B. Conducting Observations

Observing at the 140-ft is considered a hands-off operation. The observer conducts his experiment through the telescope operator, who is responsible for the telescope and observing equipment. However, the observer is expected to come to the telescope with a working knowledge of the telescope and the observing equipment. While much of this knowledge can be gleaned from the NRAO technical reports (cf. Section VII) up-to-date information and advice must come from the Green Bank staff, the engineers and telescope operators, the installation sheet (posted in the control room) and the previous observer.

In order to begin observing, the observer must give the telescope operator a set of punched cards, called "setup cards". These cards set up the equipment configuration, inform the computer of observing variables, and tell the operator which switches are to be set manually. The operator has the computer read the parameters on these cards, which are checked for consistency, and stored on the computer's disk. Setup cards are described in Section V.

Once the equipment has been set up, the observer has a choice. He can give observing instructions to the telescope operator, who in turn enters the data manually on the panels and sequences the observations himself. Alternatively, he can give the operator a set of punched cards, called the "observing deck" composed of setup and source cards. The computer then initiates the observations sequentially while the operator monitors the system. These two methods of scheduling observations are called "manual control by panels" and "card control".

Both methods of scheduling have their advantages and disadvantages. Card control is as accurate as the observer and is efficient in execution. Manual control by panels is flexible and requires less planning beforehand.

For card control, the observer converts his observing plan into parameters and commands which are coded on cards. Parameters that are not changed often during the observing ("passive parameters"), such as epoch or integration period, are coded on setup cards. Parameters that are changed often ("dynamic parameters") such as coordinates or source names, and those parameters that activate observing procedures, are coded on source cards. The combined setup and source cards constitute an observing schedule.

For manual control by panels, the observer supplies the telescope operator with his observing plan and gives the operator a deck of setup cards. These cards contain the passive parameters for the observing; the operator enters the dynamic parameters into the panel registers himself. The operator then activates the observing by means of panel push buttons. The observer-operator team can elect to initiate each telescope or observing command in turn or to compile an often repeated sequence of commands into a procedure. Observing procedures, once started by the operator, execute each command in turn, until completed or until terminated by the operator. Wise use of procedures can greatly improve efficiency without sacrificing flexibility. All particulars should be discussed and agreed upon prior to beginning observing.

Both scheduling methods allow the observer to start to observe "as soon-as-possible"; stopping either after a fixed duration or at specified times. The control system offers three time bases: Greenwich Mean Time (GMT), Local Apparent Sidereal Time (LAST), or Greenwich Sidereal Time (GST). Most observations are made using duration, but sequencing the last observation of a group by LAST stop time can prevent observing horizon.

II. Telescope Control

A. Drive System

The 140-ft is a hydraulically driven telescope on an equatorial mount, which drives in hour angle and declination. Each axis has two drive modes. The high speed drive, called "quarter-stroke" is a fixed speed of 20°/minute with servo control. The low speed drive, called "full-stroke", is varied by the computer from 0 to 10°/minute with servo control.

The telescope is driven differently for small and large axial changes. For an axial rotation of less than 6.75°, the telescope is accelerated to 10°/minute until it nears the commanded position, where it is decelerated and homes to position. For distances greater than 6.75°, the axis is accelerated to 20°/minute. It remains in quarter-stroke until it is 1.75° from the commanded position, when it is brought to a complete stop. The telescope is then accelerated to 10°/minute until it nears the commanded position. It decelerates and homes to position. There is some overshoot and oscillation in either type of move.

Overshoot and oscillations are minimized by the electronic servo package, but depend on too many variables, especially ambient air temperature and wind loading, to be critically damped all the time. The servo error in each axis is usually less than 2 seconds of arc. The observing procedures use the verb STALL to delay execution until the telescope has settled.

Times for moves including settling at the final positions can be calculated approximately by the following equations:

Long Distance: $(D - 2) * 3 + 20$ seconds

Short Distance: $D * 6 + 8$ seconds

D is the distance in degrees.

Observations taken while the telescope is driven are limited to rates less than eight degrees per minute. This limit is set two degrees per minute less than the full-stroke rate because at higher rates the drive package may choose to switch to quarter-stroke to catch a commanded position which overstresses the drive system.

