36-FOOT RADIO TELESCOPE POINTING AND FOCUSING PROCEDURES

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Summary

Pointing the 36-foot radio telescope on Kitt Peak is required in order to obtain the azimuth and elevation offsets. New pointing constants are entered into the on-line computer approximately every 3 months. Over a one week period the pointing errors in azimuth and elevation are normally 6 seconds of arc RMS. Even with this degree of accuracy it is highly advisable to obtain new azimuth and elevation offset information every 24 hours.

Pointing is best done when an intense point source can be observed through the dome opening. With our existing computer and the "FIVE POINT" and "FOCALIZE" programs, optimum azimuth/elevation offsets and focus information can usually be obtained in 20 minutes or less. It is the observer's responsibility to measure the azimuth/elevation pointing offsets, but he should be assisted by the telescope operator as much as possible.

This report gives the procedure for computer pointing techniques. Some special receiver or telescope configurations may alter these procedures. The observer and telescope operator should be made aware of any changes and the possible effect on the pointing process. Hopefully, this report will eliminate some of the common operational errors in the pointing and focusing of the 36-foot radio telescope.

Introduction

The proper pointing and focusing of the telescope beam is a prerequisite for any astronomical observations. Pointing and focusing the 36-foot radio telescope can be an arduous and time-consuming task. The 36-foot radio telescope has a very restricted field of view, and there are very few intense radio sources in the normally observed frequency range.

The 36-foot radio telescope is normally used at wavelengths between 1.3 cm and 1.3 mm. At wavelengths between 2.6 mm and 1.3 mm the half-power beam width is approximately 1 minute of arc. A pointing error of 6 seconds of arc, at these wavelengths, reduces the gain of the telescope by three percent. The 36-foot radio telescope has typical weekly pointing errors on the order of six seconds RMS (6" RMS or $\sim \pm$ 15" peak).

There are several techniques that can be used for pointing and focusing the 36-foot radio telescope. This report describes the procedures we have found to be the simplest and the most reliable. This report is not intended to give the reader an understanding of all the equipment. It is intended to serve as a "how to" guide. The corresponding internal reports can be consulted for a complete description of individual pieces of equipment.

