TECHNICAL REPORT

THEODOLITE SURVEY FOR POSITIONING THE ANTENNA FEEDS AND RESULTING POINTING ERRORS OF THE GMRT ANTENNAS IN ELEVATION.

G. Swarup

24/11/98

Keywords : **GMRT Antennas; Pointing in elevation of GMRT antennas; Feed positioning; FPS; Theodolite Survey - antenna Feeds; Antennas - elevation pointing.**

SUMMARY

This report describes results of a theodolite survey carried out during November-December 1997 for determining the angular positions of the 327 MHz feeds in the CALIBRATION POSITION of the feed Cage, i.e. when the feed cage stops as the micro-switch near 275° is hit. The procedures followed for the survey and for calculating the required COUNTS of the incremental encoder of the Feed Position System (FPS) for accurate pointing of the 237, 610/235, 150 and 1420 MHz feeds is also described. It is shown that the above procedure correctly positions the antenna feeds near the focus of the dish and also results in correct pointing of the antennas in elevation. It is estimated that this theodolite survey should result in pointing errors of the antennas in elevation of less than about ± 3 arcmin. But this will be a fixed offset error for each frequency and can be reduced by repeated astronomical calibrations on strong sources away from galactic place.

The validity of the above procedure was verified by comparing the values of the astronomical pointing errors of the antennas determined in May 1998 for 7 antennas by Observers with the offset values of the elevation encoder equal to the stowlock position minus 90°.00. It may be noted that each of the GMRT antennas is expected to be at 90°.00 in elevation in the stowlock position, within about ± 1.5 arcmin, because of the procedure that was followed for adjusting the wire-mesh surface of the antennas during their erection.

Recommendations are also made for future work.

1. INTRODUCTION

The primary antenna feeds of the 45-m parabolic dishes of GMRT are located on a square turret box, called the Feed Cage which is located just above the focus of each parabolic dish. The Feed Cage can be rotated from about 285° to -15° using a 0.5 HP DC motor controlled by a Feed Position System (FPS) which is installed at the base of each antenna (M.R. Sankararaman et.al., 1999). Fig. 1 gives the relative location of the 1420, 150, 610/233, 327 MHz feeds for the cage when the 327 MHz feed is placed at the focus of the dish. The feed at 50 MHz is still under development and will be fixed in position to the quadripods legs.

For the sake of economy, it was decided in 1992 to use an incremental encoder for determining the angular positions of the Feed Cage. The electronics of the incremental encoder is still not backed up by a non-volatile memory chip connected to a Lithium battery. Hence it becomes necessary to reset and calibrate the incremental encoder to a given CALIBRATION (CAL) value. This CAL value is taken as 17,000 counts, for the position of the Feed Cage when it hits the micro-switch located at an angle of about 275° with respect to the centre of the Feed Cage.

Unfortunately, the 275° microswitches are not located for all antennas at the same angle. Their positions vary from about 270° to 280°. The Feed Cages can be rotated from control room using FPS from N-5° to N275° within about one minute of time (N means near about). Micro-Switches are located near about 285°, 275°, -5° and -15°. Rotation can take place beyond N275° or below N-5° only if the concerned micro-switches are bad. The switches at N285° and N-15° are end limit switches beyond which the cage must not get rotated for avoiding twisting and breakage of the 230 V AC power line and the receiver coaxial cables.

When the square turret of the Feed Cage is rotated to 270°.00 after CAL, the phase center of the 327 MHz feed are required to coincide with the prime focus of the 45-m dish, within an error of about a cm with a jitter of only about 3 or 4 mm. Similarly, phase-centres of the 610/235, 150 and 1420 MHz feeds would be at prime focus, when the Feed Cage is rotated to 180°.00, 90°.00 and 0°.00 respectively. There would arise additional error if the stools supporting the feeds are not perpendicular to the mounting plates of the Feed Cage Turret Box. The overall errors are likely to be within about ± 3 arcmin but it should be stressed that this would be a fixed error for each antenna and hence of not much consequence.

In Section 2 we discuss briefly the procedure for determining the position of the 327 MHz feed in the CAL position.

In Section 3 we describe the measurements and results of the theodolite survey which was carried out during November-December 1997 for determining the positions of 327 MHz feeds for 8 of the 30 GMRT antennas.

In Section 4 is presented a comparison of the pointing errors ("astronomical offset") of 7 out of the 8 antennas measured in May 1998 by Observers (and astronomers) with the theodolite offset values of the elevation encoders in the stowlock position which are given by the actual encoder readings in the stowlock position minus 90°.00.

Conclusions and recommendations are given in Section 5.

2. THEODOLITE MEASUREMENTS AND RELATIONS FOR CALCULATING ENCODER COUNTS

Firstly, the 45-m dish is put on the stowlock position and the Feed Cage is rotated to hit the CAL micro-switch at N-275°. We then measure the elevation and azimuth angles of the centre of the cross dipoles of the 327 MHz feed within about 10 or 20 arcsec using a theodolite placed at the apex of the dish. (Enclosure-1 for recommended procedure). Using this angle called θ_{m}., we then calculate the required value of the COUNT of the encoders so that the 327 MHz feed can be placed at 270°.00 within about ± 2 arcmin. (Enclosure-2) Since all the other three feeds are located on a square turret, phase-centres of the 610/235, 150 and 1420 MHz feeds would be at prime focus, when the Feed Cage is rotated to 180°.00, 90°.00 and 0°.00 respectively. There would arise additional error if the stools supporting the feeds are not perpendicular to the mounting plates of the Feed Cage Turret Box. The overall errors are likely to be within about ± 3 arcmin but it should be stressed that this would be a fixed error for each antenna and hence of not much consequence.

In Section 2 we discuss briefly the procedure for determining the position of the 327 MHz feed in the CAL position.

In Section 3 we describe the measurements and results of the theodolite survey which was carried out during November-December 1997 for determining the positions of 327 MHz feeds for 8 of the 30 GMRT antennas.

In Section 4 is presented a comparison of the pointing errors ("astronomical offset") of 7 out of the 8 antennas measured in May 1998 by Observers (and astronomers) with the theodolite offset values of the elevation encoders in the stowlock position which are given by the actual encoder readings in the stowlock position minus 90°.00.

Conclusions and recommendations are given in Section 5.

2. THEODOLITE MEASUREMENTS AND RELATIONS FOR CALCULATING ENCODER COUNTS

Firstly, the 45-m dish is put on the stowlock position and the Feed Cage is rotated to hit the CAL micro-switch at N-275°. We then measure the elevation and azimuth angles of the centre of the cross dipoles of the 327 MHz feed within about 10 or 20 arcsec using a theodolite placed at the apex of the dish. (Enclosure-1 for recommended procedure). Using this angle called θ_{m}., we then calculate the required value of the COUNT of the encoders so that the 327 MHz feed can be placed at 270°.00 within about ± 2 arcmin. (Enclosure-2) Since all the other three feeds are located on a square turret, they would automatically get positioned at 180°.00, 90°.00 and 0°.00 in the 610/235, 150 and 1420 MHz respectively (See Figs. 1 & 2). The equations used for calculating the required counts of the encoder, using values of θ_m for point positioning the feeds at prime focus are described in Enclosure-2.

