, and symmetry of the frequency shift;

2)   The switch rate (the usual setting is 5 Hz);

3)   The total integration time of the scan.

Frequency switched scans always consist of only one record and, hence, cannot be record-edited.

EXAMPLE 7.3 FREQUENCY-SWITCHED OBSERVING

Example 1:

We are observing weak J = 1-0 DCN in a galactic dark cloud. We want a 1 hour integration on the source which is starting to set. We choose to calibrate each scan. Observations are with the 3 mm receiver which uses the fundamental of a Gunn oscillator as the LO frequency. The sideband code is SB = 2. We want an 8 MHz frequency switch with the "in-band" lines symmetric about the center, and with the signal line on the low frequency side and the reference line on the high frequency side of band center. The Gunn oscillator phase lock circuitry uses a 100 MHz loop offset frequency.

To achieve the desired shift, we want to set one oscillator to 100 + 8/2 = 104 MHz and the other oscillator to 100 - 8/2 = 96 MHz. We want the signal frequency to be lower than band center (i.e., band center higher). From Table 7.3, SB = 2 requires that the lock frequency be set higher. Therefore, set the Signal Oscillator to 104 MHz and the Reference Oscillator to 96 MHz. These setup parameters would be appropriate:

Signal Oscillator:	104 MHz
Reference Oscillator:	96 MHz
Switch Rate:	5 Hz (the default setting)
Scan length:	6 min (360 sec)
Scans per Cal:	1

Ask the operator to perform a FS scan in AUTO mode for 1 hour. To reduce the data in the LINE program, set FS = 4 and FR = -4, and issue the FOLD command.

Example 2:

We are observing J = 2-1 CO in a narrow line source. We want to make a long integration under stable skies at high elevations. Observations are with the 200-240 GHz mixer receiver which uses the tripled output of a Gunn oscillator as its LO frequency. We are using SB = 0. We want a 6 MHz frequency shift with the lines symmetric about the center, and with the signal line on the high frequency side and the reference line on the low frequency side of band center. The Gunn uses a 100 MHz loop offset frequency.

A shift of 6 MHz in the spectrum requires a shift of 6/3 = 2 MHz in the Lock I.F. because the Gunn signal is tripled. Thus one oscillator will be set to 100 + 2/2 = 101 MHz and the other to 100 - 2/2 = 99 MHz. From Table 7.3, to place the band center lower in frequency than the signal, we increase the Lock I.F. Thus, set the Signal Oscillator to 101 MHz and the Reference Oscillator to 99 MHz.

These setup parameters would be appropriate:

Signal Oscillator:	101 MHz
Reference Oscillator:	99 MHz
Switch Rate:	5 Hz (the default)
Scan length:	4 min (240 sec)
Scans per Cal:	2

Ask the operator to perform a FS scan in AUTO mode until you ask him to stop. In the LINE reduction program, set FS = 3 and FR = -3 (because of the tripling).

7.5.5 BEAM SWITCHING

Spectral line beam switching can be useful when observing small angular diameter sources and when the best possible baselines are needed. This observing mode involves the nutation (chopping) of the subreflector and a positional movement of the telescope and is thus called the BSP (beam switching plus position switching) mode. The technique is much the same as that used for continuum ON/OFF's. With the subreflector nutating at a rate of typically 1.25 Hz, the telescope is moved to place the source first in one of the beam positions and then in the other. The beam position which, for a positive source signal, produces a positive response in the spectrometer is called the "positive beam" and a sample taken in this position is called an "ON." Conversely, the beam position which produces a negative response in the spectrometer is called the "negative beam" and a sample taken there is an "OFF." A BSP scan always consists of four samples taken in the order OFF-ON-ON-OFF. The samples are taken in this order to get the best atmospheric rejection, the best baselines, and to reduce telescope movement. The integration time of one of the individual ON or OFF samples controls the total integration time of the scan (sample length times 4).

The beam switching mode usually produces very good spectral baselines. The subreflector switch rate is such that atmospheric changes and filter bank anomalies are most often subtracted out. The primary restriction for beam switching is that the source angular diameter must be smaller than the subreflector throw. The subreflector throw can be varied between 0 and 6 arc min. The default switching rate is 1.25 Hz. At this switching rate the observing efficiency is about 90% that of a position-switched scan, i.e., line intensities are about 0.9 that of a PS scan. This is because no blanking is applied during subreflector movements. Switch rates of 2.5 and 5.0 Hz are also available. The observing efficiencies are poorer at the faster rates but the cancellation of atmospheric drifts may be better.

You must decide upon the following parameters in a beam switched observation and give them to the operator:

1) The subreflector throw. Changes in the throw must be made manually;
    the computer must be updated (manually) as to the new value of the
    throw.

2) The switch rate of the subreflector.

3) The integration time per sample (ON or OFF). The total length of the
    scan is the sample time x 4.

The vane calibration method is available, although it is applied in a different manner
than for position switched data (see below).

EXAMPLE 7.4 BEAM SWITCHED OBSERVING

A galaxy is to be observed in the J = 1-0 CO line. The emission is weak
and has a very broad velocity profile. Very flat and stable baselines are
required. The angular diameter of the galaxy is 30". We want to take a long
integration of 4 min scans and calibrate every other scan. These setup
parameters would be appropriate:

Subreflector Throw: 4' (this is the default for 3 mm)

Switch Rate: 1.25 Hz (the default)

Sample integration time   1 min (60 sec). (This produces a 4 min
                           scan consisting of a single
                           OFF-ON-ON-OFF cycle.

Scans per Cal: 2

Ask the operator to perform a BSP scan in the AUTO mode until you ask him to
stop.

7.5.6 MAPPING

The 12 m system offers four modes of spectral line mapping: mapping by manual offsets, automatic mapping of rectangular grids in either the total power or position-switched modes, and automatic absolute position- or frequency-switched mapping using catalog generation routines. In addition, the system offers an automatic spectral line five-point mapping routine, which is used most often for determining azimuth-elevation pointing corrections. Mapping with manual offsets is appropriate for small maps or maps with unevenly spaced points. For most rectangular grid mapping, we recommend the automatic position-switched total power mode. With the total power mode, you can choose to observe several ONs per OFF and thereby increase the observing efficiency. The other alternative for grid mapping is through automatic catalog generation. With this method, you build a catalog of positions and step through them, either automatically or through manual selection by the operator. This method works in either the automatic position switched (APM) mode or the frequency switched mode.

7.5.6.1 MANUAL OFFSETS

Often an observer will want to make a simple source map consisting of only a few points. In such cases, manual offsets (in RA, DEC) from the center position are the easiest way to proceed. Follow these steps:

1) Enter the center position into a source catalog or tell the operator the name and position so that he can enter it manually;

2) Compute the offsets in *angular* units. For declination offsets, this is unambiguous. For right ascension, two cases exist:

a) You want *true angular offsets* in the RA direction, i.e., with the "cosine declination" correction made. Tell the operator the magnitude of the offset in minutes and seconds of arc and whether you want to go East (+RA) or West (-RA). Ask him to use the FORTH E/D (for East) or W/D (for West) offset command which makes the cosine declination correction;

b) You want an RA offset in units of time. Convert the RA offset to arc measure by multiplying by 15. Tell the operator the magnitude of the offset in units of minutes and seconds of arc and whether to go East or West. Ask him to use the FORTH EE or WW commands which do not make an undesired cosine declination correction.

3) After each integration, loop to Step 2 and select a new point in the map.

The header information on the spectrum displayed by the *LINE* data reduction program will show any offsets that have been entered. The offsets are given in (real) angular units.

EXAMPLE 7.5 MANUAL OFFSET MAPS

Example 1:

You are observing a J=2-1 CO (230 GHz) in PS mode. You wish to take a single offset point, 1 beamwidth to the East. The FWHP of the beam is 30" at 230 GHz. Ask the operator to perform a PS scan with the offset specified by

        0:30 E/D .

Example 2:

You are observing a galaxy and are reading the coordinates from a scaled optical photograph. You wish to observe a point 10^s West in right ascension from the center position. First, convert the 10^s of time to angular measure by multiplying by 15. This gives 150", or 2'30". You do not want a cosine declination correction to the angle, so ask the operator to enter the offset as

        2:30 WW .

7.5.6.2 AUTOMATIC TOTAL POWER MAPPING OF RECTANGULAR GRIDS (TPM)

With the total power mapping mode, called TPM, you can define a rectangular RA-DEC grid with different grid spacings in the RA and DEC coordinates. You can choose to observe several map positions (ONs) for each reference (OFF) position, and several OFFs for each vane calibration scan. After defining the grid, you can choose to map a subset by specifying the beginning and ending row numbers, and the

beginning and ending column numbers. The map is scanned row-wise, starting at the negative-most RA offset and the negative-most DEC offset. The TPM mapping procedure insists upon placing a map point on the center position of the map. This is regardless of whether there are an even number of rows or columns.

To use the TPM procedure, proceed as follows:

1) Give the operator the following information (FORTH commands issued by the operator are in square brackets):

   a) The catalog and name of the source (map center position).

   b) Standard setup parameters, including the (Az, El) pointing offsets, the pointing tolerance, and the focus setting.

   c) The reference position offset (relative to the map center) in either the AZ-EL frame or the RA-DEC frame. The maximum RA-DEC offset is 2°48' from the source position.

   d) The RA grid spacing in seconds of arc (real angle). [mm:ss XCELL]

   e) The DEC grid spacing in seconds of arc. [mm:ss YCELL]

   f) The number of rows (displaced in DEC) in the map. [SROW]

   g) The number of columns (displaced in RA) in the map. [SCLM]

   h) The integration time per ON or OFF (both must be the same) in seconds. [sec*10 SEC !]

   i) The number of map positions (ONs) to be observed for each reference position (OFF). [N/F]

j) The number of OFFs for each vane CALIBRATE [F/C].

k) The beginning and ending rows of the map (optional) [BROW, EROW].

l) The beginning and ending columns of the map. (optional) [BCLM, ECLM]

2) When you are satisfied with the setup, the operator will start the map with the TPM command.

3) To display the spectrum of a single map point, type

```
INSTALL TON       (loads the procedure from disk)
scan#      TON     for the first filter bank, or
scan#+1    TON     for the second,
```

where the scan numbers are those of the map positions (ONs).

4) To display a contour map of peak or integrated intensity versus position, consult the Spectral Line Data Reduction manual and auxiliary documentation.

EXAMPLE 7.6 TPM MAPPING

Example 1:

Suppose you wish to make a 5' x 6' (RA x DEC) map of a molecular cloud in the J=2-1 CO line. You want the map to be fully sampled; since the FWHM of the beam is about 30" at 230 GHz, you want a grid size in both coordinates to be 15". The source is near the Galactic plane where the emission field is complex. For this reason, you choose a "clean" reference position and specify its position by RA and DEC offsets, relative to the map center position. You expect the emission lines to be strong, and decide that 30 sec per position will give adequate sensitivity. A possible setup might be

RA grid spacing	15" [0:15 XCELL]
DEC grid spacing	15" [0:15 YCELL]
No. of Rows	13 (gives a 6' coverage in DEC with a row through the center) [13 SROW]
No. of Columns	11 (gives a 5' coverage in RA with a column through the center) [11 SCLM]
Integration time	30 sec [300 SEC !]
ONS per OFF	3 [3 N/F]
OFFs per CAL	2 [2 F/C]

If you wish to map the entire grid, you need not specify the beginning and ending row and column numbers; the default mode is to execute the entire map.

Example 2:

      Suppose you wish to make the map described in Example #1, but want to take additional observations of a 5 x 5 grid at the center so as to improve signal-to-noise there. As noted above, the beginning point of the map is negative-most RA and negative-most DEC position. Thus, you would set up the map exactly as in Example 1, and would specify in addition

Beginning Row	5	[5 BROW]
Ending Row	9	[9 EROW]
Beginning Column	4	[4 BCLM]
Ending Column	8	[8 ECLM] .

7.5.6.3 POSITION-SWITCHED MAPPING OF RECTANGULAR GRIDS (PSM)

      The position-switched mapping routine PSM will generate a position-switched RA-DEC grid map using relative offsets for its reference position. The reference offset can be specified in either the AZ-EL or RA-DEC frames. If you specify an RA-DEC reference offset, the map is equivalent to an absolute position-switched map since the reference position is always the same point on the sky. The map is done on a rectangular grid that can have different X and Y cell sizes. You can specify that only a subset of the originally specified grid be mapped. Each point of a PSM grid map is taken as a position switched scan using the PS observing algorithm, i.e., the telescope switches on and off source in the pattern OFF-ON-ON-OFF ...., where each OFF-ON pair is called a REPEAT. You can also set the integration time of individual ON and OFF samples.

      The operator will need the following information to perform a PSM map:

XCELL   the X (= RA) cell size in arc seconds;

YCELL   the Y (= DEC) cell size in arc seconds;

SROW   the number of rows to map;

SCLM   the number of columns to map;

S/C   the number of scans per vane calibrate;

SEC   the number of seconds of integration for each ON or OFF sample;

REPEATS   the number of ON-OFF pairs per mapping point.

When the map is executed, the RA step size in time measure is given by

$$XCELL\ /\ [15\ *\ cos(DEC)],$$

i.e., the cosine declination correction is taken into account automatically so that all mapping grid offsets represent real angle on the sky.

The following optional commands allow you to observe a subset of the grid specified by SROW and SCLM. The defaults for each parameter are given in parentheses.

BROW   the beginning row of the map (1);

EROW   the ending row of the map (SROW);

BCLM   the beginning column of map (1);

ECLM   the ending column of the map (SCLM).

There is no hard rule to determine whether one should use PSM or TPM, the total power mapping mode. TPM is more efficient in the sense that you can use one OFF scan with several ONs. However, PSM may produce better baselines because of the switching pattern. As a general recommendation, we suggest that you use TPM for maps of strong lines and large mapping grids; use PSM if the lines are weak and baseline stability is critical. APM is also an alternative to PSM: it uses the same OFF-ON-ON-OFF... pattern but the mapping positions are taken from discrete catalog

entries rather than a grid built from offsets from a single central position. The PSM mapping procedure (like TPM) insists upon placing a mapping point on the center position of the map.

EXAMPLE 7.7 PSM MAPPING

Suppose you wish to map a galaxy whose lines are broad and weak. The observations require extremely flat baselines, so you choose PSM as the mapping mode. You wish to perform a rectangular grid of 5 rows and 9 columns, with 30" spacing in each coordinate. You want to integrate for 6 minutes per point (you can repeat the map as many times as necessary). Tell the operator that you would like to perform a PSM map and give him the following setup parameters:

- XCELL is 30"
- YCELL is 30"
- SROW is 5
- SCLM is 9
- S/C is 2 (OK for high elevations and stable skies)
- 6 minute scan (Default sample integration is 30 s, so a 6 minute scan is comprised of 6 REPEATS. The sample integration time can be changed if desired.)
- The offsets (RA/DEC or AZ/EL) for the reference position. The offsets are specified in arc measure; the RA offset does not automatically include the cosine declination effect.

7.5.6.4 AUTOMATIC MAPPING OF RECTANGULAR GRIDS BY CATALOG GENERATION (APM)

The catalog generation mapping mode allows mapping of rectangular grids in either the *absolute* position switching mode (APM) or a frequency switching mode (FS-MAP). The grid can have different cell dimensions in the horizontal and vertical directions.

The APM and FS-MAP modes execute by automatically loading one of the standard source catalogs (5 CAT) with the coordinates of each map point. Coordinates in either the *1950 Equatorial or Galactic* frames can be generated. Although not strictly required, the map generation works best if the map center position and map reference position (for APM) are stored in different catalogs, neither of which is 5 CAT. To generate and then execute an automatic map, give the operator the following information:

1) The number of columns and rows of the grid. If n is the number of columns and m the number of rows, the operator will enter the information with the command.

   (n-1)/2   (m-1)/2   MGRID

2) The grid step size in the horizontal and vertical directions. The units are always angular, but gridding in the right ascension or galactic latitude direction does <u>not</u> automatically correct for the cosine of the declination. If the cos(dec) correction is to be made, include it in the specification of the grid spacing. The operator enters the cell dimensions with the command

   mm:ss.   mm:ss.   MCELL

where the first angle is the horizontal spacing and the second is the vertical spacing.

3) Whether the map is to be in the equatorial (RA, Dec) frame or the Galactic frame. The positions in 5 CAT will be in 1950 RA and DEC in either case.

4) Whether the horizontal or vertical map coordinate should increment first. The default is horizontal.

5) Whether the center position of the map should be reobserved every few map points and, if so, what the interval should be.

6) The number of scans to take between each vane calibration, if that calibration mode is chosen.

7) The names of the source center position and the reference positions and the catalogs that contain them.

8) The standard observing parameters such as the integration time, number of OFF-ON repeats per scan, tracking tolerance, etc.

When the operator has entered all this information, he will generate the map positions in 5 CAT. Only 34 positions will be calculated at a time. When these positions are finished, the next 34 positions can be generated without re-entry of parameters. In the normal mode, the operator will start the map at the first position and step through sequentially. He can skip about in the map upon request, however. In addition, he can also step through a catalog of mapping positions which you generate yourself.

EXAMPLE 7.8 APM MAPPING

You wish to map a grid with 11 horizontal and 7 vertical points, *i.e.*, 11 columns and 7 rows. The grid spacing is 30" in both directions. The coordinates are 1950 equatorial. The name of the source is OPH-1 and a nearby, emission free reference position is called OPH-REF. The declination of OPH-1 is -20°. You want to step horizontally along each row and then move to the next row. You want to reexamine the center position of the map at the end of every row (i.e., every 11th point) and calibrate every 2 scans. The integration time for each scan is 1 minute. Give the operator these setup parameters:

Catalog containing OPH-1:	1 CAT (any CAT except 5 is ok)
Catalog containing OPH-REF:	2 CAT (any CAT except 5 or the one containing the Source is ok)
Grid command:	5 3 MGRID
Cell command:	0:32 0:30 MCELL (the horizontal cell includes a cos(dec) correction.
Map frame:	Equatorial (ECAT)
Coord. to increment first:	Horizontal
Interval to resample center:	11
Scans per Cal:	2
Sample integration time:	30 sec (default)
ON/OFF repeats:	1 (1 min scan)

The map consists of 84 scans, counting the repeat observations of the center position. The operator will have to generate 5 CAT three times to include all the points.