B. Telescope Travel Limits

The travel of the 140-ft telescope is restricted to keep the telescope from hitting the support structure. The range is defined by hardware limit switches and software limit stops. A schematic diagram of the limits and the observing horizon is given in figure 5.

1. Hardware Limits

The 140-ft telescope has three hardware limit switches at each extreme of hour angle and declination. The first limit is a warning limit; it sounds a buzzer in the control room, but does not stop the telescope. The second limit, about ten degrees outside the first limit, sounds a buzzer, sets the brakes and shuts down the drive system. The third limit, a few arc minutes outside the second limit, is a failsafe limit. It takes several minutes to recover from a second limit, and may take hours to recover from a third limit.

The design of the hardware limits has a peculiarity. The hour angle limits change at certain declinations. If the telescope is within a warning limit for one declination range, it cannot move to a position within a warning limit for another declination range without first moving outside the first warning limit. The telescope can make such a move safely, but the hardware believes it has crossed a physical limit. In practice, this means that the telescope cannot move around a "limit corner" (see figure 5). When commanded to move to a position by going through a limit corner, the telescope moves to a pre-set point outside the warning limit and then to the commanded position. The user should be aware of the possibility when operating at low declinations and large hour angles; the move time will be much larger.

2. Software Limits

The control computer limits the telescope positioning commands to the range within the second hardware limit switches. The computer will not accept a command to move outside the second limit, or to travel toward the limit with a rate such that the telescope will coast into the limit. When a position outside the second limit is commanded, the command is ignored, and the current position CRT (right screen) will flash on and off until a new satisfactory command is given. When the telescope is commanded to drive toward a limit, the software calculates a "dynamic limit", adding to the static limit a buffer zone proportional to the drive rate. If the dynamic limit is reached, the telescope is stopped. The limit then decreases, and the telescope is restarted. This seeking continues until either the commanded position or the limit is reached.

When the telescope is commanded to a safe position, but its path goes through a corner hardware limit, the computer commands the telescope to go to a pre-set point before going to the commanded position. Thus the limits are reset. The computer will display on the position CRT (left screen) the message: 'MOVING TO UNSET LIMIT AT CORNER'.

The software limits are:

Table 2

Software Limits	
HA Range	Dec Range
$\pm 7^h\ 05^m\ 30^s$	88° to -16° *
$\pm 4^h\ 58^m\ 00^s$	-16° to -36°
$\pm 3^h\ 18^m\ 00^s$	-36° to -46°

Table 3

Pre-Set Points		
H.A.		Declination
East	West	
$-4^h\ 25^m\ 00^s$	$4^h\ 25^m\ 00^s$	-12° 30' 00"
$-2^h\ 25^m\ 00^s$	$2^h\ 25^m\ 00^s$	-32° 30' 00"

* Telescope operations limit observing to 7 hours East or West.

