300-FOOT TELESCOPE
OBSERVER'S MANUAL

by

NRAO STAFF

November 1975

The bulk of the text in this manual came from contributions by R. Fisher, J. Spargo, and B. Vance. Persons most helpful in the research and editing were W. Brundage, O. Cate, K. Cottrell, F. Crews, T. Henderson, D. Hogg, G. Liptak, K. Nottingham, F. Owen, M. Roberts, B. Sheets, C. Sutton, B. Turner, R. Viers and the many contributors of telescope measurements listed in the bibliography. A section on interference was reprinted from an internal report by C. Moore and J. Dolan.

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PREFACE

It is recognized that the background of most observers is in astronomy and not in electronics or computer programming, so many of the details of receiver set-up and telescope control are assumed by the NRAO staff. The observer is ultimately responsible, however, for the successful operation of his experiment and is expected to make enough on-line checks and ask questions to assure himself that everything is running properly. It seems reasonable to expect that the observer should understand the equipment set-up well enough to mentally trace a signal from the sky to the recording device. Many things are not obvious from looking at front panels, so some very fundamental questions which can be answered by the staff may be in order. Everyone at the NRAO will appreciate the fact that an observer cares enough about his experiment to want to understand the equipment he is about to use.

The observer's basic responsibilities are to make his equipment requirements known to the elctronics staff in plenty of time, provide the operator with telescope control cards and receiver operating instructions, and monitor and reduce the data output. He or an assistant is normally expected to be in Green Bank during the entire observing run, and it is strongly suggested that he be in Green Bank from 1 to 7 days (depending on previous experience) before the start of his run to become familiar with current procedures. One or more of the scientific staff act as "friends of the telescope" and may be called upon at any time to answer questions or refer the observer to someone who can.

CHAPTER 1

OPERATING ROUTINE AND BASIC EQUIPMENT PARAMETERS

Scheduling

Beyond normal weekly maintenance and holidays the only reasons for 300-foot telescope shut down are equipment failure, winds exceeding 25 mph, and heavy snow or ice loads. At least one engineer is available at all times to correct equipment malfunctions. Pointing accuracy and efficiency tends to degrade as the wind and snow load limits are approached, and it is the operator's duty to maintain telescope safety and to shut down at his discretion.

Telescope observing schedules are normally sent to observers one to three months in advance. Assigned times are determined on the basis of the observing requests of many scientists and a reasonably efficient use of telescope time.

Daily Routine

A scan by scan observing log is kept by the telescope operator giving time and position information of the telescope for later reference by the observer. The observer gets a copy of all observing logs taken on his program, and if he wants a limited amount of additional information on these logs, he should tell the operator at the beginning of the session. The operators will also do routine receiver tuning and frequency changes at the observer's request.

Unless otherwise instructed, the operator will send the magnetic data tape to Charlottesville each morning around 0800. Logs are sent to the Green Bank Telescope Operation Division Office, and analog monitor charts and other plots are set aside for the observer each day at the telescope. Data reduction is normally done in the IBM 360/65 computer in Charlottesville. Standard data reduction programs are available or the observer may do as much of his own programming as he likes.

Physical Limits

The primary indicated declination limits are nominally $+90^{\circ}13'$ and $-18^{\circ}30'$ but may vary by a few arcminutes depending on temperature. Beyond these limits the telescope can be driven under computer control to back up limits of $+91^{\circ}04'$ and $-19^{\circ}30'$ with the low speed motor. When operating in card control mode it should be remembered that these limits are indicated and a 1950 or true position may be beyond the limits after precession and/or pointing corrections are applied. If a primary limit is encountered the telescope will drive past the limit at 2°/min. so this must be taken into account when computing move time requirements.

Hour angle limits are $\pm$ 15 inches or about $\pm\ 2^{m}$ sec δ around the telescope's meridian on the Sterling mount (used above 1 GHz) and are $\pm$ 275 inches or about 28^{m} sec δ on the traveling feed carriage (used below 1 GHz). The limits in terms of time are very slightly dependent on frequency and aperture illumination as explained in the section on beam deflection factor. Here again it should be remembered that precession and pointing corrections will make these limits unsymmetric about the true or 1950 meridian.

Two motors are used for declination drive. One provides continuously variable speeds from 0 to $2\overset{\circ}{.}25$/minute (0 to 135'/minute), and the slew motor has a fixed nominal speed of 10°/minute.

A three second time delay is built into the declination drive system to allow for telescope deceleration before reversal of direction of travel or speed change. If the telescope position is dependent on a rate and start time with very close sequencing (e.g. in wobbles), this delay must be taken into account. A rule of thumb for slewing to a new position is to add five seconds to the time required to slew at 10°/min. for deceleration and position trim. Additional time may also be required for receiver adjustments.

Maximum hour angle drive rates on the movable feed systems are 0.5 inches/sec ($\sim 1^{\circ}$/min) on the Sterling mount and 2.0 inches/sec ($\sim 4^{\circ}$/min) on the traveling feed carriage. Note that hour angle and right ascension rates are not the same due to the apparent motion of the sky.

The traveling feed system is fixed focus and fixed rotation angle. The Sterling mount allows rotation of the receiver box up to $\pm$ 200° from indicated zero at a maximum rate of $13\overset{\circ}{.}3$/sec, and a total focus travel of 1270 mm at a maximum rate of 6.76 mm/sec. Indicated zero on the focus travel is an arbitrary point and the actual in-focus position will depend on receiver box dimensions. Refer to receiver data sheets to determine the beam configuration at zero rotation angle. Positive rotation is in the direction from north through east.

Receiver Configurations

There are quite a few receiver configurations available at the 300-foot, so it is essential that the observer specify the type of observing he intends to conduct and any special needs he may have. The observing proposal often does not contain enough detail to guide the engineer-in-charge so the observer should get in touch with the engineer to make his requirements known, preferably 2 to 5 weeks before the program is to begin. Some parameters, such as bandwidth, can be easily changed in the control room while others, such as polarization or feed and switch configurations, may require major feed or cable changes in the front end box which require several hours to accomplish.

Three most commonly used receiver configurations are shown in Figures 1-1, 1-2 and 1-3. A fourth, labeled "Pulsar System" might have been included, but it would essentially be a slight variation on Figure 1-3 with a specialized post-detection processor such as a signal averager. The feed combination and

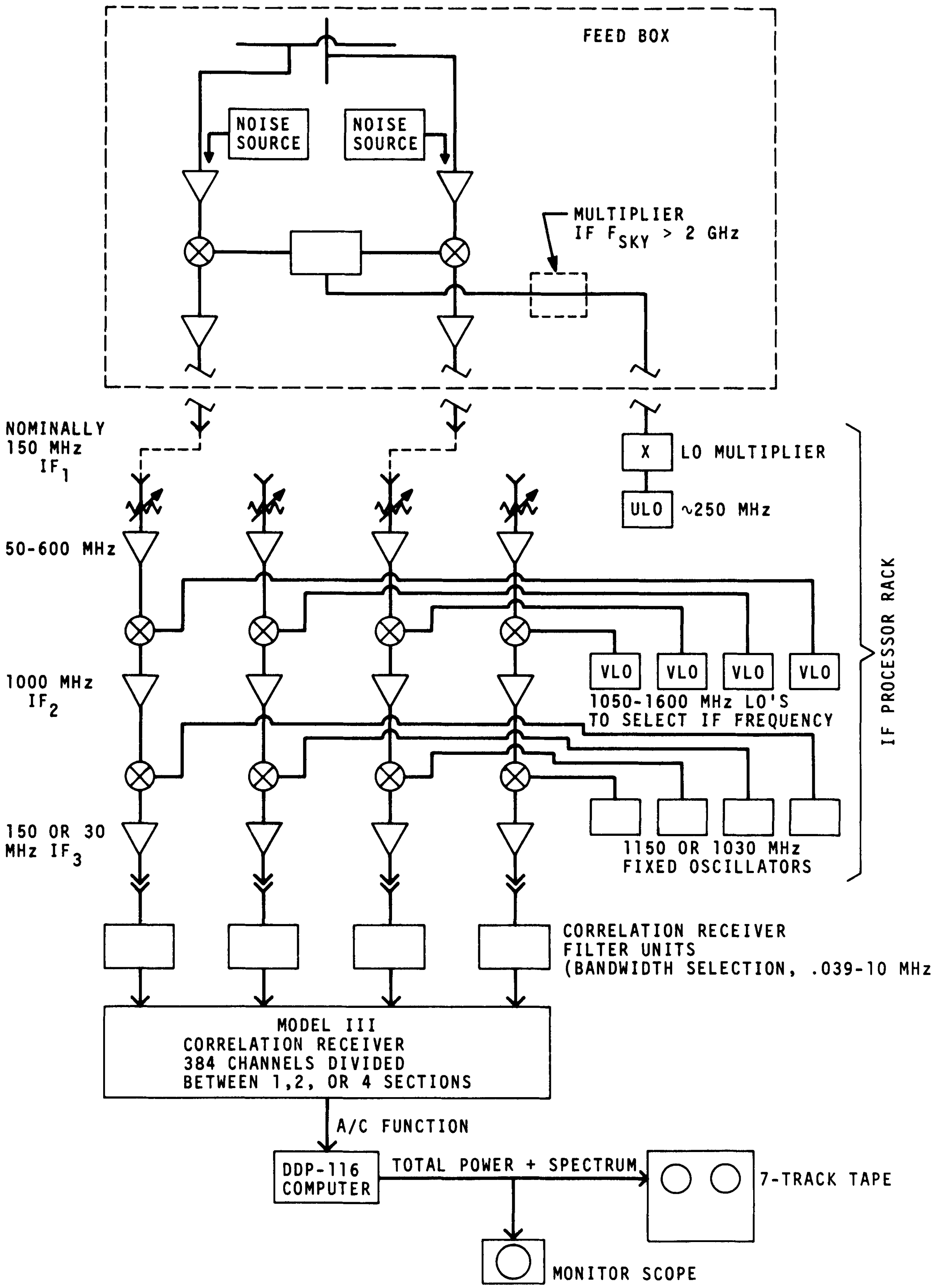


Figure 1-1. Basic spectral-line system at the 300-foot telescope.

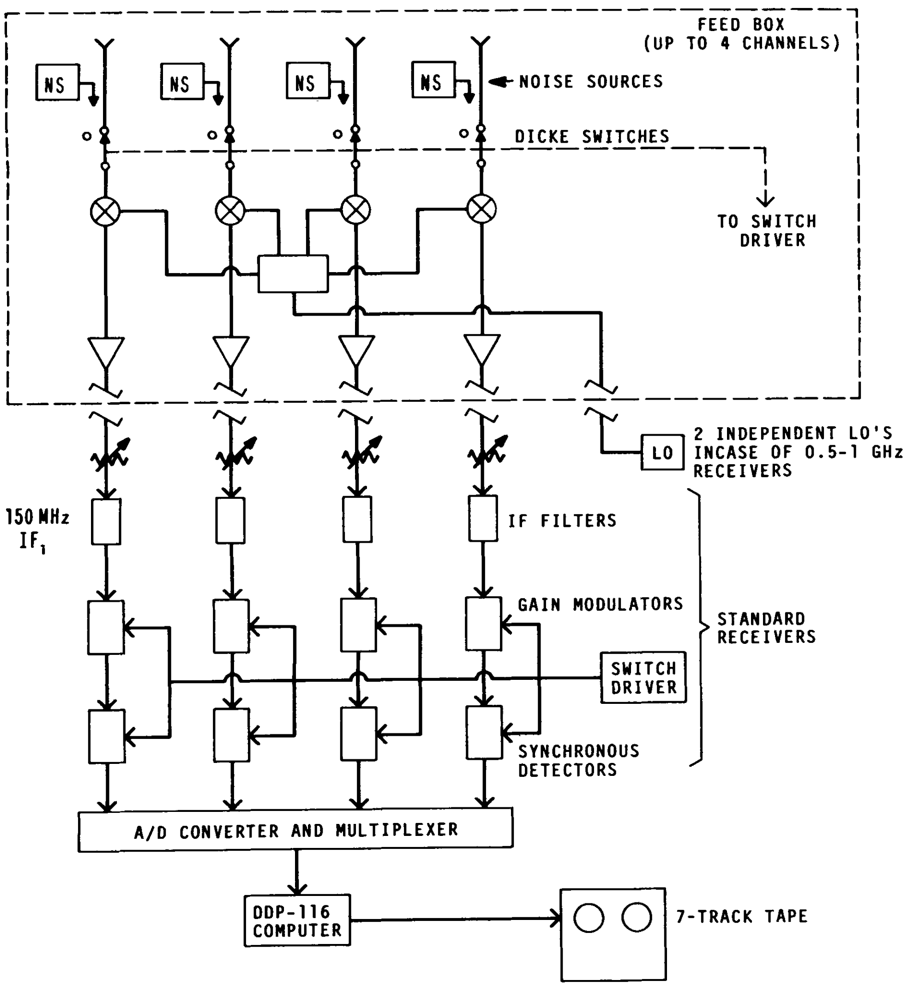


Figure 1-2. Continuum system above 500 MHz at the 300-foot telescope.

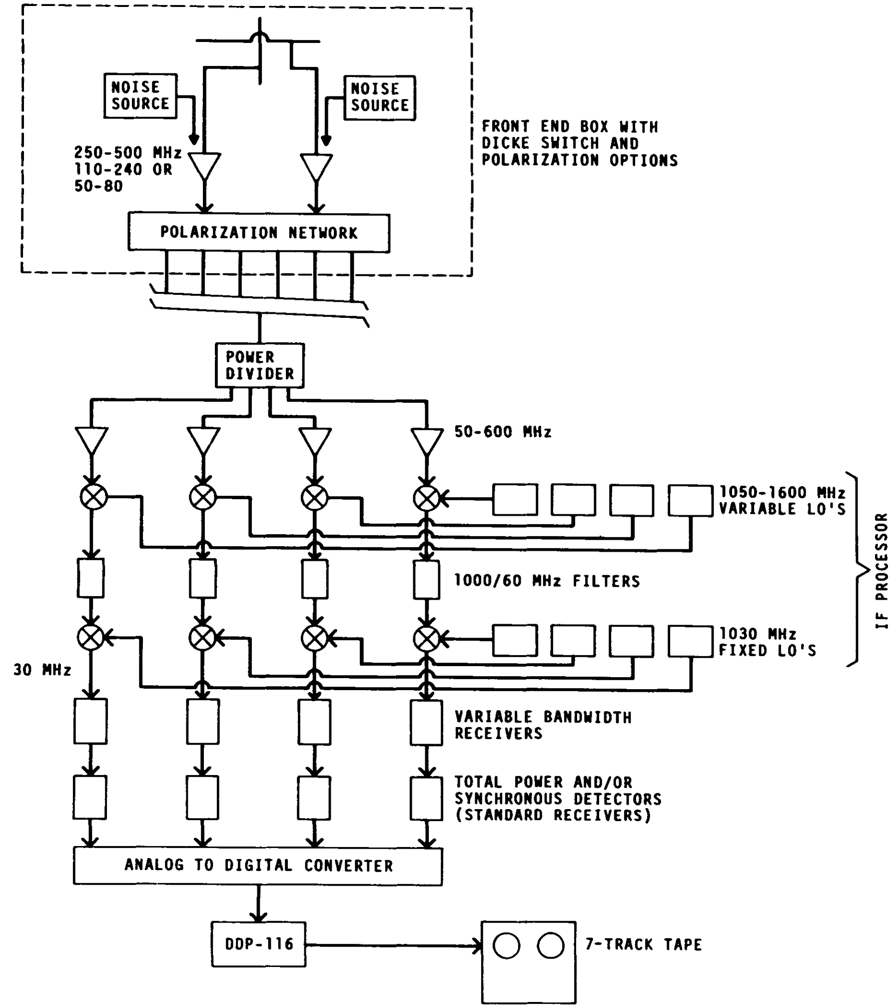


Figure 1-3. Continuum system below 500 MHz at the 300-foot telescope.

number of channels varies from one front end to another so the diagrams are meant only to be representative. For more detailed information on a particular system see the receiver sheet normally given to the observer at the time of observing and the electronics division internal reports available on request or talk to the engineer responsible for the particular receiver.

The primary frequency determining element in the spectral line system (Figure 1-1) is the Universal Local Oscillator (ULO) operating in the vicinity of 250 MHz. Its output is multiplied once or twice, depending on the sky frequency, by factors ranging from 2 to 8 to a frequency equal to the sky frequency plus or minus the intermediate frequency (IF). For instance, in the 21 cm system only one multiplier is used (usually x4) and the ULO could be set to ≈ 392.5 MHz giving a frequency ≈ 1570 MHz which is the sky frequency of 1420 MHz plus the IF of 150 MHz. A set of variable local oscillators (VLO's) is provided for the second conversion so that with a single ULO the sky frequency of two or more channels can be offset by using different IF's. The amount of offset is restricted only by the bandwidths of the front end and first IF amplifiers.

After appropriate filtering and conversion to base-band the autocorrelator digitally samples the signal and sends the autocorrelation function to the DDP-116 computer. A Fourier transform is performed by the DDP-116 which produces a spectrum to be written on magnetic tape and displayed on a monitor oscilloscope and/or an X-Y plotter. Since absolute amplitude information is lost in one bit sampling by the autocorrelator, a total power monitor with and without a calibration noise signal is also recorded on tape for scaling the spectrum in the final reduction.

The high and low frequency continuum systems (Figures 1-2 and 1-3) differ mainly in where the first conversion is made. Above 500 MHz the cable loss is too great to transmit the sky frequency to the control room so the IF signal is sent down instead. Also, in Figure 1-3 variable bandwidth receivers are shown. These are normally used to provide IF bandwidths from 3 kHz to 10 MHz. These components could also be used with the high frequency systems, but normally the need for sensitivity dictates wider bandwidths above 1 GHz.

Except for pulsar work the gain of most receivers is not sufficiently stable to operate in a continuum total power mode. Some sort of differencing technique is usually employed such as Dicke (load) switching, polarization switching or beam switching. In all cases the purpose is the same: to provide a stable reference signal which, used with the gain modulator, nearly eliminates any baseline variations due to receiver gain drifts. The intensity calibration is still affected by gain drifts, but this can be monitored by firing the noise calibration source at short enough intervals to keep track of gain changes. The function of the gain modulators is to compensate for variations in total power output caused by different signal levels from the signal and reference sources when the antenna is pointed at blank sky. The synchronous detectors then measure any imbalance between signal and reference when a source moves into the beam, and their output is filtered and sampled by the computer, typically once every second or so. A sampling time of $0^{s}.8$ is the minimum allowed by the continuum computer program except with a special patch to use $0^{s}.1$, $0^{s}.2$, $0^{s}.4$ or $0^{s}.6$ which negates the possibility of using the pulsed calibrations discussed in the computer control section. A fast sampling program is available for pulsar work with sampling times as short as 1 millisecond, but it is not normally used for continuum work.

The purpose of this and other sections is not intended to standardize observing methods. Just the opposite, the observer is encouraged to plan his program around the best technique for the purpose and not around standard setups and reduction programs. There are often good reasons why one or another technique is used, but one should find out what these reasons are and judge accordingly.

CHAPTER 2

TELESCOPE PARAMETERS AND THEIR DETERMINATION

This section is intended to outline the instrumental parameters, effects, and corrections with which an observer should concern himself when planning and executing his observations. Where parameters such as pointing corrections, aperture efficiency and beamwidth have been measured with a specific radiometer system, they are given herein. These parameters are more extensively determined for some telescope-radiometer combinations than others, depending on their purpose and the extent of feedback from previous observers. In any case, it is ultimately the observer's responsibility to satisfy himself that he is using the proper parameters, although the values given herein are the best that are currently available. It is important to remember that parameters such as pointing corrections and focus, done at a particular wavelength, are not useable for a different radiometer, even at the same wavelength; a different feed on the same radiometer will also produce different aperture and beam efficiencies. Even the declination dependence of aperture efficiency will, in general, be different for different feeds at the same frequency.

It would be most helpful if each observer would contribute any calibrations he may make during his program or call attention to incorrect information he may have received from NRAO sources.

For convenience this section has been divided into two parts: "On-axis behavior" and "Off-axis behavior." These titles refer to the declination and hour angle dependence, respectively, of the various telescope parameters.

Tracking in right ascension is accomplished by moving the feed in the focal plane. A different set of effects is associated with beam motion in each direction. Note that there are two feed carriage systems. One is a 14 meter, fixed focus, east-west set of rails, called the travelling feed, used for front-ends below 1 GHz. The other, called the Sterling mount, is a more accurate mount for radiometers above 1 GHz which is capable of focusing, rotation and east-west translation up to 45 cm on either side of the telescope axis.

Pertinent History

The 300-foot structure and surface has undergone many changes which affect its pointing and efficiency. As a consequence, many very careful measurements of antenna parameters made in the past may no longer be appropriate. To help the observer determine the validity of a previous set of calibrations, a brief history of the telescope from the installation of the present surface is given below. It is safe to say that any calibrations made before 1 December 1970 should be disregarded except as a guide for performing new measurements.

Date	Change
1 July - 7 Dec. 1970	Installation of new surface
17 Sept. 1970	Installation of cryogenic lines on feed support legs.
16 April 1971	Installation of two 7/8" Heliax cables on south leg (0.5 lb/ft/cable)
20 April 1971	Welding of north and south feed leg joints to remove pointing hysteresis.
20-28 April 1971	Installation of Sterling mount.
24 June and 16 Sept. 1971	Line of panels from south leg to north lip reinforced for walking.

11-18 Nov. 1971	Addition of counterweights: 3000 pounds at south box and 6022 pounds at counterweight box.
26 Sept. 1972	Alignment of travelling feed rails to remove twist.
29 March 1973	Welding of gusset supports.
4 June - 29 July 1973	Painting of entire structure.
22 June 1973	Welding of two broken gussets on bottom cord, south of east bearing.
17 Jan. 1974	Removed east declination encoder for repair.
15 Feb. 1974	Installed interference monitor antenna above feed cabin.
18 July 1974	Reinstalled east declination encoder.
19 Sept. 1974	Removed west declination encoder for overhaul.
24 Oct. 1974	Removed travelling feed assembly for repair and recabling.
18 Dec. 1974	Reinstalled travelling feed assembly.
27 Feb. 1974	Reinstalled west declination encoder.

Some of these changes probably had little effect on the performance of the telescope, but their effects should not be discounted without at least spot checks.

ON-AXIS BEHAVIOR

Aperture efficiency

The operational definition of aperture efficiency is given in equation (2-1).

$$\varepsilon_A = \frac{2kT_A}{SA} \qquad (2\text{-}1)$$

where T_A is the measured antenna temperature produced by a point source of flux density, S, in the peak of the beam, and A is the geometrical dish cross section ($6567\ m^2$ for the 300-foot). If S is in Jansky's and T_A in Kelvin's

$$\varepsilon_A = 0.420\ T_A/S.$$

ε_A is a function of illumination, losses in the feed, and dish deformations. The first two of these can be a strong function of frequency because of changes in VSWR and feed radiation pattern. Dish deformations have their greatest effect at short wavelengths, of course, but the detailed dependence of ε_A on them depends on the phase and amplitude structure of the wavefront striking the surface from the feed (using reciprocity and considering the feed as a transmitter). For this reason each radiometer-feed-surface combination behaves differently as a function of declination at the same wavelength.

In many cases only the relative variation of ε_A with δ is important, the measurement of which demands only that the secondary calibration source (noise tube or diode) remains steady during the measurements. Absolute determination of ε_A is much more difficult because both T_A and S must be known absolutely. T_A is derived by comparison with an internal noise standard in the radiometer which at best can be measured in the lab to a few percent and at worst can be in error by over 25%. The method of calibration of the noise standard is important because it often varies with frequency. Therefore, a wideband noise standard value is not necessarily valid for narrow band spectral line work and vice versa.

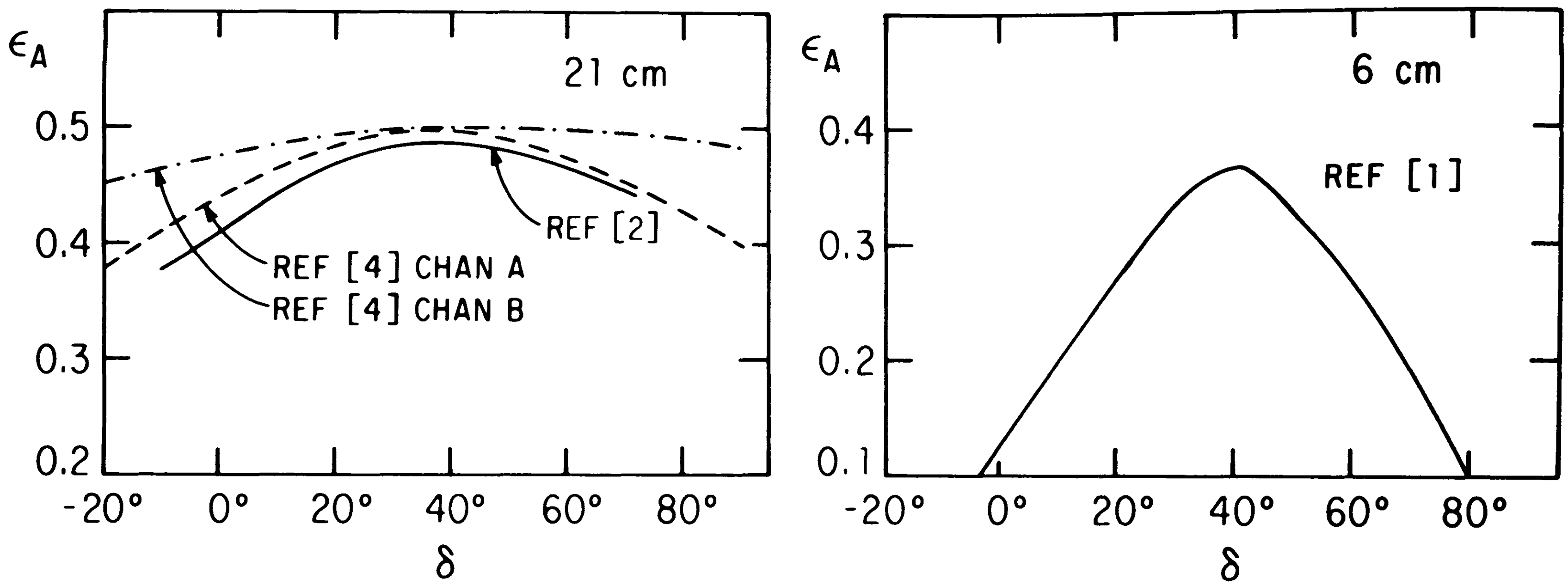
The most reliable way to determine the aperture efficiency of the 300-foot is to do drift scans of as many sources as possible of known flux over as wide a declination range as needed for one's observations. Be careful not to chose variable sources or sources with a size which is more than a tenth of a beamwidth. Good references for radio source flux densities are Bridle *et al.*, 1972 [47], Kellermann *et al.*, 1969 [48], and Fomalont and Moffet 1971 [49]. Remember that flux densities usually refer to a particular polarization angle at a particular frequency.

Immediately before and after the source passes through the beam, put a noise calibration on the record. A comparison of the peak source deflection to the noise calibration deflection will give the noise calibrator in flux units, which, if the noise calibrator is known in temperature units, can be used to find ε_A in equation (1). If the declination pointing corrections are not precisely known, drift scans at several declinations may be necessary or the peak deflection corrected assuming a beam shape once the pointing corrections are known. The on-off method of determining source deflections is difficult to use on the 300-foot because of the variation of aperture efficiency with hour angle when a source is tracked. Even if extensive calibrations have been made on a previous observing session, at least spot checks on the calibrations should be made every session.

To indicate the useful declination range of the 300-foot at several wavelengths representative plots of $\varepsilon_A(\delta)$ are given in Figure 2-1. Note the difference in curve shape for different feeds at 21 cm. All reports which are on file with the "Friend of the 300-foot" and which discuss any of the parameters in this chapter are referred to in Table 2-1. The various radiometers are too numerous to discuss individually and for some of them there is very little written information on their performance on the telescope. As more information becomes available for each radiometer, the references will be added to Table 2-1.

Beam efficiency

Beam efficiency is often a misconstrued term in observational radio astronomy. Consequently there are several definitions each of which applies only in a very specific case.



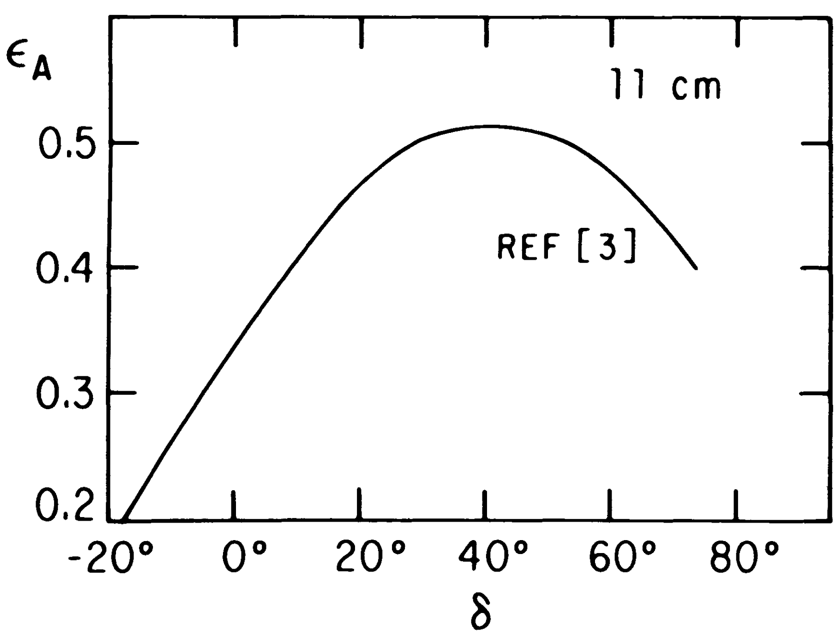


Figure 2-1. Relative aperture efficiencies as a function of declination for three wavelengths. Note that absolute levels of curves are generally not more accurate than $\pm$ 10% and will be different for different receivers at the same wavelength. Ref. [4] curves are arbitrarily normalized to ε_A (peak) = 0.5.