7.5.6.5 SPECTRAL LINE FIVE-POINTS

Spectral line five-points are used most often to determine azimuth and elevation pointing corrections, but may sometimes be of use as a general spectral line mapping routine. The data are taken in either the position-switching mode or the beam-switching mode, and the map points are taken in the same order as in a continuum five-point, i.e., +EL, -EL, CENTER, -AZ, and +AZ. A listing of sources appropriate for spectral line pointing is given in Chapter 4, Table 4.2.

To perform a spectral line five-point, the operator will need the following information:

1) Which source to observe. The source listing in Table 4.2 is by no means all-inclusive, but if another source is used, take care that it is really suitable for use as a pointing source. In particular, it should have an angular size that is smaller than, or at least comparable to the antenna beam size and possess an accurately known position;

2) The azimuth offset angle of the reference, to be used for position switching.

3) An initial guess for the azimuth and elevation pointing offsets;

4) The grid spacing "HP". As for a continuum 5-point, HP is usually chosen to be 1/2·FWHP.

5) The observing mode, position-switching (PS5) or beam-switching (BS5).

6) The integration time per point, as specified by the seconds per sample, and the number of REPEATS, consisting of an ON and an OFF sample for position-switching or an OFF-ON-ON-OFF pattern for beam

switching. The observer also must specify the integration time per sample (30 s is the default and is usually convenient). Table 4.2 gives suggestions for the integration times.

The display of the map and the fit for pointing offsets is somewhat more involved than for a continuum five point. When in the POPS/*LINE* data reduction program, you must first install the reduction procedure from its disk file by typing

INSTALL LF .

Then type

center_scan_number   LF

for the first filter bank, or

center_scan_number+1   LF

for the second filter bank. As explained in Section 7.4.1.1, a single filter bank may be split into two 128 channel halves, one for each polarization channel (PARALLEL mode), or the whole filter bank used for a single polarization channel (SERIES mode).

After typing "center_scan_number   LF", you are asked some questions by the routine:

"AVERAGE THE TWO RECEIVERS? (1=YES, 0=NO)"

This question is asked only if the data were taken in SERIES mode. If the question is answered "yes," the routine averages the first and second filter bank to improve sensitivity. You should answer "yes" only if you are reducing the first filter bank; you will usually not need to reduce the two filter banks separately if averaging the two.

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If the data were taken in PARALLEL mode, the two polarization channels in each filter bank are automatically averaged.

The next question asked is

"USE OLD BASELINE & INTEG. REGIONS? (1=YES, 0=NO)"

The observer must define baseline fitting and spectral line integration regions for this routine. If these regions have already been accurately set, as, for example, in a five-point of the same source performed immediately prior to the present one, you can answer "yes" and speed up the reduction process considerably. If you answer "no," the spectrum at the center of the map is displayed on the screen, and the question

"ENTER # OF BL SEGS"

is printed. This part of the LF routine is the same as the "BSET" procedure. The observer must enter the number of baseline segments to be used to fit a least-squares baseline. [NOTE: The order of the fit is determined by whatever NFIT is set to (the default is 1 -- see the *LINE* data reduction manual for a description of the baseline fitting facilities).] When the number of segments to be fit is entered, the graphics cross hairs appear and you must mark off the two ends of each segment with the cross hairs (move the cross hairs to the desired position and strike any key except RETURN, if using the MODGRAPH).

When this operation is finished, the baseline is removed from the center spectrum and the spectrum is replotted. The prompt

"ENTER INTEG. REGIONS"

is printed and the cross hairs reappear. You should then mark off the two velocity/frequency extremities of the spectral line (or whatever region you wish to integrate over). When this is done, the question

"DISPLAY EACH SCAN? (1=YES, 0=NO)"

is printed. If you answer "no," the map and the fit for new offsets are printed out. If you answer "yes," each scan of the map, with baselines removed, is displayed on a single plot, one spectrum on top of the other. The final question asked is

"TYPE 1 TO CONTINUE OR 0 TO STOP"

If you approve of the fits, answer 1 and the map and fit for new offsets will be displayed. An example of the five-point map with explanatory annotations is given in Figure 6.6.

7.6 CALIBRATION AND SIGNAL PROCESSING

7.6.1 VANE AND CHOPPER WHEEL CALIBRATION

The calibration mode used for almost all spectral line observations at the 12 m is the vane or chopper wheel method. In this method, a calibration signal is generated by differencing the signals recorded first on cold sky and then on an ambient temperature absorber. In 12 m vernacular, a vane is a paddle covered with microwave absorber that is switched in and out of the beam at a rate of about 1 Hz. A chopper wheel is, in this case, a chopping blade whose solid portions are covered with absorber and which rotates at a rate of typically 10 - 50 Hz. The calibration technique is identical with the two devices. The receivers currently in use at the 12 m are all equipped with vanes.

Chopper wheel calibration has been discussed extensively in the literature (see Ulich and Haas, 1976 *Ap. J. Suppl.*, 30, 247, and Kutner and Ulich, 1981 *Ap. J.*, 250, 341). The technique corrects for atmospheric attenuation and several telescope losses. At the 12 m, the temperatures resulting from this technique are on the T_R^* scale (Kutner and Ulich) which means that the temperatures are corrected for the

atmosphere and all telescope losses except for coupling of the source and beam. The beam is defined here to include the central diffraction lobe, all near-in sidelobes, and the error pattern (error pattern losses are often the largest of the uncorrected losses). Observers should be aware that other observatories using the chopper wheel method have different definitions of the basic temperature scale. Exercise care when comparing data!

An essential part of the chopper wheel calibration method is the specification of the calibration scale temperature TC. To first order, TC is equal to the ambient temperature for a single sideband receiver. In actuality, TC is a function of mean atmospheric temperature, atmospheric optical depth, sideband gain factors, the rear spillover and blockage efficiency η_{l}, and the forward spillover efficiency η_{fss}. For observations under typical atmospheric conditions, TC = 400 for single sideband operation and TC = 800 for double sideband operation for most 12 m receivers. TC varies with elevation, particularly for double sideband observations on the wings of an atmospheric line such as at 115 GHz. Recommendations for TC are available from the staff and a utility program exists on the VAX for its computation.

The procedure for performing a VANE CALIBRATE is the following:

a)   set the calibration scale temperature TC. As explained above, TC is approximately 400 for SSB receivers and 800 for DSB receivers. The precise value of TC is dependent upon efficiency factors, temperature, atmospheric optical depth and elevation or airmass. Recommended values for TC can be provided by the 12 m staff.

b)   Perform a calibration cycle (called a CALIBRATE) at intervals which you prescribe. The interval should be small enough that the atmospheric transmission during the interval does not change appreciably. This depends on the atmospheric optical depth and its stability and the elevation. During stable conditions of low optical depth, a CALIBRATE every 10-15 minutes is usually sufficient. If the atmosphere is choppy

or the elevation is changing rapidly as when the source is rising or setting, more frequent CALIBRATEs may be necessary. The operator can command the system to perform a CALIBRATE before each position switched scan or before a specified block of scans. The length and number of repeats of a given CALIBRATE can also be specified. The default is 30 seconds, with the vane and sky sampled 15 times each at 1 second per sample.

c)   The result of a CALIBRATE is loaded into the GAINS array. To examine the GAINS, type G1 for the first filter bank and G2 for the second. Exact definitions of the signal processing are given in Section 7.6.3.

During position and frequency switched observations taken in the AUTO mode, the telescope moves to the OFF position to take the CALIBRATE.

7.6.2 DIRECT CALIBRATION

Note: *The staff does not recommend this calibration procedure. We describe it here for completeness.*

In the direct calibration mode, called NO-CAL in the control system, the data are scaled by the system temperature and the atmospheric attenuation according to the relation

$$T_A - \frac{S - R}{R} * TS * \exp(\tau_0 \cdot A) , \qquad (7.5)$$

where S is the signal array, R the reference array, TS the system temperature, τ_0 the zenith optical depth, and A the airmass. The exact expressions for NO-CAL signal processing are discussed below. The observer is responsible for the computation of TS and the measurement of τ_0. The value for TS can include efficiency factors, or the

antenna temperature can be scaled up in the data reduction and post-processing stage. One reasonable definition of TS is

$$TS = \frac{(1 + G_i/G_s)(T_{Rx} + T_{sky})}{\eta_l \eta_{fss}}$$ (7.6)

where G_i and G_s are the image and signal sideband gains, T_{Rx} is the receiver noise temperature, T_{sky} is the antenna temperature of the sky, η_l is the rear spillover efficiency, and η_{fss} is the forward spillover efficiency. With this definition, the resulting antenna temperature is on the same scale (T_R^*) as with the chopper wheel calibration.

This calibration scheme has a certain appeal because it is direct and easy to understand. However, the method has several difficulties which prevent it, in general, from being as accurate as the chopper wheel method. First, in the absence of an automatic HOT/COLD/SKY load system (which the 12 m doesn't have), you must make several time-consuming observations. These include tipping scans to measure the atmospheric optical depth, and manual HOT/COLD loads to measure the receiver noise temperature and possibly the sky temperature. If these measurements are not made frequently, receiver and atmospheric drifts may introduce calibration errors. In addition, measurement of an average atmospheric optical depth may not adequately correct for local cloudlets and other atmospheric anomalies. Finally, the chopper wheel method depends only weakly on η_l, whereas the direct calibration method depends strongly on it.

Although we do not recommend the NO-CAL method for most cases, you should follow this procedure if you choose to use it.

a) Perform an ordinary VANE cal to look for bad channels in the filter banks and give the operator a list of the bad channels;

b)   Tell the operator you will be using the NO-CAL method. He will first perform a dummy CALIBRATE to zero the bad channels. You will not need to perform any more calibrates.

c)   Tell the operator the value of TS you wish to use. It's up to you to decide how to calculate this number, but you will probably want to measure the receiver noise temperature by a HOT/COLD load, in the least.

d)   Perform a tipping scan (this must be done in CONTINUUM mode - see Chapter 6).

e)   Repeat steps c) and d) at intervals short enough to catch any significant system or atmospheric changes.

7.6.3 SIGNAL PROCESSING FOR POSITION AND FREQUENCY SWITCHED DATA

7.6.3.1 VANE/CHOPPER CALIBRATES

When a vane calibration is performed, a calibration array called the GAINS array is computed according to the formula

$$C_i - \frac{R_{ci} - Z_i}{S_{ci} - R_{ci}} * TC ,$$

(7.7)

where C_i is the effective system temperature for channel i,

S_{ci} is the calibration signal (vane over the feed) for channel i,

R_{ci} is the calibration reference (cold sky) for channel i,

Z_i is the zero value response of channel i with no input signal, and

TC is the calibration scale temperature.

The array of C_i elements is called the GAINS array. The average effective system temperature of all channels in the multiplexer,

$$TS - <C_i>$$ (7.8)

is displayed and updated on the on-line status monitor each time a CALIBRATE is performed. Note that TS is an average of both receiver channels when a two-channel receiver is in use.

The calibrated antenna temperatures (T_R^*) that are recorded on disk are calculated by the formula

$$(T_R^*)_i - \frac{S_i - R_i}{R_i - Z_i} * C_i ,$$ (7.9)

where $(T_R^*)_i$ is the calibrated antenna temperature for channel i,

              S_i is the Source or ON signal, and

              R_i is the Reference or OFF signal.

7.6.3.2 NO-CAL SIGNAL PROCESSING

In the NO-CAL mode, the antenna temperatures are calculated from the relation

$$(T_A)_i - \frac{S_i - R_i}{R_i - Z_i} * TS * \exp(\tau_o \cdot A) \, , \tag{7.10}$$

where τ_o is the zenith optical depth (called TAU$\emptyset$ in the control system), and A is the airmass, calculated as 1/sin(elevation). All other symbols are defined in 7.6.3.1.

7.6.4 SIGNAL PROCESSING FOR BEAM SWITCHED DATA

Beam switched data are calibrated using the vane but the signal processing is different from position and frequency switching. When a calibrate is performed during a beam switching session, the GAINS array is defined as

$$C_i - \frac{1}{S_{ci} - R_{ci}} * TC \, , \tag{7.11}$$

where the terms are defined above. The antenna temperature scale is given by

$$(T_R^*) - (S_i - R_i) * C_i \, . \tag{7.12}$$

7.7 CHANGING THE INTERMEDIATE FREQUENCY

Occasionally an observing situation may arise in which a change in the Intermediate Frequency from the nominal 1.5 GHz is either necessary or desirable. One example of this is when the program line is just outside the tuning range of the local oscillator. Another example occurs when, for double sideband observations, it is advantageous to observe lines from both the signal and image sidebands for pointing, calibration, or simultaneous line search purposes and the image line is just outside the normal spectral bandpass.

These observing situations can be accommodated provided the I.F. needs to be changed by only a small amount. The I.F. system has a bandpass filter centered at 1500 MHz with a bandwidth of ± 300 MHz. Any change of the I.F. must thus fit within the 600 MHz I.F. bandwidth, leaving room to include the filterbank bandwidth. Hence, the minimum I.F. can be 1200 MHz plus 1/2 the filterbank bandwidth and the maximum I.F. can be 1800 MHz less 1/2 the filterbank bandwidth. Lines in opposite sidebands can be separated by at most 3600 MHz less 1/2 the filterbank bandwidth, or in the least by 2400 MHz plus 1/2 the filterbank bandwidth.

To adjust the I.F. bandwidth, the first I.F. synthesizer, which is normally set to 109.50000 MHz, must be changed. The equation for determining the synthesizer frequency is

$$f_{syn} = \frac{f_{IF} + 2442[MHz]}{36} , \tag{7.13}$$

where f_{IF} is the desired I.F. If the lines are in opposite sidebands,

$$f_{IF} = (f_u - f_\ell) / 2 . \tag{7.14}$$

where f_u is the upper sideband center frequency and f_ℓ is the lower sideband center frequency. This intermediate frequency must be entered into the control computer so that the local oscillator synthesizer frequency will be correctly calculated.

Note that if the two target lines are at the center of their respective sidebands, they will fall on top of each other in the resultant spectrum. To keep this from happening, offset the line rest frequencies from the band center. If the signal sideband center frequency is offset by an amount δ, the signal and image sideband lines will be separated by 2δ and will be symmetrically displaced about the center of the final spectrum.

To observe with a non-standard I.F., follow this procedure:

a)   Discuss your intentions with a staff member well in advance of the observations;

b)   Calculate the new synthesizer frequency according to the equations above. Make sure that you are not exceeding the 600 MHz bandwidth of the I.F. system.

c)   Ask the operator to dial the synthesizer frequency into the I.F. synthesizer that is nominally set to 109.5 MHz.

d)   Ask the operator to set the new I.F. into the control computer.

e)   If appropriate, offset the signal band center frequency from the line rest frequency to prevent overlap of signal and image lines.

f)   *Remember to have the synthesizer set back to 109.50000 MHz when the special observations are finished.*

Step (f) above is especially important to remember as the computer does not check the I.F. synthesizer for a correct setting. If you (or the next observer) resume standard observations and the synthesizer is not reset to 109.5 MHz, the band center will be offset from what you intend. In addition, we highly recommend that you check you special observing configuration on a strong test line before conducting program observations on weak lines.

EXAMPLE 7.9 CHANGING THE INTERMEDIATE FREQUENCY

Example 1:

Suppose a signal frequency of 116.200 GHz is desired but the local oscillator can be tuned only to 114.550 GHz, i.e., 1.65 GHz below signal instead of the usual 1.5 GHz required for normal upper sideband operation. Inserting 1650 MHz into equation 7.13, we get f_{syn} = 113.666667 MHz.

Example 2:

Suppose the following lines in different sidebands are to be observed simultaneously:

$$f_u = 220.39869 \text{ GHz } (^{13}CO, J=2-1)$$

$$f_l = 217.10494 \text{ GHz } (SiO, v=0, J=5-4)$$

These lines are separated by 3294 MHz and will be out of the spectral bandpass when using most of the narrow filter banks. From Equation 7.14, $f_{I.F.}$ = 1646.88 MHz. From Equation 7.13, f_{syn} = 113.579861 MHz. To separate the CO and SiO lines in the filter bank by 50 MHz, for example, add half that (25 MHz) to f_u to get 220.42369 GHz as the input frequency.

7.8 USING THE OFFSET OSCILLATOR

The 12 m I.F. system allows you to displace the frequency of one I.F. (polarization) channel relative to the other. This capability allows neighboring lines that would normally be out of the spectral bandpass to be observed simultaneously. Such an observing configuration can be advantageous for certain detection projects and when you need good relative calibration of two or more lines. In terms of observing time, the use of the offset oscillator offers no clear advantage since the two frequencies appear in only one polarization each. One could achieve approximately the same signal-to-noise per unit integration time by observing a single frequency at a time and averaging the two polarizations, and then tuning to the other line and observing it in both polarizations. Furthermore, use of the offset oscillator adds a considerable measure of complexity to the observations, so you should budget adequate check-out time.

The total separation of the main and offset sky frequencies must be within the I.F. bandpass of 600 MHz maximum for the same sideband, or 3600 MHz maximum for different sidebands. In addition, the mixer oscillators within the I.F. box must all be phase locked. For large offsets, the I.F. oscillators may not lock.

The offset frequencies are entered by changing the frequency of the first mixer oscillator in the I.F. box. Each of the two I.F. channels can be set independently. The mixer oscillators are driven by synthesizers in the control room. The output of the synthesizers are multiplied by 36 to give a nominal frequency of 3942 MHz. Thus, the synthesizers are usually set to 109.5 MHz. Under the standard configuration, one synthesizer is used to drive both I.F. channels. When offset frequencies are requested, a second synthesizer is installed to drive the other channel. For this reason, you must give the staff advance notice if you want to offset the second channel.