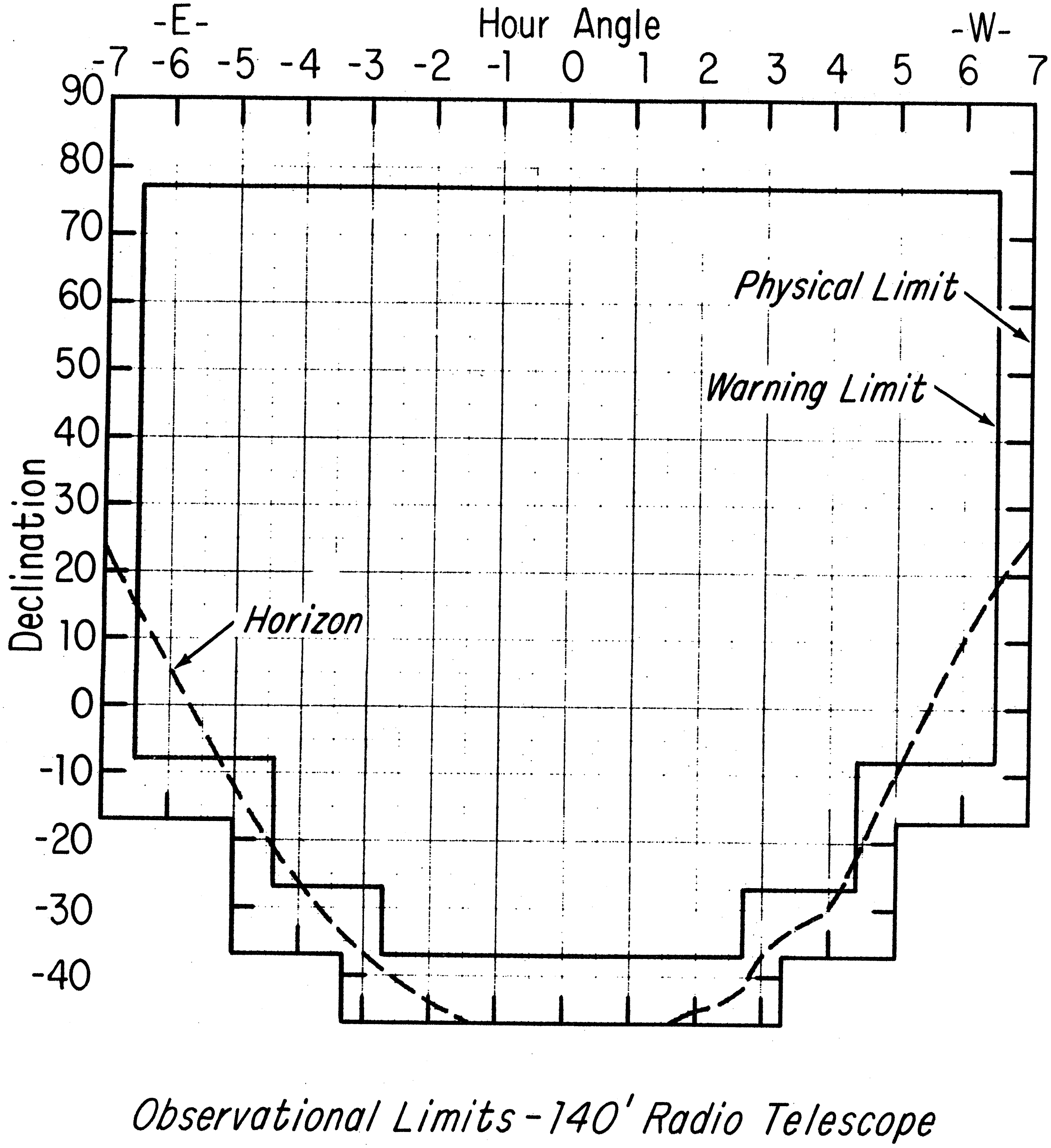

Fig. 5. - Observational Limits - 140' Radio Telescope

C. Coordinate Systems

The 140-ft telescope may be positioned in any of the following "sky" coordinates:

1) Equatorial (α, δ) epoch
2) Galactic (ℓ^{II}, b^{II})
3) Descriptive (H, V)

The descriptive coordinate system is a general system defined by the observer who specifies an origin and position angle in 1950 equatorial coordinates on the 'D' setup card. Further details are given in appendix A.

In addition to the sky coordinates, the telescope may be positioned in either of the following "Earth" coordinates:

1) Hour angle, Declination (HA, DEC)
2) Azimuth, Elevation (AZ, EL)

Note: these coordinates are fixed with respect to the telescope and thus are always moving with respect to the celestial sphere.

Positioning is controlled by an error signal generated by the computer. The computer compares the actual telescope position with the commanded position. The commanded position is calculated as follows:

$$(\alpha,\delta)_{commanded} = TxPxNx(\alpha,\delta)_{requested} + (\Delta\alpha,\Delta\delta)_A + (\Delta\alpha,\Delta\delta)_{PC}$$

where
- T = Transformation matrix from arbitrary coordinates to 1950 equatorial
- P = Precession matrix (1950 to current date)
- N = Nutation correction matrix
- $(\Delta\alpha,\Delta\delta)_A$ = Aberration correction
- $(\Delta\alpha,\Delta\delta)_{PC}$ = Pointing correction

The telescope position recorded with each observation is the actual position solved for the coordinate system in use. The commanded position is not recorded. For example, if observing in 1950 equatorial coordinates, the recorded position would be calculated by the inverse of the above equation, T being the unit matrix.