In practice, beam efficiency, ε_B, is sometimes used to convert observed antenna temperature, T_A, into source brightness temperature, T_B, for an extended source. The strict relation between T_A and T_B is

$$T_A = \frac{\iint_{\substack{\text{entire}\\ \text{source}}} T_B(\theta,\phi)\, R(\theta,\phi)\, d\theta d\phi}{\iint_{4\pi \text{ steradians}} R(\theta,\phi)\, d\theta d\phi} \tag{2-2}$$

where $R(\theta,\phi)$ is the power response of the antenna in the direction (θ,ϕ). Only if the source is of uniform brightness can an equation defining ε_B be written which contains only antenna parameters.

$$\varepsilon_B = \frac{\iint_{\substack{\text{source}\\ \text{solid angle}}} R(\theta,\phi)\, d\theta d\phi}{\iint_{4\pi} R(\theta,\phi)\, d\theta d\phi} \tag{2-3}$$

Even then the source extent appears in the integral limits. Thus, any definition of ε_B in terms of antenna parameters only is arbitrary and of little practical use except as a measure of antenna quality.

Two properties of ε_B as defined by equation (2-3) are worth mentioning, however. First, ε_B is usually greater than ε_A if the integral is over the main beam. Second, ε_B varies more slowly with declination than does ε_A because power lost in the peak of the main beam generally goes into broadening the beam and into nearby sidelobes as the dish is deformed.

The exact procedure for treating extended source observations depends on the scientific objectives. If the total source flux density is the goal, one could either correct for beam response fall off if the source is roughly a HPBW or less in extent (assuming one knows the source brightness distribution), or one can completely map the source. If the source area is mapped, the total flux is simply the integral under the source map divided by the normalized antenna beam integral. In this case the map intensities are expressed in "Jansky x beam areas" which in many cases is a much more useful physical unit than brightness temperature, and allows one to use the direct secondary noise source calibration in terms of point source flux density.

Beam width and Beam shape

Nominally the half-power beam width of the 300-foot in arcminutes is 0.5 λ(cm). It varies by as much as 15 or 20% from this (usually larger) depending on illumination taper and shadowing, declination, and to a certain extent on wavelength because of beam broadening at higher frequencies owing to surface irregularities. To a first approximation the one dimensional main beam shape is gaussian when the illumination taper is -15 db at the dish edge, as is the case with many NRAO feeds. However, the gaussian shape is a poor approximation above 1 GHz at extreme declination limits where the beam is decidedly asymmetrical, and at all frequencies when the feed is off axis, as will be discussed later. The north-south beam width is generally larger than the east-west beam width because of the feed support shadows.

Typical beam contour maps are given in Figure 2-2 at δ = +47° and -15° for the cooled 21 cm receiver [4], and much deeper contours are shown in Figure 2-3 for the 21 cm four feed system [2]. Figure 2-4 is a plot of measured half-power

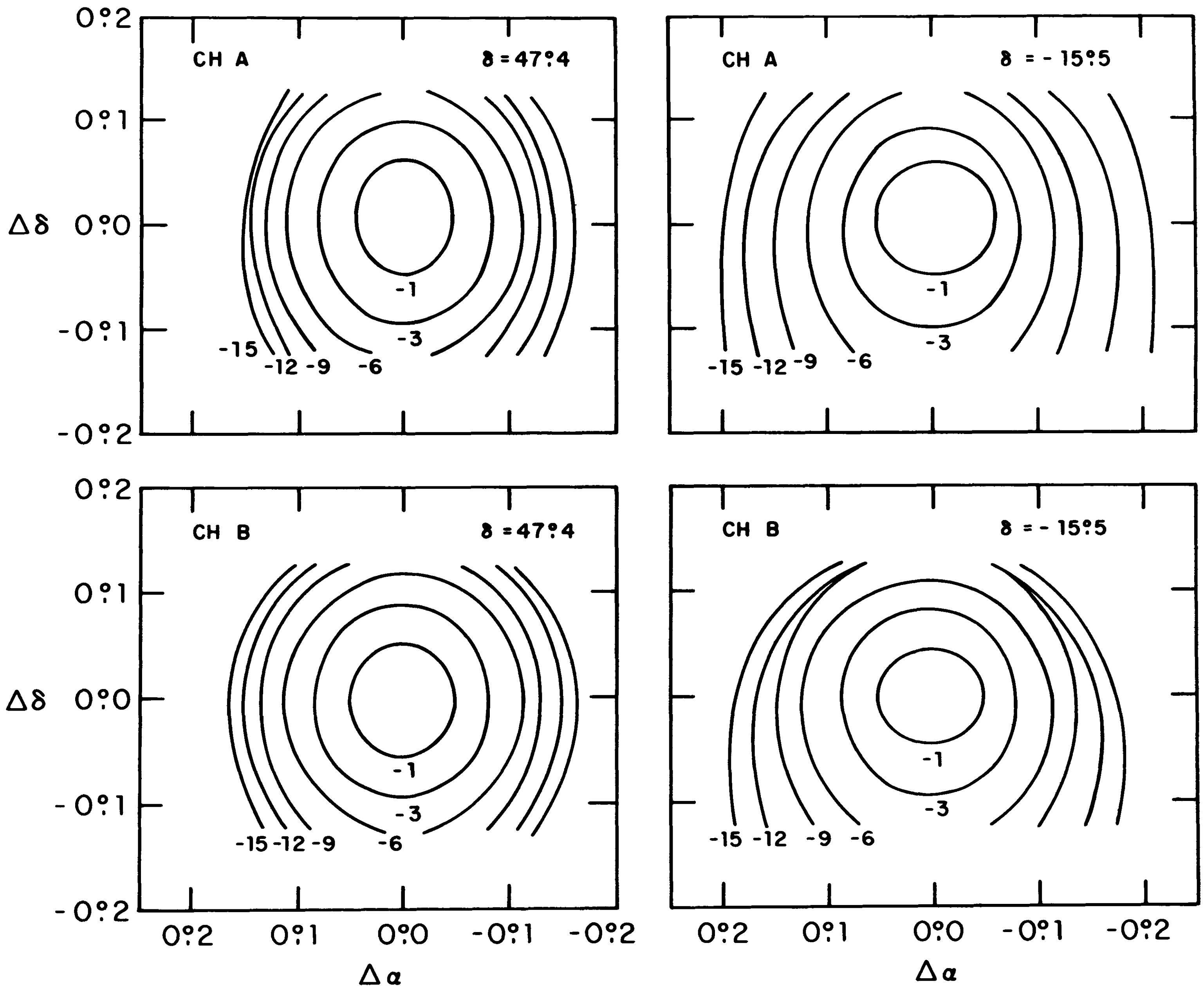


Figure 2-2. Beam shapes measured with the cooled 21-cm receiver feed on axis. Top figures are channel A with E vector north-south and lower figures are channel B with E vector east-west. Contours are at -1, -3, -6, -9, -12 and -15 db levels. Ref. [4].

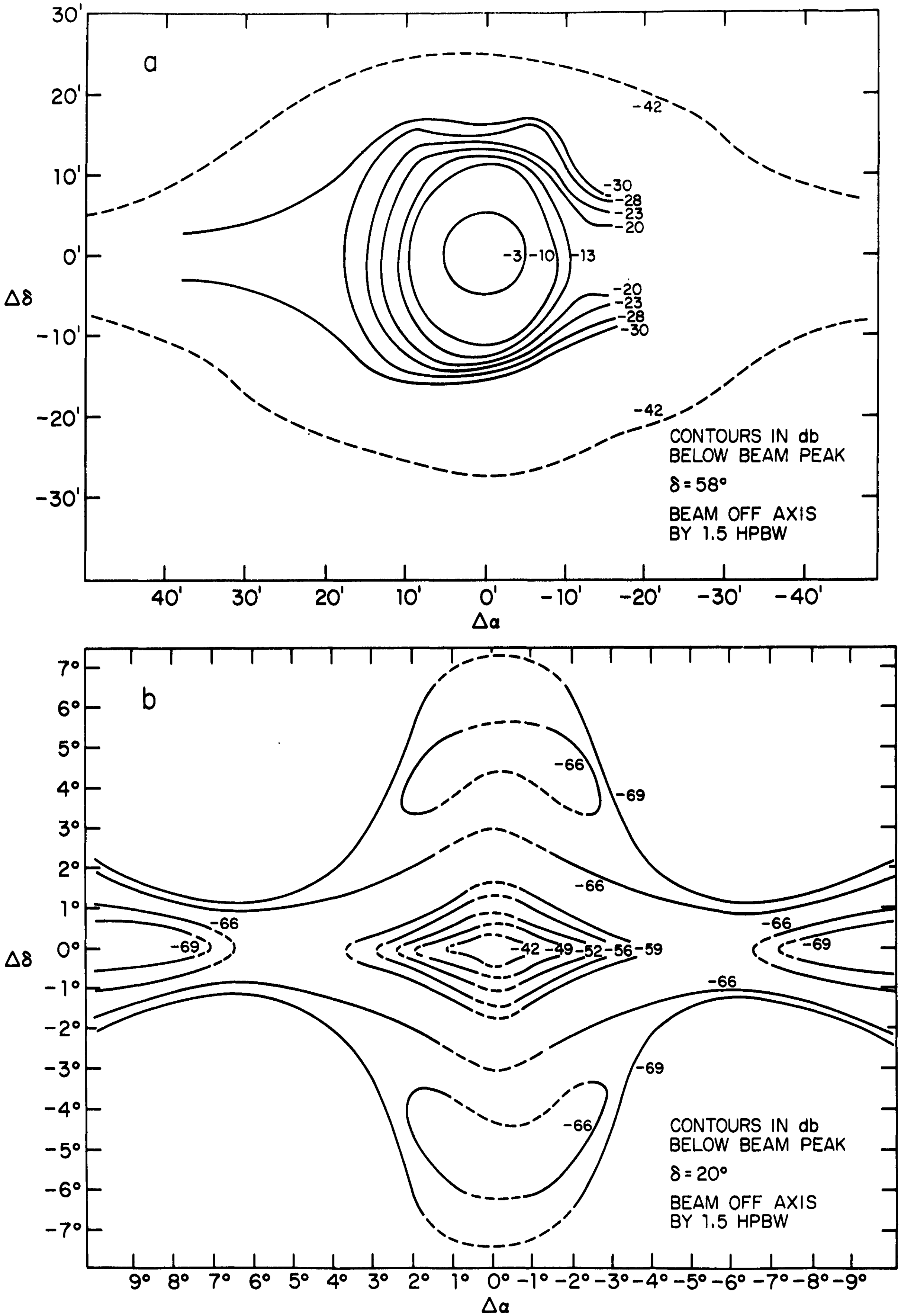


Figure 2-3. Example of low-level sidelobe pattern obtained by mapping Cas A (a) and the sun (b) with one of the 21-cm, 4-feed receivers. Ref. [2].

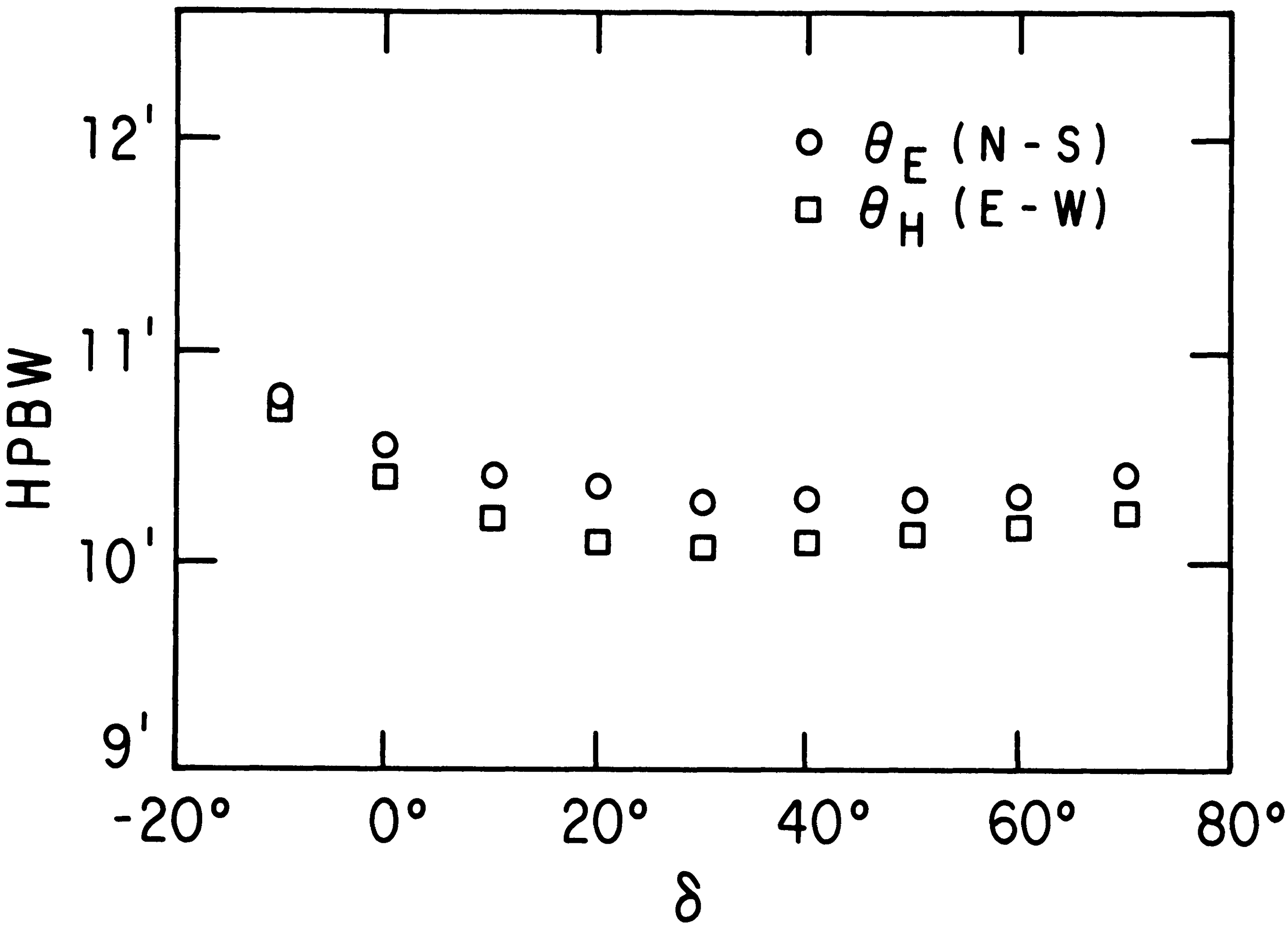


Figure 2-4. Typical behavior of half-power beamwidth as a function of declination. These data were obtained with one feed of the 21-cm, 4-feed system. Ref. [2].

beam widths for the four feed system. The declination effect on beam width is more pronounced at shorter wavelengths. Figures 2-2 to 2-4 are meant only to be representative, and each feed must be calibrated separately.

Sidelobes and spillover

The sidelobe structure will be a strong function of the feed illumination taper and surface irregularities. One feature which is always present is the east-west diffraction spike seen in Figure 2-3, which is caused by the feed supports. If the dish is heavily illuminated, Airy's rings will become apparent. These are normally suppressed by proper illumination taper. Sidelobes far from the main beam are typically 50 to 60 db down from the main beam and are the result of diffraction by sharp irregularities on the dish. Far sidelobe structure can be strongly frequency dependent; this could produce spectral baseline distortions when a strong source such as the sun is in those sidelobes.

Spillover, which is the power from the feed not intercepted by the dish, is roughly 60 db down from the main beam but subtends a large solid angle mainly in the direction of the 300 K ground. This can contribute 5 to 50 K to the total system temperature. The peak in the ground contribution to T_{sys} occurs when the antenna is near zenith position. Below 500 MHz, spillover can also pick up local power line and ignition interference.

Pointing Corrections

Pointing corrections have probably been the subject of more misinformation than any other aspect of the 300-foot. Both the mechanics of applying the corrections at the telescope, covered in another chapter, and the misconception that there is one set of pointing corrections for all feeds on the telescope have led to poor or even worthless data. The most careful observers derive their own pointing curves or at least spot check those derived by others. Few programs are so short that quick pointing check cannot be made.

The main features of the pointing curves are due to slight axis misalignment, structure sag, and encoder offsets. Significant differences in pointing between various receivers and between different polarizations on the same receiver can be caused by mechanical and/or phase center offsets, and feed flexure. More subtle effects such as differential structure heating and temperature effects on the feed position readout affect accurate source position measurements.

Figure 2-5 shows the most accurate pointing corrections obtained to date on the 11 cm three feed system [5, 29]. The root mean square of the residuals from the fitted curve in right ascension are quoted as 2.1 arcseconds at night and 9.7 arcseconds during the day with definite indication that the day-time residuals are a function of solar hour angle (Figure 2-6). This accuracy has been recently confirmed at 11 cm by Stocke [42]. Pointing offsets have been measured for the 21 cm cooled receiver [4], the 740-1000 MHz system and the 250-500 MHz system mounted on the traveling feed which was set at 0 H.A. [6]. The results are plotted in Figure 2-7 along with the curves from Figure 2-5. Note the systematic offset between feeds on the same receiver box. Repeatability of the traveling feed in hour angle is no better than 2^s to 4^s, so that some of the offset of the 750-1000 MHz points from the 11 cm, $\Delta\alpha$ curve may be due to readout error. Figure 2-7 indicates an agreement of pointing corrections with the standard 11 cm curve to better than 10% of the lower frequency half-power beam width. Such agreement would lead one to believe that the same pointing curve could be used for many measurements. This assumption is based on rather sparse data and, therefore, should be treated with some caution. When source position information is important, complete calibration of the feed in use is imperative.

From experience, the most straightforward method of determining pointing corrections for a single feed are drift scans for $\Delta\alpha$ and at least two declination scans for $\Delta\delta$. If the data is recorded on a chart recorder,

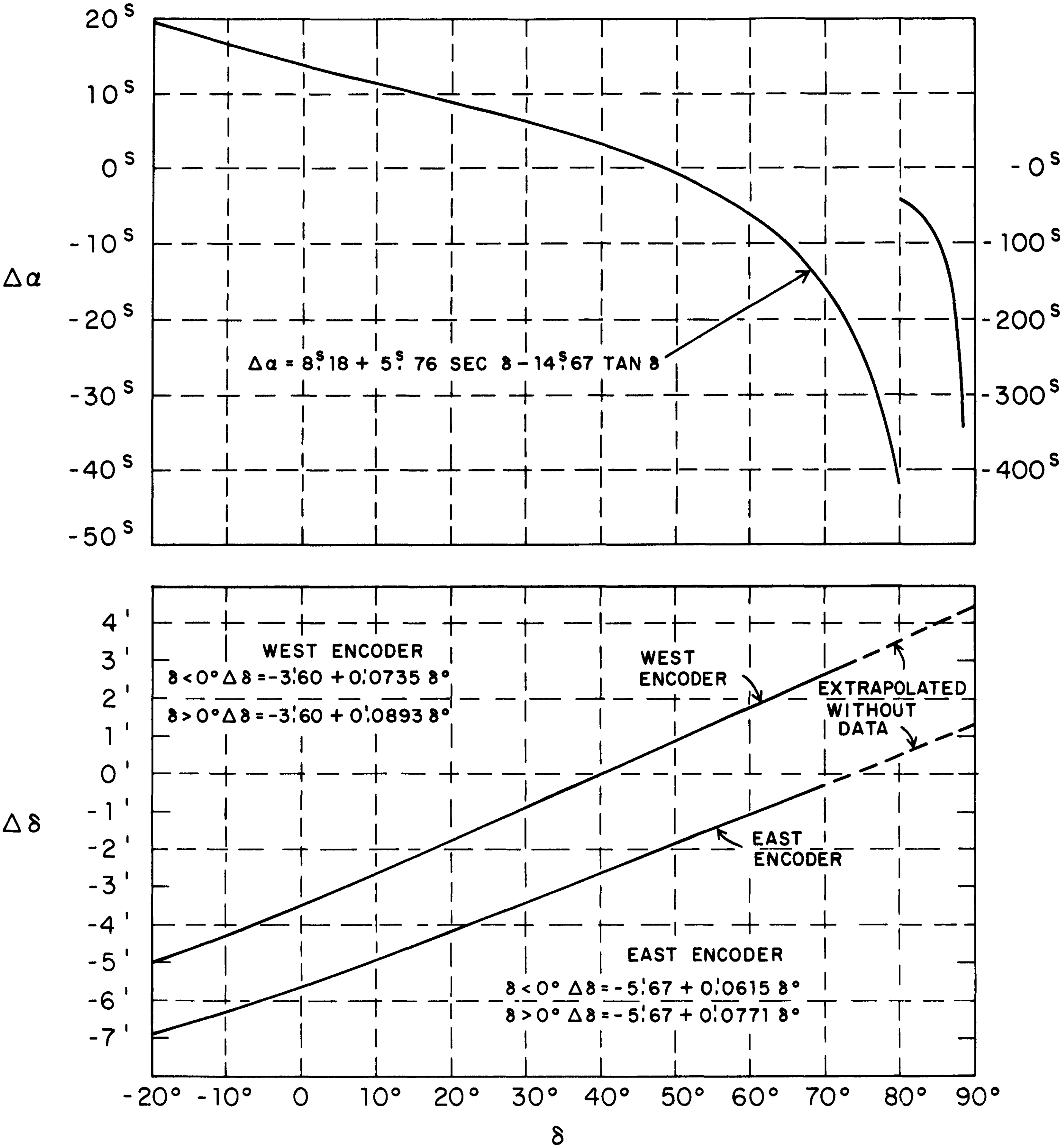


Figure 2-5. Best known pointing curves as of August 1975 determined at 11 cm.

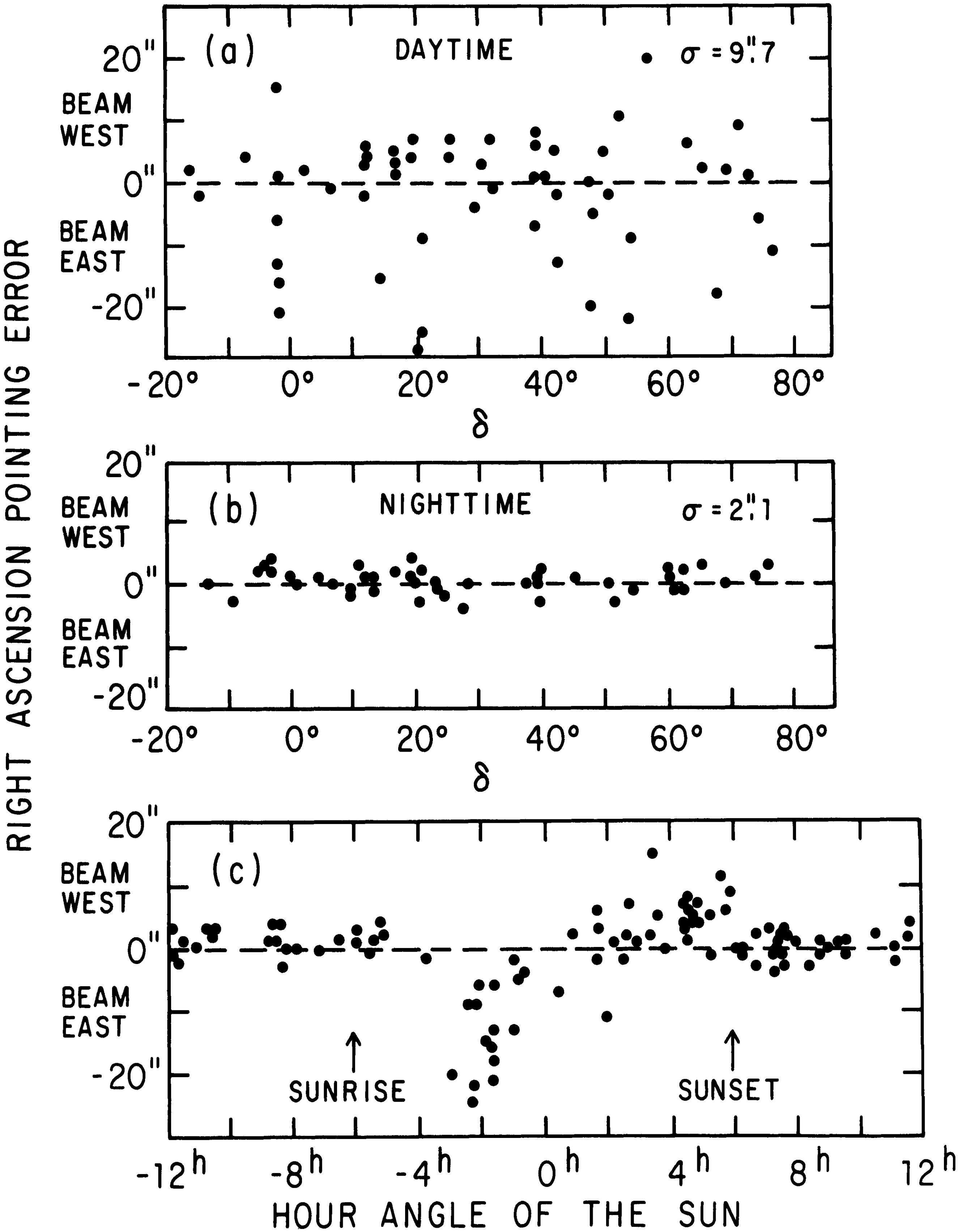


Figure 2-6. Typical pointing residuals in hour angle as a function of declination or solar time measured at 11 cm. Ref. [5].

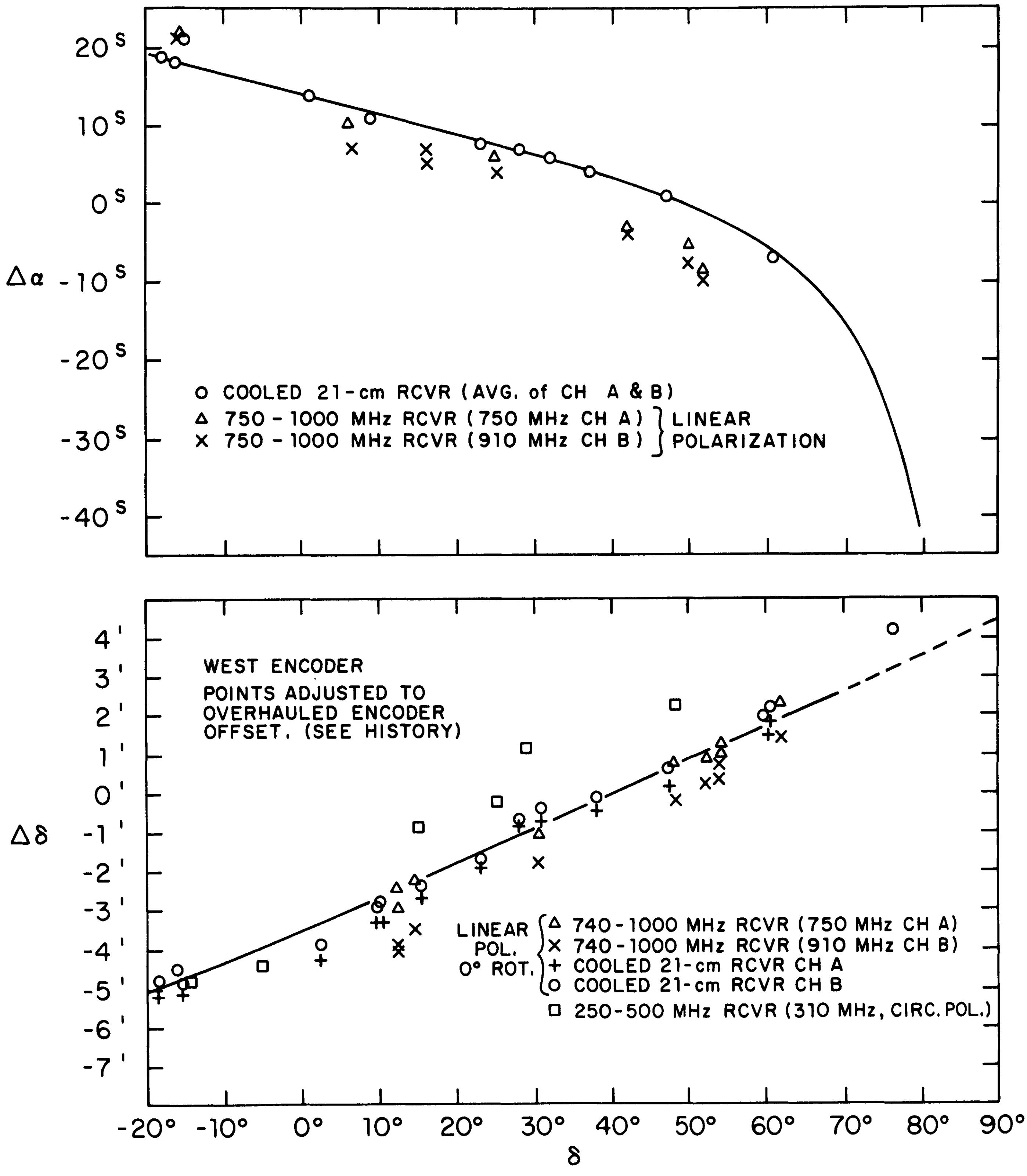


Figure 2-7. Comparison of pointing corrections obtained with several different receivers on the 300-foot. Solid lines are from figure 2-5.

one must be very careful to allow for marker pen offsets and distortions due to receiver time constants. These effects can be canceled out in determining $\Delta\delta$ by taking an equal number of scans in either direction while tracking the sources in right ascension. Be careful not to allow the feed to get so far off axis that the curvature of the sky changes the apparent source declination as measured by the 300-foot.