NATIONAL RADIO ASTRONOMY OBSERVATORY

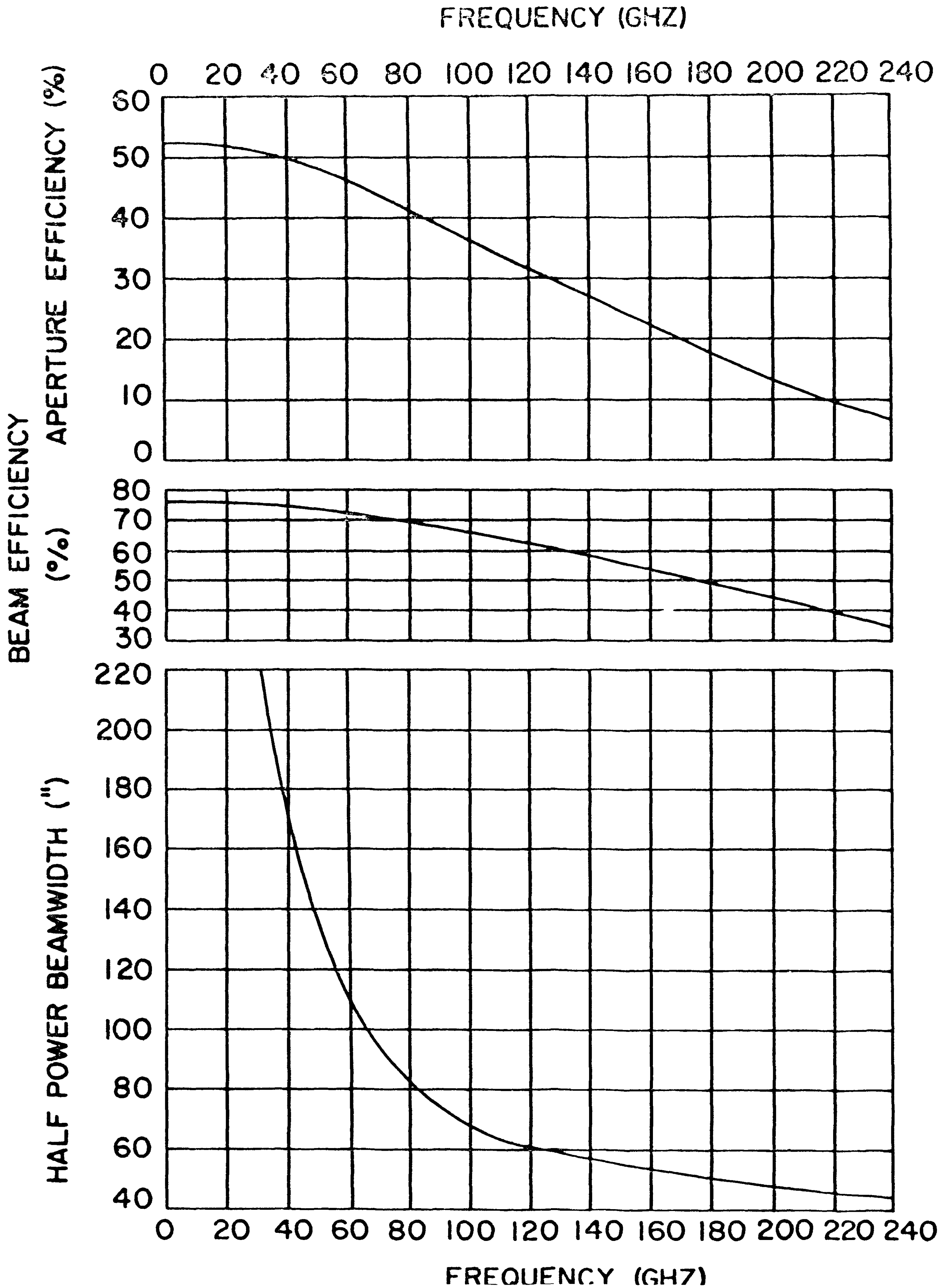
Charlottesville, Virginia

Technical Data Sheet No. 6 February 1974

36 FOOT TELESCOPE

Diameter	36 ft (10.973 m)
F/D	0.8
Elevation	6280 ft (1914 m)
Latitude	31° 57' 12.10" N
Longitude	7^{h} 26^{m} 27.408^{s} W
Mounting	Azimuth-Elevation
Elevation Coverage	16° - 90°
Azimuth Coverage	0° - 360°
RMS Surface Accuracy	0.14 mm
RMS Absolute Pointing Accuracy	7"
Slew Rate	25°/Minute (Each Axis)

Axial focusing over an interval of 10 cm and rotation of the front end box are remotely controlled at the operating console. Since the telescope efficiency is degraded by operation in direct sunlight, the dome is normally opened with observations planned so that the dish is in shadow. Observations through the fabric dome are feasible with a reduction in signal strength. A PDP 11/40 computer provides on-line acquisition and reduction of continuum and spectral line data. Any astronomical object can be tracked. The telescope is located on Kitt Peak near Tucson, Arizona.


FREQUENCY (GHZ)
0 20 40 60 80 100 120 140 160 180 200 220 240
APERTURE EFFICIENCY (%)
60 50 40 30 20 10 0
BEAM EFFICIENCY (%)
80 70 60 50 40 30
HALF POWER BEAMWIDTH (")
220 200 180 160 140 120 100 80 60 40
0 20 40 60 80 100 120 140 160 180 200 220 240
FREQUENCY (GHZ)

1. Equipment Connections and Adjustments

Approximately 80% of the observations made with the 36-foot telescope use the Cooled Cassegrain receiver. The receiver frequency range is 70 GHz to 120 GHz or wavelengths of 4.3 mm to 2.5 mm. Since this receiver is the one most often used, future references are to this receiver and the associated controls.