D. Pointing Equation *

The inherent pointing errors of the 140' arise from a combination of repeatable and non-repeatable effects. The repeatable errors result principally from structural deformation, geometric misalignment, dial errors and collimation errors. An 11-parameter empirical solution is used to correct these and other, less important, errors. The corrections are derived by:

$$\Delta h = C_6 + C_7 \sin D + C_8 \cos D + C_9 \sin H + C_{10} \sin D \sin H + C_{11} \cos D \sin H + C_2 \sin D \cos H - C_5 Q \cos L \sin H$$

$$\Delta RA = -\Delta h/\cos D$$

$$\Delta D = C_1 + C_2 \sin H + C_3 \cos H + C_4 (\sin D \cos H - 0.7926 \cos D) + C_5 Q (\sin L - \sin D \cos Z)/\cos D$$

where: ΔRA and ΔD are the pointing errors in right ascension and declination, in the sense $RA = RA_{actual} - RA_{catalogued}$, and

H = hour angle, D = declination, $L = 38.4^{\circ}$

Z = zenith distance, and

$$Q = \frac{K}{\cos z + 0.00175 \tan (z - 2.5°)}$$

and where K is weather dependent and is taken to be

$$K = 0.354\, P/T - 0.585\, P_w/T + 1701\, P_w/T^2$$

where P, P_w, and T are atmospheric pressure (mmHg), water vapor pressure (mmHG), and temperature (C).

The canonical values of the eleven parameters (C_1 through C_{11}) are stored permanently in the computer. Their current values are given in appendix B. Age and small variations in feed location require changes in C_1, C_6, and C_8. These parameters have thus been defined as:

$$C_8' = C_8 + P2 + RLPC$$

$$C_1' = C_1 + P3 + DLPC$$

$$C_6' = C_6 + P1$$

where C_1, C_8, and C_6 are the permanently stored values. P1, P2, and P3 are Box corrections described under Section E. RLPC and DLPC are RA and declination local pointing corrections as described under Section F.

*Reference:
140' Pointing Program, Engineering Division
NRAO Internal Report #102, 1976, S. von Hoerner
140' Pointing Errors, Engineering Division Internal Report #107, 1977, S. von Hoerner

E. Corrections for Box Placement

Small variations in the feed location from one receiver box to another cause substantial changes in the pointing of the telescope. Accordingly, the pointing equations have additional terms P1, P2, P3 which correct for feed offsets from the adopted electrical axis. Offsets cause an angular rotation of the beam away from the electrical axis. In declination, this effect acts as a dial error. In right ascension, the error is of two types; a dial error and a collimation error.

Terms P1, P2, and P3 can be derived by measuring the beam displacements in RA and Dec of pairs of calibrators widely separated in declination. It is important that the two sources have substantial differences in declination because P1 and P2 depend inversely on sec δ_1 - sec δ_2. For small δ differences, small errors in the measured displacements become large errors in P1 and P2. In general, the careful measurement of two sources, separated by more than 40°, will suffice for all but the most exacting observations at wavelengths longer than about 6 cm. Appendix D gives a list of sources that were used to determine the pointing coefficients. Appendix C gives the equations to solve for P1, P2, and P3. The telescope operator has a program, PVLS, in the control computer to solve for P1, P2, and P3 from the measured beam positions.

F. Local Pointing Corrections

By using local pointing corrections (LPCs) the 140-ft control system can correct for small pointing errors without changing the recorded celestial coordinates. The LPCs are entered as small additions to the dial errors of the pointing equation. The corrections, usually determined by peaking up on a source, are valid only for that source and only for short periods of time. Observers have found that a good rule of thumb is to use these local corrections for only an hour or two and to stay within 10 degrees of the measured source.

Local pointing corrections can be updated during manual or card scheduling. In manual control by panels, the LPCs are read from the register in the upper right hand corner of the position panel. When in card control, the observing procedure POINT determines the LPCs. Alternatively, procedure PEAK will determine the LPCs and move to the peak position. When observing by cards the LPCs will be used for <u>all</u> subsequent telescope moves, until either set to zero or redetermined. It is the observer's responsibility to use POINT and PEAK within their limitations or inform the telescope operator of their intentions.