If two or more offset feeds are available, such as on the 21 cm four-feed or the 11 cm three-feed systems, a fairly good measurement of $\Delta\delta$ can be made with a drift scan by measuring the relative response of two or three of the beams to the source when they are spaced approximately half of a HPBW in declination. Such spacing can always be achieved by rotating the box to the appropriate position angle. This method assumes that the beam offsets and relative efficiencies are well known.

A third method which has proven successful at 21 cm is to track a pointing calibration source and move off to half power beam positions in the cardinal directions. If the response is not equal in opposite directions, the pointing offset can be computed. This method may be applicable to other frequencies as long as baselines do not vary with feed position and enough tracking time is available to complete the sequence. Because of the variation of aperture efficiency with hour angle, opposing offsets must be measured at equal distances from and not more than about three beamwidths from transit. When done from card control this method offers the advantage of checking the entire sequence of telescope control as is used in actual observing.

Good references for accurate source positions are Bridle <u>et al</u>., 1972 [47] and Fomalont and Moffet 1971 [49].

One point worth mentioning here is that there are two declination encoders on the 300-foot -- one at each end of the axis. All pointing curves given herein apply to the west encoder because it is the most reliable and has been used most often since resurfacing. Note that the declination encoders were overhauled in 1974 so none of the earlier declination pointing curves are valid. The latest nominal corrections for both encoders are available at the telescope or from the "Friend."

Focus

Only the Sterling mount is capable of moving the feed parallel to the telescope axis. The travelling feed is a fixed distance from the dish and the placement of each feed with respect to the actual focal point is determined when the receiver front end is built. Only indirect checks, such as beam shape and sidelobe structure, can be made on the focus of receivers below 1 GHz. Even these checks are dependent on illumination and interactions with the feed support structure.

Two methods have been used to determine optimum focus for the 300-foot. The simplest, which has been successful at 21 cm, is to track a moderately strong source while quickly running the feed back and forth through the approximate focal plane. With appropriate position marks on the receiver output chart recording the peak efficiency point can be determined. For this method to work one must know the pointing corrections accurately and stay within 2 or 3 beamwidths of transit, and the receiver baseline must not change due to dish reflections when the feed is moved in either focus or translation (tracking) when pointed at blank sky.

If the baseline variations are a problem in the above method, the alternative is to make drift scans of a number of sources each at a different focal position. The relative source strengths usually are not known accurately enough to monitor the efficiency at the different focal positions, but the HPBW is a weak function of focus. With at least 5 or 6 drift scans the point of minimum HPBW can be determined with sufficient accuracy to set very close to optimum focus.

Polarization

Precise polarization measurements are difficult with any radio telescope because of the myriad of instrumental effects. However, a number of successful polarization observations have been made with the 300-foot (e.g. [10], in which most of the instrumental effects have been accounted for.) This manual does not claim to define the best way to measure polarization in each case, so only a brief mention of some of the instrumental problems will be given.

Point source and extended source measurements differ in that beam shape and sidelobes are more important in the latter. Hence, unpolarized sources used for calibration must be roughly the same angular size as the unknown source. If a dual-polarized feed is used, there may be a pointing offset between the two beams. Or, if a single-polarization feed is rotated, its beam axis may not be coincident with the axis of rotation. Spillover will be different for opposite polarizations in a dual-polarization feed or for different position angles of a single feed. This will cause a differential variation in system temperature of two feeds as the antenna is moved in declination, or a baseline variation as the feed is rotated.

The phase and amplitude distribution of the illumination will also be different for the two polarizations in a dual feed and at different position angles in a single feed, owing to the intrinsic properties of the feed and to interactions with the feed support legs. The latter is especially important at low frequencies. Also, surface panel resonances may cause significant depolarization, particularly at low frequencies. Differences in illumination will produce different aperture efficiencies at different position angles and may cause the declination correction curve of aperture efficiency to be different at different position angles.

In an effort to provide a secondary polarization calibrator, three wide-band antennas were installed at the apex of the 300-foot to radiate a polarized signal to the feed. Two antennas (400-1000 MHz and 1-8 GHz) are fixed circularly polarized and the other (100-1000 MHz) is rotatable and linearly polarized. A great deal of caution must be exercised when using these antennas because of strong reflections from the feed support legs particularly below 1 GHz. For example, in a couple of cases, between 250 and 500 MHz, the sense of circular polarization actually appeared to reverse when the feed was moved away from the feed supports. A comparison of the box rotation angle and calibration antenna angle, when the calibration signal is maximized, indicates that measurements of the position angle of linear polarization is probably good to 5 or 10° in most cases. However, one cannot trust any amplitude information obtained with the apex calibration antennas.

Baselines

In continuum observations the term baseline refers to the output of a radiometer when the source is not in the main beam. If we neglect receiver instabilities and interference, the main sources of baseline variation with the feed on axis are changes in ground radiation pick-up with changing declination, and time-variations in atmospheric radiation at frequencies above about 2.5 GHz. The first is not a problem with right ascension drift scans. The second is a strong function of the amount of water vapor in the direction of the beam. In the case of small source work, beam switching can help cancel atmospheric contributions to baseline instabilities, but at times the small-scale structure of the water vapor distribution can be so pronounced as to make 6 cm observations difficult even when beam switching.

Spectral baselines, or variation of receiver output with frequency, in the true total power sense are mainly a product of the receiver bandpass characteristics. The gross frequency-dependence of the receiver system can be taken out by subtracting a reference spectrum, taken with the antenna pointed off the source or with the receiver switched to a resistive load or to a different frequency, from the source spectrum. A number of secondary effects then become evident in the baseline, and are in general difficult to eliminate entirely.

When the reference is taken by moving the antenna, both instabilities in the receiver bandpass and strong source such as the sun or even ground radiation in the antenna sidelobes can cause undulations in the difference spectrum. Load or frequency switching can be done much more rapidly to eliminate effects of receiver bandpass drifts, but because the receiver front end characteristics will be considerably different at a different center frequency or when connected to a load, the baseline will still not be flat. Generally, if the total bandpass used is less than about 1 MHz, then load or frequency switching will produce acceptable baselines. Bandwidths above 1 MHz usually require operation in what is commonly called the total power mode, in which the reference spectrum is taken in a different part of the sky from the source. In this case one must be careful to take the reference spectrum with the feed in the same position(s) with respect to the dish (e.g., if a source is tracked, the reference point in the sky should be tracked over the same hour angles and roughly the same declinations) because of frequency dependent interactions of the feed and structure.

Some work on the 140' indicates that excess noise from either ground radiation or the sun can be scattered onto and from the dish surface and interferes with direct radiation into the feed. This interference is constructive or destructive depending on frequency and can be a source of spectral baseline ripples. Normally ground radiation effects tend to cancel out in the total power mode at the 300-foot since the reference is usually taken at the same declination as the source observation. It is known, however, that the sun can cause baseline ripple with a characteristic length of 5 to 10 MHz and an amplitude at 21 cm of up to one Kelvin. No particular correlation of baseline ripple amplitude with solar hour angle has been established and many useful spectral line observations have been made during the day with a bandwidth of 10 MHz.

All of the above comments are intended only as guidelines because other observing considerations may be more important than baseline quality.

OFF-AXIS BEHAVIOR

All of the on-axis properties of the 300-foot apply when it is used in the tracking mode, but additional effects arising from off-axis operation of a paraboloid must be taken into account. Comments on these additional effects are given below under paragraph headings corresponding to those used in the on-axis discussion. Most of the comments apply to multibeam systems where at least one of the beams is off axis. An NRAO internal report [11] treats many of the subjects in more detail.

Aperture efficiency

Figure 2-8 shows the variation of aperture efficiency as a function of beam offset for two radiometers (250-500 MHz and the cooled 21 cm). Note that all of the low frequency measurements agree to within about 2% at all frequencies. The 21 cm points are systematically higher, and this may be due to a difference in illumination taper. Heavily tapered illumination will produce less relative fall off in aperture efficiency with feed offset than will more uniform illumination. Measurements have been made at 21 cm at widely different declinations, and little or no dependence of the shape of the curve in Figure 2-8 on declination is found.

The best method for measuring relative aperture efficiency as a function of hour angle is to track the right ascension of a reasonably strong source while scanning back and forth across the source in declination at a speed consistent with the antenna beamwidth. A source smaller than a tenth of a beamwidth should be used, and the antenna pointing corrections in right ascension and hour angle must be known accurately. If an absolute value of the aperture efficiency is to be obtained with the same series of scans, a noise calibration should be put on the record before and after the set of source scans. Measuring the aperture efficiency variation by continuously tracking a source is not advisable because of possible variations in the receiver baseline when the feed is moved in the focal plane.

Since the shape of the aperture efficiency vs beam offset curve depends on illumination, it should be measured for each separate feed when it is

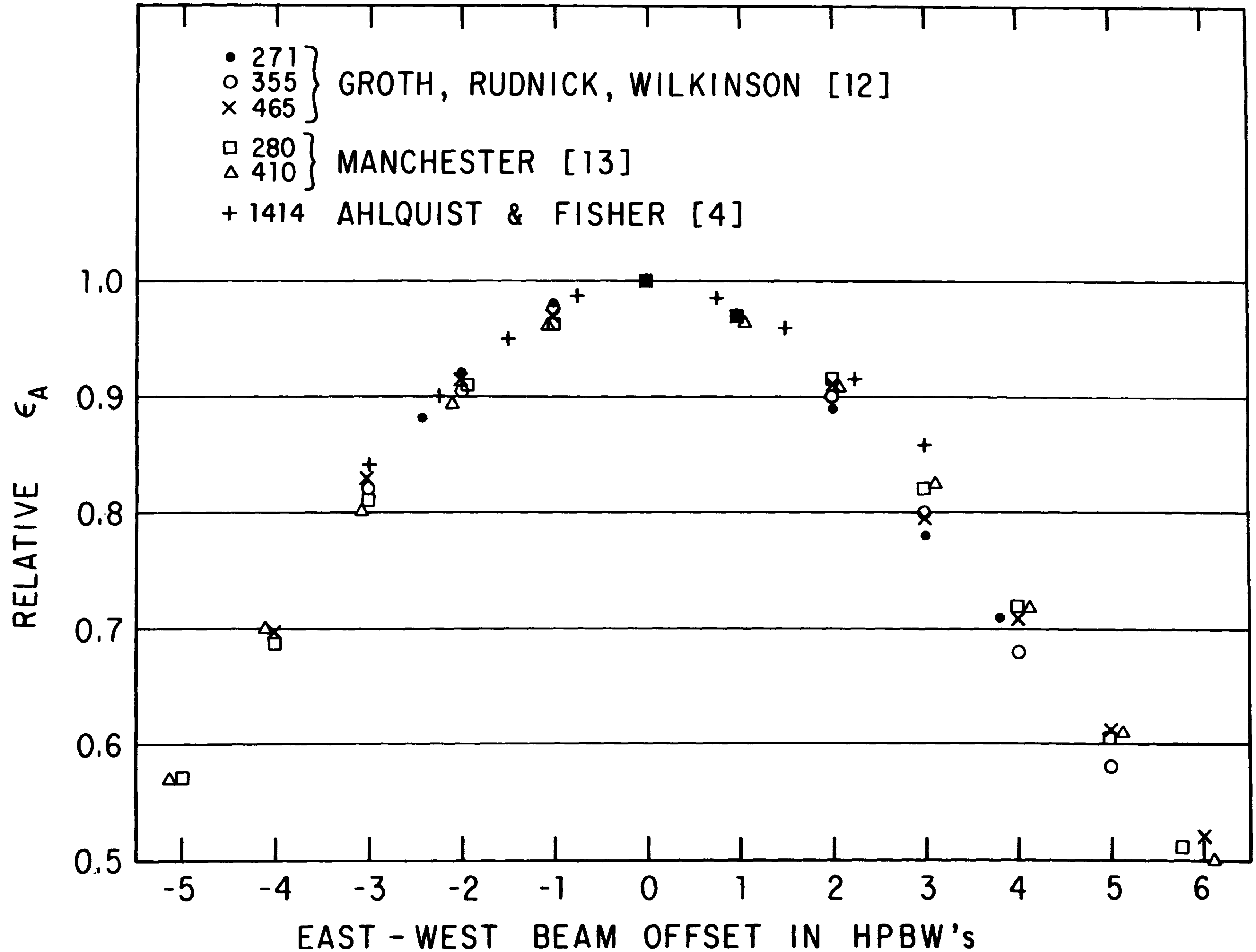


Figure 2-8. Relative aperture efficiency as a function of beam offset measured at several frequencies on the 300-foot.

important. Note that if one is using the tracking feature of the 300-foot to increase sensitivity by integration, there is often little point in going beyond 5 HPBW, because even with proper weighting of the data very little increase in signal to noise ratio can be obtained with the addition of observations taken when the aperture efficiency is less than half its on-axis value.

Beam efficiency, beam width and beam shape

The remarks under this heading in the previous section apply here with the additional complication that the beam efficiency changes while tracking a source. In equations (2-2) and (2-3), $R(\theta,\phi)$ would also be a function of time. Most of the power lost from the beam peak as the beam moves off axis goes into widening the beam (asymmetrically) and into the coma sidelobe. Thus, the limits on the integrals in equations (2-2) and (2-3) are especially critical. Figure 2-9 shows an example of beam distortion when the beam is off axis. The contour levels do not go quite low enough to show a separate coma sidelobe in this diagram. This figure is intended to be illustrative only because the details of the beam distortion will depend on individual feed properties.

Sidelobes

One important additional sidelobe, the coma lobe, appears when the beam is moved off axis. It is located approximately 1.6 beamwidths from the main beam along a vector from the main beam to the telescope axis, and its strength is strongly dependent on beam deflection and somewhat dependent on illumination taper. The coma lobe can be as high as 10% for displacements of 4 HPBW.

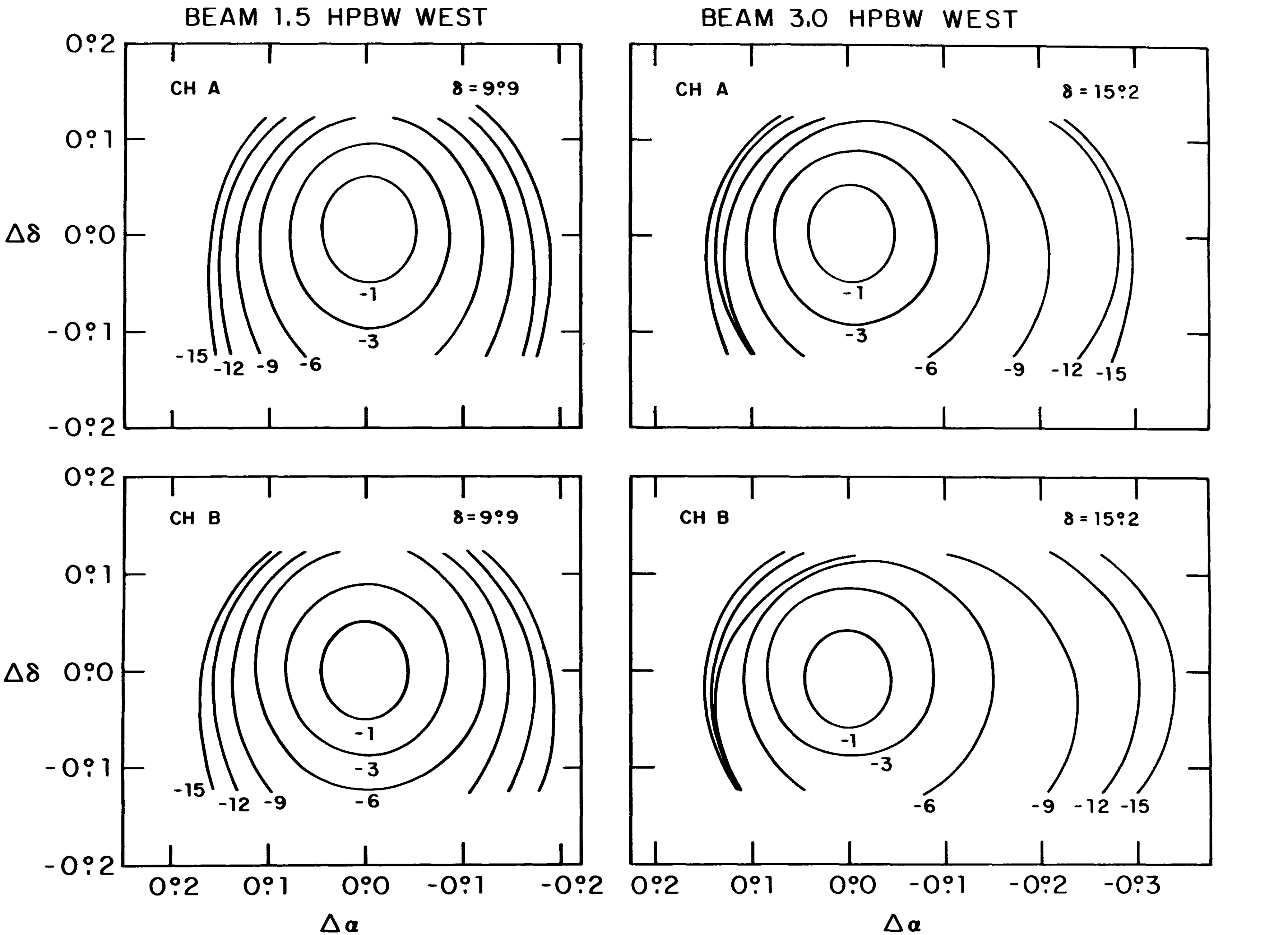


Figure 2-9. Examples of off-axis beam distortion measured with the cooled 21-cm receiver. Top figures are channel A with E vector north-south and the lower figures are channel B with E vector east-west. Contours are -1, -3, -6, -9, -12, and -15 db. Ref. [4].

The near and far sidelobes associated with on-axis operation are still present with the deflected beam, but their detailed structure will change with beam motion.

Pointing (Beam deflection factor)

The on-line computer performs the conversion of commanded hour angle into a feed offset on the travelling feed or Sterling mount, but several parameters (telescope focal length, a beam deflection factor (BDF), and a coded additional BDF) must be given to the computer with the pointing corrections (see "T" card format). The BDF is the ratio of the angular displacement of the beam to the angular feed displacement [11]. For the 300-foot the BDF is usually between 0.84 and 0.875 depending on the feed in use; also, its value at large hour angles on the travelling feed may differ from its value near the center.

The BDF can be measured fairly quickly by scanning the beam back and forth in right ascension across a reasonably strong source while recording the LST (hence source hour angle, h); linear displacement of the feed, L; and receiver response on a chart recorder. From this record the angular feed displacement (L/focal length) and the beam deflection ($h \cos \delta$) for each source-crossing peak can then be determined, and the slope of the line defined by these points is the BDF. To the accuracy of measurement all determinations of the BDF have shown a linear relationship between L and h out to about 6 beamwidths, but at a critical distance of $3^\circ\!.15$ on the travelling feed at 400 MHz the slope was found to change abruptly from 0.854 to 0.868 [9]. A value of 0.856 has been recently determined for the cooled 21 cm receiver [4]. These agree quite well with a value of 0.85 calculated for a -18 db illumination taper on the 300-foot [11]. The critical angle appears to scale with wavelength [32] so if beam displacements of more than 6 HPBW's are to be used the critical angle and additional BDF will have to be determined at the frequency of interest.

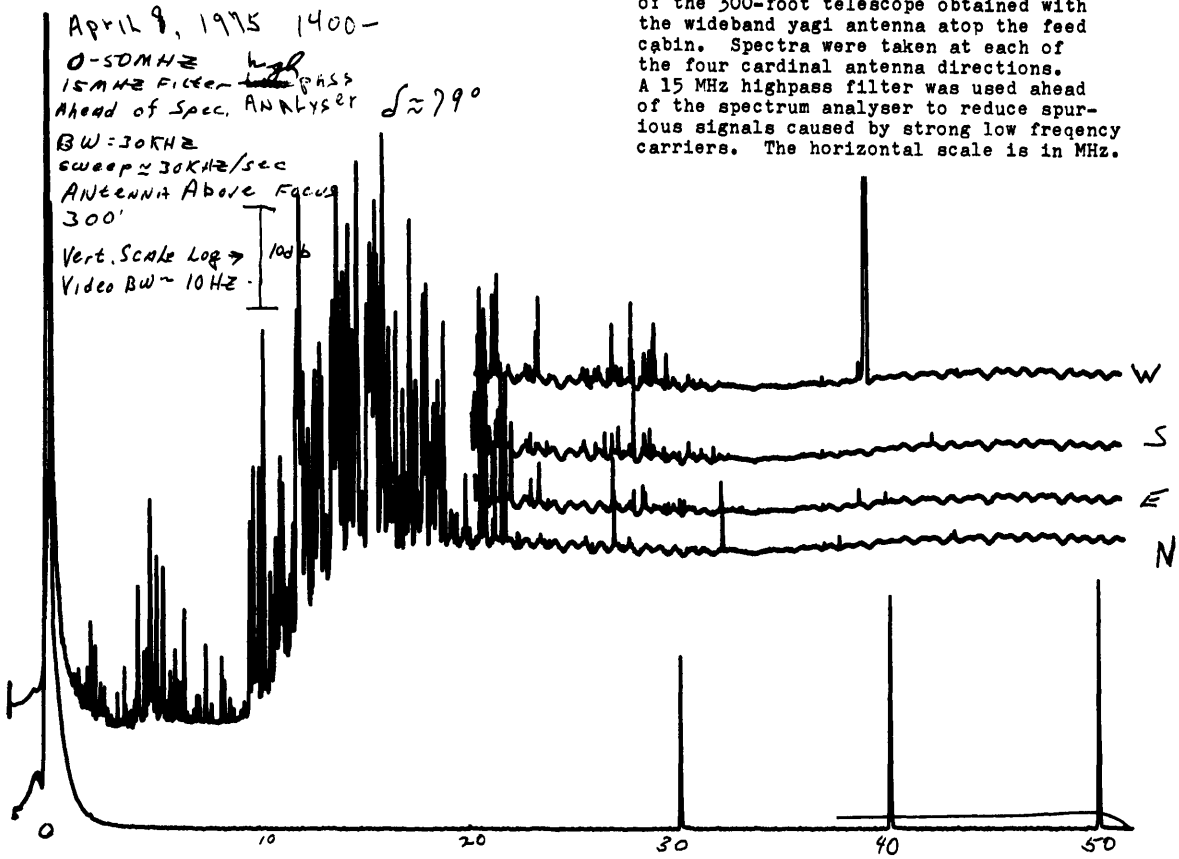
Interference

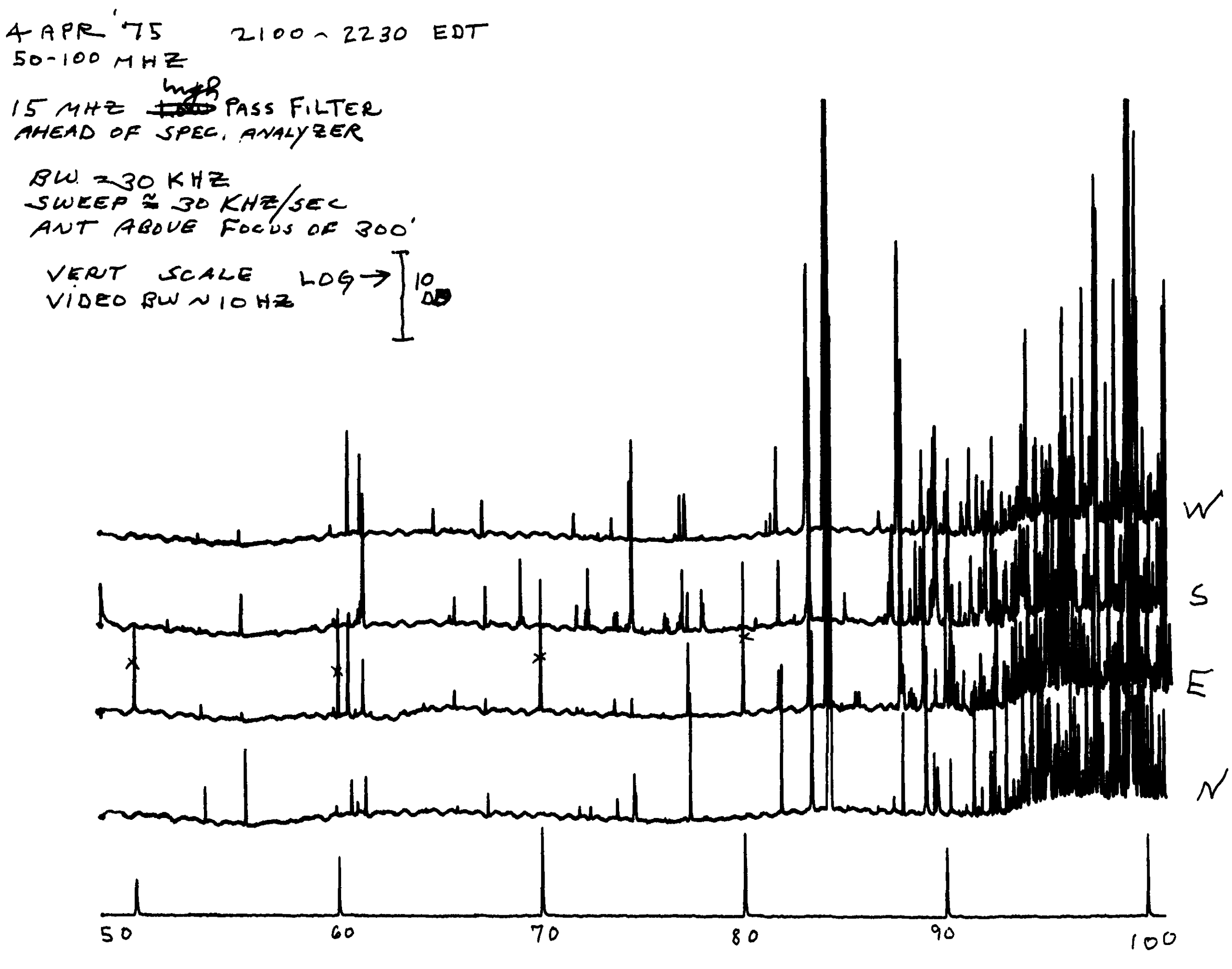
Man-made and natural wide band interference such as ignition, power line, relay, and computer noise, and local thunderstorms can be a severe problem when observing below 1 GHz. Although most of this noise has a very steep spectrum, it is sometimes strong enough to affect continuum observations at 21 cm. Since new man-made noise sources are being encountered continuously, an observer intending to make measurements below 1 GHz which would be affected by wide band noise should notify the person in charge of interference detection at least 2 weeks in advance so that steps can be taken to alleviate the worst problems. Because the radiometers on the telescope are much higher and more sensitive than those available in the mobile interference van, many of the problems will not show up until the receiver is installed on the telescope. If a problem is then encountered, the observer should seriously consider contributing some observing time, if necessary, to help find the source of interference. The observatory personnel are on hand to help in any way possible, but they need as much information as the observer can provide.

Narrow band interference is also much more of a problem at lower frequencies, but there can be errant radar signals or mixing products of lower frequency signals at even the highest usable frequency on the 300-foot. Between 500 and 1000 MHz, band widths of 10 MHz or so can be used as long as one is careful to choose a clear frequency. Below 500 MHz band widths of 1 or occasionally 3 MHz are the maximum usable in most cases without encountering frequent bursts of aircraft transmissions. If one is confined to operating at a specific frequency, chances are high that a significant interfering signal will be within a few MHz of this frequency. A list of all known fixed transmitters within the quiet zone and their approximate signal strength at Green Bank is on file at the observatory [14]. This list is a guide, but does not guarantee a given frequency to be clear because many transmitters outside the quiet zone are well above detection limits.

To provide the observer with what is known about interference at Green Bank, Electronics Division Internal Report No. 159 is reproduced here. Also a set of 50 MHz wide spectra from 0 to 500 MHz taken with the interference antenna mounted above the feed cabin are shown in Figure 2-10. This antenna has about 7 db gain over isotropic and the system temperature is of the order of 600 K. Four spectra were taken at each frequency range, one in each of the 4 cardinal directions. The instantaneous bandwidth of the swept receiver was 30 kHz; the sweep rate was 30 kHz/sec; and the pen time constant was a few tenths of a second. All spectra were taken in April 1975.