1.1 Receiver Configurations and Adjustments

There are two main receiver configurations CONTINUUM and SPECTRAL LINE. The receiver is normally phase-locked in both modes of operation, however one can run open-loop in the CONTINUUM mode. The phase lock alarm disable switch is located behind the computer racks and should be turned on to run open-loop. In CONTINUUM the detector output level should be adjusted to 3 to 3.5 volts and raised to 5 volts Total Power at the Standard Back-End. Adjust the 0-3 db INPUT LEVEL on the Square Law Detector. For the SPECTRAL LINE configuration tuning procedures are available in the Receiver Tuning Manual. The FIVE POINT can be done with the receiver set up for SPECTRAL LINE work. Make the same adjustments of the Detector Output Level.

1.2 Signal Reference Connections

When doing a FIVE POINT to determine the azimuth/elevation offsets the reference signal is generated at the subreflector. The subreflector must be switching when doing a FIVE POINT in the SPDATA mode (Switched Power data).

1.3 Standard Back-End Adjustments

It is easier to adjust the Standard Back-End when the noise tube is installed. One should make note of the settings and calibration results as they may be used if the noise tube has been removed. These settings and adjustments are used for the Cooled Cassegrain receiver. The prime focus and 9 mm Cassegrain receiver require the use of other functions and settings. The Square Law Detector should be adjusted to read 100 on meter scale with the 0 - 3 db gain control. The 60 cps filter should be in the OUT position.

Synchronous Detector

SYNC DET > 10 CPS

GAIN MODULATOR - OFF

ZERO OFFSET - OFF

SCALE EXPAND - X1

METER MONITOR - ANALOG OUT

TIME CONSTANT - 1 SEC

FULL SCALE TEMPERATURE 100

Set the subreflector to nutate position, set the calibration switch to manual and fire the noise tube. Adjust the INPUT LEVEL so that the switched power on the digital volt meter reads 5 volts. After doing a calibrate, with the proper value of TC set, the value for #C and #CP will each be approximately 4000.

BE SURE TO RETURN THE CALIBRATION SWITCH ON THE SUBREFLECTOR TO COMPUTER CONTROL.

1.4 Thumbwheel Panel Entries

Azimuth and Elevation offsets are entered into the computer via the thumbwheels. Source coordinates and Azimuth/Elevation positions can also be entered by this method. A function switch selects the coordinate system that will be used. The coordinate systems and offsets available are: AZ/EL OFFSETS, RA/DEC OFFSETS, CURRENT RA/DEC, CURRENT AZ/EL, 1950.0 RA/DEC and GALACTIC L_{II}/B_{II}.

Two banks of thumbwheels are available and are selected by the switch labeled POSI/POSII. Only one banks' position can be entered at a time. When the function switch has selected AZ/EL OFFSETS the normal procedure is to enter the MAIN beam offsets in one bank and the REF beam in the other bank.

The panel is energized by depressing the lighted switch just below the bank selection switch. Entries into the computer are made by the small toggle switch. Center position is OFF, down is momentary, and up is a hold position. Exercise caution in using the hold position, as it will not allow the computer to switch to the other position during a scan.

By typing MAIN! or REF! the position is entered into the computer and displayed on the STATUS monitor. CAUTION: the computer commands MAIN! and REF! enter offsets in both AZ/EL and RA/DEC. One should insure that all four positions, RA, DEC, AZ and EL, are correct before typing either MAIN! or REF!.

In the CONTINUUM program the AZ/EL offsets for MAIN and REF will appear in the + BEAM and - BEAM of the STATUS MONITOR. These offsets will also appear under AZ/EL OFFSETS and any RA/DEC offsets will appear under the right ascension and declination of the STATUS monitor.

2. Clock Adjustments and Computer Inputs.

Several items pertaining to the clock and computer should be checked before starting any pointing observations. The NRAO standard clock should be properly phased and set using the WWV broadcast from Boulder, Colorado. The date and planet positions in the computer should be checked. Finally, the receiver parameters on the STATUS monitor should agree with the receiver configuration being used.

2.1 NRAO Standard Clock Setting and Phasing Procedure.

Connect a BNC cable from the 1PPS output of the Adjustable Phase Clock Start Pulse Generator to the external trigger of the oscilloscope.