3. THEODOLITE SURVEY CARRIED OUT BY SHRI WAMAN IN NOVEMBER-DECEMBER 1997 FOR 8 ANTENNAS

Theodolite survey was carried out by Shri Waman under guidance by myself and Shri Rajamohan for determining positions of 327 MHz feeds for 8 of the 30 GMRT antennas. I climbed upto the Apex for one antenna and verified the procedure when myself , S/Shri Waman, Rajamohan and Kailash Gaikwad took independent readings. These were all within 30 arcsec. The results of the measurements are given in Enclosure-3. A summary is given on Page 1 of the enclosure. The procedure followed is nearly the same as given in Enclosure-1. I have suggested taking elevation angles of Node No.12 for 8 PRF numbers rather that 4 PRF numbers. It may be noted that Shri Waman had found an error in the Face Left and Face Right of the Theodolite for elevation axis so that the readings differed by 3 arcmin, as may be seen from page 2 of Enclosure-3

4. COMPARISON OF ELEVATION OFFSET FROM ASTRONOMICAL CALIBRATIONS V/S THEODOLITE SURVEY OF THE FEED CAGE.

In Column (2) of Table 1 we have listed OFFSET values determined by observers as of 13th May 1998 for 7 out of 8 antennas surveyed by Shri Waman. For CO1, astronomical offset were not available.

In Column (3) are given Elevation Encoder values in the stowlock position as determined by observers using a programme written by Prof. V.K. Kulkarni to determine the mean value, minimising the effect of backlash due to gaps between the stowlock box and stowlock pin (the antennas are rotated slowly from about 89° to 91° and back several times and a mean value is taken).

In Column (4) are given "Theodolite Survey OFFSET" equal to (90° - El. encoder reading in the stowlock position).

In Column (6) are given the difference of (Theodolite - OFFSET) - (Astronomical OFFSET) for elevation axis. The differences are less than 1/10th of antenna beamwidth at 327 MHz. Improved Astronomical Calibration for CO9, C10, C11 may give smaller differences. It is important to make astronomical calibrations for 1420 MHz as the antenna beamwidth is only about 20 arcmin and then taking average of several readings. Since stowlock position can be readily determined, it is advisable to use the value of OFFSET = (Elev. encoder reading in Stow position) - 90° for frequencies upto 600 MHz, and use astronomical calibration values only for fine tuning for the 21 cm feed, if required.

5. CONCLUSIONS AND RECOMMENDATIONS

As can be seen from Table-I that the difference between the Offset values calculated from astronomical calibration and from theodolite surveys at 327 MHz feeds (column 2 & 4 respectively) differ by about only ± 3 arcmin. for 4 antennas but by 6 to 8 arcmin for the other 3 out of 7 antennas measured by Shri Waman during November-December 1997. The larger errors of 6 to 8 arcmin. are only 1/10th of the beamwidth of the 45-m dish at 327 MHz and could have arisen due to errors in astronomical calibrations. However, this aspect needs to be verified.

My recommendations are as follows:

a) To carryout the theodolite survey expeditiously over the next 4 to 5 weeks for 13 antennas where FPS has been installed but the theodolite survey was not done by Shri Waman. Table-2 gives summary of Shri Waman's measurements for 8 antennas.

Since the recommended procedure for the theodolite survey (Encl. 1) does not require any servo engineers or FPS engineers or technicians, it should be possible to survey at least one antenna if not two antennas during one day because the main jobs are to put the antenna in stowlock position from the control room or from the shell, climb the antenna, mount the theodolite, adjust it and take readings in azimuth and elevation of 8 parabolic frames and finally readings of the 327 MHz cross dipoles, both in Face Left and Face Right 3 or 4 times. In fact, it is only a two or three hours job!

b) It is very important to record in a register or a special "pointing measurement file" any changes made to the N275 Microswitch used for calibration. The workers and engineers should give in writing that that the microswitch has been replaced exactly in the same position within 1/2 mm or better by putting a scratch line on either side of the microswitch before it is removed and refitting it accordingly. This report must be submitted to the Control room to Professor-in-Charge very promptly.

c) It is extremely important that readings are recorded systematically in a tabular form and consistency checked before one climbs down from the antenna. The analysis can be done at Khodad or Pune at a later date but within a week.

d) It is also very important that prompt notification is recorded in a file in the control room in case if any elevation encoder or its black box is removed from the antenna. It is highly desirable to take readings of the elevation encoders prior to removing the encoders or soon after on the same day or within the next day. Copies of the works carried on the encoders may be sent to the control room, Prof. A.P. Rao and Prof. V.K. Kulkarni. I would appreciate getting a copy of the same over the next 3 months. I would also appreciate if xerox copy of the past history of replacement of encoders is sent to me because I want to study the changes in the stowlock position for the last two years. While there are step changes in many cases, possibly because of replacement of encoders, there also seems to be some ups and downs in the stowlock position encoder readings for a few antennas, possibly due to loose couplings

(Enclosure-3). It is not possible to do astronomical calibrations frequently and hence stability of encoders is extremely important.

e) It is also desirable to take elevation encoder readings for the stowlock positions of all the antennas using programme by Prof. V.K. Kulkarni every fortnight so that we can study the stability of the elevation encoders in the stowlock positions.

f) We may also decide whether we should use counts or degrees (two decimals) for Feed positions. I prefer the latter so that it is immediately obvious as to which Feed is pointed to the dish. The Offset of Feed encoders for 327 MHz can be made hidden to astronomers. However, a programme is being written for both counts and degrees as per relations given in Enclosure-2.

6. ACKNOWLEDGMENTS:

I acknowledge thanks to Shri S. Rajamohan, who got the survey done by Shri Waman and other staff and Observers for various aspects of this report.

7. REFERENCES

Sankaraman et al (1999) : Feed Position System of GMRT : Technical Report, under preparation. 1999.

hck/theo.doc

Table 1 : Comparison of Astronomical Calibration of Elevation Encoder with the values of Elevation Encoder in the Stowlock Position for Seven antennas Surveyed by Waman during November-December 1997

Sr. No.	Ant	OFFSET * Astronomical (13^{th} May 97)+	Stowlock Position Elev.Encod Reading	Theo dolite offset (3)-90°	Date of stow Meas	(Elev.Encoder + offset)* 6 = (3)-(2) EL	** Error or Difference ((6)-90° = (4)-(2)
	1	2	3	4	5	6	7
1.	C04	-5'	89° 58'	-2'	19.4.98	90° 03'	+03'
2.	C05	-11'	89° 49'	-11'	19.4.98	90° 00'	.00'
3.	C06	0°	89° 57'	-3'	15.9.97	89° 57'	-03'
4.	C08	10'	90° 08'	8'	19.4.98	89° 58'	-02'
5.	C09	-37'	89° 17'	-43'	19.4.98	89° 54'	-06'
6.	C10	28'	90° 20'	20	19.4.98	89° 52'	-08
7.	C11	18'	90° 12'	12'	19.4.98	89° 54'	-06'

* OFFSET = True-(Stowlock position elevation encoder reading)

(as per Prof. V.K. Kulkarni)

Therefore, True = (Stowlock position El. Encoder Reading - Offset)

Since the Feed Cages have been surveyed by Shri Waman for these 7 antennas and 327 MHz feed for each has been accordingly placed at the Focus using FPS, true Reading should be $90^{\circ} \pm 3$ arcmin.