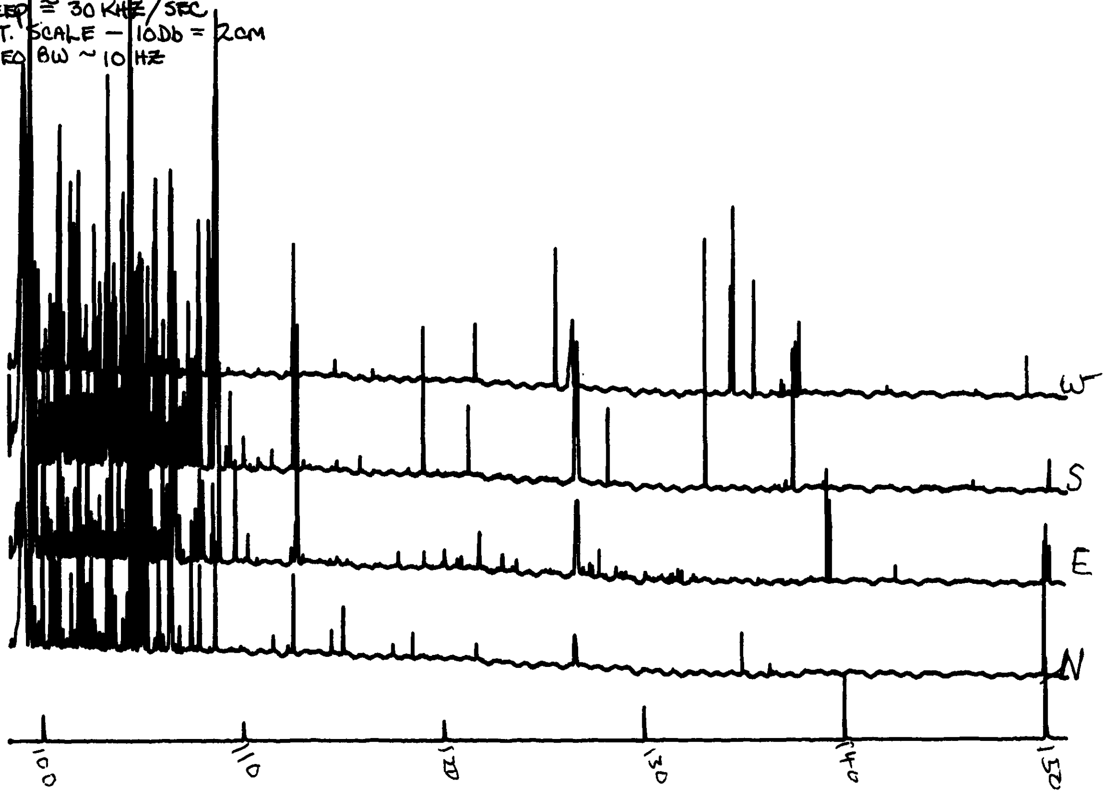
Figure 2-10. Interference spectrum in the vicinity of the 300-foot telescope obtained with the wideband yagi antenna atop the feed cabin. Spectra were taken at each of the four cardinal antenna directions. A 15 MHz highpass filter was used ahead of the spectrum analyser to reduce spurious signals caused by strong low freqency carriers. The horizontal scale is in MHz.





7 April '75
2140 – 2330
15 MHZ PASS FILTER
AHEAD OF SPEC ANALYZER
BW = 30 MHZ
SWEEP ≅ 30 KHZ/SEC
VERT. SCALE — 10Db = 2CM
VIDEO BW ~ 10 HZ

$\delta \cong 39°$
100 - 150 MHZ



5 APRIL '75
1045 —
150 – 200 MHZ

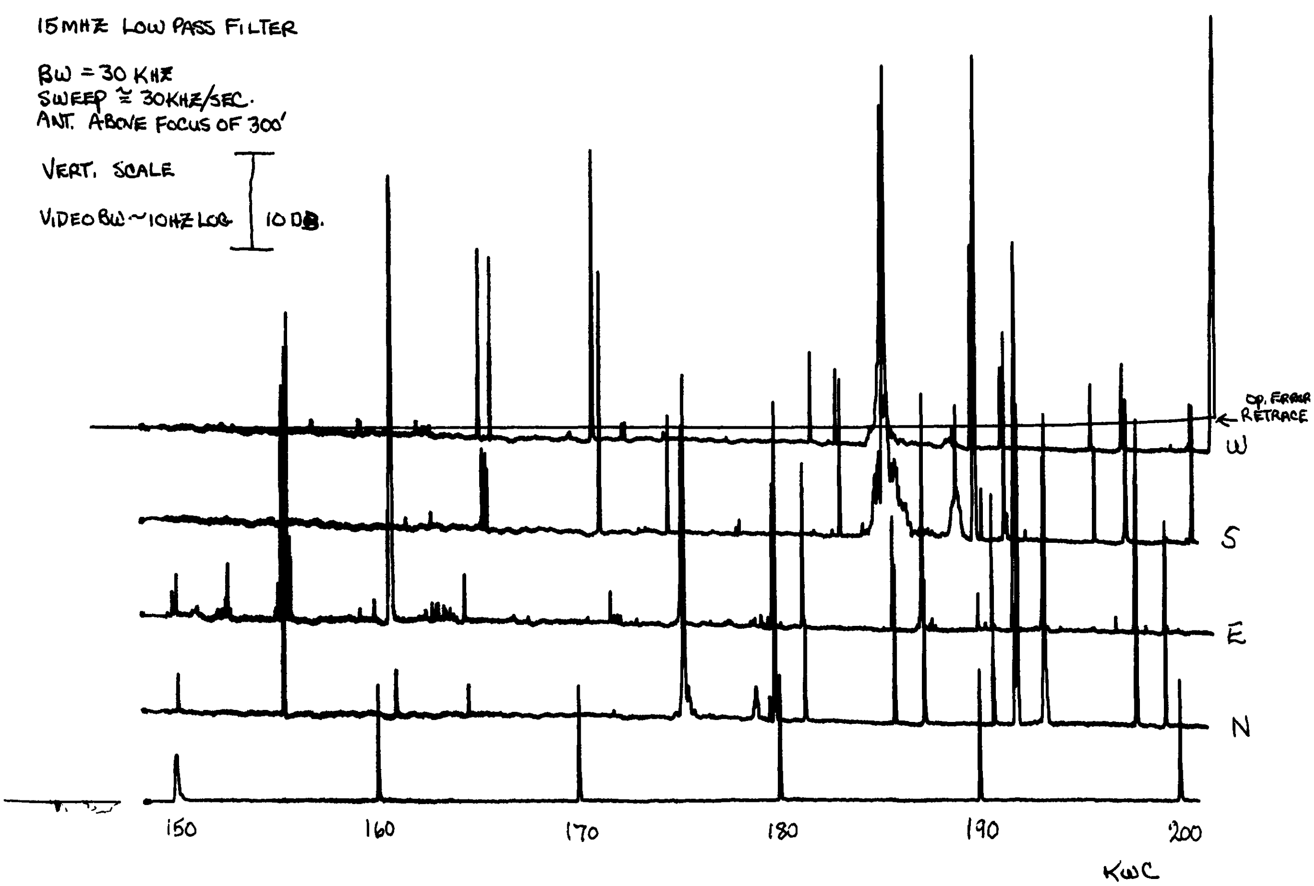
$\delta \simeq 72°$

15 MHZ LOW PASS FILTER

BW = 30 KHZ
SWEEP ≅ 30KHZ/SEC.
ANT. ABOVE FOCUS OF 300'

VERT. SCALE

VIDEO BW ~ 10HZ LOG 10 DB.



7 Apr 75

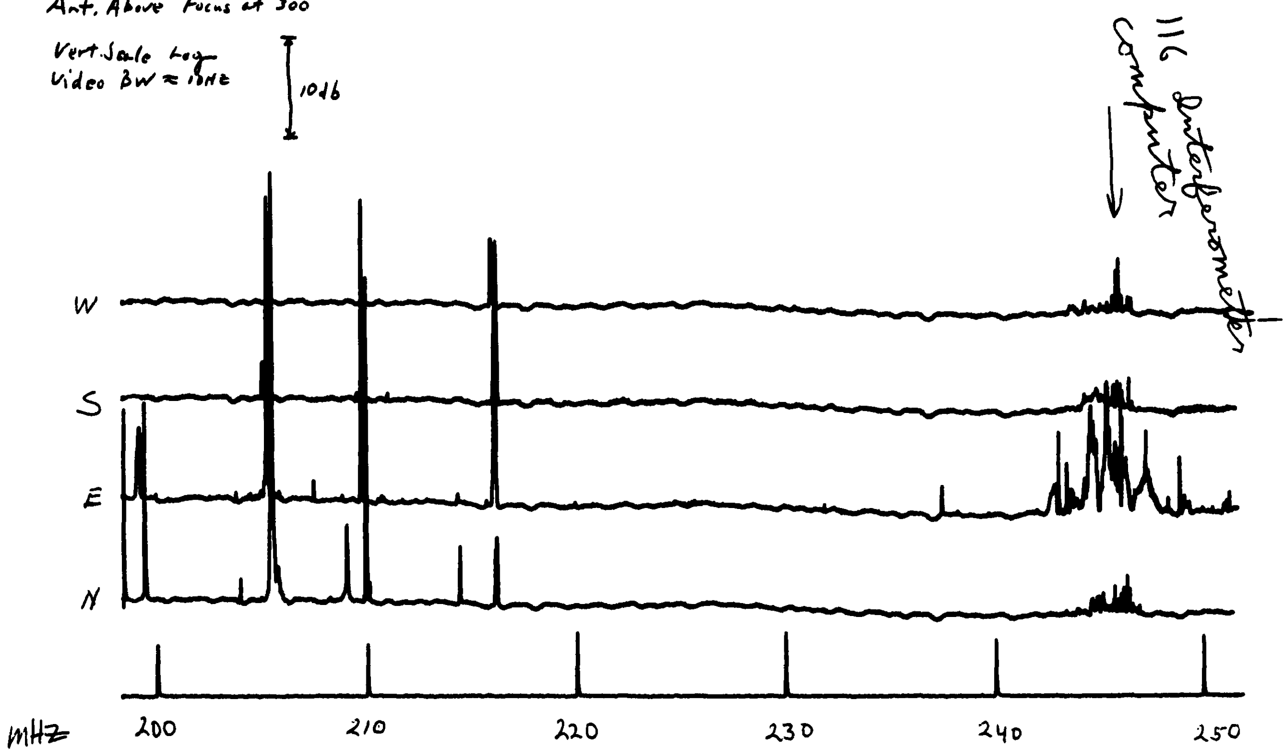
$\delta = 39^{0}$

0130 EDT — 0310 EDT

15 MHz ~~low~~ high Pass Filter ahead of Spec. Analyzer
BW = 30 KHz
Sweep ≈ 30 KHz/sec.
Ant. Above Focus at 300'

Vert. Scale Log
Video BW ≈ 10 Hz

10 db



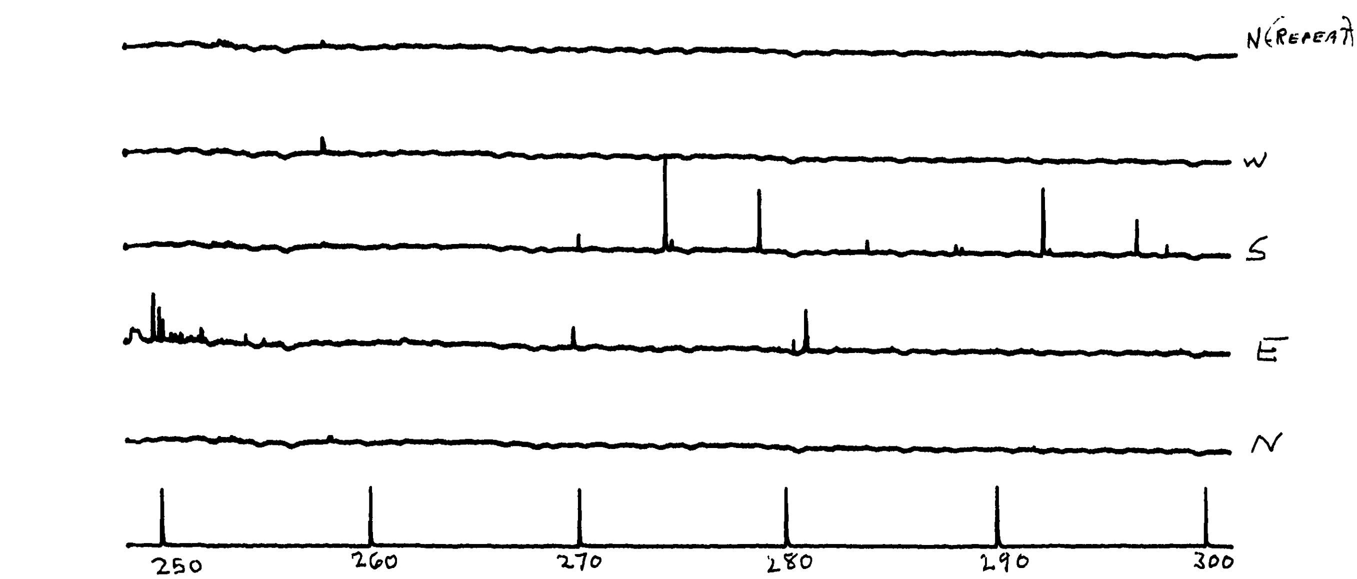
5 APR 75
2145 — ~2310 EDT

250-300 MHz
15 MHz ~~low~~ high PASS Filter
Ahead of Spec. Analyzer

BW = 30 KHZ
Sweep ≅ 30 KHZ/sec

VERT. Scale
VIDEO BW~10HZ Log.

10 db

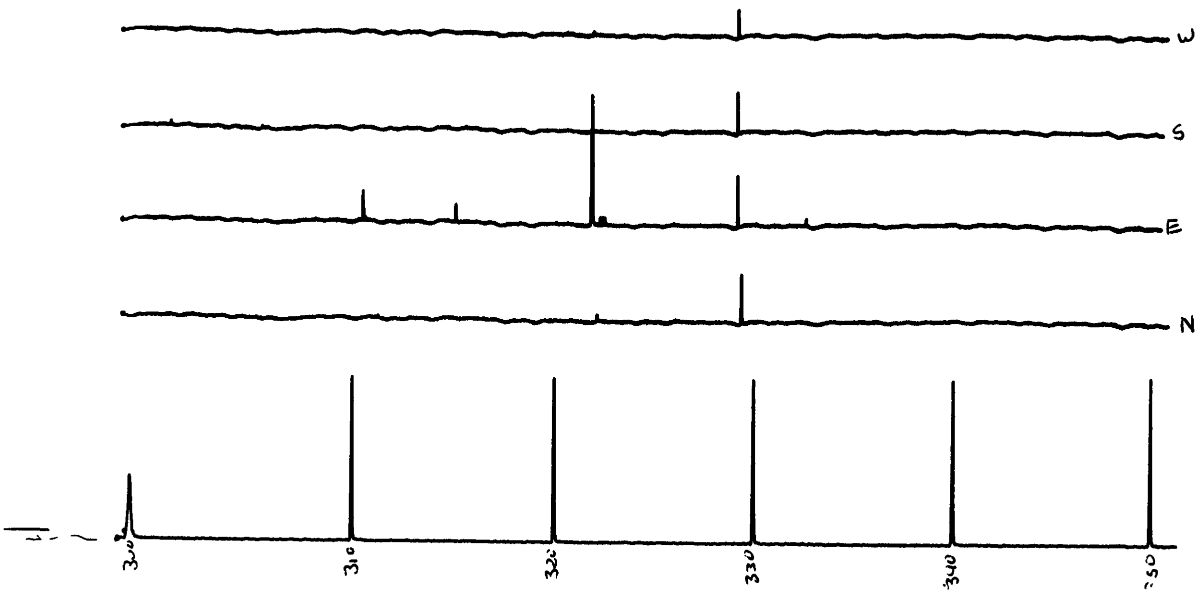


6 APR. 75

~0130 → ~300 EDT
300-350 MHZ

15MHZ high PASS Filter
Ahead of Spec Analyzer
BW = 30 KHZ
Sweep ≅ 30 KHZ/sec

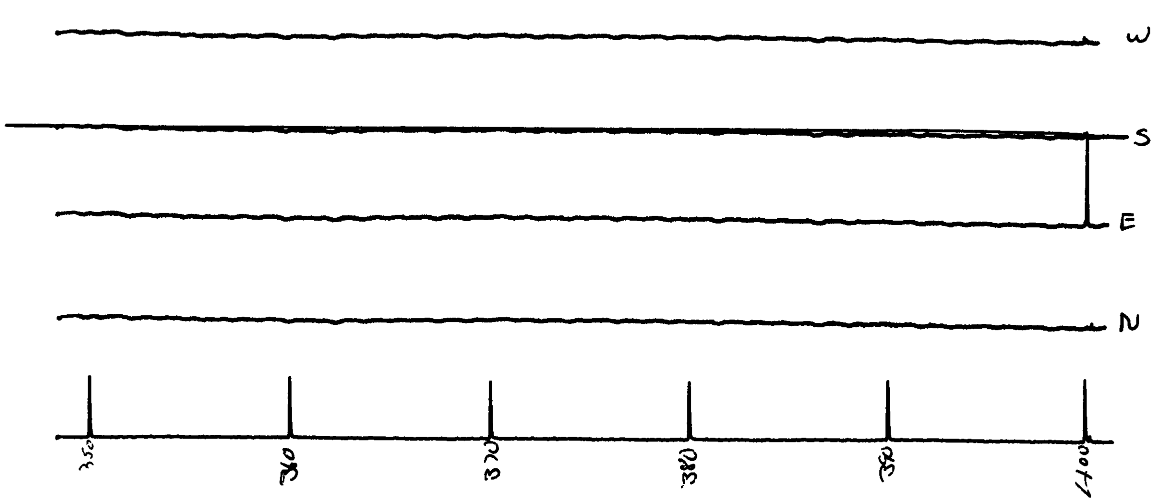
VERT. Scale Log. | 10db.
VIDEO BW ~10HZ



6 APR 75

~0300 → 0430 EDT.
350-400 MHZ

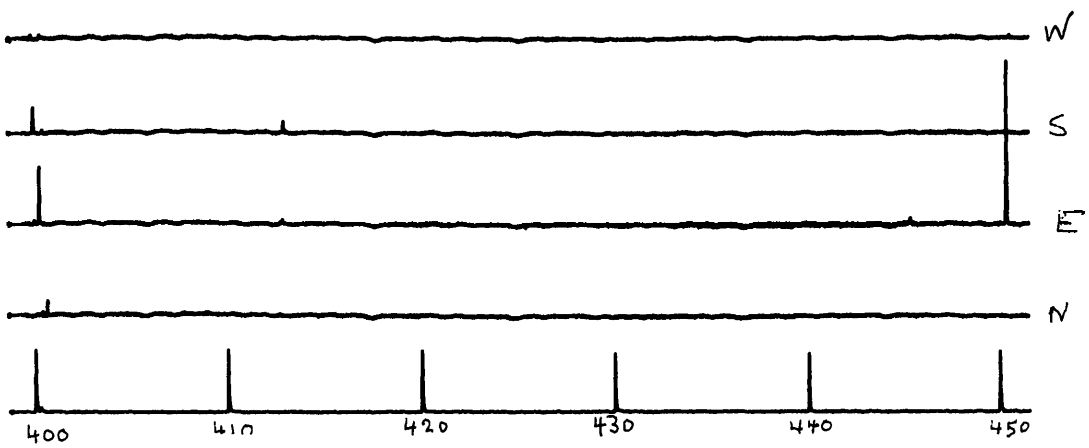
15 MHZ high PASS Filter
Ahead of Spec. Analyzer
BW = 30 KHZ
Sweep ≅ 30KHZ/sec
VERT. Scale Log | 10db
VIDEO BW ~10HZ



6 APR '75
1945–2130 EDT
400–450 MHZ

15 MHZ High Pass Filter
AHEAD OF SPEC ANALYZER
BW = 30 KHZ
SWEEP ≅ 30 KHZ/SEC

VERT SCALE LOG
VIDEO BW ~ 10 HZ
10 DB

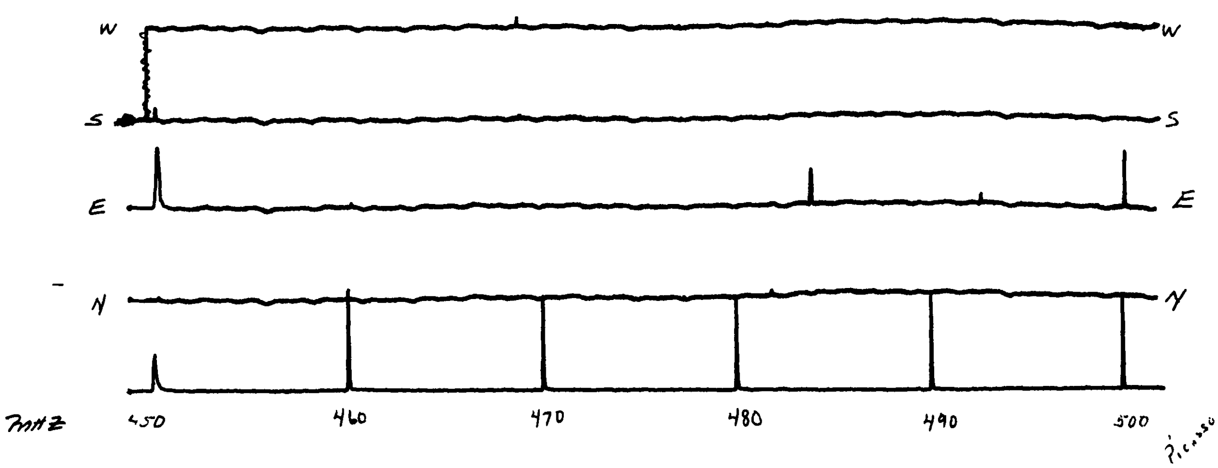


7 APR 75
0010 EDT ~ 0200 EDT

δ ~ 39°

450–500 MHZ
15 MHZ High Pass Filter ahead of
Spec. Analyzer
BW = 30 KHZ
Sweep ≅ 30 KHZ/sec.
Vert. Scale Log
Vidio BW ≅ 10 HZ

10 db.



Picasso

INTERFERENCE POTENTIAL FOR RADIO ASTRONOMY OBSERVATIONS AT GREEN BANK, WEST VIRGINIA

Craig R. Moore and James L. Dolan

Introduction

This report attempts to summarize possible sources of radio interference to radio astronomy observations at the NRAO, Green Bank, WV. The interference is considered to originate from three categories of sources: radiometers and electronics equipment at Green Bank, FCC and IRAC licensed emitters within and outside the Radio Quiet Zone, and unintentional sources of interference, i.e., emissions from automobile ignitions, power lines, TV boosters, etc. This report is intended as an aid to line observers in particular, so that they might judge the magnitude of the interference problem before they begin observations. It is strongly urged that this report be consulted whenever observations at wavelengths longer than 21 cm are contemplated. The National Radio Quiet Zone does not guarantee that there will be no interference at Green Bank; it merely provides that we will know more about the sources and potential than at any other location in the U. S.

A. Green Bank Electronics Equipment

Most of our radiometers are potential sources of narrow-band interference. A list of possible spurious signals is attached.

The most likely sources of inter-telescope interference are the Universal Local Oscillators which can generate up to 1 watt in the frequency range 1-2 GHz. We have had cases of this occurring: (1) between lab and 140-ft and (2) 140-ft and 300-ft. In these cases the RF output was tuned within the pass band of the line receivers.

The interferometer and 45-ft microwave link is also another known source of trouble, especially at 1300.0, 1347.4, 1347.5, and 1347.6 MHz. The link can be turned off for some observations; however, the 1347.5 signal might still be seen at the 300-ft telescope with the autocorrelator.

Spectral line observers would be well advised to check this list before observing. The Electronics Division engineer responsible for a system will attempt to minimize interference and warn the observers of possible problems.

It should be noted that only a few of these signals will be present at any one time, and most have never been seen as interference.

INTERFERENCE POTENTIAL OF EQUIPMENT AT GREEN BANK
LISTING BY FREQUENCY

Frequency MHz	Status	Potential Source	Location	Frequency MHz	Status	Potential Source	Location
30	P	Interferometer LO system	Interf. Baseline	1650–1950	*	2-4 GHz receiver	140'
35	P	Autocorrelator, Mark II, III	140' & 300' or Int.	1669–1731	*	Cooled 2 cm receiver	140'
40	P	Autocorrelator, Mark II, III	140' & 300' or Int.	1690–1930	*	Cooled 18 cm receiver	140' or 300'
43.0	†	VHF FM communications	Reber	1700	P	Universal LO	140' & 300'
100		Cooled 2 cm receiver	140'	1720–1780	*	Cooled 3 cm receiver	140'
100		Cassegrain receiver	140'	1823–1954	*	Cassegrain receiver	140'
100	P	Universal LO	140' & 300'	2100–2400	*	2-4 GHz receiver	140'
90–100	P	Hydrogen maser	140'	2445	*	13 cm VLB receiver	140'
103	P	IF Processor	140' & 300'	2545	*	11 cm receiver	140' or 300'
115	P	IF Processor	300' & 140'	2600–3100	*	2-4 GHz receiver	140'
100–160	P*	IF Processor - GR synthesizer	140' & 300'	2695		11 cm, 3-feed	300'
120	P	Autocorrelator, Mark II, III	140' & 300' or Int.	2695	P	Interferometer receivers	85' - 1, 2, 3
124–180	*	12.4-18 GHz line receiver	140'	3150–3270	*	Cassegrain receiver	140'
134.75		11 cm, 3-feed receiver	300'	3300–3900	*	2-4 GHz receiver	140'
240–300	P*	Universal LO - HP synthesizer	140', 300' & Int.	4400		Cassegrain receiver	140'
250–1150	*	100-1000 MHz receiver	140'	4680–5160	*	6 cm AIL receiver	140' or 300'
350–590	*	500-740 MHz receiver	140' or 300'	4680–4980	*	6 cm TRG receiver	140' or 300'
590–850	*	740-1000 MHz receiver	140' or 300'	5050–10,550	*	5.4-10.4 GHz receiver	140'
650–890	*	500-740 MHz receiver	140' or 300'	5390	P	Interferometer receivers	85' - 1, 2, 3
670	†	Temp. calibration receiver	Little Big Horn	5390		11 cm, 3-feed receiver	300'
890–1150	*	740-1000 MHz receiver	140' or 300'	6938	†	Interferometer 21 cm receiver	85' - 1, 2, 3
900		Cooled 2 cm receiver	140'	7550–7850	*	7.8 GHz cooled receiver	140'
900	P	Universal LO	140' & 300'	8085	P	Interferometer receivers	85' - 1, 2, 3
1000–1250	*	5.2-10.4 GHz receiver	140'	10,000–10,340	*	1-2 GHz receiver	140'
1000–1600	P*	IF Processor	140' & 300'	10,320–10,680	*	Cooled 3 cm receiver	140'
1000–2150	*	1-2 GHz receiver	140' & 300'	10,612		Cassegrain receiver	140'
1030	P	IF Processor	140' & 300'	11,320–11,390	*	2-4 GHz receiver	140'
1050–1090	*	Cassegrain receiver	140'	11,835		13 cm VLB receiver	140'
1050–1200	*	2-4 GHz receiver	140'	12,400–18,000	*	12.4-18 GHz line receiver	140'
1079–1121	*	7.8 GHz cooled receiver	140'	13,350–13,850	*	Cooled 2 cm receiver	140'
1100		Cassegrain receiver	140'	16,170	P	Interferometer receiver	85' - 1, 2, 3
1150	P	IF Processor	300' usually	17,450–19,050	*	Cassegrain receiver	140'
1220–1290	*	Cooled 21 cm receiver	140' or 300'	17,500	P	Link from 45'	45'
1222.5	*	13 cm VLB receiver	140'	19,150–20,150	*	Cassegrain receiver	140'
1250	†	Temp. calibration receiver	Little Big Horn	20,000–21,000		500-700, 740-1000 MHz receivers	140' or 300'
1272.5	*	11 cm Receiver	140' or 300'	20,000–22,000	†	Tourist receiver	2'
1300	P	Universal LO	140' & 300'	20,200–20,400		Cooled 21 cm receiver	140' or 300'
1300	P	Link to 45'	Interf. Tower	20,600		6 cm AIL receiver	140' or 300'
1300–1550	*	2-4 GHz receiver	140'	20,815		21 cm, 4-feed receiver	140' or 300'
1317.5	P	Interferometer LO	Interf. Baseline	20,815	†	Interferometer 21 cm receiver	85' - 1, 2, 3
1347.4	P	Link from 45'	45'	21,700		Cooled 18 cm receiver	140' or 300'
1347.5	P	Interferometer LO	Interf. Baseline	23,670		13 cm VLB receiver	140'
1347.6	P	Link to 45'	Interf. Tower	27,450		11 cm receiver	140' or 300'
1390–1630	*	Cooled 18 cm receiver	140' or 300'	31,400–35,600	*	5.2-10.4 GHz receiver	140'
1400	P	Hydrogen maser	140'	31,835		Cassegrain receiver	140'
1475–1575	*	Cassegrain receiver	140'	33,400		7.8 GHz cooled receiver	140'
1520–1590	*	Cooled 21 cm receiver	140' or 300'	39,700		6 cm TRG receiver	140' or 300'
1550		21 cm, 4-feed	300'	40,000		Cooled 3 cm receiver	140'
1560–1660	*	6 cm TRG receiver	140' or 300'	41,900		Cooled 2 cm receiver	140'
1560–1720	*	2-4 GHz receiver	140'				

P - ON SEMI-PERMANENTLY. * - MOVES AROUND DURING OBSERVING SESSION. † - INTERMITTENT USAGE.