Connect a BNC cable from the output connection of the WWV receiver to the vertical input of the oscilloscope. Set the oscilloscope time base to .2 seconds per division (.2 S/DIV).

Adjust gain, vertical position, and horizontal position on the oscilloscope so that the receiver output pulses are centered on the screen of the oscilloscope.

Turn up the volume of the WWV Receiver.

Locate, on the oscilloscope the first pulse from the left hand edge of the screen. (Listening for the tick on WWV Audio will help).

The object is to move the pulse to within about 5 ms of the left hand edge of the oscilloscope display. To do this, move the pulse using the step size push buttons on the Adjustable Phase Clock Start Pulse Generator. As the pulse moves to the left half of the oscilloscope display, increase the sweep rate. While keeping the pulse in the center of the oscilloscope screen with the push buttons, adjust the Time/DIV of the oscilloscope. Decreasing from .2 sec/DIV to .1 sec/DIV then to 50 ms/DIV, 20 ms/DIV, 10 ms/DIV and finally to 1 ms/DIV. Do not use a step that is too large. The pulse can only be moved to the left. If you move too far to the left go back to sweep speed of .2 sec/DIV and start again.

When the leading pulse is correctly set, is should begin approximately 5 ms (± 1 ms) from the left hand edge of the oscilloscope display. (5 Divisions on the 1 ms/DIV).

On the NRAO Standard Clock move the Set/Safe switch to the Set position.

Dial in the next minute plus one second into the thumbwheels, i.e., next minute 23:59:00, set into thumbwheels: 23:59:01.

While listening to WWV Audio, wait for the tone signaling the next minute, then push and release the Set Arm pushbutton within the next second.

Move the Set/Safe switch to Safe.

Check the clock visually on the next full minute against WWV Audio.

2.2 Tracking Planets.

The planets Venus, Jupiter, and Saturn are three of the intense radio point sources needed to accurately determine the focus and azimuth/ elevation offsets. For the antenna to accurately track these sources you need to insure that the planet positions for the date are entered into the computer's planets catalog. This procedure is described on pages 71, 72 and 73 of the Computer Divisional Internal Report #18 (Second Revision).

2.3 Receiver Parameters.

The computer will store default parameters for RCVR#, TS, TC, HP, %EFF, ATTN and FØ if you use the corresponding code number n with the word !RCVR. These default values will be applied, unless superseded by values supplied by an astronomer or engineer. Continuum receiver default values are on page 84 of Computer Division Internal Report #18 (Second Revision). The spectral line values are on page 138 of the same report.

2.4

OK

SCAN	SOURCE	HORIZON	LST	UTC	DUT1	1976	OBS	OPR
1321	URANUS	4:01	13:53:02	22:46:26	50	29 AUG	BLU	WS

	R. A.	DECLINATION		AZIMUTH	ELEVATION
CURRENT	14:07:55.8	-12:27:02.	COMMAND	174:51	45:25
1950.0			ACTUAL	174:53:07.	45:26:02.
OFFSET	0:00.0	0:00	ERROR	-0:00:02.	0:00:00.
ECLIPTIC	225:00:00.	-35:15:51.	OFFSET	-2:12	0:39

∞

TS	TC	ATTN	ATM	MODE	T(AMB)	RCVR	F8	POLZ
340	14.0	0.118	1.40	BS	23 63	15	23.8	0:00

	AZ	EL	HP	T(ANT)	SP %EFF	GAINS	¢C	¢CP
+BEAM:	1:38	0:01	0:30	-0.0297	20	7140	3652	4000
-BEAM:	-2:12	0:01						

	ERR	FOCUS	SP(V)	TP(V)	SCANS	SAMPLES	SEC	TIME
INPUT	0:05				5	7	20.0	11:40
ACTUAL	0:01	32.3	0.10	0.0059			0.0	

3. Calibration Considerations.

In order for the peak antenna temperature T_a of a FIVE POINT to be accurate, a thermal calibration must be accomplished. This can be done in the CONTINUUM mode and will automatically set the proper values of GAINØ, #C, #CP and give a system temperature (TS). These values will appear in the STATUS after the calibration has been done. The correct value for TC must be entered before doing the calibration. A complete explanation of the calibration procedure is available in the Computer Division Internal Report #18 under calibration procedures.