The local pointing corrections are recorded in the headers of all continuum and spectral line telescope records and displayed on 316 CRT.

G. Determining the Pointing

1. Manual

The telescope operator is prepared to manually peak up on continuum sources to determine the difference between catalogues and observed positions. Generally, he searches for the half power points on each side of the source for each axis and averages the different positions. It assumes a reasonably symmetrical beam, not guaranteed at high frequencies (refs.), but is faster than searching for the peak itself. The operator uses the position panel and the analog chart recorder. This is the usual method used to "find the beam" when a receiver box is first installed. After initial pointing, the observer may choose to continue with manual determination of pointing differences or to switch to the automatic procedure described below.

2. Procedure POINT

The 140-ft control system has a procedure which determines the difference between catalogued and observed positions. The adopted method is to drive back and forth through a source in each telescope coordinate (assuming equatorial coordinates), and to fit a baseline and Gaussian to each scan. The program uses twenty percent of the total points at each end for the baseline fit. Each back and forth scan is separately fitted, and the calculated position differences are averaged. The Gaussian is only fit to points for which the intensity exceeds half the maximum intensity; this reduces the effects of beam distortion. The results are displayed on the operator's CRT screen. The calculated difference, the full width at half intensity and the height are given for each scan. The average difference is given in three forms: the difference assuming the current P1 and LPCs the difference assuming the present P1 but with LPCs zeroed, (i.e. new values for the LPCs), and the difference assuming both the P1 and the LPCs zeroed (i.e. a correct difference for PVLS). Below is a sample output.

HORIZONTAL POSITION SCANS

CATALOGUE	OBSERVED	DIFF	HWIDTH(')	HEIGHT
12:26:33.2	12:26:32:9	0: 0: 0.3	3.21	434.71
12:26:33.2	12:26:32.7	0: 0: 0.5	3.19	431.02

AVE	DIFF	NEW P-FUDGE	DELTA FOR PVLS
	0: 0: 0.5	0: 0: 1.8	0: 0: 2.6

3. Using the Procedure POINT

Procedure POINT assumes that the following conditions are met:

1) The standard receiver output, preferably switched, is unfiltered. (It is usually taken from the monitor output on the front panel.)

2) For setups with more than one receiver, POINT uses only the output of the first receiver.

3) The setup specifies the starting A/D channel, and that channel is cabled to the first receiver.

4) The number of points collected per scan is less than:

137 points	1 - 2 receivers
103 points	3 - 4 receivers
82 points	5 - 6 receivers
68 points	7 - 8 receivers

5) Beam-switched multiple feed receivers have the feeds positioned so that no negative signals are produced when scanning through a source.

6) The COS V option is selected

7) P1, P2 and P3 are properly initialized.

Procedure POINT needs the following input:

1) Catalogue position in equatorial coordinates.

2) Drive rates in right ascension and declination.

3) Half travel size in right ascension and declination.

Use table 4 as a guide to preparing the input for POINT. The values were calculated to give the maximum number of points in the shortest observing time assuming 1-2 receivers. In many cases, the signal-to-noise ratio is large enough that faster drive rates can be used with proportionally less points, saving observing time.

TABLE 4

Wavelength CM	1/2 RA Travel Dist.	1/2 DEC Travel Dist.	Drive Rates '/minute	Integration Period Seconds
25	5^m	1° 15'	180	0.4
21	4^m	1°	150	0.4
18	4^m	1°	150	0.4
11	2^m	30'	150	0.2
9	2^m	30'	150	0.2
6	$1^m\ 20^s$	20'	100	0.2
3	40^s	10'	50	0.2
2*	24^s	6'	30	0.2
1.3*	16^s	4'	20	0.2

* Are larger than theoretical beam size owing to real 140-ft beam.

H. Positioning Verbs

1. Entering Coordinates

The 140-ft Control System has a set of verbs that activate telescope driving and tracking in celestial or telescope coordinates. Each verb requires one or more of a set of four coordinate pairs as input. These pairs are called position, rate, offset one, and offset two. They may be entered through the position panel or via the 'P' and 'S' cards. When entered through the position panel, they are referred to as registers, i.e. "position register" or offset register one". When entered through cards, they are referred to as fields, i.e., "position field" or "rate field".