If the separation between the two frequencies is small (say <200 MHz), one of the observing frequencies can be entered into the control computer as the center frequency and the other frequency can be observed by offsetting one of the synthesizers. If the separation of the two frequencies is large, the center frequency entered into the computer should be midway between the two frequencies. The formula for computing the synthesizer frequency is in all cases

$$f_{syn} = \frac{3942 + (f_1 - f_o)}{36} \, MHz \, , \qquad (7.15)$$

where f_o is the center frequency entered into the control computer and f_1 is the frequency of the center of the spectrum.

The use of the offset oscillator can be tricky. Always set up a test observation on a known, strong line to check the operation of the system before starting the main observing program. Try to make the test setup as similar to the actual observing setup as possible (same sideband, etc.). Be sure to shift the frequencies of the synthesizers and local oscillator to see how the lines move in the band when frequency shifts are applied. *Finally, remember that the synthesizers must be returned to 109.5 MHz before resuming normal observing. No safeguard exists against using the wrong synthesizer setting.*

In summary, follow this procedure when using the offset oscillators:

a) Carefully consider whether the offset oscillators are really advantageous to your project. If you decide they are, give the 12 m staff notice well before your run begins.

b) Decide where the lines should fall in the band and use Equation (7.15) to calculate the synthesizer settings.

c) Give the synthesizer frequency to the operator who will set it in.

d)   Test the setup, or one similar to it, before program observations of weak lines.

e)   Set the synthesizers back to 109.50000 MHz when the special observing is completed.

EXAMPLE 7.10 OFFSET OSCILLATOR USE

Suppose that lines at 226.42326 GHz and 226.77126 GHz are to be observed simultaneously with the offset oscillators. Center up midway between the two frequencies, i.e., 226.59726 GHz. Put the line at 226.42326 GHz in I.F. 1. According to Equation 7.15, set the I.F. 1 synthesizer to

$$f_{syn}(\text{IF 1}) = [3942 + (226423.26 - 226597.26)] / 36$$
$$= 104.66667 \text{ MHz}.$$

Put the line at 226.77126 GHz in I.F. 2. Set the I.F. 2 synthesizer to

$$f_{syn}(\text{IF 2}) = [3942 + (226771.26 - 226597.260] / 36$$
$$= 114.33333 \text{ MHz}.$$

7.9 KEY TO THE ON-LINE STATUS MONITOR

The Spectral Line On-Line Status Monitor provides basic information about the status of the telescope and the observations that are underway. The observer should check the monitor frequently to see that the telescope and control system are configured as they should be. Figure 7.3 shows a sample monitor screen divided into several blocks. Definitions of the quantities in each block follows.

Lines 1 and 2

SCAN	:	Current scan number
SOURCE	:	Source name
HORIZON	:	Time to 15° elevation (rise or set)
LST	:	Current local sidereal time
UTC	:	Current coordinated universal time
DUT1	:	UT1-UTC time correction
YEAR	:	(top) year, (bottom) date
OBS	:	Observer's initials
OPR	:	Operator's initials

Line 3:

(Far right) Receiver identification code

Lines 4 - 8:

(Left side)

CURRENT	:	Apparent right ascension and declination of date
1950.0	:	RA and DEC at Equinox 1950
ECLIPTIC	:	Source ecliptic coordinates
OFFSET	:	RA and DEC offsets (RA in time units, DEC in angle units)

OK

```
 1 SCAN          SOURCE   HORIZON      LST       UTC      DUT1               1989    OBS   OPR
 2  6868       IRC+10216        3:50     11:18:51    17:04:33        -518   16 OCT  BCK   CDC
 3 RNAME:                                                        RCVR: 3.0MMSIS
 4                   R. A.         DECLINATION              AZIMUTH   ELEVATION
 5 CURRENT        9:47:24.1     13:19:39.      COMMAND    233:39             62:01
 6 1950.0         9:45:14.8     13:30:40.      ACTUAL     233:46:15.     62:00:21.
 7 GALACTIC    221.4466         45.0597        ERROR       -0:00:11.     0:00:04.
 8 OFFSET             0:00.0          0:00     OFFSET           1:45             0:10
 9
10 ATM    REFRT   T-AMB   F0     TC     TSYS            POINT    -0:15             0:10
11  1.13    52.0    7.38    50.7   400.0       637     +BEAM     2:00             0:00
12 HP      0:30
13        BW   CHANNEL  CONFIG    VEL      VLSR/VR         SB   LO   IF'S       FREQUENCY
14 F1   250     0    -255    SPS     -26.0       -18.53       2    1    100         115.27120
15 F2   500   256    -511                                          1500        1.92692068
16|BAD:                                                       FSO:    0.00      1.89480534
17          TOL   FOCUS   SP(V)   TP(V)   MODE   SCANS   SAMPLES              SEC    TIME
18 INPUT    0:10    53.1    0.00   0.3444          FS       1        4       30.0      2:00
19 ACTUAL   0:01    52.7    0.00   0.4899    UNIT=                          23.1
```

FIGURE 7.3 -- SPECTRAL LINE STATUS MONITOR SCREEN

(Right side)

COMMAND	:	Source azimuth and elevation (spherical coordinate conversion plus pointing corrections)
ACTUAL	:	Actual AZ/EL encoder readings
ERROR	:	Difference between COMMAND and ACTUAL
OFFSET	:	Total AZ/EL offsets (sum of pointing offsets plus subreflector beam throw)

Line 9

(will contain mapping offsets when a map)

Lines 10 - 11

ATM	:	Number of airmasses (1/sin(EL)) at current elevation
REFRT	:	Refraction coefficient for elevation refraction pointing correction (")
T(AMB)	:	Ambient Temperature (Celsius)
FO	:	Radial focus zero position (in mm)
TC	:	The calibration scale factor used for VANE/CHOPPER cal
TSYS	:	The system temperature. In the VANE or CHOPPER mode, this number is an average over the multiplexer of the values in the GAINS array. In the NO-CAL mode, this is the value entered by the observer to scale the data.
POINT	:	The Azimuth and Elevation pointing offsets, used to correct the telescope pointing model at a given sky position (MM:SS format)
+BEAM	:	The beam offset, relative to the electrical axis, of the subreflector. For position-switched observations, the subreflector is locked in this position.

Line 12

   HP :   Beam half-width at half-maximum (used as grid spacing for spectral line five-point maps)

Lines 13 - 16

   F1 BW :   The resolution of the filters in the first filter bank.

   F2 BW :   The resolution of the filters in the second filter bank.

   F1 CHANNEL :   The multiplexer channels used by the first filter bank.

   F2 CHANNEL :   The multiplexer channels used by the second filter bank.

   CONFIG :   A code describing the filter bank mode in use. The key to the codes are:

   VEL :   The center velocity of the source with respect to the Local Standard of Rest (LSR).

   VR/VLSR :   The projected motion of the LSR in the source direction. The total velocity correction applied to the synthesizer setting is VEL + VR/VLSR.

   SB :   The sideband code (see Chapter 3 for definitions).

   LO :   Multiplier factor for the Local Oscillator Source

   IF'S :   The top number is the LOCK-IF (the phase lock loop offset frequency) and the bottom number is the first I.F. of the system.

   FSO :   Frequency Switching Offset

   FREQUENCY :   The top number in the input center frequency in GHz. The bottom number is the 2 GHz synthesizer setting calculated by the computer. The synthesizer setting is calculated from the LO equation and includes the velocity correction.

Lines 17 - 19

TOL	:	Pointing tolerance mm:ss (top - input, bottom - actual pointing error, sum of AZ and EL)
FOCUS	:	Actual radial focus at the current elevation (top - input, bottom - actual)
SP(V)	:	Switched power voltage from analog backend (top - Ch. 1, bottom, Ch. 2)
TP(V)	:	Total power voltage from analog backend (top - Ch. 1, bottom - Ch. 2)
MODE	:	Observing mode (e.g., PS = Position-switching)
SCANS	:	Number of scans requested
SAMPLES	:	Number of continuum ON/OFF samples requested
SEC	:	(top - total sample time requested; bottom - sample time remaining
TIME	:	(top - total integration time requested for this scan; bottom - integration time remaining)

APPENDIX A

POINTING EQUATIONS FOR THE 12 M TELESCOPE

A.1 PRIMARY POINTING EQUATIONS

The basic pointing model in use at the 12 m is much the same as that described by Ulich (1980 *Int. J. Infrared & Millimeter Waves*, 2, 293); much of this discussion is excerpted from that paper.

The azimuth and elevation terms used to correct the nominal encoder positions are given by the equations

$$\Delta A = A_o + C_o \sec(E) + C' \tan(E) + I \tan(E) \sin(A - A_t) + A_{th} \sec(E) , \quad \text{(A.1)}$$

$$\Delta E = E_o + B_o \cos(E) + I \cos(A - A_t) + E_{th} + R_o f(E) \quad \text{(A.2)}$$

where ΔA is the total azimuth encoder correction,

A is the azimuth of the source,

A_o is the azimuth encoder zero offset,

C_o is the collimation error of the electromagnetic axis,

C' is the collimation error of the mount,

I is the tilt of the azimuth axis from the zenith,

A_t is the azimuth toward which the azimuth axis is tilted,

A_{th} is the observer-applied "thumbwheel" azimuth correction;

ΔE is the total elevation encoder correction,

E is the elevation of the source,

E_o is the elevation encoder zero offset

B_o is the gravitational flexure correction at the horizon,

E_{th} is the observer-applied "thumbwheel" elevation correction,

R_o is the weather dependent term in the atmospheric refraction correction (see below),

f(E)   is the elevation dependency of atmospheric refraction correction (see below).

The weather-dependent refraction coefficient, which is practically independent of wavelength, is given by

$$R_o - 21.36 P_T/T_K - 1.66 P_W/T_K + 103030 P_W/T_K^2, \qquad (A.3)$$

where P_T is the total surface barometric pressure (in Torr)

P_W is the partial pressure of water vapor at the surface (in Torr), and

T_K is the surface ambient air temperature (in K).

P_T must be measured by a barometer at the telescope site. P_W may be calculated from the expression

$$P_W - RH \cdot e_{sat}/100, \qquad (A.4)$$

where RH is the surface relative humidity (in %) and e_{sat} is the surface saturated water vapor pressure (Torr) and is given by

$$\log_{10}(e_{sat}) - 23.636 - 2948/T_K - 5.0 \log_{10}(T_K). \qquad (A.5)$$

As the 12 m does not have on-line digital weather instruments, R_o is not calculated or updated during observations. Instead, a typical value for R_o, usually 52", is fixed as a constant in the pointing code in the control system. Under certain weather conditions, this assumption could produce pointing errors of up to 10" at low elevations. The elevation dependency of the refraction correction is given by

$$f(E) = \frac{\cos(E)}{\sin(E) + 0.00175\ \tan(87.5° - E)} \tag{A.6}$$

This term is recomputed for each elevation of observation.

The 12 m staff determines the pointing coefficients on a 3 - 6 month interval. Pointing sources are observed at as many azimuth and elevation positions as possible and the corrections necessary to receive peak flux from the source are measured. The corrections are then input to a fitting program and the coefficients are determined. The total rms of the fit is typically 3-5".

A.2 SECONDARY POINTING CORRECTIONS

In addition to the primary pointing corrections, a set of secondary pointing corrections are used at the 12 m. In azimuth, these corrections are given by the equation

$$\Delta A_1 \cos(E) = A_1 \cos(E) + C_1, \tag{A.7}$$

where the left-hand side of the equation corresponds to the "cross-elevation" azimuth correction on the sky, given at a particular elevation by the azimuth "thumbwheel" correction. In elevation, the secondary correction is

$$\Delta E_1 = B_1 \cos(E) + E_1. \tag{A.8}$$

These terms correspond to the linear (in cosine(E)) terms in the principal pointing equations given above: A_1 is the supplemental azimuth encoder offset, C_1 the supplemental electromagnetic collimation error correction, B_1 is the supplemental gravitational bend error, and E_1 the supplemental elevation encoder offset.

Each of the four receiver bays have their own set of these secondary coefficients to compensate for slight differences between feed and mirror alignments in each bay. The intent of these pointing coefficients is to keep the required pointing offsets as close to zero as possible. The determination of these coefficients requires much less data than the main pointing equations and can thus be adjusted on a more frequent basis.

VISITOR INFORMATION

for the NRAO 12-Meter Millimeter-wave Telescope

NATIONAL RADIO ASTRONOMY OBSERVATORY
949 N. Cherry Avenue
Campus Building 65
Tucson, Arizona 85721-0655

Telephone: (602) 882-8250

May 1990

I. OBSERVING OPPORTUNITIES AND RESPONSIBILITIES

The NRAO 12-meter telescope is available, on a competitive basis, to all qualified scientists and students without regard to nationality or institutional affiliation. Financial support, in the form of travel funds and publication fees, is only provided to investigators employed by U.S. institutions. The procedure for submitting proposals to the NRAO and the mechanics of the evaluation and approval of these proposals are outlined below.

Once scheduled on the telescope, the principal investigator has the responsibility for proper supervision of all aspects of the observing program. This means, for example, that each principal investigator is responsible for obtaining all calibrations and other receiver/telescope parameters necessary for the reduction of his/her data--the NRAO assumes no responsibility in these matters. For this reason it is the policy of the NRAO that the principal investigator, or one of his/her collaborators, be in residence throughout the observations to supervise the program.

II. PROPOSALS FOR OBSERVATIONS

Scientific proposals for use of the 12-meter telescope should be submitted to

        Director
        National Radio Astronomy Observatory
        Edgemont Road
        Charlottesville, Virginia 22903-2475

The proposals, no more than 3 pages in length, should contain a thorough but succinct discussion of the scientific justification for the observations being proposed as well as a discussion of the sources to be observed, the manner in which the data will be taken, and an estimate of the telescope time needed to carry out the scientific program. A source list containing source identifications and coordinates should be included. For extensive lists (~50 objects), specific criteria defining the observing sample may be substituted. Special needs, instrumentation or software, should also be noted explicitly. A Cover Sheet on which this information can be summarized is appended; it should accompany each proposal.

Once received, the proposals are sent to five referees--established scientists with broad backgrounds and considerable experience in millimeter-wave astronomy but unaffiliated with the NRAO--who consider each of the proposals individually and advise the telescope scheduling committee as to whether the scientific merit of the proposal is sufficient for them to be allocated time on the telescope and, if so, with what restrictions. Using the referees' remarks as a guide, the observations are either scheduled or the proposal is returned to the proposer for further consideration or explanation.

Proposals are reviewed, and the telescope is scheduled, in trimesters as follows:

Proposals received by:

1 January	2nd trimester (1 April to 15 July)
1 July	3rd trimester (15 Sept to 31 Dec)
1 October	1st trimester (1 Jan to 31 March)

Some time exists in each of the trimesters for proposals requesting frequencies lower than 270 GHz. Such proposals, if received before the deadline for a trimester, will either be scheduled in that trimester or, if unsuccessful, will again be considered in the subsequent trimester. A proposal unsuccessful in two consecutive trimesters will be dropped from the telescope queue and the proposer notified. Proposals for high frequencies (above ~300 GHz) can be scheduled only in the first trimester (1 January to 31 March) for reasons of atmospheric transparency. The NRAO will take receipt of high frequency proposals at any time of the year and will referee the proposals upon receipt. Scheduling consideration will be deferred until the first trimester of the year. If a high frequency proposal cannot be scheduled on its first consideration, it will be dropped from the queue and the proposer notified.

III. LOGISTICS OF OBSERVING AT THE 12-METER

A. THE ARIZONA ORGANIZATION

The following individuals should be contacted when questions arise in their areas of responsibility:

Darrel Emerson	Site Director; responsible for general matters of operations policy.
Phil Jewell	Handles detailed scheduling of the telescope; provides scientific assistance for users; handles telescope calibration and pointing.
John Payne	Responsible for telescope electronics.
Pat Murphy/ Jeff Hagen	Real-time and analysis software.
Dennis Chase	Responsible for the telescope and all operations on the mountain.
Jennifer Neighbours	Responsible for 12-meter data archives and handling of observer data tape requests.
Bill Hale	Arranges transportation to Kitt Peak; handles shipping and receiving.
Nancy Clarke	Coordinates visitor travel in and out of Tucson as well as lodging in Tucson.

In addition, more general questions or comments pertaining to Observatory-wide activities (scheduling procedures, scientific or instrumentation priorities, inter-site relations) or specific criticisms of, or suggestions for, the Arizona Operations may be addressed to the director of the NRAO located at the Charlottesville, Virginia office.

B. TRAVEL

1. <u>To the NRAO Tucson Office</u> - It is most convenient for the observer arriving at the Tucson Airport to take the airport limousine to the NRAO office. The limousine, called the "Arizona Stagecoach", departs from a stand located about 50m on the right as one exits the main terminal building on the lower level. The limousine driver will know where Steward Observatory is on the UA Campus and will also know where the Kitt Peak National Observatory (KPNO) building is. The NRAO is found on the 5th floor of the Steward Observatory building directly across Cherry Avenue from the National Optical Astronomy Observatory (NOAO) office and KPNO.

2. <u>To Kitt Peak</u> - The 12-meter telescope on Kitt Peak is 55 miles from the NRAO Tucson office. Observers travel to and from the mountain with U.S. government GSA cars. The cars, one for each observing team, are available from Bill Hale at the Tucson office. The observer should contact Bill at least a week prior to his observations to arrange for the vehicle. A current driver's license is required for those driving GSA cars. Federal regulations require that GSA vehicles are to be used for official business only. They must not be taken to local tourist attractions or local restaurants. Because we have only two vehicles for observing teams, you are requested to return the vehicle to the downtown office as soon as your scheduled observing run is completed. The principal investigator should coordinate the return of the vehicle with Bill Hale sometime during his/her observing run.