\+ Offset values taken from the printout by observers dt. 13.5.1997 enclosed (Table-3)

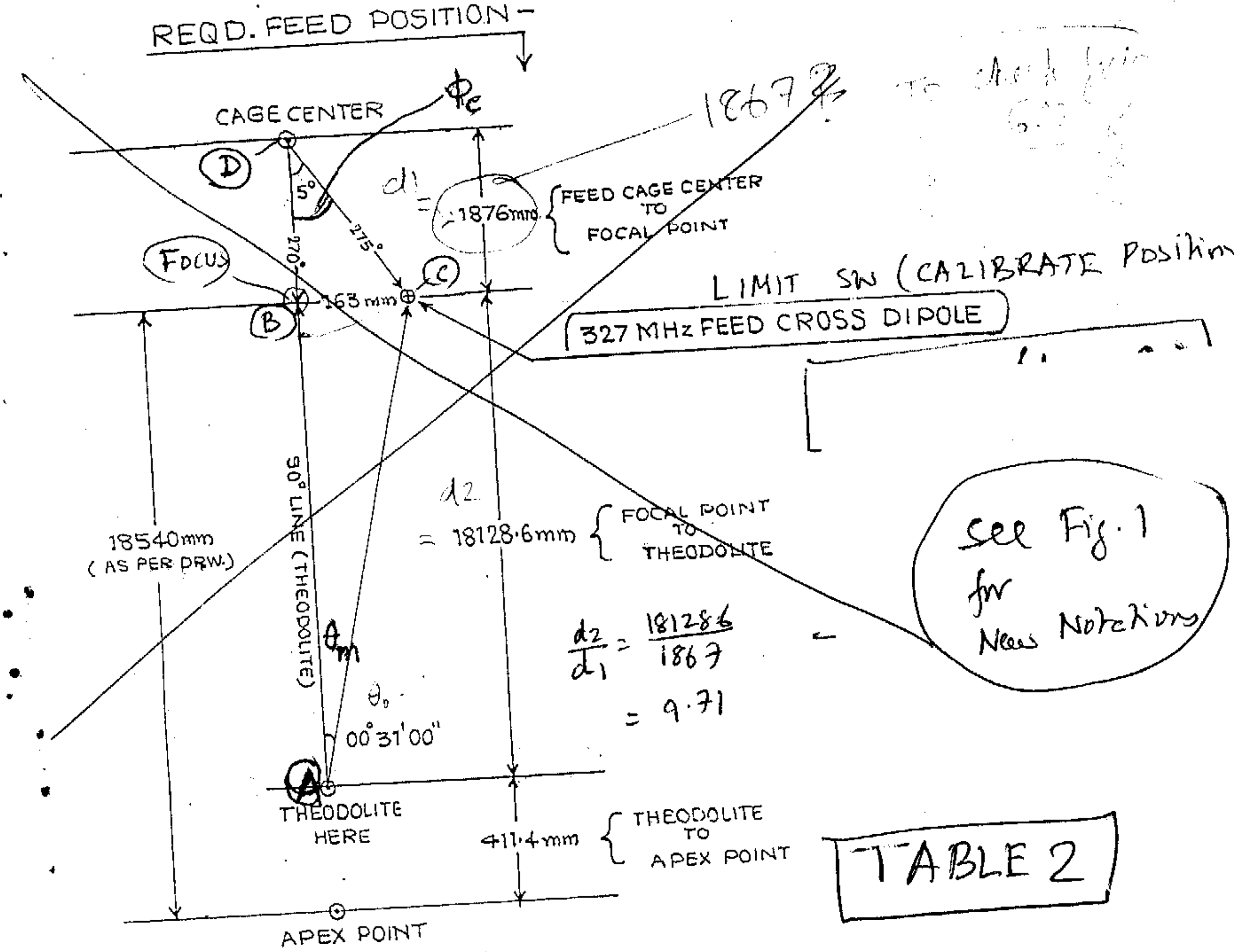
** The difference = error, is relatively large for some antennas. It could be due to errors in astronomical calibration since the beamwidth of GMRT antennas is about 83 arcmin and hence errors of $1/10^{th}$ to $1/20^{th}$ of the beamwidth could arise depending on the source flux density etc. In future we should take average of several astronomical calibrations, particularly at 21 cm.

TABLE 2

Table 2

- REPORT OF FEED POSITION CHECKING -
- SURVEY WORK -

- DATE -
17 NOV. 1997
- TO -
17 DEC. 1997



C12

GS Check for individual sheets

θ FEED. POSITION			
TOWER	OFFSET ANGLE θ ⊖	REQD. OFFSET ANGLE ⊜	ACTUAL OFFSET ANGLE
C-0	LIMIT SWITCH PROBLEM		
C-1	00° 46' 16"	00° 31' 00"	00° 15' 16"
C-2	- PROBLEM OF ROATATION SYSTEM -		
C-3	- PROBLEM OF ROATATION SYSTEM -		
C-4	00° 53' 00"	00° 31' 00"	00° 22' 00"
C-6	00° 38' 25"	00° 31' 00"	00° 07' 25"
C-8	01° 01' 16"	00° 31' 00"	00° 30' 16"
C-9	01° 00' 03"	00° 31' 00"	00° 29' 03"
C-10	00° 32' 05"	00° 31' 00"	00° 01' 05"
C-11	00° 35' 58"	00° 31' 00"	00° 04' 58"
C-13	- LIMIT SWITCH PROBLEM -		
C-14	- HONY-BEEHAVE IS THERE -		
C-5	00° 53' 45"	00° 31' 00"	00° 22' 45"
C-13	SURFACE MEASURMENT WORK		OVER

Co

REPORT

BHALCHAND
-S

Table 3

at 325 MHz

ASTRON OFFSET / as per Observers (13 May 98)

Offset

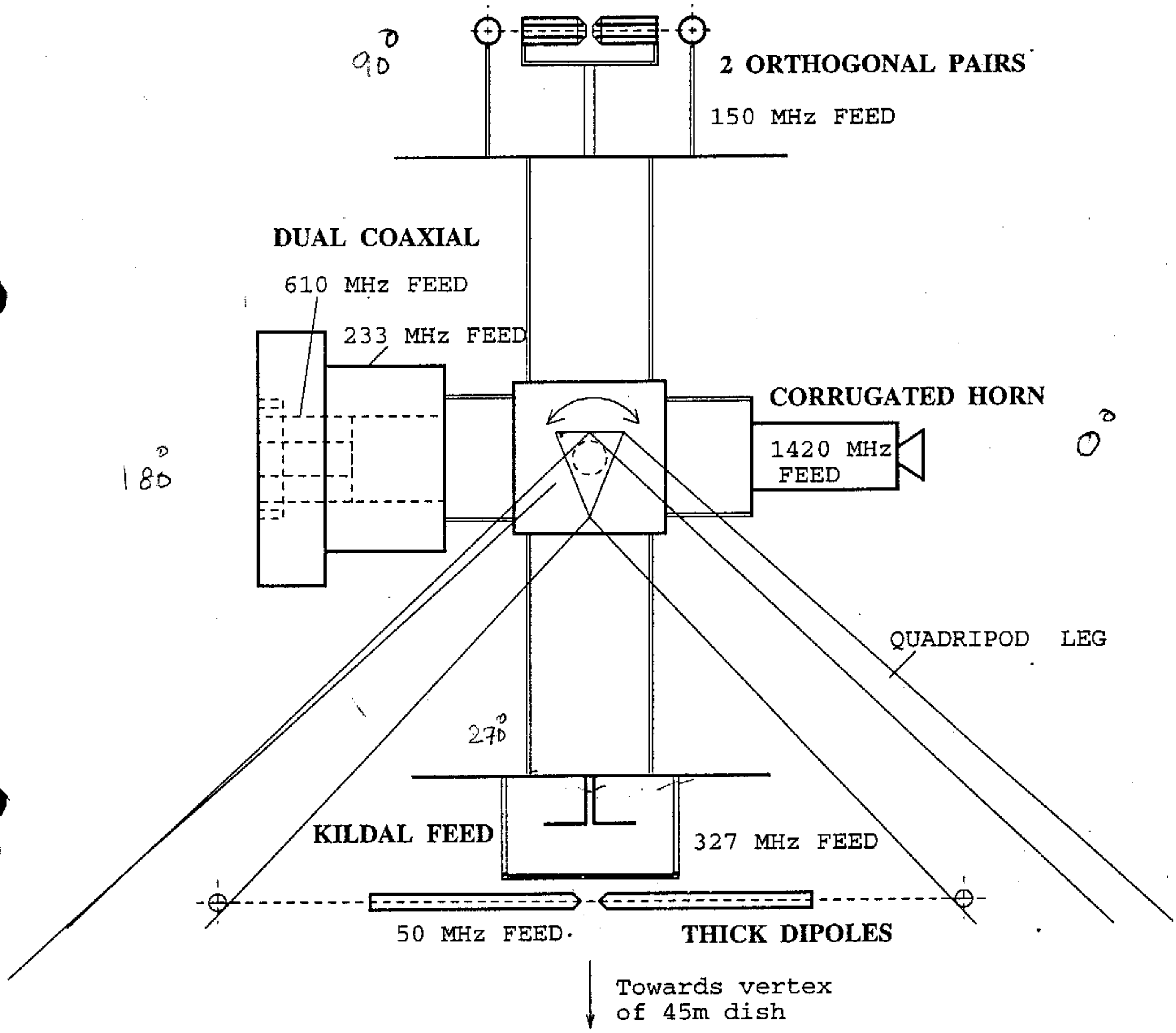
DATE: 13may98
Current antenna offset f

```
subar 0
*C04
cp 0;ante 1 3; defs 0;
ldantof(3', -5')
*C09
cp 0;ante 1 4; defs 0;
ldantof(5', -37')
*C02
cp 0;ante 1 5; defs 0;
ldantof(3d24',18')

*C00
cp 0;ante 1 7; defs 0;
ldantof(30',-27')

*C11
cp 0;ante 1 9; defs 0;
ldantof(-30', 18')
*C14
cp 0;ante 1 10; defs 0;
ldantof(30', 21')
*C13
cp 0;ante 1 11; defs 0;
ldantof(28', 35')
*C10
cp 0;ante 1  12; defs 0;
ldantof(2d12', 28')
*C05
cp 0;ante 1 19; defs 0;
ldantof(8d20', -11')
*C06
cp 0;ante 1 20;defs 0;
ldantof(0d,0d)
*C08
cp 0;ante 1 24; defs 0;
ldantof(42',10')
*S03
ante 1 27;defs 0
ldantof(7',-20')
*
```