INTERFERENCE POTENTIAL OF EQUIPMENT AT GREEN BANK

LISTING BY EQUIPMENT

Receiver	Signal on Cable	LO	Pump	Remarks
50- 80 MHz 110-250 MHz 250-500 MHz	None. None. None.	None. None. None.	None. None. None.	) IF Processor used as) frequency converter) for those receivers.
500-740	350-590, 650-890	350-590, 650-890	20-21 GHz	X2 downstairs.
740-1000	590-850, 890-1150	590-850, 890-1150	20-21 GHz	X2 downstairs.
100-1000	250-1150	250-1150	None.	X2 downstairs (if needed).
21 cm, 4-feed	1550	1550	20.215 GHz	
21 cm cooled	1220-1290, 1520-1590	1220-1290, 1520-1590	20.2-20.4 GHz	
18 cm cooled	1390-1630, 1690-1930	1390-1630, 1690-1930	21.7 GHz	
1-2 GHz	1000-2150 MHz	1000-2150	10.0-10.34 GHz	Set of four paramps.
2-4 GHz	1050-1200, 1300-1550, 1650-1950	2100-2400, 2600-3100, 3300-3900	11.23-11.39 GHz	Set of three multipliers and paramps.
2295 VLB	1222.5	2445	11,835 x 2	
11 cm, 3-feed	None.	2695	5390	2695 MHz oscillator locked to 134.75 MHz.
11 cm	1272.5	2545	27.45 GHz	
6 cm AIL	1560-1720	4680-5160	20.6 GHz	
6 cm TRG	1560-1660	4680-4980	39.7 GHz	
7.8 GHz cooled	1079-1121	7550-7850	33.4 GHz	
5.2-10.4 GHz	1000-1250	5050-10,550	31.4-35.6 GHz	Set of seven paramps.
3 cm cooled	1720-1780	10,320-10,680	40.0 GHz	
2 cm cooled	1669-1731 100	13,350-13,850 900	41.9 GHz	 2nd LO.
12.4-18 GHz	124-180 MHz	12,400-18,000	None.	Locked BWO LO.
Interferometer	30.0, 1317.5, 1347.5	1347.5	NA	Multiplexed X2,X4,X6,X12
		2695	5390	S-Band receiver
		8085	16,170	X-Band receiver
		1347.5	6930 x 3	21 cm receiver
	1300, 1347.6	NA	NA	Link to 45'
	17,500, 1347.4	NA	NA	Link from 45'
140' Cassegrain	1823-1970	17,450-19,250	NA	K-Band receiver.*
	1475-1575	19,150-20,150	NA	Ku-Band receiver.*
	100	1100 x 4	10,612 x 3	6 cm receiver.
	1080-1090	NA	3150-3270	18/21 cm receiver.*
Little Big Horn	NA	670 or 1250	NA	GR unit oscillator LO.
2' Tourist	NA	20,000-22,000	NA	

* 6 CM RECEIVER REQUIRED FOR IF AND 2ND CONVERSION.

OTHER SOURCES

(Above 15 MHz)

Equipment	Frequency	Remarks
VHF-FM Communications Transmitter	43.0	Mobile communications to 45-ft.
Autocorrelator — Mark II and Mark III	120.0 40.0 35.0	Crystal oscillators within RF enclosure.
IF Processor — 140-ft and 300-ft	100- 160 1000-1600 103 1030 115 1150	GR synthesizer. Multiplier and locked oscillator. Locked oscillator. Multiplier output. Crystal oscillator. Multiplier output.
Universal Local Oscillator	240-300 100 900, 1300, 1700	HP synthesizer. Locked oscillator) Frequency counter Multiplier output) Frequency counter
Hydrogen Maser — 140-ft	1400 90-100	1st LO Ionization oscillator.
Antenna Test Range	100 MHz - 90 GHz	Intermittent usage.

B. Licensed Transmitters Within the Radio Quiet Zone

When the radio controlled zone was authorized by the FCC and the IRAC in 1958, the NRAO started keeping records of all licenses issued within the area. Over the years some of the transmitters that were in existence before this time have been added to our records until at present the list is estimated to be about 97% complete. The computer printout of these licensed emitters is updated once each year, and copies are available to prospective observers; also, each telescope has at least one copy. The list includes pertinent technical parameters and a prediction of power density at Green Bank from each transmitter. Most of the transmitters are in point-to-point communications bands, FCC, or military aircraft bands, and broadcast bands. The list contains fixed licensed transmitters, other than amateur and citizen band, within the zone. A sample page from the report is attached.

However, stations outside the zone can also cause interference. In order to satistically sample band occupancy, a spectrum survey was made with wide-band radiometers and a spectrum analyzer. This survey was made during the summer of 1971. The data is still indicative of signals actually observable at Green Bank. The survey covered the spectrum from 100 MHz to 4.0 GHz, and copies of this Electronics Division Internal Report No. 116 are available at all telescopes. A sample page from this report is attached. It should be pointed out that the attached page from the transmitter printout shows no licensed emitters between 172 MHz and 218 MHz within the Quiet Zone, and the page from the Green Bank survey shows several strong TV signals in the 204-216 MHz band.

A brief description of the survey results follow.

From: National Radio Quiet Zone
Transmitter Print Out, 9/74.

GREEN BANK
INTERFERENCE QUICK LOOK
08/22/74

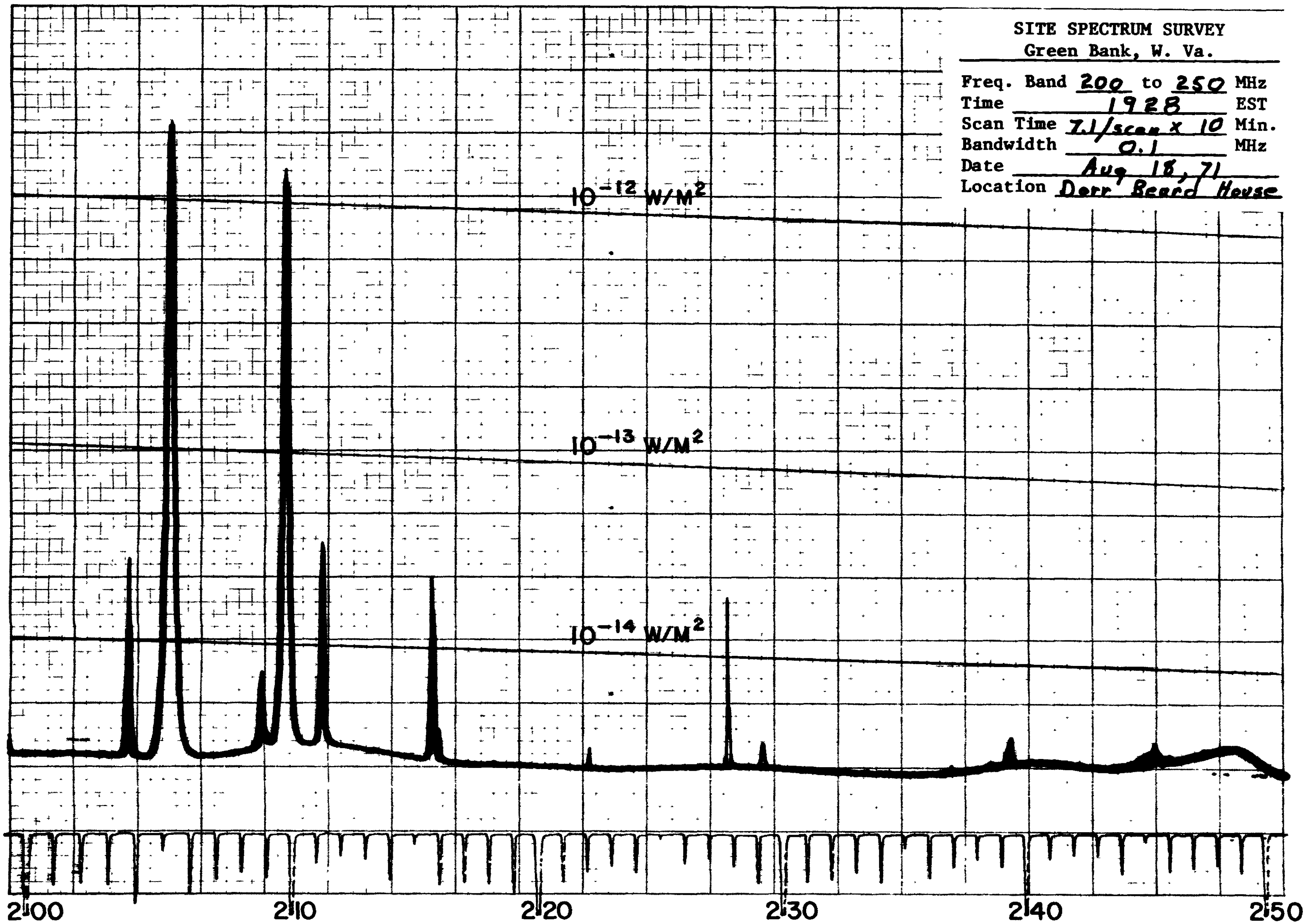
CARD CONTENTS

	STAT NO	STAT CALL	LONG	LATD	CODE	FREQUENCY	DATE	EMISN	POWER	DENSITY	AZH	DST
1151	610		8013 0	3732 0	1	0.172300E 09	7 68	16F3	0.5E 02	2.0E-15	199	105
1152	640	NAVY	79 4 0	38 9 0	1	0.218000E 09	06 57	M2P0	0.2E 07	2.0E-19	115	74
1153	1099		794415	391650	1	0.252400E 09	03 67		0.1E 03	9.0E-21	5	94
1154	641	FAA	7952 0	3853 0	1	0.255400E 09	11 53	6A3	0.1E 03	1.0E-19	358	49
1155	1343		80 558	385452	1	0.258000E 09	03 71	06A3	0.1E 03	2.0E-19	338	57
1156	642	FAA	7845 0	38 6 0	1	0.263100E 09	01 62	6A3	0.1E 03	2.0E-15	111	102
1157	643	FAA	7911 0	3748 0	1	0.269200E 09	12 61	6A3	0.1E 03	4.0E-15	141	91
1158	644	FAA	7844 0	38 6 0	1	0.279600E 09	12 57	6A3	0.1E 03	6.0E-22	111	103
1159	645	FAA	7844 0	38 6 0	1	0.301400E 09	01 58	6A3	0.1E 03	4.0E-22	111	103
1160	1362		784437	38 615	2	0.319000E 09	08 71	06A3	0.1E 03	2.0E-15	111	102
1161	646	FAA	7845 0	38 6 0	1	0.321300E 09	12 61	6A3	0.1E 03	2.0E-15	111	102
1162	1586		802412	375118	2	0.330800E 09	01 74	0.3A9	0.4E 01	2.0E-17	219	81
1163	1579		7854 6	381535	2	0.332600E 09	12 73		0.4E 01	1.0E-18	103	83
1164	1363		784437	38 615	2	0.346000E 09	08 71	06A3	0.1E 03	2.0E-15	111	102
1165	647	FAA	7911 0	3748 0	1	0.353900E 09	12 61	6A3	0.1E 03	3.0E-15	141	91
1166	648	FAA	7845 0	38 6 0	1	0.380300E 09	12 61	6A3	0.1E 03	2.0E-15	111	102
1167	649	KQC300	7951 0	3855 0	1	0.411300E 09	69	36F3	0.6E 02	1.0E-19	360	53
1168	730	KQC300	7943 0	3857 0	1	0.415300E 09	69	36F3	0.6E 02	6.0E-22	10	57
1169	1387		795059	385533	1	0.417000E 09	01 72	16F3	0.4E 01	1.0E-19	360	54
1170	1528		7911 0	374740	1	0.417500E 09	04 73	100F9	0.1E 02	7.0E-18	141	91
1171	1386		795059	385533	1	0.418000E 09	01 72	16F3	0.3E 02	1.0E-19	360	54
1172	1408		783751	3836 5	5	0.450000E 09	06 72	36F3	0.7E 00	2.0E-19	80	106
1173	1513		783757	3836 5	6	0.450000E 09	03 73	36F3	0.7E 00	1.0E-18	80	106
1174	388	KBG24	7854 2	374752	9	0.451000E 09	10 60	20F3	0.6E 02	2.0E-20	131	108
1175	1300		79 433	38 9 2	6	0.451000E 09	07 70	20F3	0.1E 02	1.0E-19	115	73
1176	872	KJ096	802037	383015	9	0.451100E 09	02 64	40F3	0.5E 03	5.0E-12	281	44
1177	30	KQE65	794239	385613	9	0.451200E 09	06 52	40F3	0.5E 03	3.0E-16	11	56
1178	157	KIB83	7938 1	374915	9	0.451500E 09	04 50	20F3	0.4E 02	1.0E-19	165	70
1179	1033	KPU26	792140	3732 0	9	0.451600E 09	11 66	40F3	0.2E 03	8.0E-21	157	108
1180	206	KJD46	791115	373415	7	0.451800E 09	01 60	40F3	0.2E 03	3.0E-16	149	111
1181	334	KJB70	791115	373415	7	0.451900E 09	06 59	40F3	0.6E 03	3.0E-16	149	111
1182	873	KJE20	791115	373415	7	0.451900E 09	03 60	20F3	0.2E 03	3.0E-16	149	111
1183	875	KRD59	79 440	385914	7	0.451900E 09	11 64	40F3	0.2E 03	4.0E-20	47	89
1184	427	KDH70	783757	3836 6	7	0.451900E 09	02 62	40F3	0.6E 03	2.0E-18	80	106
1185	1522		79 250	383610	6	0.453000E 09	04 73	20F3	0.2E 03	3.0E-17	75	71
1186	789	KVR95	791110	373330	4	0.453000E 09	02 65	20F3	0.2E 03	3.0E-23	150	113
1187	502	KQJ94	802644	374812	8	0.453300E 09	04 58	40F3	0.6E 03	2.0E-15	218	88
1188	877	KIC66	79 250	38 937	8	0.453900E 09	08 50	40F3	0.5E 03	1.0E-18	114	75
1189	878	KIY804	783757	3836 5	5	0.455000E 09	05 63	10F3	0.2E 02	2.0E-18	80	106
1190	1409		785434	382712	5	0.455000E 09	06 72	36F3	0.2E 02	2.0E-18	89	80
1191	1411		782458	382844	5	0.455000E 09	06 72	36F3	0.2E 02	2.0E-18	87	123
1192	389	KBG25	785251	374516	9	0.456000E 09	10 60	20F3	0.6E 02	1.0E-20	132	113
1193	879	KJ097	802459	382842	9	0.456100E 09	02 64	40F3	0.5E 03	1.0E-11	276	50
1194	1175	KYU56	79 311	38 755	9	0.456100E 09	10 67	20F3	0.2E 03	2.0E-19	116	76
1195	154	KQE64	7951 0	385533	9	0.456200E 09	06 52	40F3	0.5E 03	1.0E-19	360	54
1196	158	KIB82	792737	374730	9	0.456500E 09	04 50	20F3	0.4E 02	3.0E-20	155	79
1197	1027	KPU25	791115	373415	9	0.456600E 09	11 66	40F3	0.2E 03	3.0E-16	149	111
1198	880	KDH69	784057	383842	7	0.456900E 09	02 62	40F3	0.6E 02	9.0E-20	77	102
1199	1248	KBV71	801712	38 520	7	0.456900E 09	06 51	20F3	0.4E 02	6.0E-14	226	55
1200	194	KRD60	79 7 6	3859 2	7	0.457000E 09	11 66	40F3	0.6E 03	1.0E-20	46	87

POWER DENSITY SPECTRUM

	EXPONENT -21 . . . . -9
1151	. . . . * . 2 . . . . . .
1152	. . 2 . * . . . .
1153	.9. . . * . . . .
1154	. . 1 . * . . . .
1155	. . 2 . * . . . .
1156	. . . . * . 2 . . . . . .
1157	. . . . * . .4. . . . . .
1158	. . . . - . . . .
1159	. . . . - . . . .
1160	. . . . * . 2 . . . . . .
1161	. . . . * . 2 . . . . . .
1162	. . . . 2 . . . .
1163	. . . 1 * . . . .
1164	. . . . * . 2 . . . . . .
1165	. . . . * . 3 . . . . . .
1166	. . . . * . 2 . . . . . .
1167	. . 1 . * . . . .
1168	. . . . - . . . .
1169	. . 1 . * . . . .
1170	. . . .7* . . . .
1171	. . 1 . * . . . .
1172	. . 2 . * . . . .
1173	. . . 1 * . . . .
1174	. 2 . . * . . . .
1175	. . 1 . * . . . .
1176	. . . . * . . . . .5. . .
1177	. . . . * 3 . . . .
1178	. . 1 . * . . . .
1179	.8. . . * . . . .
1180	. . . . * 3 . . . .
1181	. . . . * 3 . . . .
1182	. . . . * 3 . . . .
1183	. .4. . * . . . .
1184	. . . 2 * . . . .
1185	. . . . 3 . . . .
1186	. . . . - . . . .
1187	. . . . * . 2 . . . . . .
1188	. . . 1 * . . . .
1189	. . . 2 * . . . .
1190	. . . 2 * . . . .
1191	. . . 2 * . . . .
1192	. 1 . . * . . . .
1193	. . . . * . . . . . 1 . .
1194	. . 2 . * . . . .
1195	. . 1 . * . . . .
1196	. 3 . . * . . . .
1197	. . . . * 3 . . . .
1198	. .9. . * . . . .
1199	. . . . * . . .6. . . . .
1200	. 1 . . * . . . .

From: *Electronics Division Internal Report No. 116,*
"Green Bank Environmental Spectrum Survey: Summer 1971".



FREQUENCIES ARE IN MHZ; BAND EDGES ARE APPROXIMATE.

1) 100-108: Commercial FM; no chance to observe.

2) 108-118: Radio location omni; possible to observe narrow band between transmitters.

3) 118-137: VHF aircraft, air-to-ground, ground-to-air. Very strong signals; no chance for effective observations.

4) 137-148: Government, 2-meter amateur band. Possible to observe on some frequencies; very little 2-meter amateur activity in the area. Bands should be kept narrow and tunable.

5) 148-200: Includes point-to-point communications bands and commercial television. Small chance of observations. Lots of spurious TV signals make measurements risky.

6) 200-250: More TV up to 216 MHz.

   220-225 -- 1 1/4 meter amateur band should be good spot to observe; no amateur activity in this area.

   225-250 -- fixed mobile; not much activity here; may be possible to observe with narrow bandwidth and tunable front-end.

7) 250-375: Mostly government band, with some aircraft. It may be possible to observe with selected bands and tunable front-end. Some aircraft activity and point-to-point communications.

8) 375-500: Fixed and mobile, and some meteorological aids around 400 MHz.

   406.1-410 -- allocated to radio astronomy. May be possible to observe in 410-470 MHz region, but 450-470 MHz is heavily assigned.

   470 -- beginning of UHF TV channels. Channel 15 is at Roanoke, Virginia and exceeds 10^{-12} W/m^2 at Green Bank.

9) 500-1000: TV broadcast to 806 MHz. Channel 37 (608-614 MHz) can be used for radio astronomy for the present. The remainder of the band is doubtful because of TV assignments outside the zone. It may be possible to select a band that is not assigned near Green Bank. This would have to be done on an individual basis.

10) 1000-2000: DME-TACAN on 1.1 GHz ± 100 MHz. Avoid this area; these aircraft signals make observing virtually impossible.

   1200-1350 -- considerable radar signals in this area. Possible to observe only under carefully controlled conditions. Some satellite signals just above radio astronomy band, extending up to 1700 MHz. Also radiosondes around 1680 MHz. SMS series satellites centered around 1681 MHz with sidebands extending through the 1660-1670 MHz band.

   1800-2000 -- mostly government; may be possible to observe under controlled conditions.

11) 2000-4000: Regular observations carried out on 2695 MHz (11 cm) and 3100 MHz (9 cm). Some trouble with ATS series satellites but not expected to be permanent -- at present only about 2 to 3 hours per week. Not much known about remainder of band, but it should be possible to observe relatively interference-free in selected areas.

C. Other Sources of Interference

The potential interfering signals discussed in the preceding paragraphs are intended, man-made signals of one type or another. Possibly the more troublesome type of interference is unintended radiation from various sources, particularly in the range from 100 to 1000 MHz. Interference from commercial power lines, oscillating TV boosters, gasoline engine ignition systems, defective switches, relays, etc., adinfinitum, are definite possibilities.

An effort is made to keep local sources suppressed, but astronomers and operators should report instances of this type of interference to the Electronics Division.

ADDENDUM

NATIONAL RADIO ASTRONOMY OBSERVATORY

TECHNICAL DATA SHEET — No. 16

MAY 1975 — PAGE 1 OF 1

INTERFERENCE POTENTIAL AT GREEN BANK, WEST VIRGINIA

BANDS WHERE OBSERVATIONS ARE SUBJECT TO INTERFERENCE:

88	-	108 MHz	......	FM commercial.
118	-	137 MHz	......	VHF communications bands.
174	-	216 MHz	......	Commercial VHF TV.
240	-	250 MHz	......	Wideband computer noise.
470	-	590 MHz	......	Commercial UHF TV.
1000	-	1200 MHz	......	DME, TACAN, Elkins radar 1179 MHz.
1275	-	1325 MHz	......	Radar.
1300	±	1 MHz	......	Interferometer link.
1347.5	±	1 MHz	......	Interferometer link.
1683	±	5 MHz	......	SMS satellites, radiosondes.
2660	±	30 MHz	......	ATS-6 satellite.
17500	±	1 MHz	......	Interferometer link.

BANDS WHERE OBSERVATIONS MAY BE MADE UNDER CONTROLLED CONDITIONS:

108	-	118 MHz		
137	-	174 MHz		
216	-	470 MHz		
590	-	1000 MHz	......	UHF TV. (Some channels available on high end.)
1200	-	1275 MHz	......	Airport radar at 1209 MHz.
1275	-	2000 MHz		
2000	-	4000 MHz		
4000	-	8000 MHz	......	Common carrier: 4000 MHz ± 300 MHz. Satellite : 6100 ± 300 MHz, 7300-7750 MHz.
8600	-	16000 MHz	......	Satellites around 8000-8400 MHz and 11.7-12.2 GHz. Airborne radar 9.0-9.2 GHz.
16000	-	25000 MHz	......	Interferometer link at 17.5 GHz.

BANDS PRESENTLY USED OR THAT HAVE BEEN USED SUCCESSFULLY:

Frequency	Bandwidth	
144 MHz	1 MHz	
184 MHz	1 MHz	
236 MHz	1 MHz	
258 MHz	3 MHz	
321.5 MHz	10 MHz	
394 MHz	10 MHz	
440 MHz	3 MHz	
515.5 MHz	3 MHz	(between TV video and audio)
610 MHz	10 MHz	
770 MHz	10 MHz	
835 MHz	10 MHz	
920 MHz	10 MHz	
970 MHz	10 MHz	

Plus all allocated radio astronomy bands to 40 GHz.

For detailed information, refer to Electronics Division Internal Reports Nos. 116, 147, 155, and 159. For information on licensed transmitters, see "National Radio Quiet Zone Transmitter Printout" (updated each year). It should be noted that below about 500 MHz local power distribution lines are an intermittent problem, and on-line computers can cause interference to local and adjacent instruments, particularly in the 240-250 MHz band. It is the observer's responsibility to inquire about these problems. Contact Jim Dolan, NRAO, Green Bank (304-456-2011, ext. 203).

Chapter 3

COMPUTER CONTROL OF THE TELESCOPE

This chapter outlines the mechanics of setting up an observing program including descriptions of various initialization and observing card formats required by the telescope. The different modes of control such as drift scans, tracking, and so forth are covered in the discussion of observing card formats. It will be assumed here, for purposes of discussion, that an observing program will be sequenced by cards provided by the observer. All of the observing modes are also available under manual control by the operator, but this is not normally used for routine observing.

This chapter also describes the on-line programs for data taking. The only difference between these programs is the form of the data that they are prepared to handle, e.g. spectral line, continuum, or fast sampling. Some of the initialization cards are different for the different on-line programs so these are discussed in the context of each type of data taking. Telescope tape formats are given to promote a better understanding of the form of the data expected by the computer and to provide a starting point for the observer who would like to do some or all of his own data reduction.

Any special purpose control system tends to generate some of its own terminology so to avoid some confusion a few definitions of terms are provided in the course of this chapter.

Overview

A typical sequence of telescope control cards is shown in Figure 3-1. There are two separate computers at the 300-foot telescope referred to as

116 and 316. The 316 handles telescope positioning and the 116 is mainly responsible for data accumulation and related computations. The Pointing, Setup, and Feed cards are normally read into the computers only once at the beginning of the observing program. When the on-line program is initialized a standard set of pointing equations is entered into the computer, and if these standard values are to be used no further pointing cards need by read. Observing and Local oscillator cards control receiver and data taking operations.

The "S" and "L" card formats are different for spectral line and continuum programs so they will be described with the individual on-line programs. Feed, pointing, and observing cards are universal to all programs (except for no feed card for the signal averager program) and are described below.

FIGURE 3-1
TYPICAL CONTROL CARD SEQUENCE

```
      Initialization Cards
      S         OBSERVER            SEE INDIVIDUAL PROGRAM TYPE FOR DESCRIPTION
      S         OBSERVER
116   S         OBSERVER
      S         OBSERVER
      F4         0.2389 121.1000    0.2863 226.4000    0.2440 302.2000    0.2856   46.3000
      A         8.18 -14.67    5.76
316   D WEST    0.00 -216.00    4.41   0.0000  0.000000 -216.00     5.36  0.0000  0.000000
      T        1525.0 0.865    0.000   0.00 0.865   0.000   0.00
      P         -1.10   0.31  0.00

      Observing Cards
      L11    26064800   0000000000    000000000       -150000-150000-150000-1500000111201
        11 32 41 11 36 42 8 11 33 23   56 58 00                   1 262 NGC3804
116     11 37 24 11 41 25 8 11 38 06   56 28 00                   0 262 NGC3804
      L11    260960000   0000000000   000000000       -150000-150000-150000-1500000111201
        11 44 30 11 48 31 8 11 45 12   50 48 00                   1 262 NGC3924
      etc.
      ↑         ↑         ↑         ↑         ↑         ↑         ↑         ↑         ↑
Col.  1         11        21        31        41        51        61        71        80
```

TABLE 3-1

"F" card format

COLUMN	CONTENTS	FORMAT
1	'F'	A
2	Number of OFFSET Feed Values	A
3-8	Blank	bbbbbb
9-17	RHO for Feed 1 OFFSET	NNNN.FFFF
18-26	THETA for Feed 1 OFFSET	NNNN.FFFF
27-35	RHO for Feed 2 OFFSET	NNNN.FFFF
36-44	THETA for Feed 2 OFFSET	NNNN.FFFF
45-53	RHO for Feed 3 OFFSET	NNNN.FFFF
54-62	THETA for Feed 3 OFFSET	NNNN.FFFF
63-71	RHO for Feed 4 OFFSET	NNNN.FFFF
72-80	THETA for Feed 4 OFFSET	NNNN.FFFF

Feed offset values for multi-feed systems on the 300-foot

		Feed	ρ	θ
21-cm, 4-feed		1	0.°2389	121.°1000
		2	0. 2863	226. 4000
		3	0. 2440	302. 2000
		4	0. 2856	46. 3000
11-cm, 3-feed		1	0. 0000	0. 0000
		2	0. 0000	0. 0000
		3	0. 1642	270. 0000
		4	0. 1642	90. 0000
6-cm, (Beam Switched)				
A1L and		1 (Sig)	0. 0600	0. 0000
TRG		2 (Ref)	0. 0600	180. 0000
	or	1 (Sig)	0. 0000	0. 0000
		2 (Ref)	0. 1200	180. 0000

Feed Card

The feed card specifies positions of beams in multi-feed systems with respect to the axis of receiver box rotation in polar coordinates, ρ and θ. These are in decimal degrees with θ measured eastward from north when the box is at zero rotation angle as indicated at the control console. The sole purpose of the "F" card is to provide beam position information to the off-line programs via the telescope tape header. It has no effect on the actual position of the receiver on the telescope. Figure 3-1 and Table 3-1 show the card format in detail. Table 3-1 gives nominal values for ρ and θ for multi-feed receivers currently in use on the 300-foot. Trailing zeroes must be punched on the "F" card.

Pointing Cards

In August 1975 the pointing corrections format was changed. The old method of entering pointing corrections every 20^{o} in declination lead to large interpolation errors, particularly in the right ascension corrections at high declination. The present method is to use standard equations in the computer for which coefficients can be entered via cards (A, D and P in Figure 3-1).

The right ascension pointing correction equation is

$$\Delta\alpha = m + n \tan(\delta) + c \sec(\delta)$$

where $\Delta\alpha$, m, n, and c are in seconds of time. This is the offset equation for a transit circle whose axis is displaced from true east-west and from the horizontal. The coefficients of this equation are entered through the "A" card in the format in Table 3-2.

TABLE 3-2

"A" Card Format

Column	Contents	Format
1	"A"	A
2-8	Comments	AAAAAAA
9-14	m (sec. of time)	SNN.FF
15	Blank	b
16-21	n (sec. of time)	SNN.FF
22	Blank	b
23-28	c (sec. of time)	SNN.FF
29-80	Blank	bbb...

A = Alphanumeric character, N = Integer, S = Sign, b = Blank, F = Integers after decimal.

316 display option #6, displays the current "A" card in use.

The best known $\Delta\alpha$ coefficients are given in the "A" card example in Figure 3-1. Any trailing zeroes must be punched.