C. HOUSING ON KITT PEAK

The NRAO maintains 7 rooms in 2 dormitory trailers immediately adjacent to the telescope for observers' lodging. Each room is provided with clean linens and towels. The observer is requested to make up his/her own bed upon arrival and later to return used linen, towels, and wash cloths to the clothes hamper at the conclusion of his/her visit. In addition to bedrooms, each trailer has a living area with a color television, a desk, and a small kitchen

for the observer's use. (Contact the telescope operator if you wish to use the stove in the trailer's kitchen; the gas to the stove is usually shut off.)

As at all NRAO facilities, spouses are welcome. The necessity for maintaining quiet in the vicinity of the dormitory trailers generally precludes children from using these facilities. Pets are not permitted in the trailers or on the mountain.

D. MEALS

Visitors using the 12-m telescope are welcome to use the cafeteria on the mountain operated by Kitt Peak National Observatory. Children, however, are not permitted to use the KPNO cafeteria.

The cafeteria is located at the summit of Kitt Peak approximately 2 miles from the 12-m telescope; observers usually drive their GSA cars to and from the cafeteria. Meal hours are as follows:

Breakfast	0600 - 0800
Lunch	1130 - 1300
Dinner	1700 - 1800
	(1630 - 1800 during winter months)

Note: At all the above hours a cook is present in the cafeteria to take orders. There is also a small kitchen in the KPNO dining area, open 24-hours a day, from which observers may obtain cold cuts, cereals, soup, etc. Observers may order a "night lunch" to be left in the cafeteria refrigerator, by filling out a form (found in the kitchenette area) *before 1300 each day.*

V-6

E. LAUNDRY

A free, self-service clothes washer and dryer are available for the observer's use in the recreation building on the summit.

F. RECREATION AND LEISURE

Adjacent to the KPNO cafeteria is a lounge with a color television, stereo, magazines and card tables. Pool tables, ping-pong tables, and shuffleboard are available for the observer's use at the recreation building. Candy bars, soft drinks, gum and cigarettes may be purchased either at the KPNO museum or in the recreation building.

G. CHARGES FOR ROOM AND BOARD

While observing on the 12-meter telescope all observers will be charged $30 per night. This charge will cover all meals (whether eaten or not), lodging, and mountain services. Of this $10 goes to the NRAO for lodging and $20 is allocated to KPNO for food and other services. No charge for meals will be made on the last day an observer is at the telescope if dinner is not eaten on the mountain. To facilitate accounting, a clipboard is provided at the entrance to the KPNO cafeteria. On the NRAO clipboard observers should sign for all meals when they are taken; the column for lodging also should be checked for each night's stay on the mountain. *All payments for meals and lodging are made to the NRAO.*

(1)   Payment may be made in cash, check, or credit card (VISA, MasterCard, Diner's Club or Carte Blanche) at the Cherry Avenue office between 0800 and 1530 Monday through Friday when you return the GSA car.

(2) You may sign an imprinted credit card form which is available at the 12-meter and we will fill in the amount for meals, lodging, and tapes, and send you a copy along with an itemized invoice which is marked "Paid".

(3) If you do not pay at the time of your visit, an invoice will be sent to you. Payment by check should be made promptly to the NRAO Fiscal Division in Socorro, New Mexico.

Note: *Observers from foreign countries and U.S. observers who will be away from their home institution for more than 30-60 days should make every effort to pay their bill at the Cherry Avenue office prior to departing.*

H. TELEPHONE

Long distance service is available for personal telephone calls through AT&T. All long distance calls should be recorded on the clip pad (located near each phone) unless charges are reversed or charged to a calling card/3rd number. You will be billed for all personal calls. To make an AT&T call, dial 9-1-A/C + 7-digit number.

I. LIBRARY

A modest library with recent issues of principal astronomical journals and books is located in the KPNO administration building adjacent to the 1.3 m telescope on the mountain summit.

IV. OBSERVING

INSTRUMENTATION/SOFTWARE: Visitors who require special hardware or software configurations should consult us (Electronics: John Payne; Computer Software: Pat Murphy/Jeff Hagen) well in advance of their observations.

PROPRIETY: Observers are scheduled on the telescope with the understanding that they are to pursue only the program described in their observing request. Since we have many observers from various institutions working on related programs, we require that any observer wishing to change their program or to exchange time with other observers, do so only with the consent of the Site Director.

OBSERVER COMMENTS: In an effort to improve our facilities and service, we request that observers completing their observations provide us with a brief summary of their experiences, remarks about any difficulties they encountered, or suggestions for improvements. These remarks are not normally kept confidential.

USER MANUALS: Four User Manuals are available which describe in detail the telescope control, data acquisition and data reduction programs that are implemented at the 12-meter.

1. User's Manual for the NRAO 12-m Telescope - Describes observing setup, source catalog, etc.

2. Spectral Analysis System - Spectral line reduction program and procedures.

3. CONDAR: Continuum Data Analysis - Off-line reduction of continuum data: programs and procedures.

4. Continuum Mapping with the 12-m Telescope - Observing strategies and data analysis for beam-switched maps.

Copies of these manuals can be found at the telescope and at the Tucson office.

OBSERVER ASSISTANCE: Phil Jewell is the NRAO "Friend of the 12-m Telescope."
At any time prior to, during, or after the observations, specific questions should be
referred to Phil. Since telescope time at the 12-meter is so much in demand,
observers will want to observe as efficiently as possible. A discussion with Phil prior
to the observations may enable one to optimize the observations and make the most
effective use of the time scheduled.

GETTING YOUR DATA ON TAPE: The raw data may be saved on a Forth binary
tape that is available at the end of your observing run. The charge for each tape
supplied to you by NRAO is $11.00. Analysis system (VAX) tapes require some time
to make and cannot normally be produced on the mountain. They are made on the
downtown computer after the observing run. More than one file can be written on
a tape depending on the size and density requested. All export tapes will be FITS
format unless otherwise requested. The tapes will be mailed to you, at a cost of
$13.00 each. You will receive a credit or a refund if the tape is returned to NRAO.
Please complete a Data Tape Request Form before leaving the telescope.

V. PUBLICATION OF RESULTS

PUBLICATION OBLIGATION: The results obtained by NRAO staff and visitors are
expected to appear in publication. Observers are urged to analyze their data and to
publish their results with minimum delay. The accumulation of masses of
unpublished data may be a detrimental factor in future considerations of requests for
observing time.

ACKNOWLEDGMENT: Whenever a significant portion of research was done, or
observational material taken, at the NRAO, we request that the author include the
following footnote in the text where the Observatory is mentioned:

*The National Radio Astronomy Observatory is operated by Associated Universities,
Inc., under cooperative agreement with the National Science Foundation.*

VI. NRAO TUCSON OFFICE

<u>VISITOR FACILITIES</u>: Office space has been set aside specifically for the use of visitors in the NRAO downtown office; we encourage telescope users to spend time with us prior to or upon completion of their observations. Visitors will have access to a VAX-11/750 Computer identical to that on the mountain for data reduction at a more considered pace. The downtown computer is equipped with a laser graphics printer so that one can produce publication quality spectra and maps. In addition, visitors have access to a modest library in the NRAO office as well as to the very extensive Steward Observatory library.

<u>INFORMATION SHARING</u>: The Arizona NRAO staff is very interested in the scientific results of the research that they support. Feedback, positive or negative, is desirable because it helps assure that our efforts are consonant with your goals. To this end we would particularly appreciate it if you would summarize your work in a brief and very informal talk, a "brown-bag" lunchtime talk, while you are with us in Tucson. Let any of us know if you would be willing to give such a presentation.

VII. NRAO REIMBURSEMENTS

A. TRAVEL REIMBURSEMENT:

The NRAO will partially reimburse travel to and from the 12-meter telescope under the following conditions:

(1) A reimbursement request must be submitted within 30 days of the completion of travel.

(2) The NRAO will reimburse the cost of actual round-trip fare (not to exceed the normal coach airfare) less a deductible. The deductible is $150 or $0.25*$ ($300 + air fare) whichever is greater.

(3) Original ticket receipts must be submitted to the NRAO when reimbursement is claimed.

(4) Only travel originating within the United States or Puerto Rico will be considered for reimbursement.

(5) Reimbursement will be made only to supporting institutions and organizations -- not to an individual.

This policy is limited to persons affiliated with U.S. institutions. Reimbursement will be provided for one round-trip per person. As a rule, the reimbursement can be provided to only one observer per observing program, although reimbursement can often be made to a second person. If a second person desires travel reimbursement, he/she should petition the Arizona Site Director; the decision will be based on need and the current budget status of the Observatory. The secretary can provide the observer with a travel authorization form which the observer should send, together with the original air ticket stub, to the NRAO Fiscal Division, Post Office Box O, in Socorro, New Mexico 87801. Visitors should expect to pay for all lodging and meals connected with their visit -- the NRAO does not reimburse these charges.

B. NRAO SUPPORT FOR PAGE CHARGES:

Users of the NRAO telescopes and facilities are encouraged to publish their scientific results in a timely manner. To this end the NRAO provides partial page charge support to scientists at U.S. educational institutions. When requested, the NRAO will pay the larger of the following:

1. One third (33%) of the page charges of papers reporting original observations made with NRAO instruments when at least one of the authors is eligible for such support.

2. 100% of the page charges prorated by the fraction of authors who are NRAO staff members.

(Further details can be found in the NRAO Newsletter of October 1988.)

The specific procedure to be followed to obtain page charge support is:

1. At the time of submission, please send four publication copies of the paper to the NRAO Librarian, Charlottesville, Virginia, indicating the journal to which the paper has been submitted. One copy is for the Director's office; three copies are for the libraries. If you wish to have the preprint placed at the 12 m telescope, send one additional copy and indicate that it is for the telescope. The Observatory does not desire to referee visitors' publications prior to submittal.

2. At the time of acceptance for publication, please notify the Librarian in Charlottesville of the proposed date of publication and apportionment of page charges, so that the necessary purchase orders can be initiated.

3. All other scientific and administrative communications should be kept between the authors and the journals.

Attached Figures:

1. Map of Tucson showing route from the airport to the NRAO downtown office.

2. Map of southeast Arizona showing route from Tucson to Kitt Peak.

3. Map of Kitt Peak showing mountain facilities.

4. Map of 12-m site.

    The following forms are appended when the *Visitor Guide* is printed as a stand-alone document; these forms also appear in the *Preface* to the *User's Manual*.

5. Observing Application Cover Sheet

6. Data Tape Request Form

7. Observer's Comment Sheet

GRANT RD

MIRACLE MILE STRIP

NATIONAL RADIO
ASTRONOMY
OBSERVATORY

NOAO

SPEEDWAY   BLVD

2ND ST

PARK AVE

6TH ST

UNIVERSITY
OF
ARIZONA

STONE AVE

CONGRESS W   SOTO   BROADWAY

CHERRY AVE

CAMPBELL AVE

10

-N-

6TH AVE

KINO PARKWAY

TUCSON, ARIZONA

MILES
0   1   2

0   1   2   3
KILOMETERS

TO
KITT PEAK

86   AJO WAY

BENSON HIGHWAY

10   TO LAS CRUCES

19   89

PARK AVE

CAMPBELL AVENUE

VALENCIA   BLVD   RD

TUCSON

TUCSON
INTERNATIONAL
AIRPORT

TERMINAL   LIMO

TO
TUCSON
BLVD
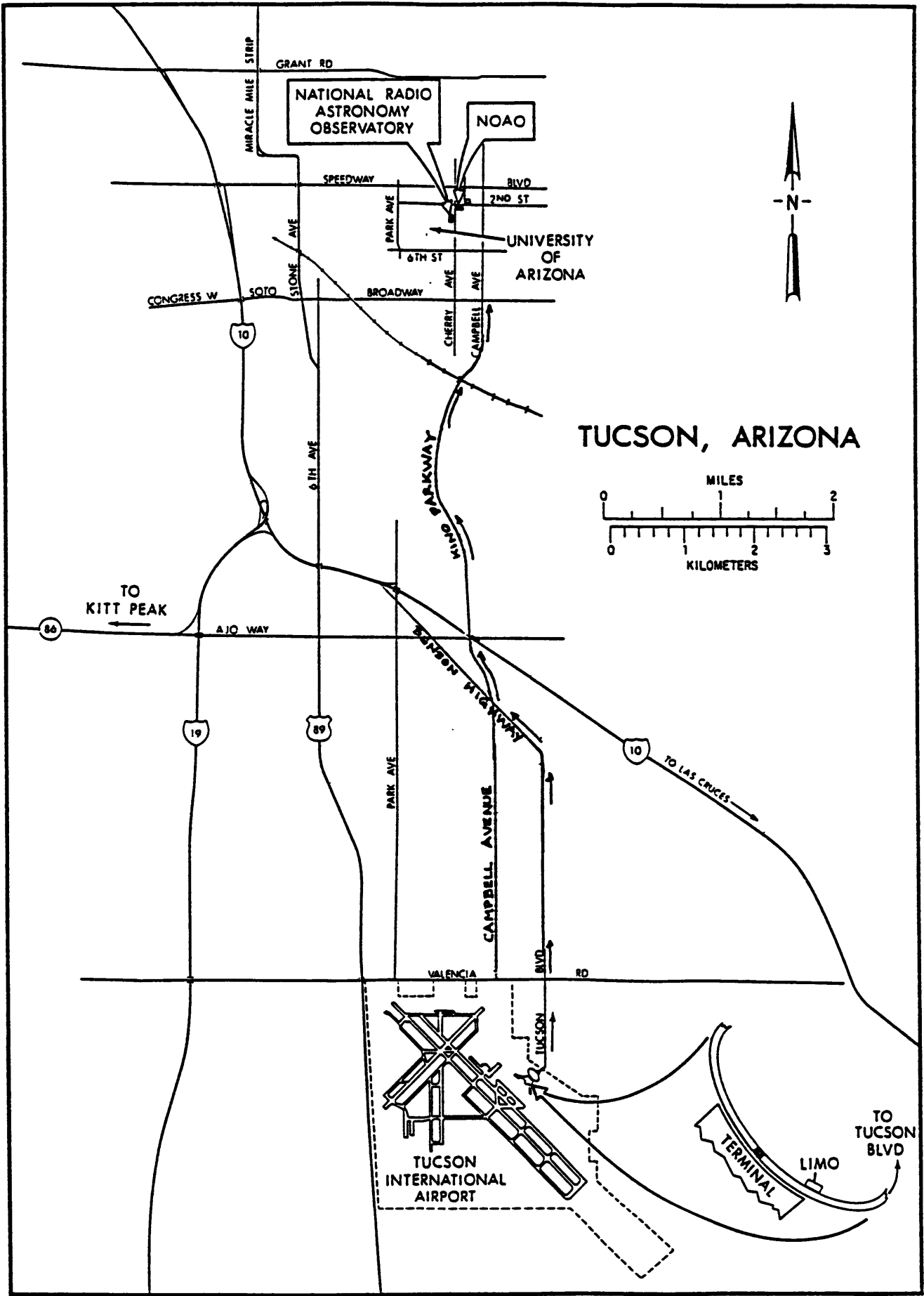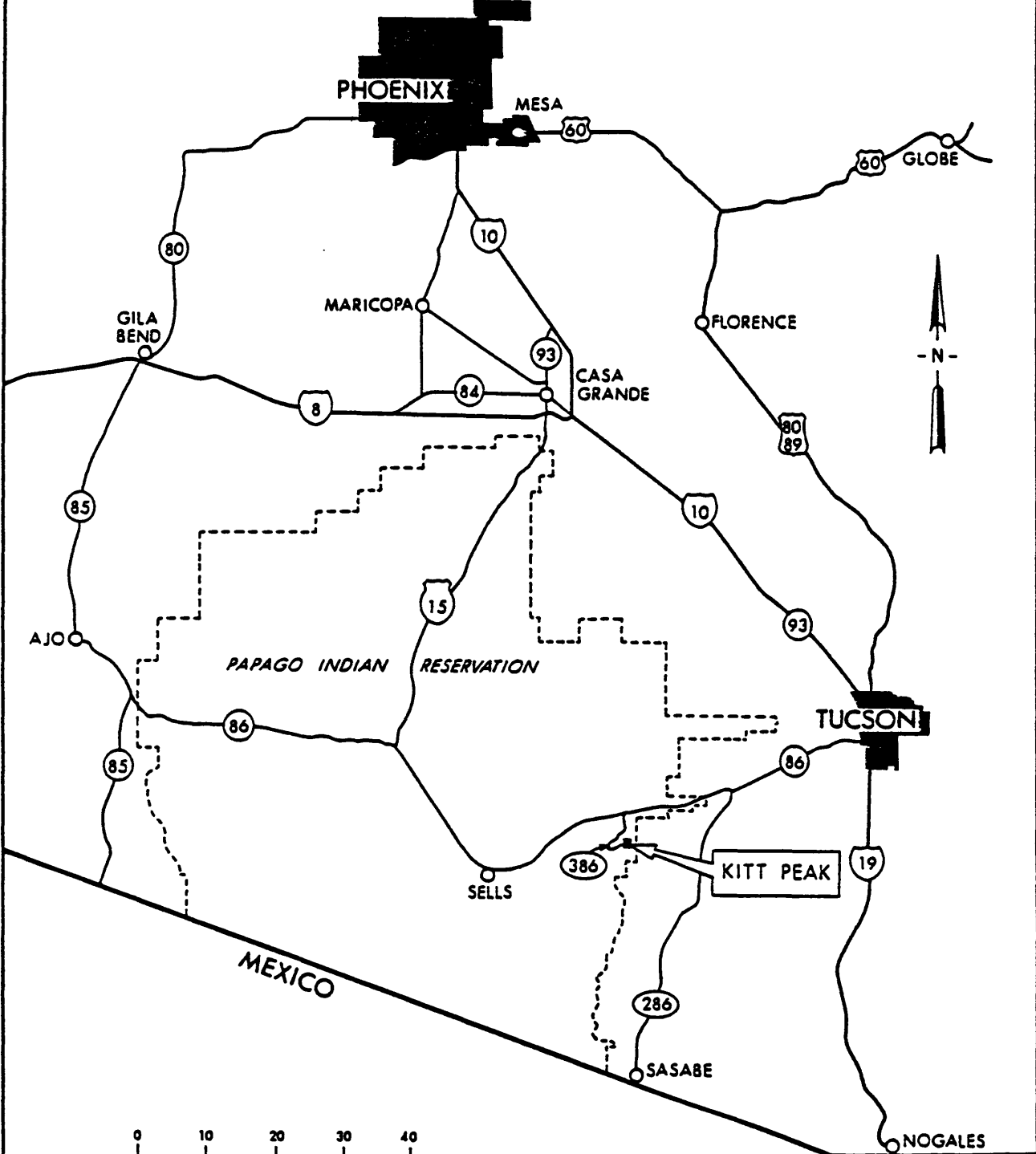
KITT PEAK, ARIZONA