6
82

FIG. 1

GMRT PRIME FOCUS FEEDS



Parameters	50 MHz	150 MHz	233 MHz	327 MHz	610 MHz	1420 MHz
Taper w/o space loss	-8.6 ± 1 dB	-9 ± 1 dB	-9 ± 0.5 dB	-12.2 ± 1 dB	-9.8 ± 1 dB	-19 dB
Cross-polar peak	---	-17.4 dB	---	-27.5 dB	-22.8 dB	-24 dB
Side lobe level	-9 ± 1 dB	-22 ± 4 dB	-15 ± 1 dB	-22 ± 4 dB	-17 ± 3 dB	---
Aperture efficiency	0.515	0.718	0.693	0.742	0.698	0.47
Bandwidth (SWR < 1.5)	20 MHz	122 MHz	4.5 MHz	67 MHz	104 MHz	600 MHz
Gain	---	8.5 dB	7.7 dB	5.4 dB	8.6 dB	12.8 dB

Fig 2

REQD. FEED POSITION IS AT F

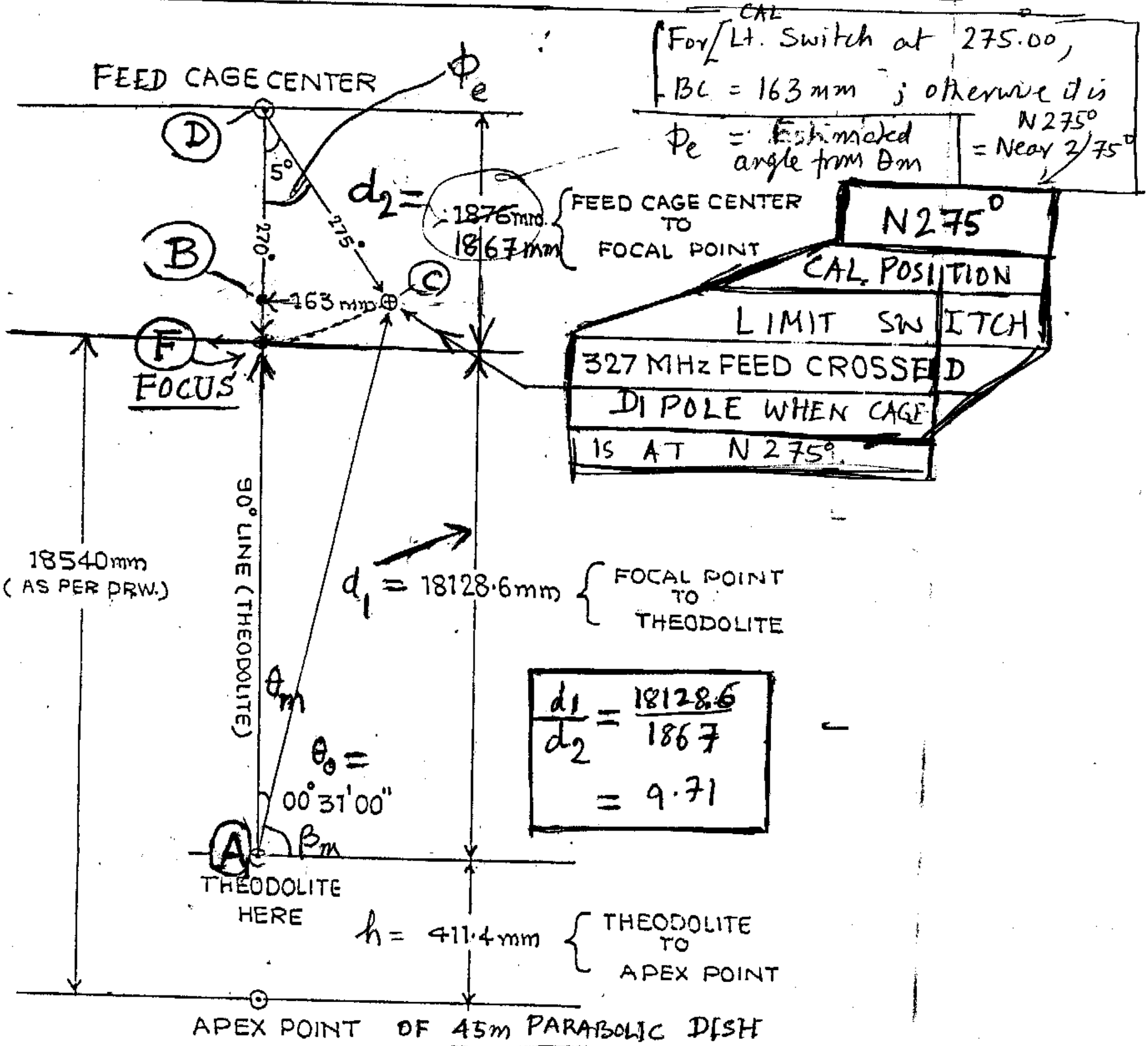


FIG. 2 : Shows the position of the 327 MHz feed when located at the ~~HDI micro~~ CAL microswitch position. The angle Φ_e is ~~and~~ the required rotation angle ~~(Φ_e)~~ for positioning the 327 MHz Feed to the Focal point. Values of Φ_e are estimated ~~for~~ from the known constants d_1 and d_2 ~~for~~ the 45-m dishes and values of θ_m as measured with ~~by placing~~ a theodolite placed near the Apex of the dish and sighting the 327 MHz feed when the Cage hits the CAL micro-switch.