3.1 Calibrations With a Noise Tube.

This procedure is fully explained in the Computer Division Internal Report. The numbers are only valid when the proper value for TC has been entered into the STATUS monitor prior to doing the calibration. This value (TC), corresponds to the value of the noise tube temperature in K and is entered in tenths of K (150 TC ! will enter as 15.0). This value will be furnished by the engineering staff.

3.2 Typical Values For Use Without a Noise Tube.

For Spectral Line observations the standing wave disc may have been installed. When this device is installed the noise tube is removed. With the noise tube removed approximate values have to be substituted for a calibration. The resulting antenna temperatures for the FIVE POINT will not be correct. Typical values for the cooled Cassegrain receiver are:

GAINØ	10,000
#C	4,000
#CP	4,000
TC	15.0

4. Computer Controlled Pointing (FIVE POINT).

Part of a computer program provides a means for determining the correct azimuth/elevation offsets (pointing). This program is available in the CONTINUUM mode and is called FIVE. The best results are obtained by commanding the telescope to track an intense radio source, such as a planet, through the dome opening. The procedure for taking data with this program is described in the Computer Division Internal Report #18. Five separate scans are taken, of which four are evenly spaced around the center point. This spacing is the value of HP on the monitor screen and is half the half-power beamwidth.

4.1 FIVE POINT Check List.

1. Insure that the UTC time, date, and the DUT1 correction are properly set and appear in the status monitor.
2. Command the telescope to track a planet such as Venus, Mars, Jupiter or Saturn. Check the RA and DEC positions given with the position in the American Ephermeris and Nautical Almanac of the proper year.
3. Enter the azimuth/elevation offsets in the thumbwheels and status monitor as described in section 1.4. The values entered should be the latest values from the pointing and focusing log book. Check the sign of the offsets and make sure that the RA/DEC offsets are zero.
4. Check the receiver parameters. These parameters can be set individually or by using the computer command n !RCVR, where n is the correct receiver number. The most important parameters are: HP, %EFF, ATTN, TC, FØ and MODE. The value of TC will be given to you by the engineer as a value for the noise tube.

5. Insure that you have done a calibration or substituted the approximate values for GAINØ, #C, #CP, and TC. the substitute values are given in section 3.2.

6. Connections and adjustments to the Receiver and Standard Back-End should be made according to the procedures outlined in section 1.2 and 1.3.