Mayall 4-Meter Telescope

90" Telescope
20" Telescope ⎫ University of Arizona
36" Telescope ⎭ Steward Observatory

0 ——————————————— 1/4 MILE
SCALE

apx. 1 mile

12" Telescope

-N-

NRAO
12 m RADIO
TELESCOPE

VISITOR CENTER

ADMINISTRATION
BUILDING   50" Telescope

QUONSET HUT
(Laundry)

McMath
Solar Telescope

McGraw-Hill
52" Telescope

EMPLOYEES'
DINING HALL

36" Telescope   84" Telescope

Solar
Vacuum Telescope

16" Telescope   36" Telescope

16" Telescope

386   TO
TUCSON

Pima
Tower

Weather Tower

To McGraw-Hill Observatory

Water Tank

Pump House

Dome Entrance

Parking

(Visitor's Residence)

Trailer #2

Parking

Trailer #1

(Visitor's Residence)

Parking

Dome

Operators' Dorm

Loading Dock

Lab

W

N

12m SITE LAYOUT

Access Road From AZ-386
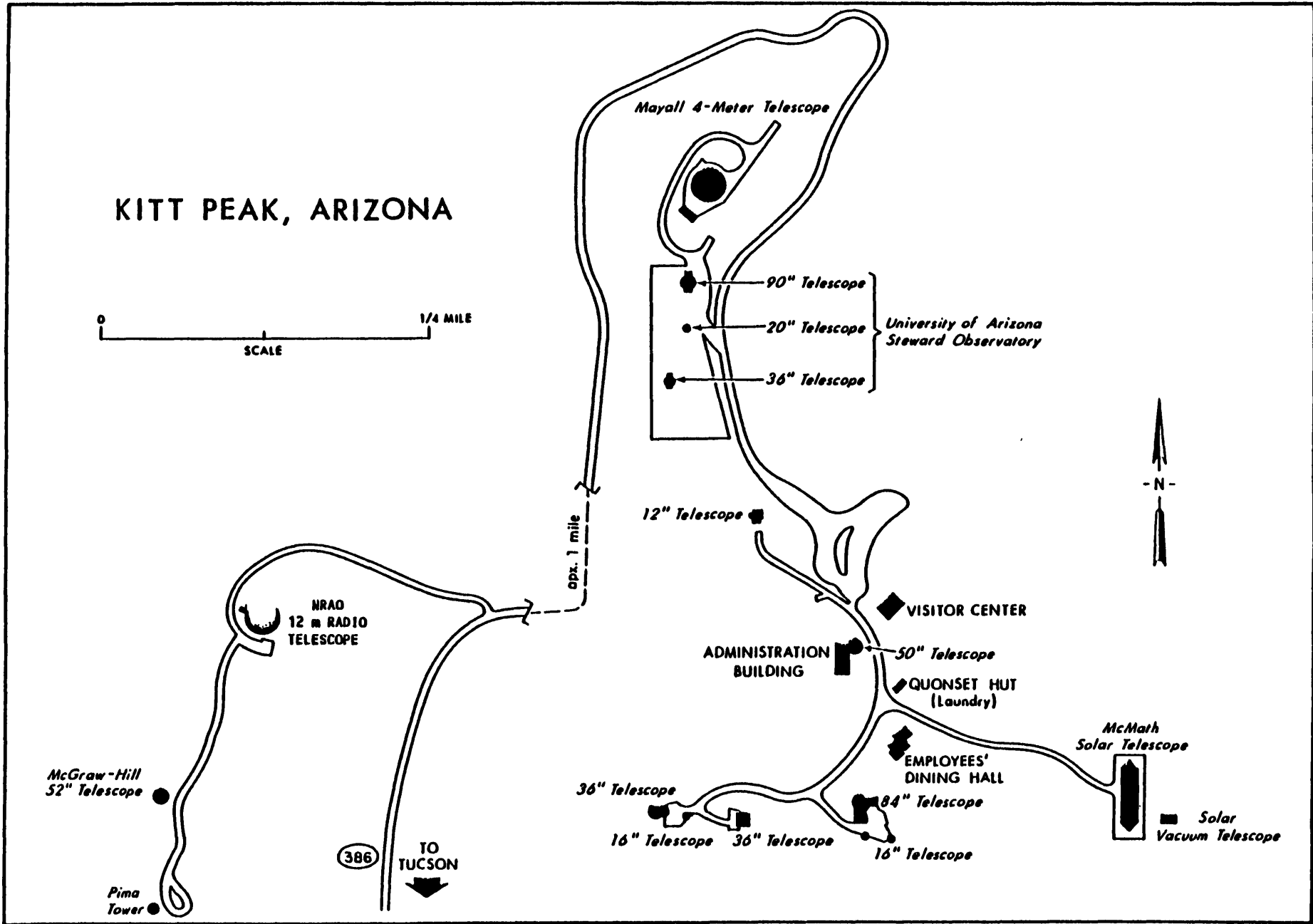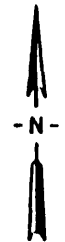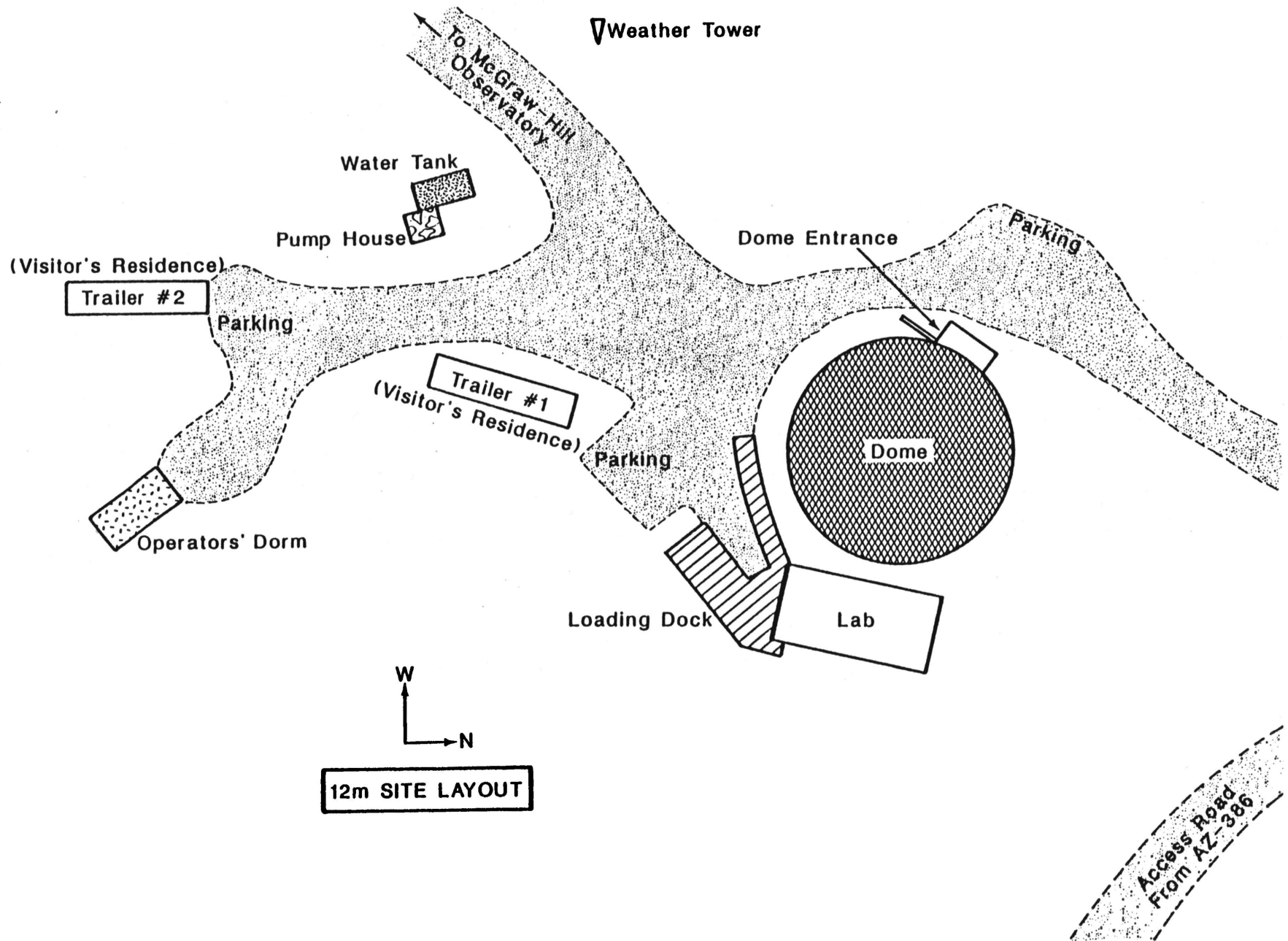
EQUIPMENT AND CALIBRATION STATUS

for the NRAO 12 m Telescope

July 1990

Edited by

P. R. Jewell

I. INTRODUCTION

This report summarizes the current status of equipment and system calibration at the NRAO 12 m telescope. The following two sections give some general comments about equipment and calibration; the figure captions give detailed information about each of the graphs displayed. This report will be updated on a regular basis as the equipment and system calibration status changes. Before using the information contained in this report, check with the NRAO Tucson staff to see that you have the most recent version.

II. RECEIVER STATUS

The receivers available for general use at the 12 m are listed in Table 1, *The NRAO 12 m Front-End Box Status Sheet.* For each receiver, the table lists the frequency coverage, the amplifier type, a typical receiver noise temperature, the continuum sensitivity for each polarization channel, the bandwidth, the feed type, polarization of the feed(s), the calibration system, any remarks, and the engineer in charge of maintaining the receiver.

Graphs of the receiver noise temperatures as a function of frequency are presented in Figures 1 - 5 for five receivers. Because the majority of observations done on the 12 m are of spectral lines, the noise temperatures are referred to the single sideband (SSB) scale. The 1.3 mm SIS receiver and all Schottky receivers are, in fact, double sideband (DSB) systems with no inherent sideband rejection. The noise temperatures are measured on the DSB scale. We assume, with some confidence, that the gains of the image and signal sidebands are equal and thus derive the SSB temperatures by doubling the DSB temperatures. The 90 - 115 GHz SIS receiver can be tuned to have a single sideband or double sideband response. Continuum observations are usually performed as DSB observations. Continuum sensitivity is

often determined by low frequency excess noise rather than the noise temperature, however. Continuum sensitivities are listed in Table 1.

Some of the noise temperatures were measured in the laboratory and some were measured on the telescope. The laboratory measurements were made through most or all of the receiver optics (in particular, the lens-corrected feed system and L.O. diplexer), and are representative of the values an observer will obtain with a hot/cold load measurement on the telescope. Measurements made on the telescope are made by holding hot and cold loads above the window to the receiver box.

Note that the numbers plotted are *receiver* temperatures, not *system* temperatures. The effective system temperature is defined as

$$T_{sys}^{*} = \frac{T_{Rx}[SSB] + (1 + G_i/G_s) T_A[sky]}{\eta_l \eta_{fss} \exp(-\tau)} \qquad (1)$$

where G_i and G_s are the image and signal sideband gains, respectively, T_{Rx} is the measured receiver temperature using broadband hot and cold loads, η_l and η_{fss} are the rear and forward spillover efficiencies (see § III), and τ is the atmospheric optical depth at the position of the observation. $T_A[sky]$ is the antenna temperature of the sky, defined as

$$T_A[sky] = \eta_l T_M[1 - \exp(-\tau)] + (1 - \eta_l)T_{spill} + \eta_l T_{bg}\exp(-\tau). \qquad (2)$$

In the equation above, G_i/G_s is 1 for a double sideband tuning and 0 for a single sideband tuning, T_M is the mean atmospheric temperature, T_{spill} is the spillover temperature, and T_{bg} is the cosmic background temperature. Additional information about the receivers is given in the Figure Captions.

All 12 m coherent receivers use Gunn oscillators as local oscillator (L.O.) sources. Although most of the Gunns have broad tuning ranges, observing programs utilizing a wide range of frequencies may require more than one Gunn oscillator. We have included the coverage of the L.O. sources for the 3 mm, 1.2 mm, and 870 μm bands.

Note that the 1.2 mm receivers (200 - 310 GHz) use a tripler and the 330 - 360 GHz receiver uses a quadrupler.

A calibration curve for the throw of the nutating subreflector is also included. This curve will change if the control electronics are adjusted. The nutating subreflector is used for beam switched observations in both spectral line and continuum modes. This curve will be of use in varying the throw of the subreflector. The range of the throw is 0 - 6 arc minutes and is always switched in azimuth.

III. CALIBRATION STATUS

This section gives efficiency and calibration parameters for the 12 m telescope as they are presently understood. The aperture efficiencies and the corrected beam efficiencies have been measured at several standard frequencies. From these measurements, we have parameterized the telescope in terms of Ruze theory. All efficiency measurements were made at the Cassegrain focus and include the losses of the feed and all optics. The Ruze parameters thus include the net effect of the entire telescope and receiving system, not just the primary reflector. Several of the graphs are not based on direct measurement but are inferred from Ruze theory. These curves are identified in the figure captions.

These calibration factors are intended for "first order" calibration of 12 m data and as an indication of system sensitivity in assessing the feasibility of observing programs. Observers requiring precise calibration should make calibration measurements at their specific observing frequencies. The NRAO staff will be glad to assist in these measurements. The calibration parameters of the telescope are listed in the following table.

12 M TELESCOPE PARAMETERS

Dish diameter	D	12.0 m
RMS surface accuracy	σ	77-85 μm
Infinite wavelength aperture efficiency	η_{AO}	0.52
Surface deviation correlation size	c_σ	28 cm
Feed taper function	κ	1.22
Forward Spillover Efficiency	η_{fss}	0.75
Rear spillover and blockage efficiency	η_l	
(70 - 310 GHz receivers)		0.85
(330 - 360 GHz receiver)		0.78

Note: *A range of values are given for the RMS surface accuracy. The aperture efficiency is fit best by the larger RMS values while the beam efficiencies are fit best by the smaller RMS values. This is probably the result of the astigmatism associated with the primary reflector. The astigmatism tends to broaden the beam which will degrade the response to a point source more than for an extended source.*

The numbers given above are appropriate for the conventional hyperbolic subreflector. An error-correcting subreflector is sometimes in use which improves the efficiency of the antenna. Consult the staff for the latest numbers.

A final figure included in this report shows how the 230 GHz gain of the telescope to a point source varies with elevation angle. For extended sources, the fall-off in gain may not be as sharp as for a point source. The measurements and the estimated best fit curve are plotted.

Additional discussion of antenna calibration theory is given in Baars (1973, *IEEE Trans. Ant. Prop.*, AP-21, 461), Kraus (1986, *Radio Astronomy*, Cygnus-Quasar Books), and Kutner and Ulich (1981, *Ap. J.*, 250, 341).

FIGURE CAPTIONS

Figure 1   The single sideband receiver noise temperatures for the 1.3 mm SIS receiver. As this receiver is new at this writing (July 1990), the noise temperature measurements were made in a laboratory test assembly. All other receivers were measured in the telescope receiver chassis and include all receiver optics.

Figure 2   The SSB receiver noise temperatures for the 200 - 240 GHz mixers in the 1 mm receiver package. The 1 mm receiver box contains 4 dual polarization mixer sets (8 mixers in all) covering the range 200 - 360 GHz.

Figure 3   The SSB receiver noise temperatures for the 240 - 270 GHz Schottky mixer pair of the 1 mm receiver package.

Figure 4   The SSB receiver noise temperature for the 270 - 310 GHz Schottky mixer pair of the 1 mm receiver package.

Figure 5   The SSB receiver noise temperature for the 330-360 GHz Schottky mixer pair of the 1 mm receiver package.

Figure 6   The L.O. frequency range of the Gunn oscillators available for use with the 3 mm receivers. The I.F. of 1.5 GHz allows signal sideband observations to extend another 1.5 GHz on either end of the plotted bars.

Figure 7   The L.O. frequency range of the Gunn oscillators (and tripler) available
for use with the 1.2 mm receivers (200 -270 GHz).

Figure 8   The L.O. frequency range of the Gunn oscillators (and quadrupler)
available for use with the 270 - 310 GHz and the 330 - 360 GHz
receivers.

Figure 9   The calibration curve for the subreflector control dial as a function of
measured beam throw on the sky. This curve is subject to change if the
electronics are adjusted.

Figure 10   The conventional aperture efficiency, defined by the relation

$$\eta_A - \eta_{AO} \exp(-\delta^2),   \tag{3}$$

where

$$\delta - \frac{4\pi\sigma}{\lambda} .   \tag{4}$$

Representative measurements of this quantity at several frequencies
are plotted.

Figure 11   The conventional main beam efficiency, defined by the relation

$$\eta_M - \eta_A \frac{A_p \Omega_M}{\lambda^2} ,   \tag{5}$$

where

$$\Omega_M - 1.13 \theta_M^2 ,   \tag{6}$$

and A_p is the physical aperture (113 m²). η_M was derived from the aperture efficiency and the theoretical FWHP beamwidth.