ENCLOSURE-1

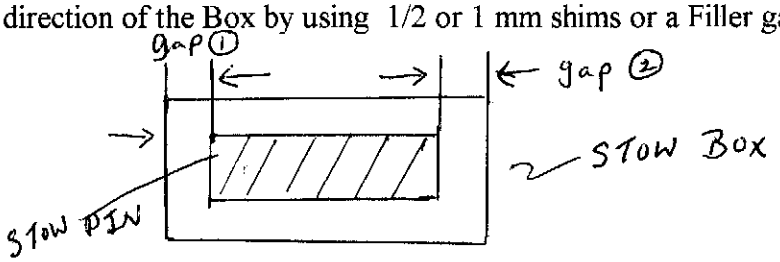
24/11/1998

PROCEDURE FOR THEODOLITE SURVEY FOR DETERMINING POSITION OF THE 327 MHz FEED WHEN THE FEED CAGE HITS THE CAL MICROSWITCH

G. Swarup

1. From either the Control Room or bottom of the antenna being surveyed, rotate the Feed Cage till it hits the CAL micro-switch (i.e. CALIBRATE FPS). Note the FPS encoder value, which will be a bit higher than 17,000.

2. Bring the antenna to STP position and insert stowlock pins from Control Room or Shell. Measure approximately the gaps between the stowlock pins and stowlock box in the longer direction of the Box by using 1/2 or 1 mm shims or a Filler gauge.



3. Check alignment of the theodolite when it is on ground by measuring Az & El angles of a distant target both in FACE LEFT and FACE RIGHT. Both readings should be nearly the same. Any theodolite with at least 10 or 20 arcsec. accuracy and capability to use DIAGONAL EYE PIECE will do. It is preferable if the theodolite has optical readout for convenience of reading. If the Face left & Face Right readings have more than one arcmin difference, Feed Cage angles will have to be measured both along

Face Left and Face Right position of theodolite and a mean value taken. It is advisable to take both readings any case. In due course, the Theodolite adjustment may be done.

4. Place the Theodolite on the Theodolite Mount or Pipe stand at the APEX of the 45-m dish. (Make a rough sketch of the type of the Mount for record sake - because there are more than one type of Mounts welded to the dish by V.M. Jog Engineering Ltd. and Southern Structurals Ltd.).

5. Level the theodolite and measure Az and Elevation angles of Node no. 12 for PRF 01, 03, 05, 07, 09, 11, 13, 15 and again for PRF 01 for cross-checking purpose. Face left and Face right readings are not required for PRF. Please note that PRF 01 and PRF 09 are along the Pin Sector direction. Record the readings in a Tabular format as per Enclosure-A. (Please note that the 45-m dish is in a "horizontal position" when the stowlock pin is inserted because of the method used for erection and alignment of the dish; the dish was lifted, levelled by surveying Nodes 12 & 17 for 8 or 16 frames and the stowlock pin was welded to the Yoke structure and then the inner surface of the dish inside the HUB was erected and adjusted). The above PRF measurement values will also cross check any departure of the dish from horizontal position and particularly also determine a small positional error of the 327 MHz feed in Azimuth. A separate Note is being written for reduction of the data.

6. Now inset the Diagonal Eye Piece on to the theodolite and measure Az and El angles of the centre of the crossed-dipoles of the 327 MHz feed. Take Face left and Face right readings as per Table A.

7. Height of the theodolite above the Apex of the dish is to be measured. It is expected to be 411 mm. If the Theodolite Mounts are intact and the height of the base-plate of the mount is available from previous records, it is sufficient to measure the height of

rotation axis of the theodolite telescope from the base plate. Otherwise measure the height with respect to the Elevation axis (see a sketch by Shri S. Rajmohan). An accuracy of about 1 cm is required.

8. Fig. 2 and Table 2 give a copy of the feed survey done by Shri Waman for general guidance

G. Swarup

24/11/1998

ENCLOSURE-2

RELATION BETWEEN THE ANGLE θ_c OF THE FEED CAGE AND ANGLE θ_m MEASURED BY A THEODOLITE FOR THE 327 MHz FEED WHEN AT THE CALIBRATE (CAL) POSITION. ALSO, THE REQUIRED VALUE OF COUNTS OF THE FPS ENCODER FOR POSITIONING THE ANTENNA FEEDS.

---

1. Figure 2 shows the geometric relation between angles θ_m for the 327 MHz feed when at the CAL position.

2. The distance, d_1, between the focal point of 45-m dish, F, and rotation axis of the theodolite equals (18540- h), where h is the height of the theodolite above the Apex of the dish. The distance between the Apex of the 45-m dish and its focal point, F, equals 18540 mm as per TCE drawings. V.M. Jog Engineering Ltd. and Southern Structurals Ltd. have welded a permanent theodolite mount on many antennas, for which h = 411 mm. This needs checking w.r.t. elevation rotation axis and then by subtracting the height of the Apex w.r.t El rotation axis as per TCE drawings.

3. d_2 = distance between the centre of the rotation axis of the Feed Cage and the Focal point F.

4. The angle θ_m is the measured angle of the 327 MHz feed when at the CAL position w.r.t the vertical direction or zenith direction (see Fig.1). It is equal to (90° - Elevation angle β_m as measured with a theodolite located above the apex point of the 45-m dish.).

5. The angle ϕ_e is the required rotation angle of the Feed Position System (FPS) drive for positioning the 327 MHz feed to the focal point.

6. We have the following relations :

$$BC = d_2 \sin\phi_e \qquad (1)$$

also

$$BC = AB \tan\theta_m$$

$$= (AF + FB) \tan\theta_m$$

$$= (d_1 + d_2 - d_2 \cos\phi_e) \tan\theta_m \qquad (2)$$

because FB = (DF - DB)

7. By equating (1) + (2), we get

$$\sin\phi_e = \{(d_1 + d_2(1 - \cos\phi_e)) \tan\theta_m\}/d_2 \qquad (3)$$

If ϕ_e has a small value, $(1-\cos\phi_e)$ is nearly zero, and we can approximate value of ϕ_e as

$$\phi_e' = \sin^{-1}((d_1/d_2) \tan\theta_m) \qquad (4)$$

Where d_1 = 18128 mm and d_2 = 1867 mm.

In the next iteration by inserting ϕ_e' on RHS of Eq. 3, we can find more accurate value of ϕ_e.

Since $\theta_m < 1^\circ$ and $\phi_e < 10^\circ$, we can also approximate

$$\phi_e = (18128/1867)\theta_m$$

$$= 9.71\ \theta_m \qquad (5)$$

This relation should be used only for a broad check.

8. For the FPS drive, one full rotation of 360° = 20, 480 counts of the incremental encoder (In fact, 360° = 5, 120 counts but the associated electronics multiplies the incremental encoder values by a factor of 4). Hence the required value of count, ΔN, corresponding to the angle ϕ_e is given by :

$$\Delta N_{327} = (20480/360)\ \phi_e$$

$$= 56.888\ \{ \sin^{-1} ((d_1/d_2) \tan \theta_m))\}, \text{ or more accurately,}$$

$$= 56.888\ \{ \sin^{-1} ((1/d_2) \times (d_1 + d_2 - d_2 \cos \phi_e) \times \tan \theta_m))$$

and hence, the required value of counts of the incremental encoder for 327 MHz, N_{327}

$$N_{327} = (17{,}000 - \Delta N_{327}) \text{ Counts} \qquad (6)$$

9. Since 90° rotation = (20,480)/4 = 5,120 counts, hence

$$N_{610} = (N_{327} - 5120) \text{ Counts} \qquad (7)$$

$$N_{150} = (N_{327} - 10240) \text{ Counts} \qquad (8)$$

$$N_{1420} = (N_{327} - 15360) \text{ Counts} \qquad (9)$$

10. It may be noted that an error of one Count = 1.05 arcmin. of the Feed Cage rotation and approximately (1.05/10.8) = 0.1 arcmin. of the 45-m antenna w.r.t. to the elevation axis. It is desirable that the positioning of the antenna feeds is within about ± 5 Counts on a repeatable basis, corresponding to ± 0.5 arcmin. or about ($1/40^{th}$) of the beamwidth of 45-m dish at 1400 MHz.