The declination pointing correction equation is more complex because the dish deformations are not easily modeled. To provide maximum flexibility at the risk of undue complexity a combination of two cubic equations have been provided for fitting the declination pointing corrections. These equations are:

$$\Delta\delta = C_{11} + C_{12}\,\delta + C_{13}\,\delta^2 + C_{14}\,\delta^3 \quad (\delta \leq \delta_B)$$

and

$$\Delta\delta = C_{21} + C_{22}\,\delta + C_{23}\,\delta^2 + C_{24}\,\delta^3 \quad (\delta > \delta_B)$$

where $\Delta\delta$ is in arc seconds, δ_B is the break point or transition declination from one equation to the other. Of course these equations can be greatly simplified by setting higher order coefficients to zero and/or setting δ_B outside the telescope declination range. The "D" card format for specifying the declination correction coefficients is given in Table 3-3. The best known values for the two declination encoders are given in Table 3-4. Trailing zeroes must be punched on this card.

TABLE 3-3

"D" Card Format

Column	Contents	Format
1	'D'	A
2-8	Comments	AAAAAAA
9-14	Break Point (degrees)	SNN.FF
15	Blank	b
16-22	C_{11} (Arc seconds)	SNNN.FF
23	Blank	b
24-29	C_{12} ("/Deg.)	SNN.FF
30	Blank	b
31-37	C_{13} ("/Deg.^{2})	SN.FFFF
38	Blank	b
39-47	C_{14}("/Deg.^{3})	SN.FFFFFF
48	Blank	b
49-55	C_{21}(Arc seconds)	SNNN.FF
56	Blank	b
57-62	C_{22} ("/Deg.)	SNN.FF
63	Blank	b
64-70	C_{23} ("/Deg.^{2})	SN.FFFF
71	Blank	b
72-80	C_{24} ("/Deg.^{3})	SN.FFFFFF

316 display option #7, displays the current "D" card in use.

TABLE 3-4

Nominal declination correction coefficients

Encoder	δ_B	C_{11}	C_{12}	C_{13}	C_{14}	C_{21}	C_{22}	C_{23}	C_{24}
West	$0^\circ.00$	-216.00	4.41	0.0000	0.000000	-216.00	5.36	0.0000	0.000000
East	$0^\circ.00$	-340.00	3.69	0.0000	0.000000	-340.00	4.63	0.0000	0.000000

Fortran programs are available in Green Bank for least-squares solution of the pointing equations if the observer has a sufficient number of pointing corrections measurements. If the observer is satisfied with the nominal coefficients given here he may make simple corrections to the standard curves for small feed offsets through the "P" card shown in Figure 3-1. The format for this card is shown in Table 3-5 where the corrections P_1, P_2 and P_3 enter the equations as follows:

$$\Delta\alpha = (m + P_2/4) + n \tan(\delta) + (c + P_1/4) \sec(\delta)$$

$$\Delta\delta = (C_{11} + 60\ P_3) + C_{12}\ \delta + C_{13}\ \delta^2 + C_{14}\ \delta^3 \quad (\delta \leq \delta_B)$$

$$\Delta\delta = (C_{21} + 60\ P_3) + C_{22}\ \delta + C_{23}\ \delta^2 + C_{24}\ \delta^3 \quad (\delta > \delta_B)$$

TABLE 3-5

"P" Card Format

Column	Contents	Format
1	"P"	A
2-8	Comments	AAAAAAA
9-14	P_1 (RA Box Offset) Arc Minutes	SNN.FF
15-20	P_2 (RA Dial Error) Arc Minutes	SNN.FF
21-26	P_3 (Dec Dial Error) Arc Minutes	SNN.FF
27-80	Blank	bbb...

In principle P_1 and P_3 could be determined from the measurement of a single source if P_2 were assumed to be zero. However, the separation of right ascension box offset and dial error requires at least one pair of sources at widely separated declinations. If N pairs of sources are measured the solutions for the pointing offsets are:

$$P_1 = \frac{1}{N}\sum_{m=1}^{N}\left(\frac{\Delta\alpha_1 - \Delta\alpha_2}{\sec\delta_1 - \sec\delta_2}\right)_m$$

$$P_2 = \frac{1}{N}\sum_{m=1}^{N}\left(\frac{\Delta\alpha_1 \sec\delta_2 - \Delta\alpha_2 \sec\delta_1}{\sec\delta_2 - \sec\delta_1}\right)_m$$

$$P_3 = \frac{1}{2N}\sum_{m=1}^{2N}\left(\Delta\delta\right)_m$$

where subscripts 1 and 2 refer to the two measurements within a pair. If these offsets are not to be used be sure that a P card with zeroes for all values has been entered into the computer.

The "T" card in Figure 3-1 allows space for seven parameters to be used by the on-line computer in controlling either the travelling feed or sterling mount east-west motion. Table 3-6 gives the format for this card. The second parameter is the beam deflection factor, BDF, for the travelling feed system, where

$$\text{BDF} = \frac{\text{(focal length) x (angular beam displacement)}}{\text{linear feed displacement}}$$

Parameters 3 and 4 are correction factors for the fact that the BDF changes abruptly at some critical beam displacement angle. This critical angle was measured to be 3°.15 at 400 MHz by Greenhalgh [9] and a more recent measurement by Giuffrida and Hascheck [31] indicates that this critical angle scales inversely with frequency. Beyond the critical angle the BDF increases in the sense that the feed must not be moved as far to obtain a given beam deflection. Parameter 3 is the critical angle in degrees. Parameter 4 is

TABLE 3-6

"T" Card Format

Column	Contents	Format
1	'T'	A
2-8	Comments	AAAAAAA
9-14	Focal Length (inches)	NNNN.N
15-20	Trav. Feed Beam Deflection Factor (BDF)	SN.FFF
21-28	Trav. Feed Critical Distance (Degrees)	SNNN.FFF
29-35	Trav. Feed Additional BDF	SNNN.FF
36-41	Sterling Mount BDF	SN.FFF
42-49	Sterling Mount Critical Distance (Deg.)	SNNN.FFF
50-56	Sterling Mount Additional BDF	SNNN.FF
57-80	Blank	bbb....

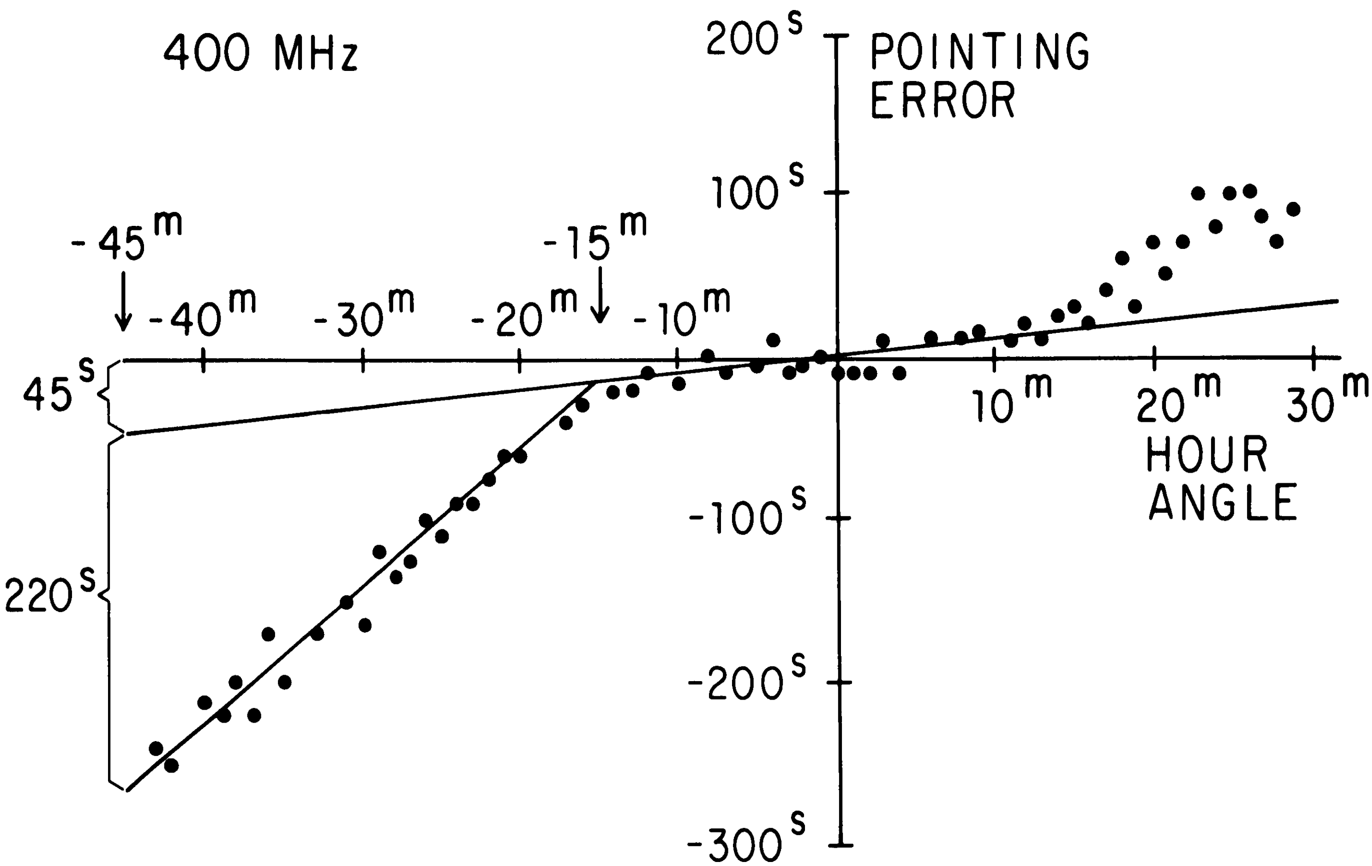
The focal length of the 300-foot is nominally 1525.0 inches and need not be changed for different feeds.

the additional BDF computed by the following equation:

$$\Delta BDF = \frac{\Delta T}{T} \times 2^{15}$$

where ΔT is the pointing error in seconds of time incurred by using the central BDF and T is the time in seconds from the critical angle to the time of observation of ΔT. A specific example is shown in Figure 3-2 taken from [9].

Parameters 5, 6, and 7 are for the Sterling Mount and are similar to parameters 2,3, and 4. Except for very critical pointing requirements or tracking beyond about 5 beamwidths off the meridian the "T" card values shown in Figure 3-1 should suffice. Decimal points and trailing zeroes must be punched in all



SOURCE $\delta = 33°$

ASSUMED BDF = 0.84 AS FIRST APPROXIMATION

1. CENTRAL BDF $= 0.84 \left(1 + \frac{45^s}{45^m \times 60}\right) = \underline{0.854}$
2. CRITICAL DISTANCE $= 15^m \cos 33° = \underline{3.15°}$
3. ADDITIONAL BDF $= \frac{220^s}{30^m \times 60} = 0.12222$

   ENTER AS FRACTION OF 2^{15}

   $0.12222 \times 2^{15} = \underline{4004.9}$

Figure 3-2. Illustration of the change of the beam deflection factor as a function of hour angle. Ref. [9].

parameter fields on the "P" cards even through some of the parameters may not be relevant to a particular observation.

Be sure you understand what pointing parameters are in the computer before you start observing.

Observing Cards and Available Modes of Telescope Control

At the present time there are eight different types of position control cards which can be used at the 300-foot telescope. Figure 3-3 illustrates the formats of the observing cards for the various modes. Each one will be discussed separately, but there are some entries which are common to all card types. Columns 20 and 21 contain the position code which designates the format of the rest of the card. Columns 54, 55, 56, and 57 are provided for receiver control parameters, for example, and these will be discussed with the individual on-line programs. In most cases they are blank. The observer code is right justified in columns 58 through 61. Columns 62 through 73 are for source identification read by the computer in alphameric format and printed directly on tape with each data record. The last seven card columns are not read by the computer, and may be used by the observer for secondary card identification.

Except for position codes "0", "13" and "18", the first two entry blocks on the observing cards specify the local sidereal times to start and stop taking data. The positions of the blank columns are important. As soon as a card is read by the computer, the telescope is moved into position and then waits for the start time to arrive before taking data. If a coordinate rate is specified, the telescope will pick up a track at this rate which will cause

COLUMN	1	2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19	20 21	22	23 24 25 26 27 28 29 30	31 32	33	34 35 36 37 38 39 40 41	42 43	44 45 46 47 48	49 50 51 52 53	54 55 56 57	58 59 60 61	62 63 64 65 66 67 68 69 70 71 72 73	74 75 76 77 78 79 80
DESCRIPTION		START TIME H H M M S S	STOP TIME H H M M S S	POS CODE		PARAMETER 1			PARAMETER 2		PARAMETER 3 I5	PARAMETER 4 I5	PARMS. 5 6 7 8 I1 Form.	OBSERVER CODE I4	SOURCE NAME 12A1	
DUMMY	BLANK IN EVERY CASE	Time computer leaves dummy card & goes to next one	BLANKS	0	+ or -	Indicated Dec. D D M M S S	BLANK IN EVERY CASE		BLANKS	BLANK IN EVERY CASE	BLANKS	BLANKS	SEE OBSERVING PROGRAM DESCRIPTIONS FOR USAGE	N N N	MAY BE ANYTHING WITH ANY COMBINATIONS OF ALPHA, NUMERIC, OR SPECIAL CHARACTERS FOR ALL PROGRAMS	NOT READ BY PROGRAM DOES NOT INITIATE ANYTHING
INDICATED DECLINATION		LST start for data taking	LST stop for data taking	1	+ or -	Indicated Dec. D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
TRUE DECLINATION		LST start for data taking	LST stop for data taking	2	+ or -	True Declination D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
1950 DECLINATION		LST start for data taking	LST stop for data taking	3	+ or -	1950 Declination D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
CONSTANT GALACTIC LATITUDE		LST start for data taking	LST stop for data taking	4	+ or -	B II D D D . D D D			BLANKS		BLANKS	Galactic Rotation ± D D D		N N N		
CONSTANT GALACTIC LONGITUDE		LST start for data taking	LST stop for data taking	5	+ or -	L II D D D . D D D			BLANKS		BLANKS	BLANKS		N N N		
WOBBLES		LST start for data taking	LST stop for data taking	6	+ or -	South Indicated Dec. D D M M S S		+ or -	North Indicated Dec. D D M M S S		Dec. Rate '/min ± R R R	BLANKS		N N N		
CELESTIAL COORDINATES (Time control of data)		LST start for data taking	LST stop for data taking	8		1950 R. A. H H M M S S		+ or -	1950 Dec. D D M M S S		R.A. Rate '/min ± R R R	Dec. Rate '/min ± R R R		N N N		
1950 DECLINATION 1950 Time Control		1950 LST start for data taking	1950 LST stop for data taking	13	+ or -	1950 Declination D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
CELESTIAL COORDINATES 1950 Time Control		1950 LST start for data taking	1950 LST stop for data taking	18		1950 R. A. H H M M S S		+ or -	1950 Dec. D D M M S S		R.A. Rate '/min ± R R R	Dec. Rate '/min ± R R R		N N N		

LEGEND: D-Degrees
M-Minutes of arc or time
S-Seconds of arc or time
R-Rate
N-Number

Note: Where + is indicated, a blank will suffice.

Figure 3-3 300' OBSERVING CARD FORMAT

NOTE: For declination between 0° and -10°, the leading zero(s) must be punched in the degrees column (e.g. -05°). If this is not done, the computer will reject the card.

it to cross the start coordinate(s) at the LST start time. The observer should be careful not to drive the telescope into a declination limit by allowing a card with a δ rate to take control long before the start time.

When a series of cards is read into the computer, the first card is acted upon immediately and the second takes control at the stop time of the first and so forth. Sufficient time must be allowed for movement of the telescope in declination at 10°/minute plus about 5 seconds for position trim, and in hour angle at the rate of 30 inches per minute (240^{s} H. A./min at the equator) on the Sterling mount and 120 inches per minute (960^{s} H. A./min at $\delta = 0^{\circ}$) on the travelling feed [32], plus 4 or 5 seconds for trim. The trim time may be reduced if a position error of a few arc minutes can be tolerated at the start of a scan.

Three types of right ascension and declination coordinates are used at the 300-foot telescope. They are defined as follows:

1. Indicated coordinates: These are coordinates defined by the telescopes position encoders. In the case of the 300-foot, indicated declination and right ascension (hour angle) are different from true declination and right ascension because of a slight offset of the telescope's axis of rotation from exactly east-west and deformations in the structure.

2. True or apparent coordinates: Either term applies to the right ascension and declination referred to the equator and equinox of the date of observation.

3. 1950 coordinates: This term specifies right ascension and declination referred to the equator and equinox of the epoch 1950.0. Some of the NRAO literature also uses "1950 True" to denote the same thing.

COLUMN	1	2 3 4 5 6 7 8 9 10	11 12 13 14 15 16 17 18 19	20 21	22	23 24 25 26 27 28 29 30	31 32	33	34 35 36 37 38 39 40 41	42 43	44 45 46 47 48	49 50 51 52 53	54 55 56 57	58 59 60 61	62 63 64 65 66 67 68 69 70 71 72 73	74 75 76 77 78 79 80
DESCRIPTION		START TIME H H M M S S	STOP TIME H H M M S S	POS CODE		PARAMETER 1			PARAMETER 2		PARAMETER 3 I5	PARAMETER 4 I5	PARMS. 5 6 7 8 I1 Form.	OBSERVER CODE I4	SOURCE NAME 12A1	
DUMMY	BLANK IN EVERY CASE	Time computer leaves dummy card & goes to next one	BLANKS	0	+ or -	Indicated Dec. D D M M S S	BLANK IN EVERY CASE		BLANKS	BLANK IN EVERY CASE	BLANKS	BLANKS	SEE OBSERVING PROGRAM DESCRIPTIONS FOR USAGE	N N N	MAY BE ANYTHING WITH ANY COMBINATIONS OF ALPHA, NUMERIC, OR SPECIAL CHARACTERS FOR ALL PROGRAMS	NOT READ BY PROGRAM DOES NOT INITIATE ANYTHING
INDICATED DECLINATION		LST start for data taking	LST stop for data taking	1	+ or -	Indicated Dec. D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
TRUE DECLINATION		LST start for data taking	LST stop for data taking	2	+ or -	True Declination D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
1950 DECLINATION		LST start for data taking	LST stop for data taking	3	+ or -	1950 Declination D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
CONSTANT GALACTIC LATITUDE		LST start for data taking	LST stop for data taking	4	+ or -	B II D D D . D D D			BLANKS		BLANKS	Galactic Rotation ± D D D		N N N		
CONSTANT GALACTIC LONGITUDE		LST start for data taking	LST stop for data taking	5	+ or -	L II D D D . D D D			BLANKS		BLANKS	BLANKS		N N N		
WOBBLES		LST start for data taking	LST stop for data taking	6	+ or -	South Indicated Dec. D D M M S S		+ or -	North Indicated Dec. D D M M S S		Dec. Rate '/min ± R R R	BLANKS		N N N		
CELESTIAL COORDINATES (Time control of data)		LST start for data taking	LST stop for data taking	8		1950 R. A. H H M M S S		+ or -	1950 Dec. D D M M S S		R.A. Rate '/min ± R R R	Dec. Rate '/min ± R R R		N N N		
1950 DECLINATION 1950 Time Control		1950 LST start for data taking	1950 LST stop for data taking	13	+ or -	1950 Declination D D M M S S			BLANKS		Dec. Rate '/min ± R R R	Rotation Angle ± D D D		N N N		
CELESTIAL COORDINATES 1950 Time Control		1950 LST start for data taking	1950 LST stop for data taking	18		1950 R. A. H H M M S S		+ or -	1950 Dec. D D M M S S		R.A. Rate '/min ± R R R	Dec. Rate '/min ± R R R		N N N		

LEGEND: D-Degrees
M-Minutes of arc or time
S-Seconds of arc or time
R-Rate
N-Number

Note: Where + is indicated, a blank will suffice.

Figure 3-3 300' OBSERVING CARD FORMAT

NOTE: For declination between 0° and -10°, the leading zero(s) must be punched in the degrees column (e.g. -05°). If this is not done, the computer will reject the card.

it to cross the start coordinate(s) at the LST start time. The observer should be careful not to drive the telescope into a declination limit by allowing a card with a δ rate to take control long before the start time.

When a series of cards is read into the computer, the first card is acted upon immediately and the second takes control at the stop time of the first and so forth. Sufficient time must be allowed for movement of the telescope in declination at 10°/minute plus about 5 seconds for position trim, and in hour angle at the rate of 30 inches per minute (240^{s} H. A./min at the equator) on the Sterling mount and 120 inches per minute (960^{s} H. A./min at $\delta = 0^{\circ}$) on the travelling feed [32], plus 4 or 5 seconds for trim. The trim time may be reduced if a position error of a few arc minutes can be tolerated at the start of a scan.

Three types of right ascension and declination coordinates are used at the 300-foot telescope. They are defined as follows:

1. Indicated coordinates: These are coordinates defined by the telescopes position encoders. In the case of the 300-foot, indicated declination and right ascension (hour angle) are different from true declination and right ascension because of a slight offset of the telescope's axis of rotation from exactly east-west and deformations in the structure.

2. True or apparent coordinates: Either term applies to the right ascension and declination referred to the equator and equinox of the date of observation.

3. 1950 coordinates: This term specifies right ascension and declination referred to the equator and equinox of the epoch 1950.0. Some of the NRAO literature also uses "1950 True" to denote the same thing.

Observing Cards

Dummy card (0). The dummy card is used to hold the telescope at a particular declination in anticipation of further commands. Parameter 1 (Figure 3-3) is read as an indicated declination, and the time in the start time block is interpreted as a release time to execute the commands of the next card. The dummy card is useful for setting up near the start position of a variable declination scan, thus preventing the telescope from encountering a declination limit by picking up a computed track long before the start of data taking. It may also be used to set the telescope for a drift scan through a calibration source to be recorded on a chart record. No data is put on tape with this card, and the feed is automatically driven to center track.

Indicated declination card (1). This card drives the telescope to the indicated declination specified by parameter 1, and data is put on tape between the LST start and stop times. A declination rate entered as parameter 3 in arcminutes per minute may be used to drive the telescope at a constant rate with the feed at center track. This motion is closed-loop meaning that the commanded declination is computed at frequent intervals and corrections made to the drive rate so that the position of the telescope at any given time is completely predictable. Any declination rate up to 130'/min may be specified in steps of 1'/min. A fast slew rate of 600'/min can be used, but the motion is less predictable because the single speed slew motor is used with no provision for vernier rate trim. If this high rate is to be used, it is best to specify a rate of $\sim$ 620'/min to prevent computed position from getting ahead of the actual position and momentarily shutting down the slew motor. One other consequence of not having rate trim at high speed is that the acceleration time of the telescope causes a lag of about 50' behind the 600'/min computed position which cannot be made up.

A feed rotation angle may also be specified on the indicated declination card as parameter 4. This angle is measured eastward from north on the sky. Slew rate for rotation angle on the Sterling mount is 13.3 degrees/second and limits are $\pm$ 200°. No rotation is provided on the travelling feed mount. The position and polarization angle of the beam(s) at zero rotation angle may be found in the electronics division reports on the individual feeds, or front end boxes, or on receiver installation sheets.

True declination (2). This card has exactly the same function and controls as the indicated declination card except that parameter #1 is interpreted as true declination. The difference between true and indicated position is the declination pointing correction.

1950 declination (3). This card is identical to the indicated declination card except that parameter 1 is interpreted as 1950 declination. The difference between indicated and 1950 declination at the 300-foot is the declination pointing correction plus precession, aberration and nutation.

Constant galactic latitude (4). Position code 4 provides for scanning at a constant galactic latitude (new galactic coordinates) by moving the declination of the telescope at a slowly varying rate with the feed box at center track. The feed box is continuously rotated during the observation so as to maintain a constant galactic rotation angle. The latitude is specified by parameter 1 in decimal degrees and the angle by parameter 4. Galactic rotation angle is defined for this purpose as the angle measured counterclockwise on the sky from the direction of the north galactic pole. By pointing the center of a receiver box at a constant latitude and maintaining a constant galactic rotation angle, each beam of a multi-beam front-end system follows a constant latitude. The chosen value of rotation angle should allow for variation during the observation without impinging on the rotation limits of $\pm$ 200° with respect to the direction of the north celestial pole.

Constant galactic longitude (5). With this card a constant galactic longitude (new galactic coordinates) is maintained by continuously varying the telescope declination with the feed at center track. No provision is made for automatically maintaining a constant galactic rotation angle. The coordinate ℓ^{II} is entered as parameter 1 in decimal degrees.

Wobbles (6). The wobble card initiates a zig-zag track in the sky by driving the telescope at a rate specified by parameter 3 alternately north and south with the feed at center track. The motion is closed loop, and all of the rates and limitations outlined under position code 1 apply here. The sign on the declination rate is ignored, and the first track is always northward. A dummy card (0) is useful in setting up just south of the south limit to allow a smooth start.

Parameters 1 and 2 are the south and north indicated declination limits, respectively, between which the wobbles are performed. There is a delay of 6 seconds between passing out of the declination range and re-entering it traveling in the opposite direction to allow time for reversal. Data is taken continuously, even during reversal, however. No provision is made for card control of rotation angle.

Celestial coordinates (8). This is one of two card types which allow computer control of hour angle. Within the hour angle limits of the travelling feed or Sterling mount, a position in the sky can be tracked or scanned in either right ascension or declination. Positions in parameters 1 and 2 are in 1950 coordinates which means that the on-line computer will apply pointing corrections, precession, aberration and nutation.

Parameter 4 specifies a declination rate, and all of the limitations outlined in the indicated declination card section apply here. The right ascension rate is entered as parameter 3 in arcminutes per minute in 1'/min. increments. The maximum east-west tracking rate of either the travelling feed or Sterling mount is 0.25 inches per second or about +3 and -1 minute of time per minute in right ascension depending on the BDF. Maximum slew rates are 2.0 and 0.5 inches per second, and travel limits are $\pm$ 275 inches ($\sim 9^{\circ}$) and $\pm$ 15 inches ($\sim 0\overset{\circ}{.}5$) for the travelling feed and Sterling mount, respectively. Maximum system position errors in the east-west direction are $\pm$ 0.5 inches ($\pm$ 1 arcminutes) and $\pm$ 0.086 inches ($\pm$10 arcseconds), respectively, with the loop closed by the computer.

In specifying start and stop times on the position code 8 card, one must keep in mind that these times must be centered on the indicated source position if the source is to be tracked for an equal time on either side to the feed track center, while the source position itself is in 1950 coordinates.

1950 Declination (13). This card is identical to the 1950 declination (3) card except that start and stop times are referenced to 1950 coordinates. These times are converted to LST by adding precession, aberration, nutation, and pointing corrections. Caution must be used to avoid start and stop time conflicts when source scheduling due to precession and pointing corrections being different at different declinations.

Celestial coordinates (18). This card is identical to position code (8) except that start and stop times are referenced to 1950 coordinates.

These times are converted to LST's by adding precession, aberration, nutation, and pointing corrections. This card is more convenient for producing scans symmetric about the telescope meridian from 1950 coordinates, but because precession is different at different declinations one must be careful to avoid stop and start time conflicts when scheduling sources in close succession.

Spectral-Line Programs

On-line programs

In the past on-line programs have been available for the use of either the Model II or Model III autocorrelator at the 300-foot. Since the Model III contains all of the capabilities of the Model II, the programs for the latter have fallen into disuse and will not be described here. If, for some reason, they are needed, the observer should contact the computer division well in advance of the scheduled telescope time to arrange proper support.

There are three spectral line programs. CA2 is a switched receiver program (usually frequency switching) normally used for spectral mapping. Two sets of 384 channel spectra, signal and reference, are recorded on tape every correlator dump cycle. One dump normally occurs every ten sidereal seconds but can be reduced to as low as seven seconds by using the front time mode on the autocorrelator [31]. The seven second minimum is set by the Fourier transform time in the DDP 116. The set-up card description summarizes the various timing sequences available.

On-line program CA4 is also a switched receiver program, and the main difference between it and CA2 is that signal and reference spectra are recorded on tape at any of the even multiples of the dump time, e. g. 20^s, 40^s, 60^s... This program is normally used where long integrations are taken of a single point in the sky. The integration time is set at the control console and is usually a compromise between keeping the off-line data averaging to a manageable amount and having the ability to eliminate interference in one or more records (integration periods) without losing too much data. The third, CA6, is an unswitched receiver program which is often referred to as a "total power" system. Here again the integration period is even multiples of the dump time, but in this case only one set of 384 spectral channels are recorded on tape. The signal and reference spectra are then two separate observations taken at different positions in the sky.

Setup Cards

Figure 3-1 shows the position of the setup "S" cards in the initialization card sequence and Table 3-7 gives the contents of these cards for the spectral-line programs. Four "S" cards are required (one each with A, B, C, and D in column 31) no matter which of the receiver configurations is used. The observer name(s) in columns 11-30 must agree exactly on all setup cards.

The pointing code (col. 34 and 35) specifies which of the feed offsets on the "F" card applies to the channel specified by the "S" card. The calibration code (col. 36) determines whether the system temperatures are to be calculated from the signal portion of the switch cycle (0) or both signal and reference portions separately (1).

The inversion indicator (col. 37) controls whether the velocity or sky frequency increase with increasing channel number both on the on-line display scope and as the data is written on tape. To make the velocity increase from left to right on the display scope, the inversion indicator should be 0 if the first local oscillator is lower than the sky frequency and 1 if it is higher than the sky frequency.