Figure 12   The main diffraction beamwidth (FWHM). This curve is plotted from the standard relation,

$$\theta_M - \kappa \frac{\lambda}{D} \, ,$$ (7)

At high frequencies, the azimuth beamwidth is broadened beyond its theoretical width by the astigmatism of the primary reflector.

Figure 13   Janskys per Kelvin of T_A. This conversion factor is appropriate for converting point source antenna temperatures (standard calibration) to flux densities. If the source is extended relative to the beam, a beam resolution factor must be applied. *Do not use this conversion for spectral line data calibrated by chopper wheel or vane.* This curve is plotted from the relation

$$\frac{S_\nu}{T_A} - \frac{1}{\eta_A} \frac{2k}{A_p} \, .$$ (8)

Figure 14   Janskys per Kelvin of T_R^*. This quantity can be used to convert point source antenna temperatures *measured on the vane or chopper wheel calibration scale, T_R^*, to flux densities.* Measurements of this quantity at three different frequencies are plotted on the graph. This factor is given by the relation

$$\frac{S_\nu}{T_R^*} - \frac{\eta_l \eta_{fss}}{\eta_A} \frac{2k}{A_p} \, .$$ (9)

S-8

Figure 15   The corrected beam efficiency. This quantity can be used to convert
              a $T_R{}^*$ temperature to a main beam brightness temperature, provided
              that the source is not extended beyond the main beam. The corrected
              beam efficiency is the fraction of forward power in the main
              diffraction beam relative to the total forward power in the main beam
              plus error beam. The quantity is given by the relation

$$\eta_M^* - \left[1 + \frac{A_E \theta_E^2}{A_M \theta_M^2} \right]^{-1} , \tag{10}$$

              where A_E and A_M are the amplitudes of the error and main beams,
              respectively, and θ_E and θ_M are the FWHM of the error and main
              beams, respectively.

Figure 16   The FWHM of the error beam. This quantity has been measured at
              only one frequency; the plotted curve should be used only as a rough
              indicator of the extent of the error beam. The theoretical relation on
              which the curve was generated is given by

$$\theta_E - 2(\ln 2)^{1/2} \frac{\lambda}{\pi c_\sigma} , \tag{11}$$

              where c_σ is the correlation scale size of surface deviations.

Figure 17   The amplitude of the error beam relative to the amplitude of the main
              beam. As with the width of the error beam, this quantity is based on
              a theoretical estimate rather than hard measurement; use the curve
              only as a rough indicator of the relative amplitudes of the main and

error beams. The theoretical relation on which the curve was generated is given by

$$\frac{A_E}{A_M} = \frac{1}{\eta_{AO}} \left[\frac{2c_\sigma}{D}\right]^2 \{\exp(\delta^2) - 1\}, \tag{12}$$

where all the parameters have been defined above.

Figure 18   The variation of antenna gain with elevation angle at a wavelength of 1.3 mm. The data points and a fitted curve are plotted. This curve is valid only for point sources.

TABLE 1
NRAO 12 M FRONT END BOX STATUS
July 1990

APPLICABLE TELESCOPE	FREQUENCY (GHz)	AMPLIFIER TYPE	RECEIVER TEMPERATURE (KELVIN)	CONTINUUM SENSITIVITY (JANSKY √SEC)	3 dB BANDWIDTH (MHz)	FEED TYPE	POLARIZATION	CALIBRATION VALUE	SWITCHING SYSTEM	REMARKS	PERSON(S) IN CHARGE
12 M	90-115	SIS	125 SSB	1.0	600	HORN-LENS	DUAL-LINEAR	6 K	NUTATING SUBREFLECTOR	HYBRID CRYOSTAT	LAMB
12 M	200-250	SIS	150 SSB	TO BE MEASURED	600	HORN-LENS	DUAL-LINEAR	N/A	NUTATING SUBREFLECTOR	CLOSED-CYCLE CRYOSTAT	LAMB
12 M	200-240	COOLED SCHOTTKY	500 SSB	7.0	600	HORN-LENS	DUAL-LINEAR	N/A	NUTATING SUBREFLECTOR		LAMB
12 M	220-240	COOLED SCHOTTKY	600 SSB	NOT MEASURED	600	HORN-LENS	DUAL-LINEAR	N/A	NUTATING SUBREFLECTOR	8-BEAM RECEIVER	PAYNE
12 M	240-270	COOLED SCHOTTKY	900-1200 SSB	NOT MEASURED	600	HORN-LENS	DUAL-LINEAR	N/A	NUTATING SUBREFLECTOR		LAMB
12 M	270-305	COOLED SCHOTTKY	1100-1600 SSB	NOT MEASURED	600	HORN-LENS	DUAL-LINEAR	N/A	NUTATING SUBREFLECTOR		LAMB
12 M	330-360	COOLED SCHOTTKY	1800-2200 SSB	NOT MEASURED	600	HORN-LENS	DUAL-LINEAR	N/A	NUTATING SUBREFLECTOR		LAMB
12 M	5	ROOM TEMP. HEMT	100 SSB	N/A	100	HELIX	CIRCULAR	N/A	NONE	FOR VLBI USE	PERFETTO
12 M	38	ROOM TEMP. HEMT	200 SSB	N/A	50 kHz	HORN-LENS	CIRCULAR	N/A	NONE	HOLOGRAPHY RECEIVER	PERFETTO

200 — 250 GHz SIS Receiver Noise Temperatures
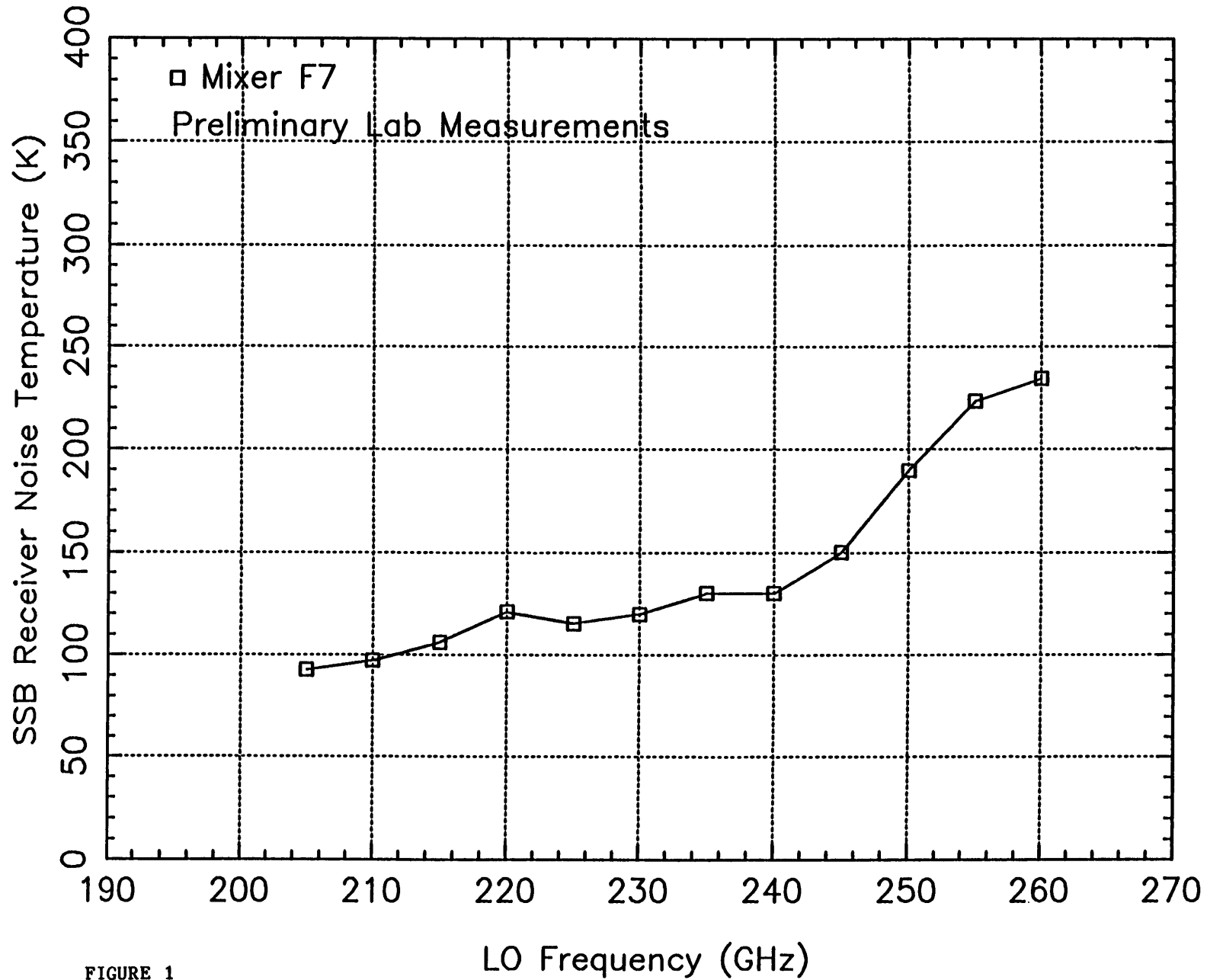
FIGURE 1

200 – 240 GHz Schottky Receiver Noise Temperatures

□ Polarization 1 (Mixer 3)
△ Polarization 2 (Mixer 17)
Measured 1987 Sep.
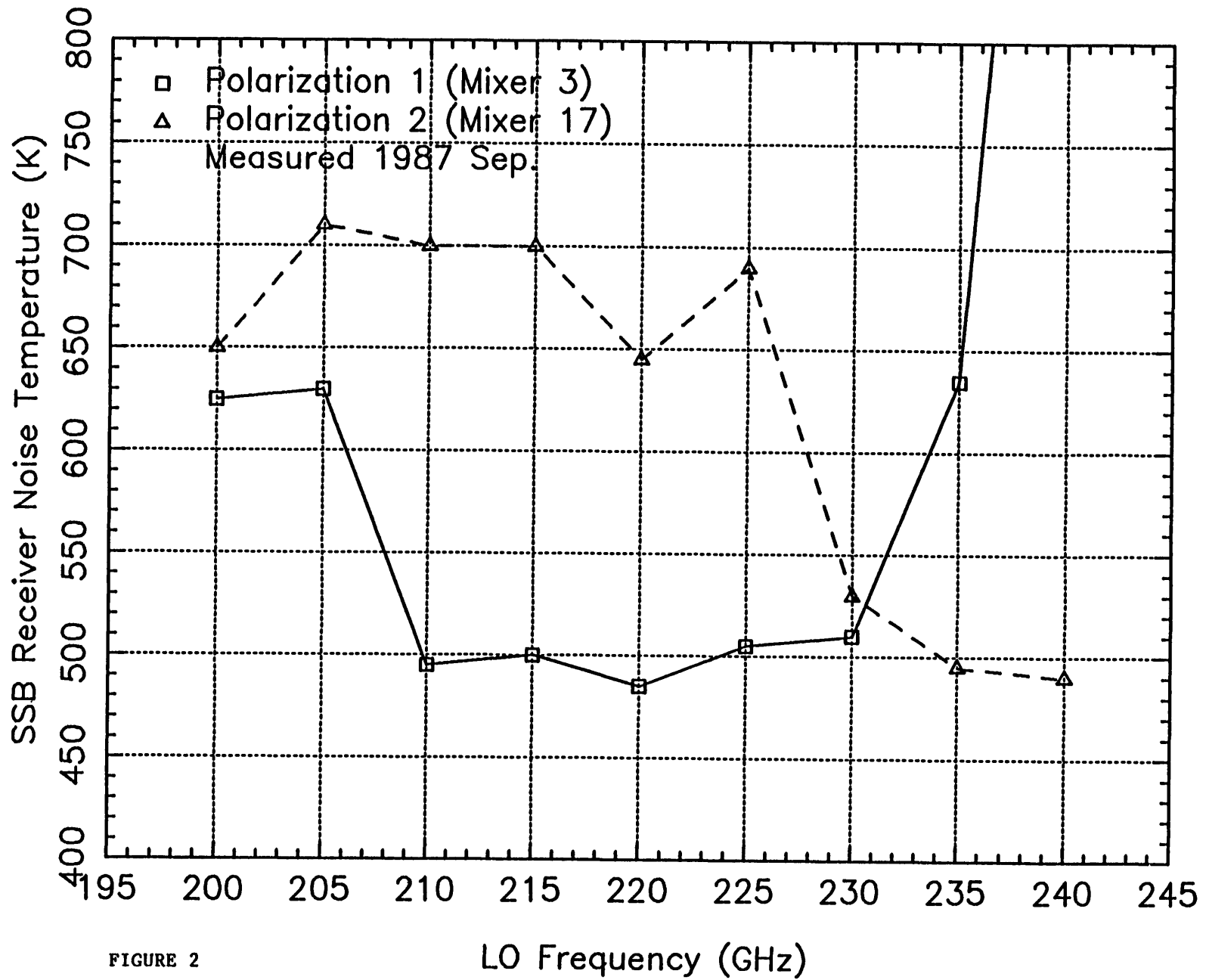
FIGURE 2

240 — 270 GHz Schottky Receiver Noise Temperatures
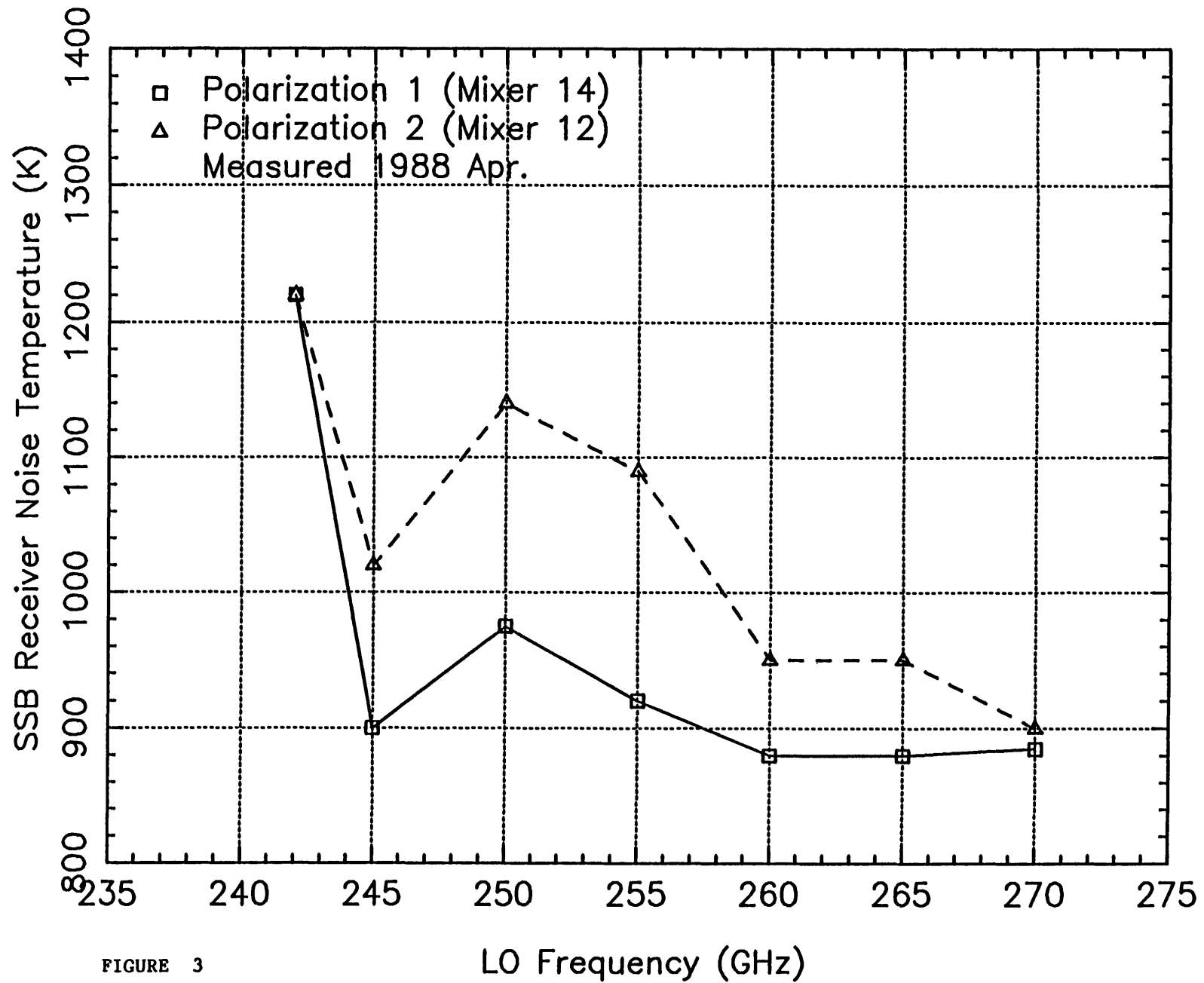
FIGURE 3
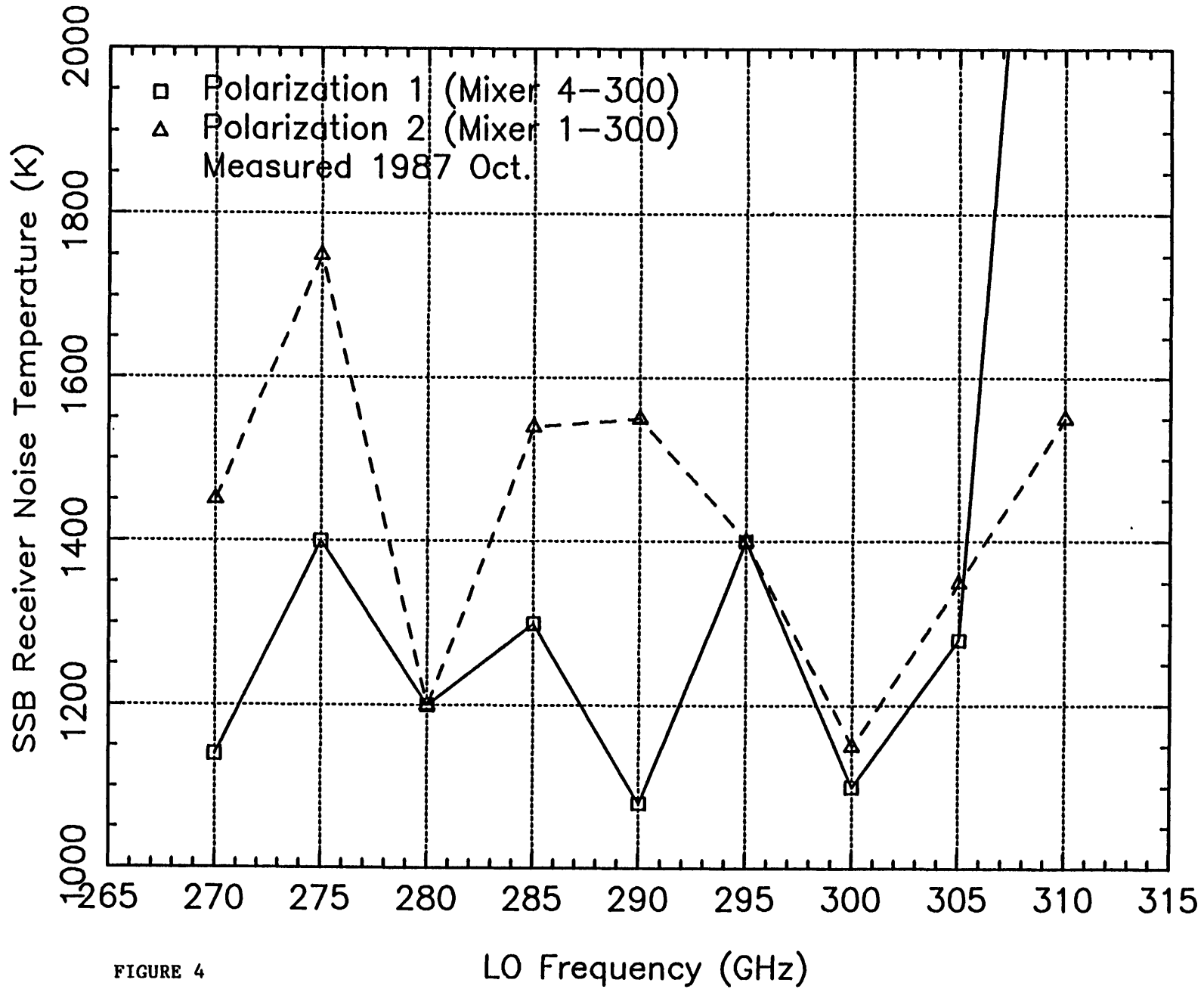
FIGURE 4