(G. SWARUP)

24/11/1998

-CURRENT STOW POSITIONS OF ANTENNAS 13 May 98 Encl.

Ant name (1)	Date Mon day Year (2)	Mean dd ' " (3)	RMS arc m (4)	Std.Dev arc min (5)	90-(3) Remarks
C00	24 Jul 1995	89 44 11	8.45	2.99	
C00	11 Aug 1995	89 44 11	8.53	3.01	
C00	20 Aug 1995	89 44 25	8.71	3.08	
C00	9 Sep 1995	89 44 36	(H) 8.66	3.06	
C00	26 Sep 1995	89 44 27	8.77	3.10	
C00	1 Oct 1995	89 45 47 ← Max	8.00	2.53	
C00	14 Oct 1995	89 44 11	8.64	3.05	Highly stable
C00	21 Nov 1995	89 44 21	8.28	2.93	July 95 - Apr 98
C00	4 Feb 1996	89 43 58	7.66	2.21	
C00	11 Mar 1996	89 43 55	8.24	2.38	
C00	25 Apr 1996	89 44 20	1.69	0.69	variation approx
C00	1 Jun 1996	89 43 57	2.14	0.96	
C00	18 Jun 1996	89 43 55	1.21	0.54	
C00	11 Jul 1996	89 44 10	1.93	0.79	89° 44' 10"
C00	21 Apr 1997	89 43 14 ← Min	1.63	0.81	± 30"
C00	26 May 1997	89 44 14	2.25	0.92	
C00	17 Jun 1997	89 44 0	(M) 1.42	0.58	
C00	15 Sep 1997	89 44 5	2.23	0.91	
C00	26 Sep 1997	89 44 20	2.80	1.98	89° 44'
C00	19 Apr 1998	89 43 44	2.46	1.01	
C01	5 May 1995	89 57 5 ←	12.84	4.54	
C01	3 Aug 1995	89 56 28	5.41	1.91	
C01	11 Aug 1995	89 45 19 ?	2.79	1.98	
C01	2 Sep 1995	89 55 41	5.52	1.95	
C01	16 Sep 1995	89 55 6	6.30	2.23	
C01	1 Oct 1995	89 54 35	5.24	1.85	
C01	14 Oct 1995	89 54 38	6.00	2.12	encoder value
C01	3 Nov 1995	89 53 15	5.51	1.95	seems to vary
C01	13 Nov 1995	89 52 8	(H) 4.51	1.60	
C01	21 Nov 1995	89 53 27	5.31	1.88	
C01	1 Feb 1996	89 52 57	4.63	1.34	from 89° 52' to
C01	11 Mar 1996	89 52 25	6.95	2.01	
C01	15 Apr 1996	89 54 59	5.32	1.54	89° 57'.
C01	11 May 1996	89 54 10	3.96	1.62	Perhaps, ~~He~~ there is
C01	20 May 1996	89 52 51	4.33	1.77	
C01	20 Jun 1996	89 55 25	7.79	3.18	~~Stowlock~~ a larger
C01	11 Jul 1996	89 53 45	5.26	2.15	gap between the stowlock
C01	20 Mar 1997	89 55 13	4.70	1.92	box and pin for C01.
C01	21 Apr 1997	89 52 45	6.76	3.38	
C01	4 Aug 1997	89 57 11 ←	5.32	2.17	
C01	9 Aug 1997	89 55 11	5.03	2.05	Mean = 89° 54'
C01	15 Sep 1997	89 53 50	3.82	1.56	
C02	1 Nov 1994	90 19 35	6.14	1.54	
C02	11 Nov 1994	90 18 7	6.56	1.64	~ 90° 19'
C02	25 Nov 1994	90 19 51	6.61	1.65	
C02	14 Feb 1995	89 35 36	7.77	1.88	
C02	16 Feb 1995	89 35 21	7.77	1.94	~ 89° 33.5'
C02	27 Feb 1995	89 30 23	6.10	1.52	
C02	15 Mar 1995	89 48 7	7.53	2.66	89° 46'
C02	1 Apr 1995	89 42 0	7.28	1.63	
C02	8 May 1995	89 38 40	7.03	2.49	
C02	22 Jun 1995	89 33 5	6.99	2.47	
C02	24 Jun 1995	89 34 31	6.97	2.32	89° 33.5
C02	20 Jul 1995	89 33 9	7.19	2.54	
C02	24 Jul 1995	89 33 4	7.47	2.64	
C02	2 Aug 1995	89 33 35	3.50	1.24	
C02	10 Aug 1995	89 8 35	3.22	1.14	89° 8'
C02	20 Aug 1995	89 8 47	3.25	1.15	

C02	26	Aug	1995	89	25	15	3.54	1.25
C02	9	Sep	1995	89	25	50	3.10	1.10
C02	16	Sep	1995	89	25	44	3.16	1.12
C02	1	Oct	1995	89	27	48	8.86	5.11
C02	14	Oct	1995	89	24	53	3.17	1.12
C02	2	Nov	1995	89	25	54	3.29	1.16
C02	13	Nov	1995	89	26	27	3.89	1.38
C02	16	Jan	1996	89	26	33	4.47	1.58
C02	23	Jan	1996	89	25	9	4.03	1.42
C02	1	Feb	1996	89	23	31	3.49	1.23
C02	11	Mar	1996	89	25	13	3.95	1.14
C02	7	Nov	1996	90	24	16	0.60	0.24
C02	23	Dec	1996	90	24	13	0.81	0.36
C02	30	Dec	1996	90	24	32	0.81	0.40
C02	20	Mar	1997	90	24	44	0.32	0.13
C02	25	Apr	1997	90	24	12	0.34	0.14
C02	11	May	1997	90	23	55	0.65	0.46
C02	26	May	1997	90	24	18	0.82	0.34
C02	17	Jun	1997	90	24	46	0.61	0.25
C02	4	Aug	1997	90	24	50	1.15	0.47
C02	9	Aug	1997	90	24	26	1.23	0.50
C02	26	Sep	1997	90	23	35	0.88	0.63
C02	26	Sep	1997	90	23	35	0.88	0.63
C02	6	Jan	1998	89	53	55	4.86	1.98
C02	6	Jan	1998	89	53	55	4.86	1.98
C02	6	Jan	1998	89	53	55	4.86	1.98
C02	19	Apr	1998	90	24	16	0.89	0.36

89° 25′

90° 24′

step between Sep 97 – Jan 98 and Jan 98 to Apr 98

89° 54′

90° 24′

C03	5	Jul	1994	90	0	16	6.68	1.53
C03	11	Jul	1994	89	56	59	4.64	1.03
C03	15	Jul	1994	90	0	25	5.58	3.03
C03	29	Jul	1994	90	0	20	4.56	1.84
C03	7	Sep	1994	90	0	20	3.67	1.91
C03	21	Sep	1994	90	0	29	9.50	1.94
C03	26	Oct	1994	90	0	32	9.99	2.50
C03	11	Nov	1994	90	0	45	9.19	2.30
C03	23	Nov	1994	90	45	21	9.98	2.50
C03	15	Feb	1995	90	42	45	15.66	3.80
C03	7	Mar	1995	90	45	26	10.79	5.39
C03	30	Mar	1995	90	45	25	11.08	3.92
C03	2	Apr	1995	90	45	39	9.67	2.16
C03	1	May	1995	90	45	32	9.94	3.51
C03	8	May	1995	90	45	17	10.60	3.75
C03	2	Aug	1995	90	45	32	11.47	4.05
C03	10	Aug	1995	90	45	39	11.16	3.95
C03	4	Dec	1995	89	56	3	11.99	4.24
C03	16	Jan	1996	89	56	2	11.58	4.09
C03	23	Jan	1996	89	56	6	10.56	3.73
C03	1	Feb	1996	89	55	54	11.10	3.93
C03	11	Mar	1996	90	0	21	13.32	4.21
C03	25	Apr	1996	89	55	39	1.18	0.48
C03	20	Mar	1997	89	55	32	0.73	0.30
C03	11	May	1997	89	55	7	0.97	0.49
C03	26	May	1997	89	55	20	1.79	0.90
C03	17	Jun	1997	89	55	0	0.93	0.38
C03	15	Sep	1997	89	55	38	1.76	0.72
C03	6	Jan	1998	90	22	13	0.24	0.10
C03	6	Jan	1998	90	22	13	0.24	0.10

step

step Jan 98 : [illegible]