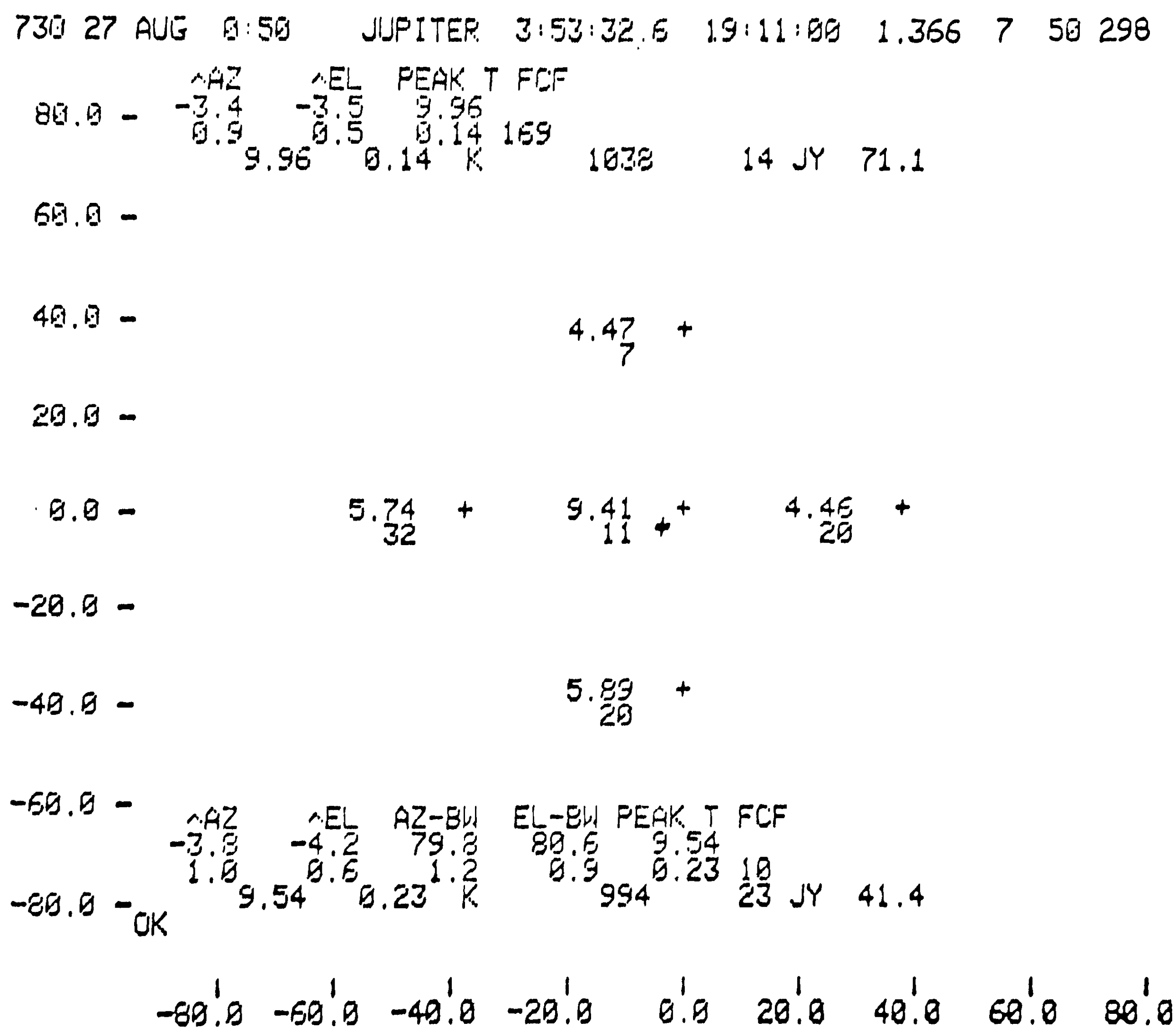
7. Set the chart recorder to a reasonable chart speed and input sensitivity. If the Standard Back-End is adjusted as in section 1.3 typical values for the chart recorder are: chart speed 15 cm/min, Total Power input sensitivity 1V/cm, Switched Power input sensitivity 5V/cm. The FST, time constant and input level of the Standard Back-End will cause the above values to vary.

8. Check the number of decimal units displayed under T(ANT) on the status monitor. Except for the Sun and Moon and after a calibration there should be at least two decimals displayed.

4.2 Data Reduction and Interpretation.

The FIVE point data reduction procedures are explained in the Computer Division Internal Report #18 under FIVE data fitting. The example on the next page shows a typical FIVE taken on Jupiter. The corrections for the azimuth/elevation offsets are the numbers under AZ and EL at the top of the page. The Δ AZ and Δ EL values are to be added to the existing azimuth/elevation offsets and entered via the thumbwheels. The new MAIN and REF positions should be entered and appear on the status monitor. The present fitting program must have some residual values (the number under the T_a for each data point) in order to properly fit the data. The Δ AZ and Δ EL should be suspect if these residuals are zero.

4.3


730 27 AUG 0:50 JUPITER 3:53:32.6 19:11:00 1.366 7 50 298
^AZ ^EL PEAK T FCF
-3.4 -3.5 9.96
0.9 0.5 0.14 169
9.96 0.14 K 1038 14 JY 71.1
80.0
60.0
40.0
20.0
0.0
-20.0
-40.0
-60.0
-80.0
4.47
7
5.74
32
9.41
11
4.46
20
5.89
20
^AZ ^EL AZ-BW EL-BW PEAK T FCF
-3.8 -4.2 79.8 80.6 9.54
1.0 0.6 1.2 0.9 0.23 10
9.54 0.23 K 994 23 JY 41.4
OK
-80.0 -60.0 -40.0 -20.0 0.0 20.0 40.0 60.0 80.0

4.4 Common Problems (FIVE POINT)

Following are some common problems and possible causes. Most are covered in detail elsewhere in the report.