330 – 360 GHz Schottky Receiver Noise Temperatures

□ Polarization 1 (Mixer 67)
△ Polarization 2 (Mixer 61)
Measured 1989 January

X-axis: LO Frequency (GHz)
Y-axis: SSB Receiver Noise Temperature (K)

FIGURE 5

#2H27

#2H20   (SIS RX)

#2H23

#2H30

L.O. Frequency
70 75 80 85 90 95 100 105 110 115 120 (GHz)

FIGURE 6

#H53

#H40

#166   #156

#149   #167

#119   (8FEED RX)   #140 →

#129   #168

#118   #150

L.O. FREQUENCY
(GHz)

196 200 204 208 212 216 220 224 228 232 236 240 244 248 252 256 260 264 268 272 276 280

LOW FREQUENCY ← |→ HIGH FREQUENCY
PAIR MIXERS   PAIR MIXERS

L.O. Frequency = Gunn freq. X 3

FIGURE 7

#140 (X4)

#207 (X3)

#168 (X4)

#139 (X3)

#156 (X4)

#140 (X3)

#167 (X4)

L.O. FREQUENCY
(GHz)

270   280   290   300   310   320   330   340   350   360   370

FIGURE 8

Subreflector Beam Throw Calibration

[DIAL SETTING] = 0.5224 * [TOTAL BEAM THROW] − 0.0050
Measured 03 Oct 1989
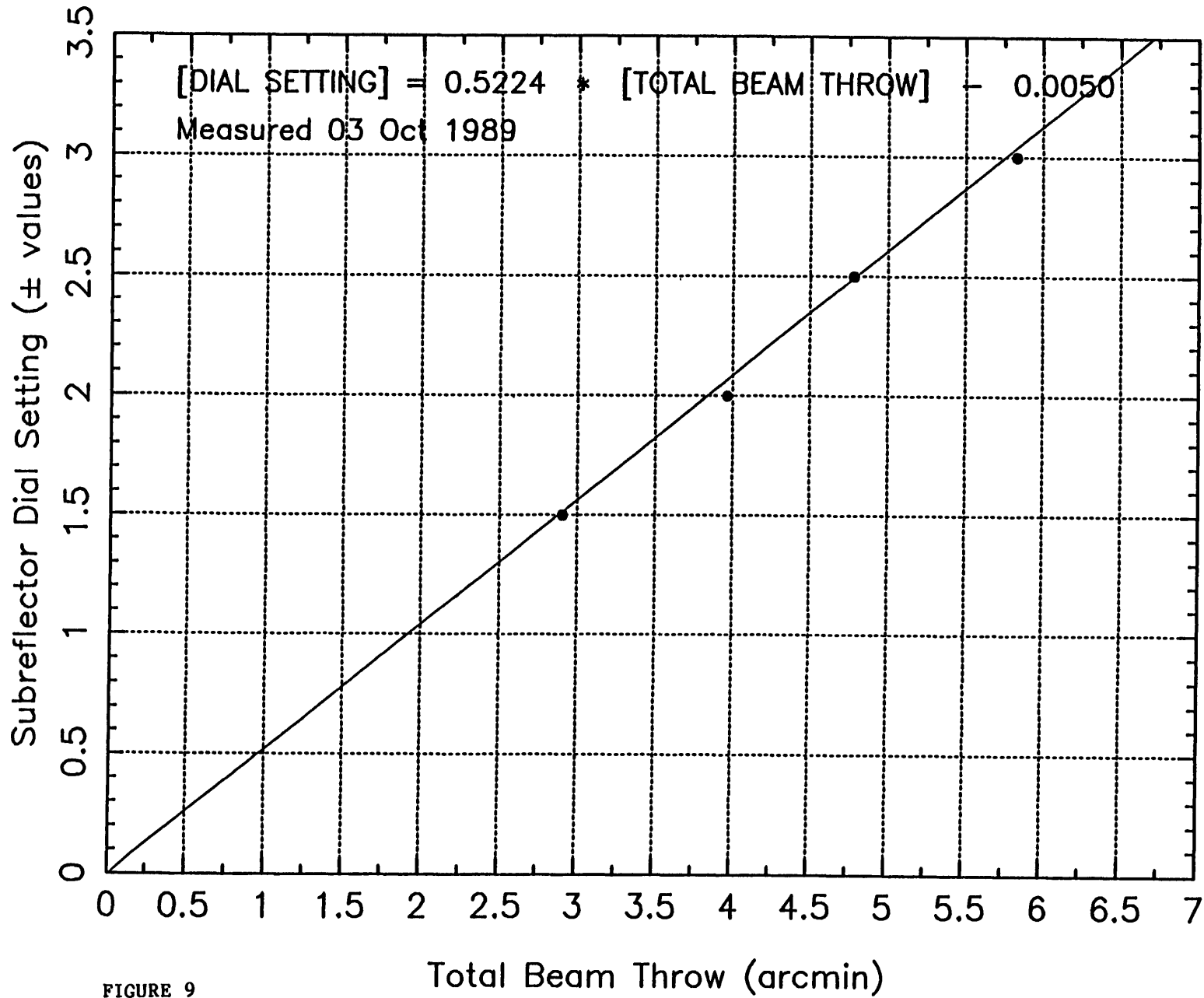
FIGURE 9

Aperture Efficiency

$\sigma = 85\ \mu m$

$\eta_{A0} = 0.52$

FIGURE 10

Frequency (GHz)
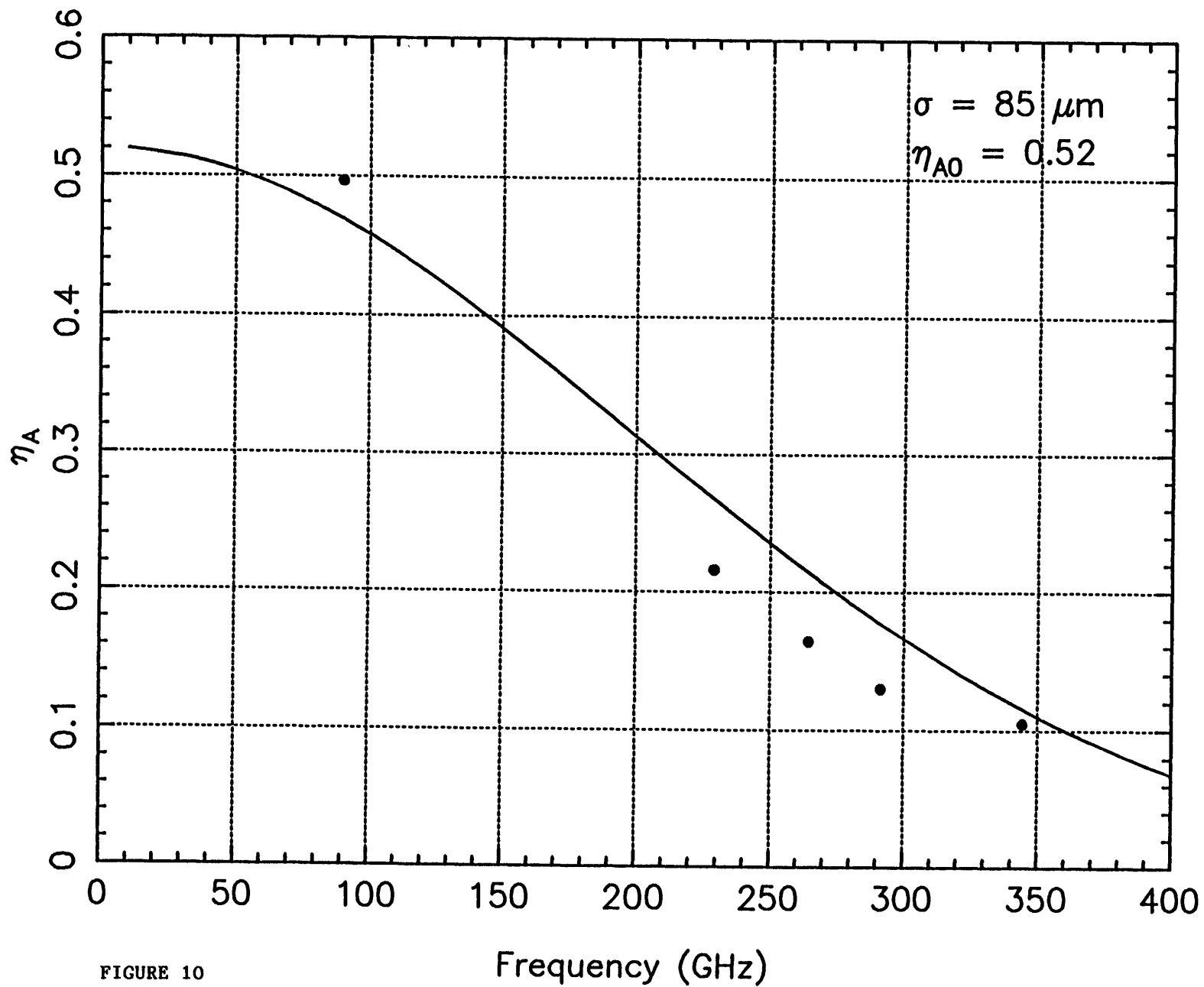
Standard Beam Efficiency

$\sigma = 77\ \mu m$

$\eta_{AO} = 0.52$

FIGURE 11

Frequency (GHz)
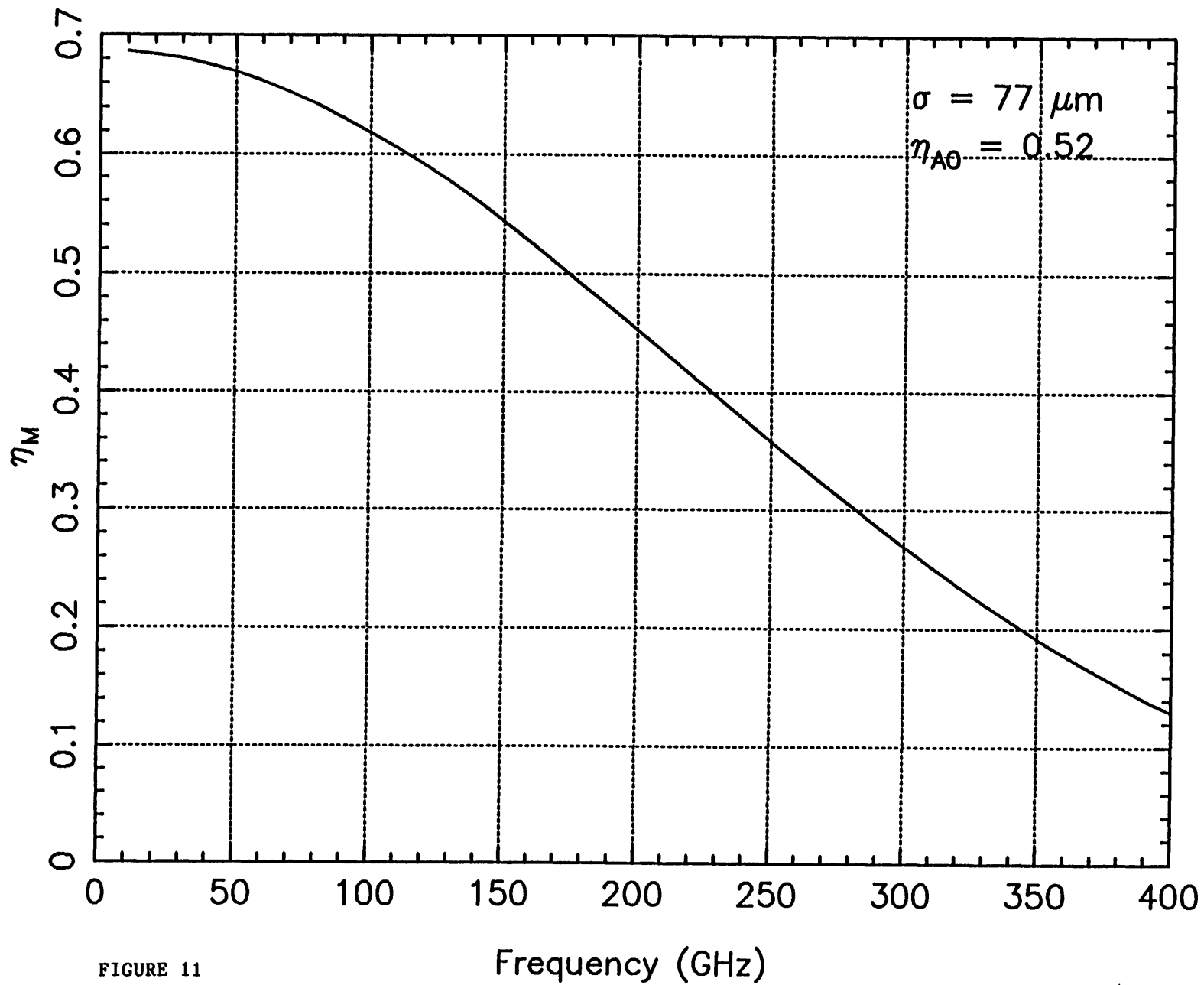
Main Diffraction Beamwidth (FWHM)
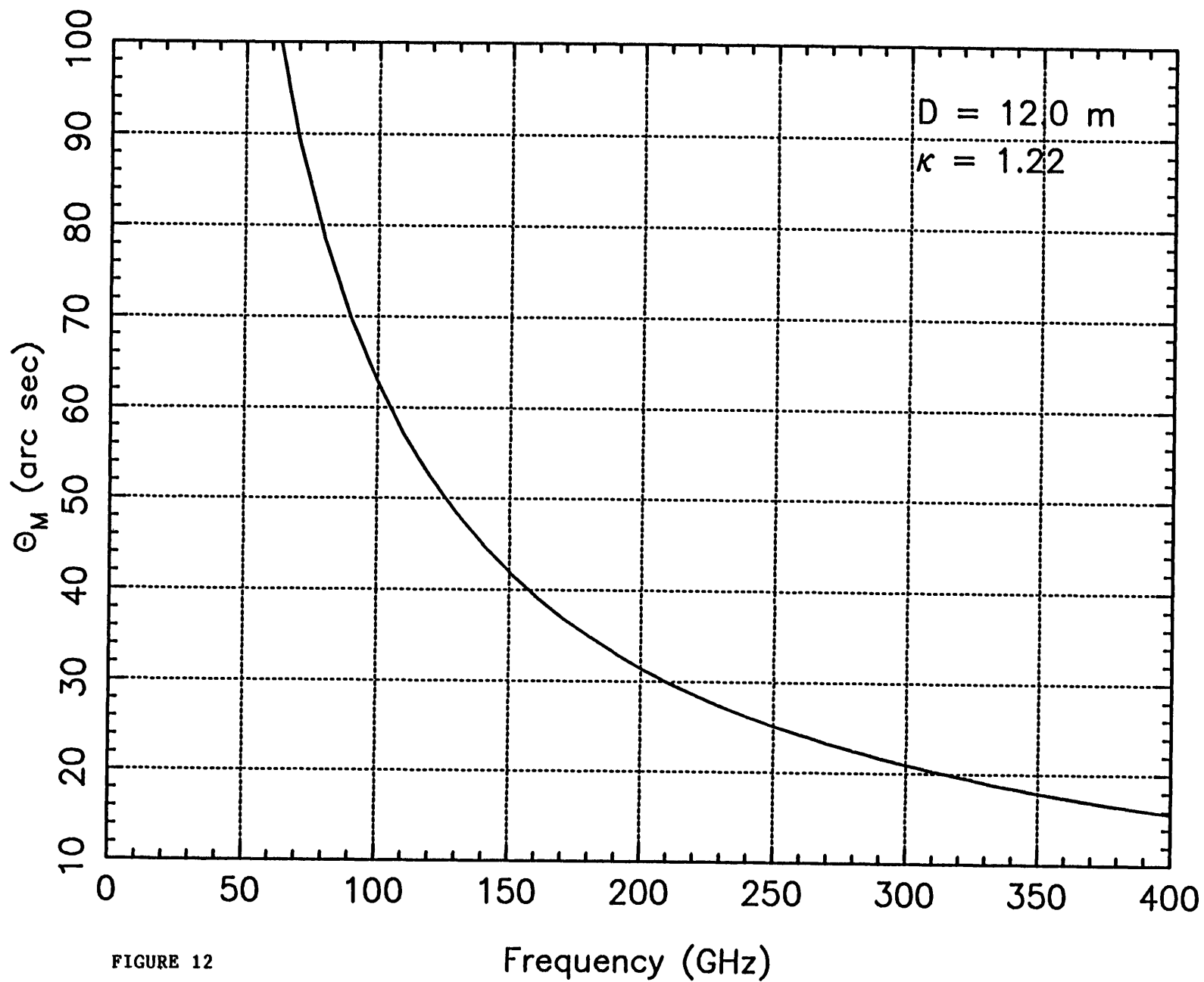
FIGURE 12