The noise tube temperature (col. 38-43) is used to assign a vertical

TABLE 3-7

SETUP CARD FORMAT - CA2, CA4, CA6

Col.	Contents	Format
1	'S'	A
2-10	Blanks	bbbbbbbbb
11-30	OBSERVER NAME	2ØA's
31	'A', 'B', 'C', or 'D'	A
32-33	Blanks	bb
34-35	Pointing Code	NN
36	Calibration Code (=0 or 1)	N
37	Inversion Indicator (=0 or 1)	N
38-43	Noise Tube Value (XXX.XX)	NNN.FF
44-46	Blanks	bbb
47-55	Rest Frequency/(M*N) (HERTZ)	NNNNNNNNN
56-73	Center Frequency Formula	18A's
74-75	Multiplier M(Synthesizer)	NN
76-77	Multiplier N(Front-End)	NN
78	Velocity Reference Indicator	N
79	Velocity Definition Indicator	N
80	Blank	b

scale and system temperature to the off-line spectrum. Normally nominal values from the receiver installation data sheets are entered here in Kelvins with corrections for aperture efficiency and so forth to be done in a later stage of data reduction. The decimal point must be in column 41.

The spectral-line rest frequency, f_o, (col. 47-55) is used both on and off-line in the radial velocity calculations and is expressed in Hz with no decimal. The center frequency formula (col. 56-73) is a FORTRAN expression for off-line computing of the center sky frequency from the IF and local oscillator frequency. The symbol convention is as follows: L1 = the synthesizer primary frequency, F_o; L1F1 is the first synthesizer offset frequency, F_1, (used in frequency switching); and L1F2 is the second synthesizer offset frequency, F_2. L2, L2F1, and L2F2 are similar frequencies for a second local oscillator, if used. LA, LB, LC, and LD are the IF's dialed into the IF processor in channels A, B, C and D, respectively. Typical equations would be 6*L1 + 150.0 or 6*L1 + LA.

The multipliers M and N (col. 74-77) from the first "S" card are used in the automatic computation of L. O. frequencies as explained later. M is the multiplication factor before the LO signal is sent up to the front end and N is the multiplication factor in the front end. Check with the engineer in charge of the receiver to determine the appropriate values.

The velocity reference indicator (col. 78) specifies the rest frame with respect to which radial velocities are computed off-line. The same rest frame is used in interpreting velocities in the automatic L. O. computations. Zero (0) causes no radial velocity corrections to be made, 1 refers to the LSR, 2 refers to the sun, and 3 refers to the center of the earth. The velocity definition (col. 79) indicates whether the velocities are to be interpreted by the radio ($v = c\ \Delta f/f_o$) (1) or optical ($v = c\ \Delta\lambda/\lambda_o$) (2) definition.

Each "S" card could have its own velocity and inversion indicators, noise tube temperature, rest frequency, and/or center frequency formula depending on how the receiver is divided to observe different lines or velocity ranges with one or more receiver front-end channels.

Automatic L. O. Card

The automatic local oscillator "L" card is used to specify Model III autocorrelator and synthesizer settings. Autocorrelator settings must be done manually by the operator and are only checked by the "L" card, but, if the observer chooses, the L. O. synthesizer can be under computer control. The automatic L. O. system provides continuous frequency counter checking of the synthesizer output and IF frequencies to be sure that they agree with the specified frequencies on the "L" card. In automatic control the synthesizer settings on the "L" card are recorded on tape. The "L" cards go in the observing card sequence, and each card controls receiver settings for all subsequent cards until another "L" card is encountered.

There are 3 modes of L. O. control. Mode 1 specifies synthesizer settings directly with no doppler corrections done by the computer. Mode 2 will take a frequency in the source reference frame and apply doppler corrections to center the L. O. on the frequency in the telescope reference frame. Mode 3 applies a specified velocity offset to the rest frequency on the "S" card, applies doppler corrections to get it into the telescope frame, and derives an L. O. setting to center on the offset velocity. Both Modes 2 and 3 update the settings every 10 seconds.

The card formats for the "L" card are shown in Table 3-8. Many of the parameters are elaborated upon in the notes to Table 3-8. Nearly all operations use only one L. O. so column 2 usually contains a 1. A separate card would be used for each of multiple L. O.'s. F_o is the primary L. O. frequency (first receiver L. O. frequency divided by the multipliers), and Fref 1 and Fref 2 are the offset frequencies used in frequency switching. In modes 2 and 3 the reference frequencies are derived by applying specified offsets to the calculated F_o. All of these frequencies are normally in the 250 to 500 MHz range. LA through LD are the IF values set into the IF processor rack and are positive if the L. O. is below the sky frequency. The front end switch indicator (col. 77) only has effect if a switch (such as a Dicke switch) in the front end is being controlled by the autocorrelator. Otherwise this number may be any of those allowed in note 4. The standard time mode

TABLE 3-8

MODEL III CORRELATOR

"L" CARD DESCRIPTION

I. Mode 1 "L" card

COLUMN	CONTENTS	FORMAT	NOTES
1	'L'	A	
2	ULO Number	N	
3	Mode=1	N	
4-6	Blank	bbb	
7-15	F_o in Hertz	NNNNNNNNN	
16-18	Blank	bbb	
19-27	Fref. 1 in Hertz	NNNNNNNNN	
28-30	Blank	bbb	
31-39	Fref. 2 in Hertz	NNNNNNNNN	
40-43	Blank	bbbb	
44-50	±LA in kilohertz	SNNNNNN	1
51-57	±LB in kilohertz	SNNNNNN	1
58-64	±LC in kilohertz	SNNNNNN	1
65-71	±LD in kilohertz	SNNNNNN	1
72	Bandwidth Rx. A Indicator	A	2
73	Bandwidth Rx. B Indicator	A	2
74	Bandwidth Rx. C Indicator	A	2
75	Bandwidth Rx. D Indicator	A	2
76	Mode of Operation Indicator	A	3
77	Front End Switch Indicator	A	4
78	Standard Time Mode Indicator	A	5
79-80	Blank	bb	

A = Alphanumeric character, N = number, S = sign, b = blank, F = numbers after decimal.

TABLE 3-8 (cont)

II. Mode 2 "L" Card

COLUMN	CONTENTS	FORMAT	NOTES
1	'L'	A	
2	ULO Number	N	
3	Mode=2	N	
4-6	Blank	bbb	
7-15	F_{source} / (M*N) in Hertz	NNNNNNNNN	
16-17	Blank	bb	
18-24	±Ref. Freq. 1 Offset in MHz	SNN.FFF	6,7
25-31	±Ref. Freq. 2 Offset in MHz	SNN.FFF	6,7
32-43	Blank	12 b's	
44-80	Same as Mode 1 'L' Card		

III. Mode 3 "L" Card

COLUMN	CONTENTS	FORMAT	NOTES
1	'L'	A	
2	ULO Number	N	
3	Mode = 3	N	
4-17	Blank	14 b's	
18-24	±Ref. Freq. 1 Offset in MHz	SNN.FFF	6,7
25-31	±Ref. Freq. 2 Offset in MHz	SNN.FFF	6,7
32-40	±Velocity Offset km/sec	SNNNNN.FF	7
41-43	Blank	bb	
44-80	Same as Mode 1 'L' Card		

TABLE 3-8 (cont)

NOTES:

1. The sign of the IF's should indicate the desired direction of the offset.

   ONLY LA and LC are checked on-line.

2. Bandwidth Indicators Are:

1 ----	10 MHz	6 ----	312.5 KHz
2 ----	5 MHz	7 ----	156.25 KHz
3 ----	2.5 MHz	8 ----	78.125 KHz
4 ----	1.25 MHz	9 ----	39.0625 KHz
5 ----	625 KHz		

3. Mode of Operation Indicators Are:

   1 ---- 1 ea. 384 ch. A/C
   2 ---- 2 ea. 192 ch. A/C
   3 ---- 2 ea. 96 ch. and 1 ea. 192 ch. A/C
   4 ---- 4 ea. 96 ch. A/C
   5 ---- Not allowed
   6 ---- Not allowed
   7 ---- Not allowed
   8 ---- 1 ea. 192 ch. A/C double frequency

4. Front-end Switch Setting Indicators:

   0 ---- Signal
   1 ---- Reference
   2 ---- Modulate

5. Standard Time Mode Indicators Are:

   Ø ----Use the digi-system settings on the A/C panel

	BT	ST	RT	C/D
1 ----	1ØØØØ	Ø49ØØ	Ø49ØØ	Ø1Ø
2 ----	3ØØØØ	Ø47ØØ	Ø47ØØ	Ø1Ø
3 ----	1ØØØØ	Ø89ØØ	ØØ9ØØ	Ø1Ø

TABLE 3-8 (cont)

II. Mode 2 "L" Card

COLUMN	CONTENTS	FORMAT	NOTES
1	'L'	A	
2	ULO Number	N	
3	Mode=2	N	
4-6	Blank	bbb	
7-15	F_{source} / (M*N) in Hertz	NNNNNNNNN	
16-17	Blank	bb	
18-24	±Ref. Freq. 1 Offset in MHz	SNN.FFF	6,7
25-31	±Ref. Freq. 2 Offset in MHz	SNN.FFF	6,7
32-43	Blank	12 b's	
44-80	Same as Mode 1 'L' Card		

III. Mode 3 "L" Card

COLUMN	CONTENTS	FORMAT	NOTES
1	'L'	A	
2	ULO Number	N	
3	Mode = 3	N	
4-17	Blank	14 b's	
18-24	±Ref. Freq. 1 Offset in MHz	SNN.FFF	6,7
25-31	±Ref. Freq. 2 Offset in MHz	SNN.FFF	6,7
32-40	±Velocity Offset km/sec	SNNNNN.FF	7
41-43	Blank	bb	
44-80	Same as Mode 1 'L' Card		

TABLE 3-8 (cont)

NOTES:

1. The sign of the IF's should indicate the desired direction of the offset.

   ONLY LA and LC are checked on-line.

2. Bandwidth Indicators Are:

1 ----	10 MHz	6 ----	312.5 KHz
2 ----	5 MHz	7 ----	156.25 KHz
3 ----	2.5 MHz	8 ----	78.125 KHz
4 ----	1.25 MHz	9 ----	39.0625 KHz
5 ----	625 KHz		

3. Mode of Operation Indicators Are:

   1 ---- 1 ea. 384 ch. A/C
   2 ---- 2 ea. 192 ch. A/C
   3 ---- 2 ea. 96 ch. and 1 ea. 192 ch. A/C
   4 ---- 4 ea. 96 ch. A/C
   5 ---- Not allowed
   6 ---- Not allowed
   7 ---- Not allowed
   8 ---- 1 ea. 192 ch. A/C double frequency

4. Front-end Switch Setting Indicators:

   0 ---- Signal
   1 ---- Reference
   2 ---- Modulate

5. Standard Time Mode Indicators Are:

   Ø ----Use the digi-system settings on the A/C panel

	BT	ST	RT	C/D
1 ----	1ØØØØ	Ø49ØØ	Ø49ØØ	Ø1Ø
2 ----	3ØØØØ	Ø47ØØ	Ø47ØØ	Ø1Ø
3 ----	1ØØØØ	Ø89ØØ	ØØ9ØØ	Ø1Ø

TABLE 3-8 (cont)

These modes produce the following conditions:

	DT	BT	SW RATE	DUTY
1 ----	1Ø sec.	1Ø ms.	1 cps.	5Ø / 5Ø
2 ----	1Ø sec.	3Ø ms.	1 cps.	5Ø / 5Ø
3 ----	1Ø sec.	1Ø ms.	1 cps.	9Ø - 1Ø

6. The sign of the reference frequency offsets should indicate the desired direction of the offset.
7. Decimal point must be punched in the proper column in the field followed by numeric characters.

NOTE: In all sign fields, a blank may be used to indicate positive values.

(col. 78) is one of three preset autocorrelator duty cycles available if front panel control is not assumed. The switch rate and duty cycle refer to a switched receiver system (CA2 or CA4). The duty cycle is the signal time to reference time proportion. Time mode 3 is usually only used when a long reference average is going to be taken off-line. DT is the dump time and BT is the blanking time to suppress switching transients for which 10 milliseconds is often sufficient. With an unswitched system (CA6) time mode 1 is always used.

Most receivers at the 300-foot can be treated as single conversion (one L. O. and one IF) systems where the simple frequency equation

$Fsky = F_o*M*N + IF$ is assumed by the computer in the L. O. computations. The new 1.0 to 1.45 GHz system will require a more elaborate equation, however, since it is an up-conversion system so provision has been made through an "E" card to specify constants in the following equation to be used by the computer:

$F_o = D* (FSKY - (C + E * LA + F * LB))/(M * N)$ where M and N are specified on the "S" card. The "E" card enters values for C, D, E, and F through the format shown in Table 3-9.

The "E" card could be entered at anytime, but would normally go into the 116 with the "S" and "F" cards. If no "E" card is read after the on-line program is loaded default values of C = 0, D = + 1, E = + 1, and F = 0 are assumed. This reduces the L. O. equation to the simpler single conversion receiver equation. Once an "E" card is entered the default values are lost

TABLE 3-9

"E" Card Format

Column	Contents	Format
1	"E"	
2-8	C value (khz/(M*N))	SNNNNNN
9-10	D value (+ 1 or - 1)	SN
11-12	E value (+ 1, 0, or - 1)	SN
13-14	F value (+1, 0, or -1)	SN

until the on-line program is reinitialized. As an example, if the following values were entered: C = 812500, D = +1, E = -1 and F = 0, M = 4 and N = 1 the equation would read:

$$F_o = (Fsky - 3250 \text{ MHz} - LA)/4$$

The "E" card would have no effect on the operation of a mode 1 "L" card.

If the observer so chooses he can still set the L. O. frequency manually by switching the synthesizer out of computer control. In this case an "L" card is not used and the frequency recorded on tape is the checking counter value which has an accuracy of $\pm$ 100 Hz.

Off-line Data Reduction

The standard NRAO spectral-line data reduction programs are completely described in the TPOWER-SPOWER manual so they will not be discussed here. It may be useful, however, to briefly describe the information on tape and the steps taken in doing the basic spectral scaling. For one reason or another, the observer may want to do some or all of his own data handling, but in any case he should understand the procedures involved.

Tables A-1, A-2, A-3 of Appendix A give the 7-track telescope tape formats for CA2, CA4 and CA6 respectively. The various word formats are also described. The observer can either read the 7-track tape directly with the FORTRAN subroutine RED116 in the 360/65 as described in the NRAO 55/1M(S) compûter division sub-program report, read the 9-track tape generated by TPOWER or SPOWER as described in their manual, or use all of the features associated with TPOWER or SPOWER.

Once the word formats are understood, the interpretation of the time and position information in the tape record is fairly straightforward. Interpretation of the spectral numbers involves several assumptions, however.

Since the total spectral intensity information is lost in the digitization process of the autocorrelator, it must be restored through the use of an auxiliary total power monitor. The tape contains the outputs of total power counters for each receiver integrated over periods when the calibration noise source is on, P_{on}, and when the noise source is off, P_{off}. The total system temperature may then be computed by

$$T_{sys} = \frac{P_{on} + P_{off}}{2(P_{on} - P_{off})} T_{NS}$$

where T_{NS} is the calibration noise source excess temperature.

Each receiver generally has two sets of arbitrarily scaled spectral numbers. Let S_i and R_i represent the relative intensity in channel $\underline{i}$ for the signal and reference spectra, respectively. The reference may be either half of the switch cycle in the case of CA2 and CA4 or a separate scan in the case of CA6. The antenna temperature in channel $\underline{i}$ would then be

$$T_i = \frac{S_i - R_i}{R_i} T_{sys} .$$

This equation provides a first order correction for the large scale instrumental profile. The assumptions which go into this calibration procedure are that the system temperature is uniform across the signal and reference passbands and that the signal to reference gain ratio in each channel is the same for all channels. Usually these assumptions are good to first order, but if a strong line is in the signal, or particularly the reference, or if, for instance, widely separated parts of the front end passband are used in frequency switching, these assumptions deserve some thought. A simple baseline correction will not necessarily compensate for differential gain across the passband.

Continuum Program (slow sampling)

A single on-line program, CR8, is used at the 300-foot for moderate data rate continuum observations. Any sampling interval equal to or greater than $0\overset{s}{.}8$ in steps of $0\overset{s}{.}2$ may be selected at the telescope control console (except by special program patch when a $0\overset{s}{.}1$ period may be used). Up to 8 channels may be sampled simultaneously.

Calibration Modes

Two firing sequences of the receiver's internal noise calibration can be controlled by the observing card. A blank or zero (0) in column 54 of the observing card(s) will cause the noise source to be turned on every 15th integration period beginning with the 3rd. This is referred to as "pulsed cal." mode. Since $0\overset{s}{.}3$ of data are ignored at the beginning and end of the calibration period to suppress transients, this mode is not available with the $0\overset{s}{.}1$ patch.

The "timed cal" mode is implemented with a 1 in column 54 of the observing card. This is a single shot calibration sequence the total duration of which is set on the telescope control console. If, for example, a 30^s time cal duration is set with a $1\overset{s}{.}0$ integration time, the computer will start taking data with the noise source off at the start time on the observing card. After 15^s the noise source will be turned on for 30^s then off again for 15^s at which time the scan will end even if the stop time has not been encountered. A separate observing card must be used for the timed calibration.

One must keep in mind when deciding on a calibration mode that the only monitor of system performance may be the calibrations put on tape. The calibrations must therefore be frequent enough to correct for receiver instabilities and readjustments. For this reason and the fact that the data reduction is somewhat simplified, the pulsed cal mode is most frequently used where possible.

A 2 in column 54 of the observing cards will cause no calibration to be superposed on the data. Also, if the console switch is not set on "pulsed" or "timed cal", the cards will have no control, so if these automatic modes are wanted the operator must be alerted.

Setup Cards

For the continuum program the setup cards are used to specify the channels in the analog to digital converter to be sampled and to pass along some information to the automatic L. O. and the off-line programs via the tape header. Table 3-10 outlines the "S" card format for CR8. Column 31 contains an "X" on the first card only and is blank on all others. The first channel to be read from the analog to digital converter is identified in columns 32-33 with these columns being blank on subsequent "S" cards. All of the channels to be read must be in continuous sequence and the number to be read is controlled by the number of "S" cards (up to 8). ~~Note that channels 0 through 3 are normally used for internal functions so the channel on the first "S" card is generally 04.~~ The observer should have it made clear to him by the engineer in charge which channels his receiver is connected to. Consult the receiver installation sheet.

The pointing code (cols. 34-35) specifies which of the 4 beam offsets

($\rho\theta$) on the "F" card apply to the channel represented by the "S" card. The observing wavelength in centimeters (cols. 36-39) is used by the off-line programs to scale the beam offsets in beamwidths. The noise source value (cols. 40-45) is used to apply a scale to the off-line intensity axis. A decimal point must be punched in column 43.

The multipliers, M and N, used in the first local oscillator system are given in columns 64-67. These apply if automatic L. O. setting and checking are desired.

TABLE 3-10

SETUP CARD FORMAT-CR8

Column	Contents	Format
1	'S'	A
2-10	Blanks	bbbbbbbbb
11-30	Observer Name(s)	20A's
31	'X' (First card only--Must be blank on subsequent cards)	A
32-33	Starting Multiplexer Channel (First card only, blank on all others)	NN
34-35	Pointing Code	NN
36-39	Lambda (in centimeters)	NNNN
40-45	Noise Tube Value	NNN.FF
64-65	Multiplier M (Synthesizer)	NN
66-67	Multiplier N (Front End)	NN

NOTES: Decimal point and trailing zeroes must be punched in proper columns.

A = Alphanumeric Character, b = Blank, N = Number, F = Number following decimal.

Automatic L. O. card

Normally with continuum observations only one L. O. frequency is used during an entire run. Automatic L. O. control is available, however, through a mode 1 "L" card similar to the one described in the spectral-line section. (format shown in Table 3-11). FREF1 and 2 (col. 19-39) usually have no use in a continuum program. F_o is the frequency synthesizer setting and is equal to the first L. O. frequency divided by the L. O. multipliers, M and N, on the "S" cards. F_o is continuously checked with a frequency counter to see that the synthesizer output agrees with the specified value.

TABLE 3-11

'L' Card Description (CR-8)

A. Mode 1 'L' Card (only type allowed)

Column	Contents	Format
1	'L'	A
2	ULO Number	N
3	Mode = 1	A
4-6	Blank	bbb
7-15	F_o in Hertz	NNNNNNNNN
16-18	Blank	bbb
19-27	FREF1 in Hertz	NNNNNNNNN
28-30	Blank	bbb
31-39	FREF2 in Hertz	NNNNNNNNN

NOTE: Modes 2 and 3 are not usable for lack of rest frequency input.

Off-line Data Reduction

A continuum data reduction system called "CONDARE" is available for use on the 360/65 computer in much the same way as the spectral line program. This system is completely described in its own manual so this information does not need repeating here. For observers who would like to work directly with the telescope tapes, the format for tapes written by CR-8 are given in the appendix. The subroutine RED116 is available in the 360/65 for reading these tapes with FORTRAN and is described in the computer division subroutine report number NRAO 55/IM(S). No matter how the data is reduced, consider the fact that the receiver outputs written on tape are in arbitrary units and some reference calibrations (e.g. a pulsed cal) must also be put on the same tape.

Fast-Sampling Program

The fast-sampling program, FS2, is intended for high data rates such as in pulsar observations. The number of receiver channels sampled can be 1, 2, 4, or 8 with sample intervals of 1, 5 or multiples of 5 milliseconds as set on the control console. The engineer in charge of the receiver should be informed as to which sample rate is to be used (1 ms or $\geq$ 5 ms) so he can install the proper low pass filters in the analog to digital converter. One should also realize that a large amount of tape is used by this program (at 1 ms rate a 2400' tape lasts $\sim 15^m$) so arrangements should be made well in advance if more than 3 or 4 tapes are to be consumed.

In the past a program, FS6, was available for sampling 50 channels at a 30 millisecond rate, but since it has fallen into disuse it is no longer maintained on a regular basis. A special effort on the part of the Green Bank programmers would be required to resurrect it, so the

the computer division should be contacted before considering its use. Also, there are no standard off-line programs for handling data from FS2 or FS6, so the observer should generally expect to provide his own data reduction program. The 7-track telescope tape format for FS2 is given in the appendix. These tapes may be read with the FORTRAN subroutine RED116 as described in the computer division report NRAO 55/IM(S).

Setup Cards

The information on the setup cards for FS2 is basically the same as on those for CR8 except that the observing wavelength is omitted. Table 3-12 gives the "S" card format for FS2. Refer to the discussion of the various parameters in the CR8 setup card section. A decimal point must be punched in column 39.

Multichannel Programs

There are three multichannel receiver programs: MC2, MC4 and MC6 which handle 50, 40 and two 25 channel receivers, respectively. These programs were originally used for spectral line observations before the autocorrelation receivers were built. They are still used occasionally for multichannel continuum observations. A 10 Hz switch cycle (e. g. Dicke or frequency switching) is automatically set on the on-line program and the data is normalized by firing a calibration noise source for 50 ms during the signal half of one of the switch cycles every 2 seconds and applying this calibration to the data. The data is organized in 2-second chunks so the integration time, set on the control console, may be any multiple of 2 seconds. A calibration time must also be set on the control console. This is set in units of $0^{s}.1$ and controls when, during the 2^{s} interval, the noise source is fired. Since this time is normally not very important, it may be set to anything less than or equal to $1^{s}.9$. To

TABLE 3-12

SETUP CARD FORMAT-FS2

Column	Contents	Format
1	'S'	A1
2-10	Blank	
11-30	Observer name(s)	20A1
31	'X' on first card Blank on all others	A1
32-33	First channel of A/D converter to be sampled. Blank on all others	I2
34-35	Pointing code for channel	I2
36-41	Noise source value for channel	F6.2

prevent the loss of the last integration period, make the interval between start and stop times on the observing cards equal to an integral multiple of the integration time plus at least 1 second. Every scan begins with a "zero-check" which momentarily removes the IF input to the multichannel receiver in order to remove the zero offset voltage from each channel.

Off-line data reduction programs are no longer maintained for the multichannel systems. There is a program called PK50CH which reformats the telescope tape information and writes it on a 9-track tape. The telescope tapes may also be read directly with the FORTRAN subroutine RED116 which is permanently available in the 360/65 computer. The 7-track telescope tape formats are given in the appendix.

Setup Cards

Table 3-13 outlines the setup card format for the multichannel programs. Only one "S" card is needed for MC2 and MC4. For MC6 two cards are required, the first of which describes receiver parameters for channels 0-25, and the second is for channels 26-50. Channel 0 is a full bandwidth total power monitor, which is not available on all multichannel receivers.

Columns 1 through 33 in Table 3-13 should be self explanatory. The pointing code (cols. 34-35) specifies which of the four feed offsets on the "F" card applies to the "S" card channel. The noise source value (cols. 36-41) is used to assign a vertical scale to the on-line spectral displays. Under the old off-line data reduction system a zero (0) in column 42 caused no velocity information to be calculated and a 1 supplied velocity information. The inversion indicator in column 42 is zero (0) if the sky frequency increases in the same direction as the channel number and 1 if the sky frequency decreases as the channel number increases. Consult with the receiver engineer since this varies with the receiver system. Since the off-line data reduction programs will generally be written by the observer, the information in columns 34 through 54 which is written in the tape record header may be adapted to fit the observing situation. The on-line program does require that a decimal point be punched in column 39 however. The multipliers and velocity indicator have the same meanings in the spectral line programs.

Automatic L. O. Card

The computer controlled L. O. may be set with the same card format used in the continuum program (Table 3-10). The synthesizer output frequency is not checked by the counters and compared with the input value.

Signal Averager Program

A 4096 channel Fabri-Tek signal averager is available for use at the 300-foot for synchronously integrating repetitive signals such as those from pulsars. The complexity and variety of timing and synchronization schemes employable with this system are beyond the scope of this manual, however.

TABLE 3-13

SETUP CARD FORMAT-MC2, MC4, MC6

COL	CONTENTS	FORMAT
1	"S"	A
2-10	Blank	bbbbbbbbb
11-30	Observer Name	20A's
31	x - First Card	A
32-33	Starting Multiplexer Channel No.	NN
34-35	Pointing Code	NN
36-41	Noise Tube	NNN.FF
42	Inversion Indicator	N
43-45	Blank	bbb
46-54	Rest Freq./M*N (Hertz)	NNNNNNNNN
55-56	Multiplier M (Synthesizer)	NN
57-58	Multiplier N (Front-End)	NN
59[1]	Velocity Reference Indicator	N
60[2]	Velocity Definition Indicator	N

NOTES: 1. Velocity Reference (Frame) Indicators Are:

Ø - Use no radial velocity corrections

1 - Use LSR

2 - Use SUN

3 - Use EARTH

2. Velocity Definition Indicators Are:

1 - Use radio definition,

$$v = c. \frac{f\phi - f}{f\phi}$$

2 - Use optical definition,

$$v = c. \frac{f\phi - f}{f}$$

There is an on-line program, SA2, which will record data sent from the signal averager on the 7-track magnetic tape. Once a scan is initiated by an observing card, the signal averager controls the integration times and data transfers.

The details of the electronics setup at the telescope for this type of program have been the result of close cooperation of the observer and the Green Bank electronics staff. New observers should plan on considerable preparation before the observing begins. No standard off-line programs are supported for the signal averager tapes so the observer is expected to provide his own. The telescope tape format is outlined in the appendix. These 7-track tapes may be read with the FORTRAN subroutine RED116 available in the 360/65 computer in Charlottesville.

Setup Card

Only one setup card is needed for program SA2, and the only thing it contains is an "S" in column 1, the observer name(s) in columns 11-30, and the synthesizer and front end multipliers as shown in Table 3-14.

Automatic L. O. Card

The computer controlled L. O. may be set with the same card format used in the continuum program (Table 3-10). The synthesizer output frequency is not checked by the counters and compared with the input value.

SETUP CARD-SA2

COL	CONTENTS	FORMAT
1	"S"	A
2-10	Blanks	bbbbbbbbb
11-30	Observer Name	20 A's
31-32	Synthesizer Multiplier (M)	NN
33-34	Front-End Multiplier (N)	NN

NOTE: One "S" card only is required to make this program operate. No "F" card is required since only one input channel is allowed.

APPENDIX A

Seven Track Telescope Tape Formats

For the benefit of observers who choose to or must write their own data reduction programs, the 7-track telescope tape formats are given in this appendix. The individual word formats are described after the last tape format table, and notes unique to particular data groups are included with each tape format. The 360/65 computer subroutine, RED116, description and a sample FORTRAN program are at the end of this appendix. As new features are added to the on-line programs, it may be necessary to change tape formats so the programmer should be sure he has the latest one. Hopefully, they will not have to be changed more than once every year or two.