Four verbs, GT01(n), GT02(n), MOVE(n), and SLEW(n), command motion in a cardinal direction using only the absolute value of the horizontal or vertical coordinate offset. GT01 uses offset one and GT02 uses offset two. The argument (n) is a number from 1 to 5 specifying a move to the center, East, West, South, or North respectively. The move is made from the reference position given in the position register. These verbs are generally used in procedures to specify the "off" position or the starting point of a driven scan.

By convention, all references to coordinate pairs assume that they are entered into the position panel. Naturally, all descriptions apply equally to pairs entered in card fields.

2. Verbs on the Position Panel

The following positioning verbs are available to the telescope operator through fixed buttons on the position panel.

Verb	Description
HALT	Stops the telescope at the current position and tracks that position.
MTP	Moves the telescope to and tracks the position specified by the position register, plus the offset register if "offset (one/two) in use" is pushed.
MFPWR	Moves the telescope from the current position at the rate specified in the rate register.
MWR	Moves the telescope from the position specified by the position register, plus the offset register if "offset (one/two) in use" is pushed, at the rate specified in the rate register.

3. Verbs for Procedures

The following positioning verbs are available for procedures. Their input may be from the position panel coordinate registers or from coordinate fields on the 'S' and 'P' cards.

Verb	Description
GT01(n)	Moves the telescope to the position that is given by the position register plus an offset in the cardinal direction (n) by the amount in offset register one.
HALT	Stops the telescope at the current position and tracks that position.
GT02(n)	Moves the telescope to the position that is given by the position register plus an offset in the cardinal direction (n) by the amount in offset register two.
MOVE(n)	Moves the telescope to the position specified by the sum of position register, offset register, and an amount proportional to the rate register. (Used to position the telescope prior to a SLEW.)
MTPØ	Moves the telescope to the position specified by the position register.
MTP1	Moves the telescope to the position specified by the position register plus offset register one.
MTP2	Moves the telescope to the position specified by the position register plus offset register two.
MWR	Moves the telescope from the position specified by the position register, plus the offset register if "offset (one/two) in use" is selected, at the rate specified in the rate register.
MFPWR	Moves the telescope from the current position at the rate specified in the rate register.
SLEW(n)	Moves the telescope in a cardinal direction (n) from the current position at the rate specified in the rate register.
STALL	Waits until the command and actual positions have been within PTTOL seconds of arc for two and one-half seconds, and the focus has not changed by more than one millimeter for two and one-half seconds.

I. COS V Effect

In a spherical coordinate system, the angular distance corresponding to a fixed horizontal coordinate distance decreases from the equator to the pole. We call this property of spherical coordinate systems the "Cosine V" effect. Observers using horizontal rates or offsets may wish to have the control system apply a correction. The option is called COS V. If selected, the horizontal rates and offsets are divided by the cosine of the vertical coordinate (declination, latitude, etc.) prior to use. The option can be selected by pushing a button on the position panel and by altering an option on the 'P' card. COS V is generally used when making equally spaced observations, such as maps or grids.

J. Focus

The 140-ft telescope is focused by a mechanical drive that moves the receiver back and forth in the prime focus configuration. The mechanical drive has a travel distance of 700 mm. The focal distance varies from receiver to receiver. The installing engineer gives a rough value and the telescope operator does a focus check to refine the focus value. This value is entered on the 'P' card as the focal distance at the zenith. (Solve for F_o in the focus equation given below.)

The focal distance varies with the zenith distance and with the ambient temperature. The following empirical formula describes the focal behavior.

$$\text{Focus} = F_o - A * (1.0 - \cos(\theta)) + B * T$$

where F_o is a zero point term (determined by the observer)

- A is the magnitude of the gravitational deformation (17.6)
- θ is the zenith distance
- B is the magnitude of the temperature deformation (undetermined)
- T is the ambient temperature.

The observer can choose either to track or not to track the focus. The control system always outputs the commands to track the focus, but the observer can hold a focus by having the telescope operator set the focus brakes. A word of caution is needed. The observer must rely on the brake indicator light and the focus error displayed on the operator's left CRT screen as the only indicators of the focus status.

At the time of publication, the temperature term in the focus equation has not been determined; it is presently set to zero.