Janskys per Kelvin of T_A
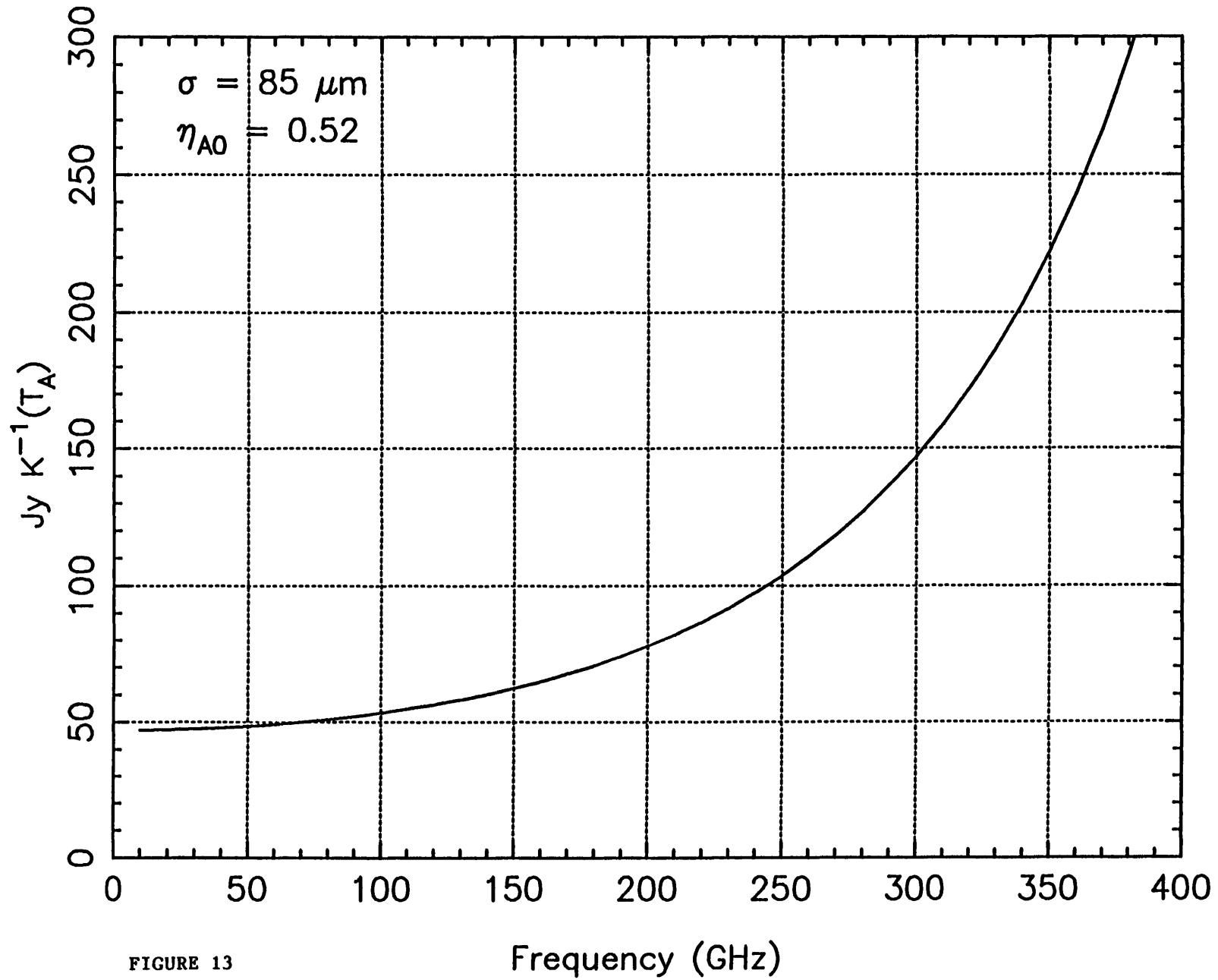
FIGURE 13

Janskys per Kelvin of T_R^* (For Vane Cal.)

$\sigma = 85 \; \mu m$
$\eta_{AO} = 0.52$
$\eta_\ell = 0.85$
$\eta_{fss} = 0.75$

Jy $K^{-1}(T_R^*)$

Frequency (GHz)
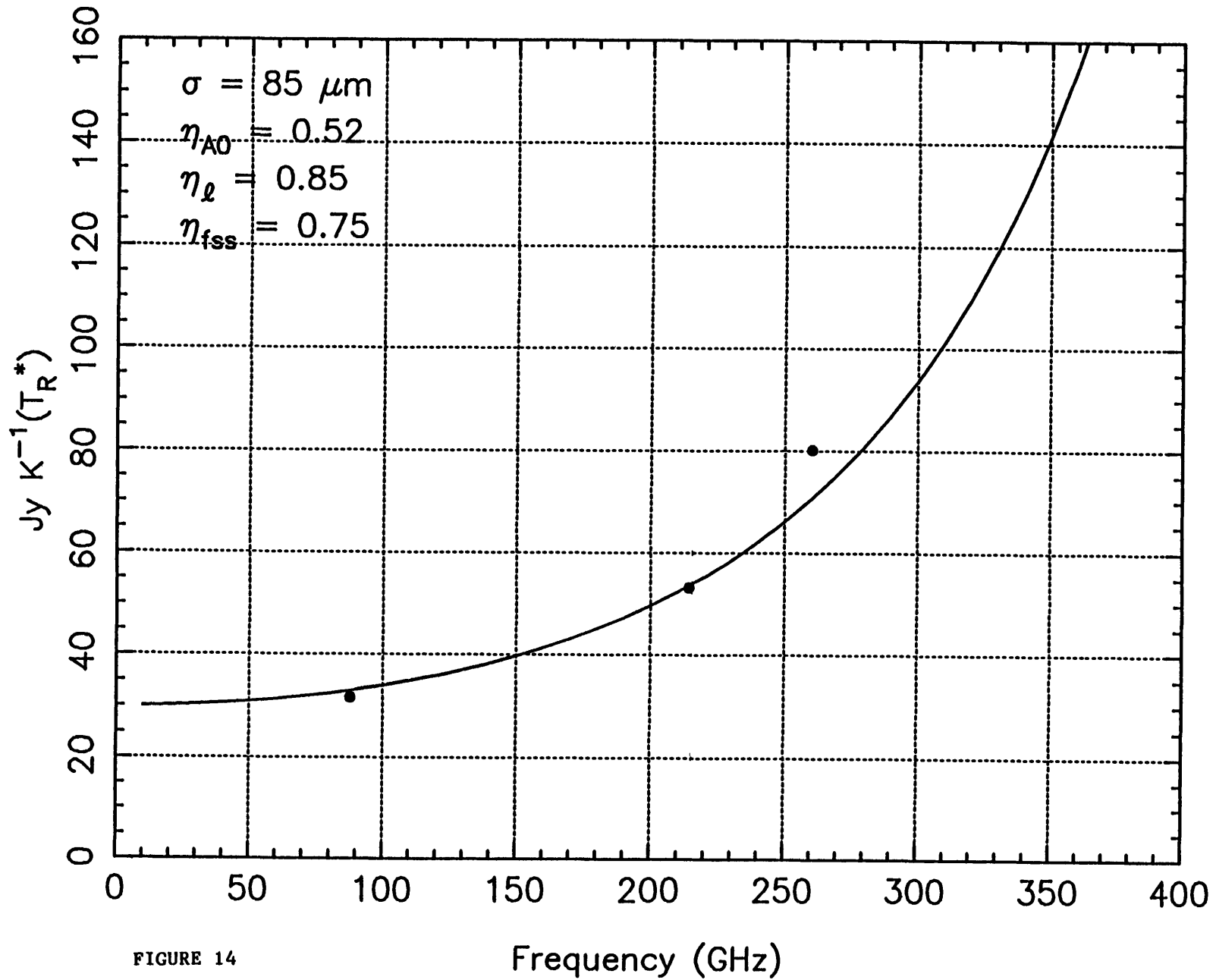
FIGURE 14

Corrected Beam Efficiency

$\sigma = 77 \, \mu m$
$\eta_{AO} = 0.52$
$\eta_{\ell} = 0.85$
$\eta_{fss} = 0.75$

FIGURE 15

Frequency (GHz)

Error Beam FWHM

$c_\sigma = 28$ cm

Θ$_E$ (arc min)

Frequency (GHz)
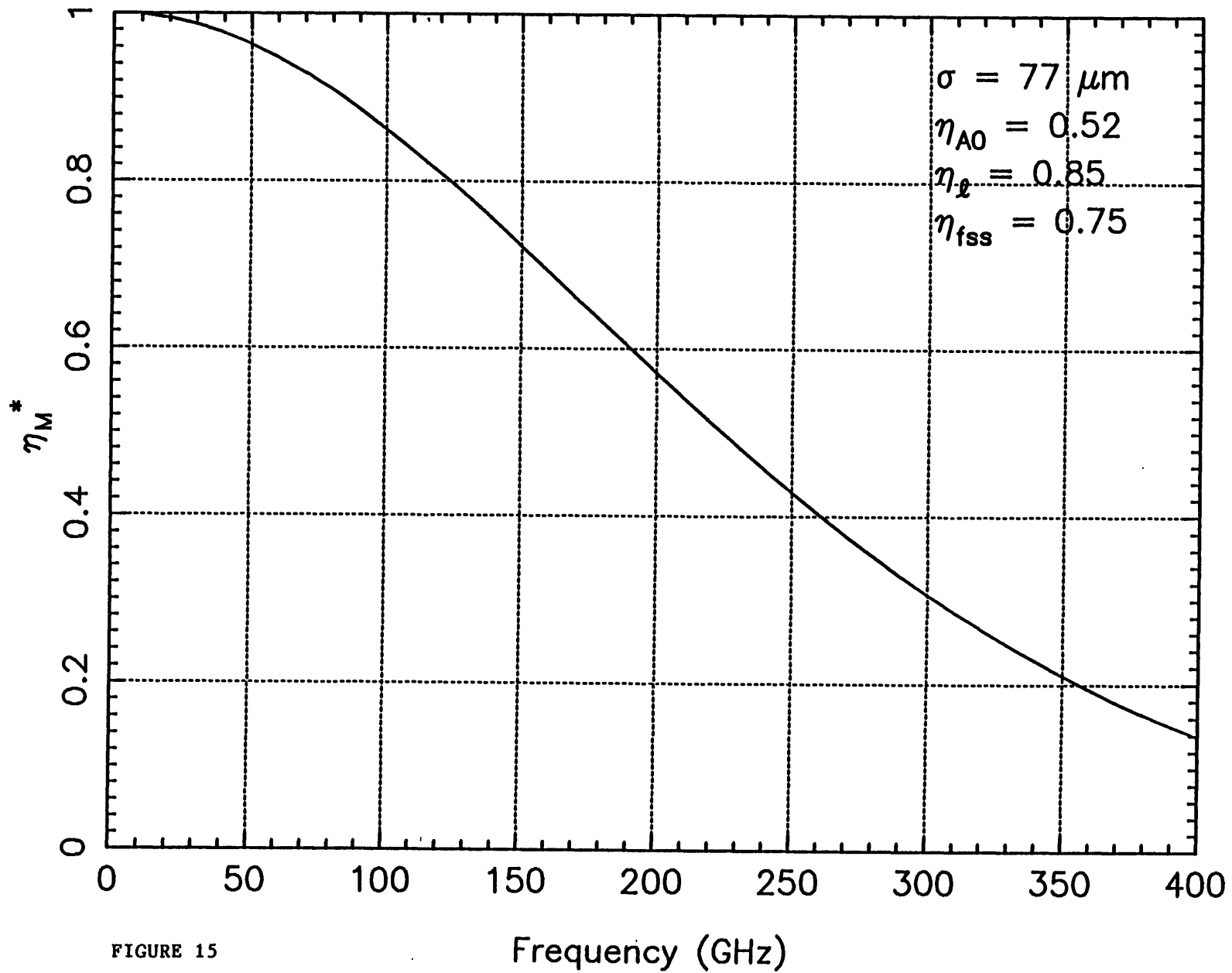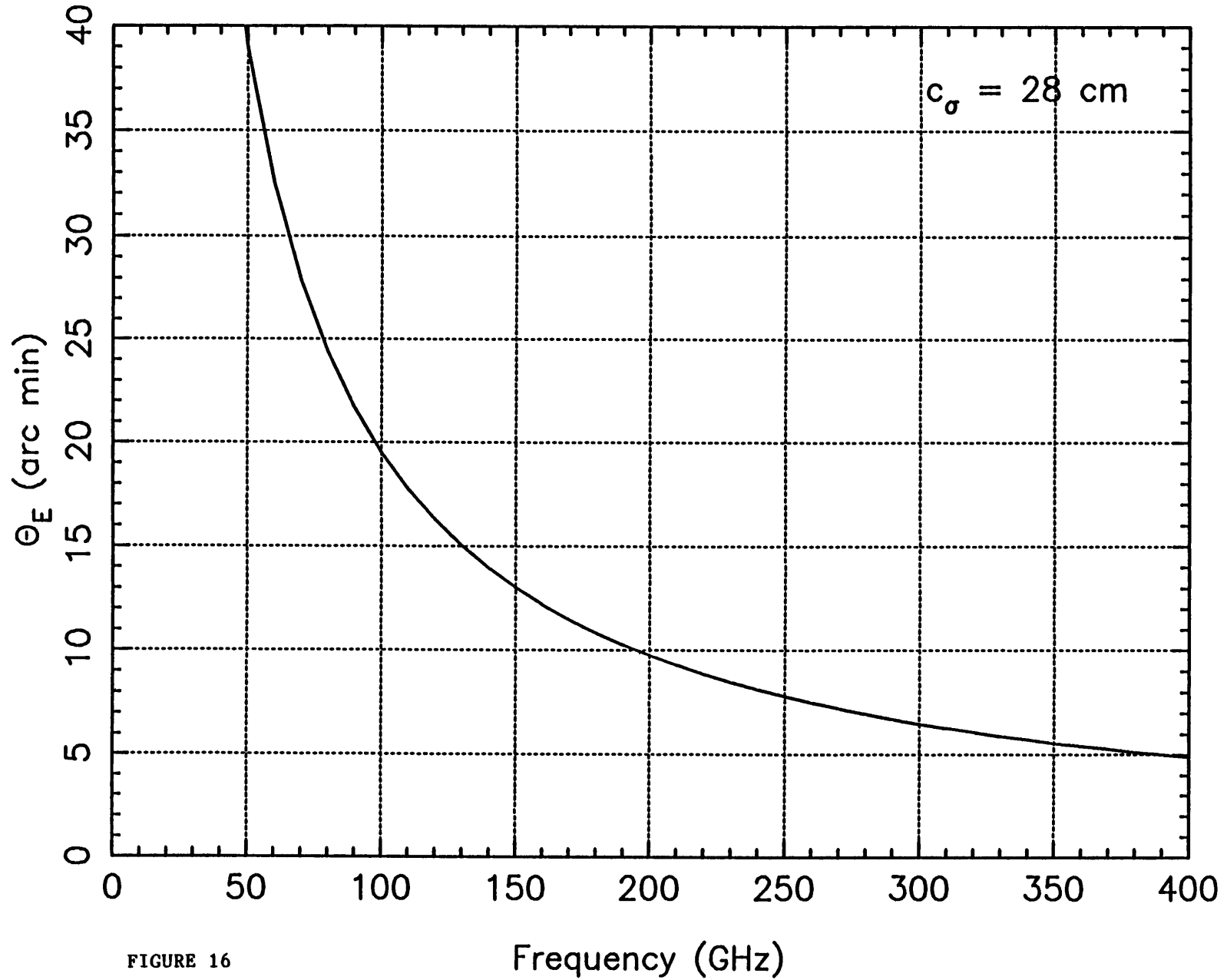
FIGURE 16

Ratio of Error Beam Amplitude to Main Beam Amplitude

FIGURE 17

λ1.3 mm Gain–Elevation Curve

Source: DR21
Frequency: 229.0 GHz
Measured 1987 April 15

Normalized Antenna Temperature

Elevation Angle (Degrees)

FIGURE 18

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