C04	11	Jul	1994	89	54	59	3.09	1.12
C04	15	Jul	1994	89	56	2	5.89	1.46
C04	7	Sep	1994	90	0	5	4.81	4.28
C04	21	Sep	1994	89	59	45	5.77	1.29
C04	26	Oct	1994	90	2	3	7.51	1.88
C04	11	Nov	1994	90	14	26	7.93	1.98
C04	23	Nov	1994	91	25	1	7.08	1.45

C04	15 Feb	1995	91	24	56	8.87	2.22		
C04	27 Feb	1995	91	25	50	8.87	2.22		91° 25′
C04	2 Apr	1995	91	26	6	8.97	2.01		
C04	1 May	1995	91	25	30	10.22	3.61		
C04	8 May	1995	~~91~~	~~29~~	~~22~~	8.49	3.00		91° 28′ ± 2′
C04	19 Jun	1995	91	30	10	7.05	2.49		
C04	24 Jun	1995	91	29	52	7.32	2.59		
C04	10 Jul	1995	91	28	45	9.86	3.48		
C04	1 Aug	1995	91	28	8	9.67	3.42		
C04	20 Aug	1995	91	26	55	10.16	3.59		
C04	25 Aug	1995	90	0	14	8.86	2.67		
C04	9 Sep	1995	90	0	51	9.49	3.35		
C04	16 Sep	1995	90	0	40	10.65	3.77		
C04	1 Oct	1995	90	1	47	9.07	3.21		90° 01′ ± 2′
C04	14 Oct	1995	90	1	23	7.35	2.60		
C04	7 Nov	1996	90	2	1	3.97	1.62		
C04	23 Dec	1996	90	1	56	3.57	1.46		
C04	20 Mar	1997	89	59	56	4.36	1.78		
C04	27 May	1997	89	57	32	6.70	2.73		
C04	18 Jun	1997	89	57	55	4.22	1.72		
C04	19 Jun	1997	89	56	12	6.72	2.74		89° 58′ ± 2′
C04	11 Aug	1997	89	57	45	5.41	2.21		stable
C04	15 Sep	1997	89	58	44	3.59	1.46		Mar-Sept 97
C04	26 Sep	1997	89	58	57	7.62	5.39		
C05	25 Apr	1997	89	49	57	1.96	0.80		
C05	26 May	1997	89	50	25	2.91	1.19		
C05	4 Aug	1997	89	49	56	1.03	0.42		89° 50′ stable
C05	15 Sep	1997	89	49	9	1.38	0.56		May-Sept 97
C05	19 Apr	1998	89	49	32	0.65	0.27		
C06	26 May	1997	89	58	19	0.41	0.17		
C06	18 Jun	1997	89	58	9	0.38	0.16		
C06	4 Aug	1997	89	58	25	0.58	0.24		89° 58′ stable
C06	15 Sep	1997	89	57	47	0.74	0.30		May-Sept 97
C08	12 Aug	1997	90	7	39	1.07	0.44		
C08	26 Sep	1997	90	8	14	1.87	0.76		
C08	15 Feb	1998	~~85~~	~~42~~	~~57~~	0.00 ?	0.00 ?		→ perhaps wrong reading – ?
C08	20 Feb	1998	90	7	53	3.38	1.38	(M)	so stable Aug 97 – Apr 98
C08	19 Apr	1998	90	7	50	2.06	0.84		90° 08′ ~~Stable Aug~~
C09	5 Jul	1994	89	46	7	6.24	2.56		
C09	11 Jul	1994	89	47	59	5.35	2.14		
C09	15 Jul	1994	89	45	46	6.87	2.37		
C09	7 Sep	1994	(90	15	1)	4.36	2.73		
C09	6 Oct	1994	89	44	48	5.36	1.34		
C09	6 Oct	1994	89	44	0	6.84	3.42		Many steps
C09	6 Oct	1994	89	44	15	6.61	3.31		
C09	14 Feb	1995	89	45	48	6.33	3.31		
C09	15 Feb	1995	89	44	33	5.64	1.78		stable Oct 94-May 95
C09	27 Feb	1995	89	43	50	5.93	1.48		
C09	14 Mar	1995	89	43	25	6.14	2.17		
C09	1 Apr	1995	89	43	27	5.46	1.22		
C09	1 May	1995	89	44	38	5.94	2.10		
C09	8 May	1995	89	44	37	6.31	2.23		
C09	21 Jun	1995	89	44	53	6.22	2.20		
C09	17 Jul	1995	89	41	42	6.79	2.77		
C09	31 Jul	1995	89	36	54	23.39	7.80		
C09	26 Aug	1995	89	26	11	6.08	2.15		
C09	9 Sep	1995	89	24	31	6.07	2.14		
C09	16 Sep	1995	89	25	36	5.89	2.08		
C09	1 Oct	1995	89	25	18	6.02	2.13		
C09	14 Oct	1995	89	24	24	7.92	5.60		Stable Sept 95-Oct 96
C09	30 Oct	1995	89	23	53	6.03	2.13		
C09	13 Nov	1995	89	24	39	6.30	2.23		