K. Cassegrain Subreflector

The H316 computer software and associated hardware controls the subreflector deformation when used in the cassegrain mode by the following equation:

$$A(\beta) = \text{Scale factor} * 8.70\text{mm}\ (.8028 - \sin\beta)$$

where: scale factor = 1.0

β = elevation angle

This routine is updated every minute when subreflector control panel is powered on and in computer control.

A cassegrain receiver push-button must be selected on the operator's control panel in order to use the pointing coefficients for the cassegrain receivers.

The scale factor can be changed by an authorized person when performing tests with the cassegrain receiver for pointing purposes by reading a 'C' card into the H316 computer.

The format is as follows:

Col	Contents	Format
1	'C'	A1
2-10	Scale factor	F9.4 (xxxx.xxxx)

N.B. It is the responsibility of the person making the tests to maintain the scale factor. Reloading the H316 program will reset the factor to 1.0.

(Appendix G of this manual describes the geometry, definitions, operation, description and tuning of subreflector-nutator.)

III. Equipment

The following is a short description of the 140-foot observing equipment and the computer interface. The equipment and programs are often modified to meet observing demands, so the observer should consult the telescope operator and the engineers about the system status prior to observing.

A. Clock and Calendar

The Local Apparent Sidereal Time (LAST) and a civil midnight pulse are distributed to each telescope from the NRAO Clock Room, located in the basement of the Jansky Laboratory. The LAST used, usually referred to as LST, is actually a least squares linear approximation of the yearly change in the real LAST. Adjustments are made weekly to maintain agreement within ±5 milliseconds with the LAST approximation. The midnight pulse is used to step a mechanical month-day-year calendar located at the telescope. A power loss is sometimes mistakenly interpreted as a midnight pulse. The calendar should be checked after recovery from a power loss.

The control system maintains its own internal clock and calendar based on external sidereal timing pulses. The program calculates the current time from the number of counted pulses and a starting time. The starting time is obtained from the site clock when the computer is started. The site clock and the computer clock agree to within 5 milliseconds. The program maintains a second internal clock which keeps Eastern Standard Time (EST). Its accuracy is ±1 second.

All times quoted in this manual are assumed to be sidereal unless otherwise noted.

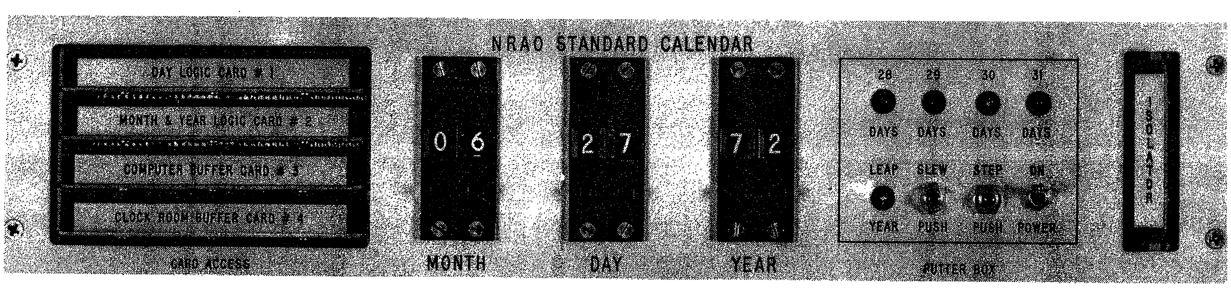

Figure 7. - NRAO Calendar

B. Position Panel

The position panel (Figure 9) is used to enter position information and commands. Figure 8 shows the layout of the panel. The four pairs of registers are called coordinate, rate, offset one, and offset two. The two top registers are used for the epoch and the local pointing corrections. The push buttons on the top row activate telescope positioning commands, like "move to position", "halt", etc.

The uppermost rotary switch selects the coordinate system and the format for the coordinate registers. The second switch is unused. The third switch selects the input format for the offset registers; the coordinate system for the offset registers is the same as that of the coordinate registers. There is no capability to offset in a different coordinate system. When a format is selected, the position panel turns on light emitting diodes (LEDs) to mark the positions of colons and decimal points in the input registers. Table 5 lists the coordinate systems and their input formats.