1. The planet antenna temperatures are incorrect. The values of TC, #C or #CP might be wrong. Re-calibrate.
2. No data received during FIVE as implied when all the temperatures are 0 or 1. The FST on Standard Back-End is set too high, the subreflector is not nutating, the antenna is not tracking or source was not in the beam. Check the source position with the ephemeris. Check to insure that the RA/DEC offsets are zero and the AZ/EL offsets are correct. Check to insure that the clock, date and DUT1 are properly set.
3. The FIVE POINT did not fit. The source is too far from center of the beam for program to fit, check #2 above. If the residuals (the number that appears below the point temperatures) are zero the program will not fit properly.
4. If the FIVE POINT and FIVE SHAPE do not fit in approximately the same place, enter the FIVE POINT corrections called for by Δ AZ/Δ EL and do another FIVE POINT. If Δ AZ and Δ EL are larger than one half of HP, the FIVE SHAPE might be incorrect. If so, enter the FIVE POINT corrections and do another FIVE POINT.
5. The intensity of the source is low, but the calibration appears to be alright. Insure FØ is correct and that the focus controls are in computer control position.

5. Computer Controlled Focusing (FOCALIZE)

The on-line computer provides a means for determining the optimum focus for the 36-foot radio telescope. The program is available in the continuum mode and is called FOCALIZE. Focusing results are best when a FIVE POINT has already been accomplished as described earlier. The data taking procedure is described on page 95 of the Computer Division Internal Report #18 (Second Revision). The data reduction and interpretation instructions are available on page 110 of this same report. Two parameters you will need to know how to obtain are FØ and WL.

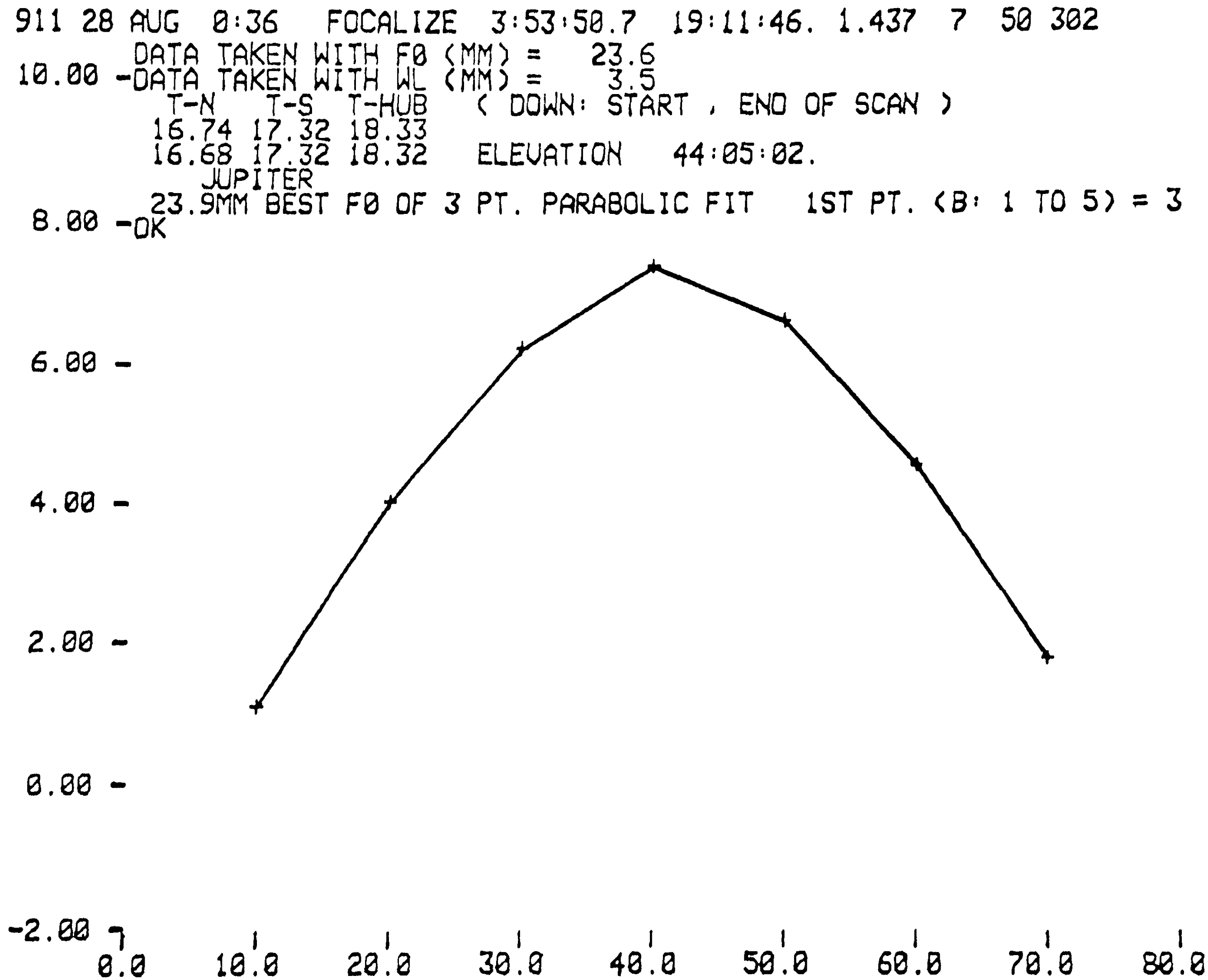
5.1 FØ is a temperature-independent quantity in the focus formula. This formula takes into account changes in dish temperature. When starting with a new receiver or subreflector a best guess for FØ can be obtained from the Pointing and Focusing Log Book.