C09	4	Dec	1995	89	23	38	5.88	2.08
C09	16	Jan	1996	89	23	17	6.09	2.15
C09	4	Feb	1996	89	22	18	5.96	1.72
C09	11	Mar	1996	89	21	37	6.24	1.80
C09	15	Apr	1996	89	21	27	6.10	1.76
C09	25	Apr	1996	89	21	44	0.43	0.18
C09	20	May	1996	89	22	32	0.16	0.06
C09	7	Nov	1996	89	17	52	1.93	0.86
C09	25	Dec	1996	×89	12	0	18.31	7.48
C09	1	Jan	1997	89	17	48	0.55	0.28
C09	25	Apr	1997	89	17	43	6.57	2.68
C09	9	Aug	1997	89	16	27	1.07	0.62
C09	19	Apr	1998	89	17	13	low 0.18	0.07
C10	31	Dec	1996	90	17	17	3.52	1.44
C10	20	Mar	1997	90	19	22	3.64	1.48
C10	17	Jun	1997	90	18	4	4.20	1.72
C10	26	Sep	1997	90	18	27	3.76	1.53
C10	19	Apr	1998	90	20	23	4.32	1.76
C11	20	Aug	1995	89	56	52	3.56	1.26
C11	2	Sep	1995	89	56	13	3.55	1.26
C11	23	Jan	1996	90	23	11	2.36	0.83
C11	1	Feb	1996	90	23	11	2.54	0.73
C11	11	May	1996	90	23	53	(L) 0.76	0.31
C11	20	Jun	1996	90	24	28	0.85	0.35
C11	20	Mar	1997	90	23	32	low 1.10	0.45
C11	25	Apr	1997	90	23	45	1.36	0.61
C11	19	Jun	1997	90	23	20	0.87	0.35
C11	11	Aug	1997	90	23	25	1.62	0.73
C11	19	Apr	1998	90	12	32	0.79	0.32
C12	5	Jul	1994	90	5	47	5.34	2.05
C12	11	Jul	1994	90	7	30	5.21	2.54
C12	15	Jul	1994	90	6	0	4.92	1.12
C12	29	Jul	1994	90	6	9	3.89	1.85
C12	7	Sep	1994	90	5	30	(H) 5.92	3.25
C12	4	Oct	1994	89	56	49	5.37	2.69
C12	4	Oct	1994	89	59	10	high 7.10	1.59
C12	1	Nov	1994	90	0	5	7.65	1.91
C12	11	Nov	1994	89	58	42	7.39	1.85
C12	22	Nov	1994	91	10	58	13.58	2.23
C12	24	Nov	1994	90	15	14	3.50	0.87
C12	5	Apr	1995	91	26	26	5.57	1.97
C12	1	May	1995	90	1	56	4.85	1.72
C12	8	May	1995	90	2	16	5.78	2.04
C12	20	Jun	1995	90	2	49	5.60	1.98
C12	24	Jun	1995	90	2	11	4.27	1.51
C12	10	Jul	1995	90	2	13	5.22	1.85
C12	31	Jul	1995	90	3	29	6.03	2.13
C12	20	Aug	1995	91	2	46	5.73	2.02
C12	26	Aug	1995	90	22	57	5.51	1.95
C12	9	Sep	1995	90	23	6	5.39	1.91
C12	1	Oct	1995	90	22	53	5.92	2.09
C12	14	Oct	1995	90	22	50	(L) 5.29	1.87
C12	30	Oct	1995	90	22	3	5.17	1.83
C12	13	Nov	1995	90	22	11	low 5.88	2.08
C12	20	Nov	1995	90	21	44	4.42	1.56
C12	18	Jun	1996	90	22	40	0.36	0.16
~~C12~~	~~25~~	~~Dec~~	~~1996~~	~~90~~	~~10~~	~~9~~	~~30.79~~	~~12.57~~
C12	25	Dec	1996	90	10	9	30.79	12.57
C12	21	Apr	1997	90	21	45	0.20	0.10
C12	25	Apr	1997	90	21	46	? 4.52	1.85
C12	4	Aug	1997	90	22	32	(L) 1.05	0.43
C12	9	Aug	1997	90	22	17	low 1.33	0.54

step : why ?

ignore : why wrong?
89° 17.3 ± 1′
Stable Dec 96 – Apr 98

90° 20′

stable

step : why ?
90° 13′

large errors

ignore
many

why large errors ??

90° 22′ stable Apr 97 – Aug 97

C13	1	Jun	1996	89	40	32		0.44	0.20	gradual shift why?? !!
C13	2	Dec	1996	89	37	24		0.60	0.30	
C13	4	Dec	1996	89	38	2		0.12	0.07	
C13	1	Jan	1997	89	36	41	L	0.48	0.24	
C13	11	May	1997	89	35	19		0.85	0.43	
C13	26	May	1997	89	33	57		0.76	0.31	
C14	1	Nov	1995	90	6	44		1.89	0.67	
C14	20	Nov	1995	90	5	1		1.81	0.64	
C14	1	Feb	1996	90	5	34		2.18	0.63	
C14	1	Jun	1996	89	51	50		0.91	0.41	Steps
C14	14	Jun	1996	90	1	22		1.90	0.78	
C14	11	Jul	1996	89	44	52		2.89	1.18	Why ?
C14	5	Dec	1996	89	45	39		2.35	0.96	
C14	31	Dec	1996	89	45	27		2.02	0.90	
C14	20	Mar	1997	89	43	53		2.62	1.07	
C14	25	Apr	1997	89	44	2		2.45	1.00	
C14	11	May	1997	89	33	6		2.40	2.35	
C14	11	JUN	1997	84	59	50		2.40	2.35	← large err
C14	15	Sep	1997	90	24	25		1.80	0.73	
C14	19	Apr	1998	90	23	36	M	3.22	1.31	90° 24′ Sept 97 - Apr 98
W01	6	Sep	1995	90	13	20		2.59	0.92	
W01	25	Sep	1995	90	17	31		2.69	0.95	
W01	17	Oct	1995	90	17	14	M	2.85	1.01	
W01	2	Nov	1995	90	17	15		2.93	1.04	
W01	1	Feb	1996	90	16	18		7.20	1.12	90° 17′ stable
W01	20	May	1996	90	17	15		3.22	1.31	Sept 95 - Dec 96
W01	13	Dec	1996	90	17	55		2.66	1.09	
W02	2	Dec	1996	89	56	14		0.55	0.22	
W02	4	Dec	1996	89	56	2		0.75	0.31	
W02	20	Mar	1997	89	55	55		0.67	0.27	
W02	21	Apr	1997	89	55	59		0.70	0.35	
W02	25	Apr	1997	89	56	7	L	0.75	0.31	
W02	10	May	1997	89	55	36		0.67	0.34	89° 56′
W02	19	Jun	1997	89	55	49		0.45	0.18	
W02	4	Oct	1997	89	55	8		0.63	0.26	
W03	4	Dec	1996	90	20	43		2.87	1.66	
W03	19	Jun	1997	90	22	44	L	1.47	0.60	
W03	12	Aug	1997	90	22	26		1.65	0.74	
W04	13	Dec	1996	90	20	52		2.87	1.17	
W04	13	Dec	1996	90	20	54		0.39	0.16	
W04	30	Dec	1996	90	20	9	L	1.05	0.47	
W04	25	Apr	1997	90	21	27		0.40	0.16	
W04	10	May	1997	90	20	48		0.63	0.31	
E02	16	Dec	1996	90	19	15		5.63	2.30	
E02	11	Aug	1997	90	19	40		6.30	2.57	
E02	13	Jan	1998	90	18	0		8.98	3.67	
E02	6	Feb	1998	90	18	51	H	9.37	3.82	
E02	15	Feb	1998	90	19	0		9.56	3.90	
E02	20	Feb	1998	90	19	5		8.33	3.40	
E03	25	Dec	1996	89	53	4		26.64	10.87	~~wrong~~ large error? wrong meas ?
E03	1	Jan	1997	90	2	15		1.59	0.65	
E03	11	Aug	1997	90	2	58		1.49	0.61	
E03	13	Jan	1998	90	2	4		1.42	0.58	90° 2′ stable
E03	15	Feb	1998	90	1	39		2.01	0.82	Jan 97 - Feb 98
E03	20	Feb	1998	90	1	46		1.92	0.79	
S01	15	Feb	1998	90	11	29		41.24	23.81	← wrong meas ?
S01	20	Feb	1998	90	35	40		1.78	0.73	90° 36′

TABLE-A : THEODOLITE SURVEY OF 327 MHz FEED IN CAL POSITION*

Antenna No.	Theodolite No	Measured by	Date	Time

1. SURVEY OF PRF

PRF No.	Azimuth (Node 12)	Elevation (Node 12)
01		
03		
05		
07		
09		
11		
13		
15		
Av of El only		
Av of Az of PRF 01 to 09		

2. THEODOLITE MEASUREMENTS OF 327 MHz FEED IN CAL POSITION

a) Put antenna in stowlock position from control room or base of the antenna. Measure the gaps on long side between the stowlock position and stowlock box using 1/2 or 1 mm shims.

b) Put 327 MHz feed in CAL position from Control room or base of the antenna.

Sr. No.		Azimuth	Elevation
1.	Face Left		
2.	Face Right		
3.	Face Left		
4.	Face Right		
5.	Face Left		
6.	Face Right		