Effective Date: April 1975

TABLE A-1

FORMAT 55, CA2

WORD	FORMAT	CONTENTS
1	2	*Scan Number
2	2	Zero
3-12	1	Observer Name
13-18	1	Source Name
19	2	Zero
20-21	5BB17	Julian Date (-2400000 Days)
22	6B1	True Orientation Angle (Turns)
23	6B1	Ind. Orientation Angle (Turns)
24-25	4	*L.S.T.
26-27	4	*E.S.T
28	2	*Month
29	2	*Day
30	2	*Year
31	2	Type of Observing (55)
32	2	*Observer Number
33	2	Integration Period (.1 Sec)
34	2	Telescope
35	2	Position Code
36	2	Zero
37-38	5BB15	R.A. Rate (Epoch)
39-40	5BB15	Dec. Rate (Epoch)
41-42	5BB15	Epoch Observed In
43	6B10	True Focus (Millimeters)
44	6B10	Ind Focus (Millimeters)
45-46	2	Reserved
47-48	4	*R.A. Indicated
49-50	4	*Dec. Indicated
51-83	Note 1	Rx. A Descriptor Block
84-116	Note 1	Rx B Descriptor Block
117-149	Note 1	Rx. C Descriptor Block
150-182	Note 1	Rx. D Descriptor Block
183-214	Note 2	L.O. Data Block
215-598	Note 3 (6B3)	Signal Spectrum
599-982	Note 3 (6B3)	Reference Spectrum
983-998	Note 4	Signal Power Counters
999-1014	Note 4	Reference Power Counters
1015-1030	4	Chan. Zero Words
1031-1034	4	Chan 385 Words
1035-1066	Note 5	A/C Control Words (1572-1603)
1067-1068	4	Spectral Scaling Factor
1069-1095	----	Reserved Words

* At dump from autocorrelator

See notes at the end of the CA6 format

Effective Date: April 1975

TABLE A-2

FORMAT 56, CA4

WORD	FORMAT	CONTENTS
1	2	*Scan Number
2	2	Zero
3-12	1	Observer Name
13-18	1	Source Name
19	2	Zero
20-21	5BB17	Julian Date (-2400000 Days)
22	6B1	True Orientation Angle (Turns)
23	6B1	Ind. Orientation Angle (Turns)
24-25	4	*L.S.T.
26-27	4	*E.S.T.
28	2	*Month
29	2	*Day
30	2	*Year
31	2	Type of Observing (56)
32	2	*Observer Number
33	2	Integration Period (.1 Sec)
34	2	Telescope
35	2	Position Code
36	2	Zero
37-38	5BB15	R.A. Rate (Epoch)
39-40	5BB15	Dec. Rate (Epoch)
41-42	5BB15	Epoch Observed In
43	6B10	True Focus (Millimeters)
44	6B10	Ind. Focus (Millimeters)
45-46	2	Reserved
47-48	4	*R.A. Indicated
49-50	4	*Dec. Indicated
51-83	Note 1	Rx. A Descriptor Block
84-116	Note 1	Rx. B Descriptor Block
117-149	Note 1	Rx. C Descriptor Block
150-182	Note 1	Rx. D Descriptor Block
183-214	Note 2	L.O. Data Block
215-1750	4 Note 3	Signal and Reference Spectra
1751-1782	4 (B30) Note 4	Power Counters
1783-1798	4	Chan. Zero Words
1799-1802	4	Chan. 385 Words
1803-1834	Note 5	A/C Words 1572-1603
1835-1836	4	Spectral Scaling Factor
1837-1850	----	Reserved Words

*At midpoint in time of the integration

See notes at the end of CA6 format.

TABLE A-3

FORMAT 57, CA6

WORD	FORMAT	CONTENTS
1	2	*Scan Number
2	2	Off Scan Number
3-12	1	Observer Name
13-18	1	Source Name
19	2	Zero
20-21	5BB17	Julian Date (-2400000 Days)
22	6B1	True Orientation Angle (Turns)
23	6B1	Ind. Orientation Angle (Turns)
24-25	4	*L.S.T.
26-27	4	*E.S.T.
28	2	*Month
29	2	*Day
30	2	*Year
31	2	Type of Observing (57)
32	2	*Observer Number
33	2	Integration Period (.1 Sec.)
34	2	Telescope
35	2	Position Code
36	2	Zero
37-38	5BB15	R.A. Rate (Epoch)
39-40	5BB15	Dec. Rate (Epoch)
41-42	5BB15	Epoch Observed In
43	6B10	True Focus (Millimeters)
44	6B10	Ind. Focus (Millimeters)
45-46	2	Reserved
47-48	4	*R.A. Indicated
49-50	4	*Dec. Indicated
51-83	Note 1	Rx. A Descriptor Block
84-116	Note 1	Rx. B Descriptor Block
117-149	Note 1	Rx. C Descriptor Block
150-182	Note 1	Rx. D Descriptor Block
183-214	Note 2	L.O. Data Block
215-982	4 Note 3	Spectrum
983-998	4 (BB30) Note 4	Signal Power Counters
999-1014	4 (BB30) Note 4	Reference Power Counters
1015-1030	4	Chan. Zero Words
1031-1032	4	Chan.385S Words
1033-1034	4	Chan. 385R Words
1035-1066	Note 5	A/C Words 1572-1603
1067-1068	4	Spectral Scaling Factor
1069-1095	----	Reserved Words

* At midpoint in time of the integration

NOTES: For Formats (55, 56, 57)

1. Format of Rx. Descriptor Block

WORD	FORMAT	CONTENTS
1	2	Pointing Code
2	2	Calibration Code
3	2	Inversion Indicator
4-5	5BB15	Noise Tube
6-7	5BB30	Rest Freq. (Hz)
8-16	1	Center Freq. Formula
17-18	5BB30	Center Freq./M*N (FSKY)
19-20	5BB19	Radial Velocity of System
21	2 (BYTE1 = REF) (BYTE2 = DEF)	Velocity Indicator (REF. & DEF.) REF = 1, NO DEF = 1, RADIO 2, LSR 2, OPTICAL 3, SUN 4, EARTH
22-23	4	*Apparent R.A.
24-25	4	*Apparent Dec
26-27	4	*1950 R.A.
28-29	4	*1950 Dec
30-31	4	RHO for Feed
32-33	4	Theta for Feed

2. L. O. Data Block - For Formats (55,56,57)

WORD	FORMAT	CONTENTS	
1-2	5BB30	L1	Signal L. O. (Hz)
3-4	5BB30	L1F1	First Ref. L.O. (Hz)
5-6	5BB30	L1F2	Second Ref. L.O. (Hz)
7	2B15	M	Front End Multiplier
8	2B15	N	Syn. Multiplier
9-10	5BB30	LA	I.F. Offsets
11-12	5BB30	LB	I.F. Offsets
13-14	5BB30	LC	I.F. Offsets
15-16	5BB30	LD	I.F. Offsets
17-18	5BB30	L2	Second L.O. Data
19-20	5BB30	L2F1	Second L.O. Data
21-22	5BB30	L2F2	Second L.O. Data
23	2B15	M2	Second L.O. Data
24	2B15	N2	Second L.O. Data
25-26	5BB30	L3	Third L.O. Data
27-28	5BB30	L3F1	Third L.O. Data
29-30	5BB30	L3F2	Third L. O. Data
31	2B15	M3	Third L. O. Data
32	2B15	N3	Third L.O. Data

3. 384 channels of relative spectral intensities are contained here. In CA2 and CA4 the set of signal channels appear first followed by 384 reference channels. The spectral intensities in CA2 are contained in single 16 bit integer words. In CA4 and CA6, however, 2-16 bit words are used in series and must be combined off-line to produce a 32-bit integer. (See the sample program).

4. The power counters are integrated for the period of time indicated in word 33. They are recorded in the same order as A/C words 770-785 and 1556-1571 as described in Appendix I of ref. [31].

5. See Appendix I of ref. [31] for the order and format of these words.

Effective Date: October 1974

TABLE A-4

FORMAT 61, CR8

WORD	FORMAT	CONTENTS
1	2	Scan Number
2	2	Zero (except NEG-Terminated LAST record of scan)
3-12	1	Observer Name in ASCII
13-18	1	Source Name in ASCII
19	2	Number of Channels
20-21	5BB17	Julian Date (-2400000 Days)
22	6B1	True Orientation Angle (Turns)
23	6B1	Ind. Orientation Angle (Turns)
24-25	4	**L.S.T.
26-27	4	**E.S.T.
28	2	Month
29	2	Day
30	2	Year
31	2	Type of Observing (61)
32	2	Observer Number
33	2	Integration Period (.1 Sec)
34	2	Telescope Number
35	2	Position Code
36	2	Calibration Mode
37-38	5BB15	RA Rate (Epoch Observed)
39-40	5BB15	Dec Rate (Epoch Observed)
41-42	5BB15	Epoch Observed In
43	6B10	True Focus (Millimeters)
44	6B10	Ind. Focus
45	2	Zero
46	2	Subblock Counter
47-48	4	**Indicated R.A.
49-50	4	**Indicated Dec
51-66	Note 1	Rec. Descriptor Block 1
67-82	Note 1	Rec. Descriptor Block 2
83-98	Note 1	Rec. Descriptor Block 3
99-114	Note 1	Rec. Descriptor Block 4
115-130	Note 1	Rec. Descriptor Block 5
131-146	Note 1	Rec. Descriptor Block 6
147-162	Note 1	Rec. Descriptor Block 7
163-178	Note 1	Rec. Descriptor Block 8
179-184	5BB30	L.O. Data (Hertz)
185	2	Multiplier M
186	2	Multiplier N
187-191	2	Reserved
192	2	Scan Number
193-204	Note 2	Data Subblock 1
205-216	Note 2	Data Subblock 2
--	--	--
589-600	Note 2	Data Subblock 34

** Center of integration

Note 1: (Format 61) Receiver Descriptor Block (At Center of Integration of 1st Data Point of Record)

WORD	FORMAT	CONTENTS
1	2	Pointing Code
2	2	Lambda (centimeters)
3-4	5BB15	Noise Tube Value
5-6	4	*Apparent RA
7-8	4	*Apparent Dec
9-10	4	*1950 RA
11-12	4	*1950 Dec
13-14	4	RHO
15-16	4	Theta

* Stored in first descriptor block only at the time of moving header for record. This corresponds to words 47-48 and 49-50 of header less pointing corrections.

Note 2: Data Subblock

WORD	FORMAT	CONTENTS
1-2	4	**Apparent R.A.
2-4	4	**Apparent Dec
5	2	Radiometer 1 Output
6	2	Radiometer 2 Output
7	2	Radiometer 3 Output
8	2	Radiometer 4 Output
9	2	Radiometer 5 Output
10	2	Radiometer 6 Output
11	2	Radiometer 7 Output
12	2	Radiometer 8 Output

Effective Date: October 1975

TABLE A-5

FORMAT 26, FS2

WORD	FORMAT	CONTENTS
1	2	Scan
2	2	Zero
3-12	1	Observer Name in ASCII
13-18	1	Source Name
19-32	1	Blanks
33	2	# of Channels
34	3	True Orientation Angle
35	3	IND. Orientation Angle
36-27	4	L.S.T. first sample in block
38-39	4	E.S.T. first sample in block
40	2	Month
41	2	Day
42	2	Year
43	2	Type of Observing (26)
44	2	Observer Number
45	2	Sample Rate in Milliseconds
46	2	Telescope
47-49	2	Zero's
50	2	Subscan Counter
51-52	4	R.A. Indicated
53-54	4	Dec. Indicated
55-1078	2	See Next Page

FORMAT 26 (cont)

Layout of Words 55-1078

This layout varies according to the number of channels being recorded. The table below illustrates the variation. The entries give the channel number and the sample number.

WORD	1 Channel Recording	2 Channel Recording	4 Channel Recording	8 Channel Recording
55	1/1	1/1	1/1	1/1
56	1/2	2/1	2/1	2/1
57	1/3	1/2	3/1	3/1
58	1/4	2/2	4/1	4/1
59	1/5	1/3	1/2	5/1
60	1/6	2/3	2/2	6/1
61	1/7	1/4	3/2	7/1
62	1/8	2/4	4/2	8/1
63	1/9	1/5	1/3	1/2
64	1/10	2/5	2/3	2/2
65	1/11	1/6	3/3	3/2
66	1/12	2/6	4/3	4/2
	.	.	.	.
	.	.	.	.
	.	.	.	.
	.	.	.	.
1075	1/1021	1/511	1/256	5/128
1076	1/1022	2/511	2/256	6/128
1077	1/1023	1/512	3/256	7/128
1078	1/1024	2/512	4/256	8/128

For example, for 2 channel recording, word 65 contains the sixth sample of the first channel.

The program requires that the number of channels be 1, 2, 4 or 8.

Table A-6

FORMAT 22, MC2, MC4, MC6

WORD	FORMAT	CONTENTS
1	2	*Scan Number
2	2	Zero
3-12	1	Observer Name
13-18	1	Source Name
19-32	1	Blanks (ASCII)
33	2	Zero
34	6B1	Rotation Angle (True)
35	6B1	Rotation Angle (Actual)
36-37	4	*L.S.T.
38-39	4	*E.S.T
40	2	*Month
41	2	*Day
42	2	*Year
43	2	Type of Obs. (22)
44	2	*Observer Code
45	2	Integration Period
46	2	Telescope Number
47	2	Zero
48	2	Scan No. (Again)
49	2	CRT Option Switch
50	2	*Position Code
51-52	4	*RA Indicated
53-54	4	*Dec Indicated
55-156		51 Channels of Normalized Data
157-162	Note 1	*L.O. Frequency 1
163-168		* L.O. Frequency 2
169-189	Note 2	Receiver Descriptor 1
190-210		Receiver Descriptor 2

* At Center of Integration

FORMAT 22 (cont)

NOTE 1: L. O. Data Block

WORD	FORMAT	CONTENTS
1-2	5BB30	L1 (FØ in Hertz)
3-4	5BB30	L1F1(F1 in Hertz)
5-6	5BB30	L1F2(F2 in Hertz)

NOTE 2: Receiver Descriptor Block

WORD	FORMAT	CONTENTS
1	2	Pointing Code
2-3	5BB15	Noise Tube
4	2	Inversion Indicator
5-6	5BB30	Rest Frequency/M*N
7	2	Multiplier M (Synthesizer)
8	2	Multiplier N (Front-end)
9	2	Velocity Indicator (Byte 1 = REF, 2 = DEF)
10-11		LA
12-13		LB
14-15		LC
16-17		LD
18-19		Radial Velocity of system
20-21		Reserved

TABLE A-7

FORMAT 51, SAZ

WORD	FORMAT	CONTENTS
1	2	Scan Number
2	2	Zero
3-12	1	Observer Name
13-18	1	Source Name
19	2	Zero
20-21	5BB17	Julian Date (-2400000)
22	3	True Orient. Angle
23	3	Ind. Orient. Angle
24-25	4	*L.S.T
26-27	4	*E.S.T.
28	2	Month
29	2	Day
30	2	Year
31	2	Type of Observing (51)
32	2	Observer Number
33	2	Zero
34	2	Telescope
35	2	Position Code
36	2	Zero
37-38	5BB15	G.C. Rate
39-40	5BB15	L.C. Rate
41-42	5BB15	Epoch
43	6B10	True Focus
44	6B10	Ind. Focus
45-46	2	Zero
47-48	4	*R.A. Indicated
49-50	4	*Dec. Indicated
51-52	2	Zero
53	2	Multiplier (Synthesizer)
54	2	Multiplier (Front-End)
55	2	# of Signal Ave. Words
56-57	5BB30	L1 (Hertz)
58-59	5BB30	L1F1 (Hertz)
60-61	5BB30	L1F2 (Hertz)
62-104	2	Spare Words
105-4200	2	Signal Averager Words

*Start Time of Integration of Signal Averager

Word formats for all programs

1 - This is an alphanumeric format in ASCII code with two characters per word. To convert these to the code used by the IBM 360/65 computer, use the subroutine CNVAE as described in the RED116 write-up.

2 - This is a standard 16-bit integer which ranges from -32768(-2^{15}) to 32767.

4 - This format is used where double precision is required. It uses 2 16-bit words in series, the first containing the sign and 15 highest order bits, and the second contains a zero in the sign bit and the 15 low order bits. To handle this in FORTRAN, use the equation

```
IFOUR = ID(24) * 32768 + ID(25),
```

where IFOUR is an INTEGER*4 word and ID(24) and ID(25) are examples from the CA2 format.

Unless otherwise noted, all of the time and angle measures (e.g. R.A., Dec, E.S.T., L.S.T., and Polarization angle) are in turns times 2^{30}. To convert the above example into decimal hours, the following statements would be needed:

```
REAL*8  C,HLST
C = 2.**30
HLST = DFLOAT(IFOUR)/C
```

Double word spectral values and power counters could best be handled by converting them to REAL*4 since they are only relative numbers and must be used in ratios.

5 - These are also sets of double 16-bit words like word format 4, but the decimal may be specified to be anywhere in the bit sequence as specified in the BB--notation. For example, BB17 would indicate that the decimal is 17 places from the left in a 30 bit word.

For example, to convert the Julian date in the CA8 format to a decimal number, the following numbers would be required:

```
REAL*8  JD,C
C = 2.**13
JD = DFLOAT(ID(20)*32768+ID(21))/C
```

This could also be done in single precision if all of the accuracy were not required.

By definition, the time and angle measures in word format 4 are BBO.

6 - Same as 5 except that it applies to a single 16-bit word, i.e. 6BB10 would indicate the decimal is 10 bits from the right of a 16-bit word.

NRAO 55/1M (s) DATE: NAME: RED116

EXPLAN. OF NAME: This multi-entry point routine REaDs one record from a telescope

(SHORT DESCRIPTION) tape produced by a DDP 116 on line computer. The record will be stored in an array in the IBM 360. Tape errors and machine errors are checked. Other entry points are: CNVLO, CNVAE, TAPENO, REDEND. They may be used after RED116 has been called at least once.

AUTHOR: D. Vitiello, J. Greenhalgh, A. Braun

LANGUAGE: ASM NO. OF STATEMENTS

MACHINE: IBM 360/50

TIMING: Depends on length of record. Average 1 second per record.

STORAGE

LIBRARY CARD DECK: 68

SUBPROGRAMS CALLED FROM DISC: None

FROM CARDS: None

INPUT DATA (CARDS, TAPE, BOTH): DDP116 telescope tape (7-track tape)

OUTPUT DATA (CARDS, TAPE, BOTH): None

(DETAILS IN DESCRIPTION)

CALL: RED116 (IH, N, LENGTH, ICODE) Other entry points. See description

NAME	DIM'N	TYPE	UNIT	G/R	EXPLANATION
IH	N	I2	-	R	array which obtains data read from tape
N		I4	-	G	length of array=(3*K/2)+1, where K= number of words to be read from tape.
LENGTH		I4	-	R	actual number of tape characters read. LENGTH=3*N, where N is the number of words in the tape record.
ICODE		I4	-	R	Error code: 1=good; 2=parity error; 3=end of file; 4=IBM 360 operator intervention.

(G = GIVEN, R= RESULT)

PROGRAM DESCRIPTION

1. References: -------

2. General Description:

This subroutine can be used in any main program to read telescope tapes which were generated by the DDP116 computers at the 140' or the 300' telescope.

(a) RED116: Main entry point. If you call RED116, a record is read from the telescope tape, converted into IBM 360 words and stored in an array. Quality of the record, length of the record, end of file and IBM 360 operator intervention are checked.

(b) CNVLO: If the record which was read by RED116 contains local oscillator frequency information, this information is CoNVerted into a double precision value of the LO frequency (in MHz) and submitted to the calling main program in binary form.

(c) CNVAE: If the record which was read by RED116 contains comments in the ASCII format, these comments are CoNVerted into AlphamEric format and stored at the place where the original comment was stored.

(d) TAPENO: This gives you the TAPE NO (tape number) of the tapes which are specified on your DD cards. You may use this information to print the numbers of the tapes which are involved on your data output for data retention purposes.

(e) REDEND: You may call this if RED116 has detected an end of file on the tape. It rewinds the tape and allows you to program multiple telescope tape input.

3. This is a description of RED116, CNVLO, and CNVAE, subroutines which can be used in FORTRAN to read telescope tapes produced by the DDP-116 on-line computers.

(a) RED116:

The following program is an example of how the routine RED116 should be used. The example assumes that 500 word records are recorded on the telescope tape.

```
        INTEGER*2 IH(751)
             :
             :
      1 CALL RED116(IH,751,LENGTH,ICODE)
        GO TO (100,200,300,400),ICODE
    100 IF(LENGTH.NE.1500)GO TO 500
             :
             :
             :   statements to process record
             :
             :
```

Statements 200, 300, 400, and 500 are not specifically described but are locations where special conditions are handled. They are, in order: parity error, end of file, 360 operator intervention, and length error.

If a given telescope tape contains more than one type of observing and, therefore, different length records, a check should be made for the type of record before a length error is assured.

If and end of file has been encountered, no attempt should be made to read further on the tape.

A dimension of 751 is specified in the example for IH. 1500 characters (750 halfwords) are required to record 500 words (at 3 char/word) on tape. An extra halfword is added to allow detection of a length error if the record is too long. After the record is read, the information is re-formatted into 16-bit halfwords.

If an error is encountered, up to 15 attempts to reread the record are made. Usually, this consists of backspacing and rereading the record. On every fifth reread, however, the tape is backspaced twice, forward spaced and reread. Backspacing twice passes the tape over the tape cleaner (a metal abrasive surface on the tape drive) and insures that loose particles of dust and dirt do not interfere with reading.

No attempt is made to reread a record if it is encountered within 4 records after another error record. Tape units do not position exactly the same on backspacing and rereading. An infinite loop can occur if the check for preceding error- free records is not made.

(b) CNVLO:

```
REAL*8  F(3)
INTEGER*2 IH(2626)
INTEGER*4  FLO(11)
LLO=11
CALL CNVLO(IH(1745),LLO,FLO,LOERR,LOCODE)
```

CNVLO converts decimal bytes into full word numbers so that a FORTRAN program can process them.

LLO is the number of LO bytes -1 in the IH array. In this example, there are 12 LO bytes (6 halfwords) so LLO = 11.

FLO is the array dimensioned by LLO that contains the converted decimal numbers.

LOERR is an error code which indicates the validity of the decimal bytes that were on tape. If LOERR = 1, it means that all the decimal bytes are valid numbers. LOERR = 2 means that one or more decimal bytes on tape was an invalid decimal number. When an invalid decimal number is discovered the value 1073741824 is stored in its location in FLO.

LOCODE indicates the scaling of the LO frequencies.

LOCODE $\geq$ 128 500 MH

LOCODE < 128 50 MH

An example for the scaling of 50MH is

```
F(1) = FLO(1) + FLO(2)*1.0D-2 + FLO(3)*1.0D-4 + FLO(4)*1.0D-6 + FLO(5)*1.0D-8
F(2) = FLO(1) + FLO(6)*1.0D-2 + FLO(7)*1.0D-4 + FLO(8)*1.0D-6 + FLO(5)*1.0D-8
F(3) = FLO(1) + FLO(9)*1.0D-2 + FLO(10)*1.0D-4 + FLO(11)*1.0D-6 + FLO(5)*1.0D-8
```

; likewise for the 500MH

```
F(1) = FLO(1)*1.0D01 + FLO(2)*1.0D-1 + FLO(3)*1.0D-3 + FLO(4)*1.0D-5 + FLO*D-7
FLO(1) = FLO(1)/10
ITEMP = FLO(4)
FLO(4) = ITEMP/10
FLO(5) = (ITEMP - FLO(4)*10)*100 + FLO(5)
F(2) = FLO(1)*1.0D02 + FLO(6) + FLO(7)*1.0D-2 + FLO(8)*1.0D-4 + FLO(5)*1.0D-7
F(3) = FLO(1)*1.0D02 + FLO(9) + FLO(10)*1.0D-2 + FLO(11)*1.0D-4 + FLO(5)*1.0D-7.
```

(c) CNVAE:

```
LAE = 30
CALL CNVAE (IH(3),LAE)
```

CNVAE converts ASCII format to alphameric format so that the character can be printed under an A2 format in FORTRAN. IH(3) is the initial location of the ASCII character in the IH array, and the LAE tells the subroutine to convert 30 of these characters. Once the conversion is finished the character is stored back into its own location in the IH array.

```
C
C    THIS PROGRAM TAKES A TELESCOPE TAPE WRITTEN WITH ON-LINE PROGRAM CA6,
C    CONVERTS SOME OF THE WORD FORMATS TO ONES MORE EASILY HANDLED IN LATER
C    REDUCTION, AND WRITES THE REFORMATTED DATA ON A 9-TRACK TAPE.  THE FOLLOWING
C    FORTRAN CODE MAY BE HELPFUL IN INTERPRETING THE TAPE FORMATS PREVIOUSLY
C    DESCRIBED.
C
      REAL*8 C5,C6
      REAL*4 FIF(7)
      INTEGER*4 FLO(11),ISP(402)
      INTEGER*2 IDAT(1644),IT(12),SER
      C1=1.073741824D9
      C2=2.4D1
      C3=3.6D2
      C4=6.0D1
      C5=2.5D5
      C6=1.0D6
  251 CALL RED116(IDAT,1643,LEN,ICODE)
      GC TO (10,20,30,40),ICODE
   10 IF(IDAT(32).NE.262) GO TC 251
      GO TO 11
   20 WRITE(6,100)
  100 FORMAT(1H0,'PARITY ERROR')
      GO TO 1C00
   30 WRITE(6,200)
  200 FORMAT(1H0,'END OF FILE')
      GO TO 1CC0
   40 WRITE(6,300)
  300 FORMAT(1H0,'OPERATOR INTERVENTION')
   11 IF(LEN.EQ.3285)GO TO 50
      WRITE(6,101) LEN
  101 FORMAT(1H0,'L =',I5)
      GO TO 1000
   50 CALL CNVAE(IDAT(3),16)
      FREQ= DFLOAT(IDAT(183)*32768+IDAT(184))/C5
      FIF(1)= DFLOAT(IDAT(191)*32768+IDAT(192))/C6
      FIF(2)= DFLOAT(IDAT(193)*32768+IDAT(194))/C6
      FIF(3)= DFLOAT(IDAT(195)*32768+IDAT(196))/C6
      FIF(4)= DFLOAT(IDAT(197)*32768+IDAT(198))/C6
      DO 44 I=1,4
   44 FIF(I)=ABS(FIF(I))
      J=24
      I=1
  104 T=(DFLOAT(IDAT(J)*32768+IDAT(J+1))/C1)*C2
      IT(I)=T
      ITD=IT(I)
      T=(T-FLOAT(ITD))*C4
      IT(I+1)=T
      ITD=IT(I+1)
      IT(I+2)=(T-FLOAT(ITD))*C4
      IF(I.GT.1) GO TO 105
      I=4
      J=26
      GC TO 104
  105 IF(I.GT.4) GC TO 106
      I=7
      J=47
      GC TO 104
  106 D=(DFLOAT(IDAT(49)*32768+IDAT(50))/C1)*C3
      IT(10)=D
```

```
      ITD=IT(10)
      D=ABS(D-FLOAT(ITD))*C4
      IT(11)=D
      ITD=IT(11)
      IT(12)=(D-FLOAT(ITD))*C4
      DO 107 I=1,392
      J=I*2+213
  107 ISP(I)=IDAT(J)*32768+IDAT(J+1)
      DO 108 I=393,402
      J=I*2+229
  108 ISP(I)=IDAT(J)*32768+IDAT(J+1)
      SER=IDAT(1)
      WRITE(10) SER,IDAT(1),(IDAT(I),I=3,18),FIF,(IDAT(J),J=28,30),IT,
     *IDAT(33),(IDAT(L),L=1035,1065),FREQ,ISP
C
C  THE QUANTITIES IN THE 9-TRACK TAPE FORMAT (WRITE(10)) ARE AS FOLLOWS:
C    SER               = SCAN NUMBER
C    IDAT(1)           = SCAN NUMBER (REDUNDANT)
C    IDAT(3-18)        = OBSERVER AND SOURCE NAMES IN A2 FORMAT.
C    FIF(1-7)          = INTERMEDIATE FREQUENCIES IN MHZ.  ONLY FIF(1-4) CONTAIN
C                        ANYTHING USEFUL.
C    IDAT(28-30)       = MONTH, DAY, AND YEAR.
C    IT(1-3)           = L.S.T. IN HOURS, MINUTES, AND SECONDS.
C    IT(4-6)           = E.S.T. IN HOURS, MINUTES, AND SECONDS.
C    IT(7-9)           = INDICATED R.A. IN HOURS, MINUTES, AND SECONDS.
C    IT(10-12)         = INDICATED DEC. IN HOURS, MINUTES, AND SECONDS.
C    IDAT(1037-1067)= AUTOCORRELATOR WORDS 1572-1602.
C    FREQ              = FIRST LOCAL OSCILLATOR FREQUENCY IN MHZ.
C    ISP               = THE SPECTRAL DATA ARRAY, AND POWER COUNTERS.

      GO TO 251
 1000 CONTINUE
      STOP
      END
//GO.FT10F001 DD DSN=FISHER,UNIT=TAPE,VOL=SER=3679,
//     DISP=MOD,DCB=(RECFM=VS,LRECL=1774,BLKSIZE=1778,BUFNO=1)
//GO.DDP116 DD UNIT=SYSSQ7,DISP=(OLD,KEEP,KEEP),LABEL=(,BLP),
//             VOL=SER=1081,DCB=(,DEN=1)
```

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Parameter / Radiometer	ε_A	ε_B	Beam width and shape	Sidelobes	Pointing	Baselines	Coma lobe	BDF	Polarization
50-80 MHz									
110-240 MHz	6,25,26								
250-500 MHz	6,12,13				6,8,9				
500-750 MHz	37		37						
740-1000 MHz	6				6,32				
Cooled 21 cm	4		4,40	40	4			4	
21 cm Zeeman									
21 cm scalar					22				
21 cm four feed	2,23	2	2	2	17,21	15			
11 cm three feed	3,24,29,34				3,29,30,42				3,19
6 cm AIL Dual beam	1,50				1,50				
6 cm AIL Orthog									
6 cm TRG									
General	16	16		16					

Focus: 21 cm 4 feed [21,23] 21 cm scalar [22]