WL is the wavelength being observed. Wavelength (λ) can be calculated from the frequency to which the receiver is tuned. For spectral line observations this frequency is available on the STATUS monitor. For continuum observations you will have to know the frequency to which the receiver is tuned.

$$WL = \lambda = \frac{300}{f} \text{ mm} \qquad f = \text{frequency in GHz}$$

$$\text{Example } WL = \lambda = \frac{300}{115.27120} = 2.60 \text{ mm}$$

5.2



911 28 AUG 0:36 FOCALIZE 3:53:50.7 19:11:46. 1.437 7 50 302
DATA TAKEN WITH F0 (MM) = 23.6
DATA TAKEN WITH WL (MM) = 3.5
T-N T-S T-HUB (DOWN: START , END OF SCAN)
16.74 17.32 18.33
16.68 17.32 18.32 ELEVATION 44:05:02.
JUPITER
23.9MM BEST F0 OF 3 PT. PARABOLIC FIT 1ST PT. (B: 1 TO 5) = 3
OK
10.00
8.00
6.00
4.00
2.00
0.00
-2.00
0.0
10.0
20.0
30.0
40.0
50.0
60.0
70.0
80.0

5.3 Common Problems

Some of the common problems that can occur during the computer controlled focusing are:

1. Clouds or other interference can cause bad data points. The focus curve may not be smooth or accurate.
2. FØ is too near the extreme end of travel for focus equipment. Focus will go into the IN or OUT LIMIT. WL can be set smaller than the calculated value to reduce the overall travel.
3. Focus curve too flat. WL could be set too small or the antenna was not tracking the source.
4. Focus curve is upside down and program picks highest value data point for best focus. TC is of the wrong sign. Use the procedure on page 110, Item #4 of Computer Division Internal Report #18 and set n B ! for the first of the three data points that you want to fit (starting from the left).

REFERENCES

Hollis, J. (1976) "36 Foot Telescope Computer Systems Manual" National Radio Astronomy Observatory Computer Division Internal Report #18. (Second revision).

National Radio Astronomy Observatory (1967) "Instruction Manual NRAO Standard Receiver."

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