GBT Memo No. 34

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, WV

MEMORANDUM

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To: GBT Memo Series

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Subj: **GBT Feed/Subreflector Positioning Coefficients**

Several years ago, J. Ruze published an analysis of antenna beam direction sensitivity to feed and subreflector positions, for symmetrical antennas. Ron Maddalena has looked at this derivation and feels that the Ruze equations are valid for the offset configuration.

The pages attached summarize the Ruze equations and state the calculated coefficients for the proposed GBT geometry. For illustration, the remaining pages look at what feed and subreflector positioning specifications might be required for certain pointing specifications.

The positioning requirements can be divided into two parts. Tracking stability, meaning how accurately the feed or subreflector must be held (or known) while tracking a source, and registration, the accuracy a subreflector or feed should be positioned when taken off and then returned to service. Since all these errors can add, the sum of all must meet the overall pointing specifications. What remains to be done is to set the overall pointing operational requirements, and then to allocate the errors among the many contributing factors.

RDN/cjd

Attachments

Summary of Ruze Pointing Equations

<u>For Small Displacements:</u> (angles in degrees)

Feed Offset at Prime Focus, ΔX:

$$\Delta\theta_{FT/\Delta X} \simeq BDf/f \cdot 180/\pi$$

Main Reflector Rotation, $\Delta\alpha$

$$\Delta\theta_P/\Delta\alpha = (1 + BDf)$$

Secondary Feed Displacement, ΔX_S

$$\Delta\theta_{FS}/\Delta X_S = BDF/Fe \cdot 180/\pi$$

Subreflector Rotation (ellipse vertex), $\Delta\beta$

$$\Delta\theta_{SR}/\Delta\beta = (BDf + BDF)\ (C/2f)\ (1 - e)/e$$

Subreflector Translation, ΔS

$$\Delta\theta_{ST}/\Delta S = (BDF/f + BDF/Fe) \cdot 180/\pi$$

For GBT, $f = 60$ m $BDf \simeq 0.94$

For M1: $C = 11$ m, $e = 0.528$, $Fe = 190$ m, $BDF \simeq 1$

For M2: $C = 11$ m, $e = 0.680$, $Fe = 338$ m, $BDF \simeq 1$

where:

- f is paraboloid focal length
- C is distance between foci of subreflector ellipsoid.
- e is subreflector eccentricity
- Fe is effective focal length of subreflector-paraboloid combination
- BDf is prime focus Beam Deviation Factor
- BDF is secondary focus Beam Deviation Factor

GBT Pointing Coefficients

For M1:

$\Delta\theta_{FS}/\Delta X_S$ = 0.18 arc-min/cm (0.45 BW/λ) (Feed Translation)

$\Delta\theta_{SR}/\Delta\beta$ = 0.16 (Subreflector Rotation)

$\Delta\theta_{ST}/\Delta S$ = 0.70 arc-min/cm (1.74 BW/λ) (Subreflector Translation)

For M2-1:

$\Delta\theta_{FS}/\Delta X_s$ = 0.10 arc min/cm (0.25 BW/λ) (Feed Translation)

$\Delta\theta_{SR}/\Delta\beta$ = 0.08 (Subreflector Rotation)

$\Delta\theta_{ST}/\Delta S$ = 0.64 arc min/cm (1.59 BW/λ) (Subreflector Translation)

Prime Focus:

$\Delta\theta_{FT}/\Delta X$ = 0.54 arc min/cm (1.34 BW/λ) (Subreflector Translation)

$\Delta\theta_P/\Delta\alpha$ = 1.94 (Parabola Rotation)

where:

$\Delta\theta$	is antenna beam pointing error.
ΔX_S	is secondary feed lateral translation.
$\Delta\beta$	is subreflector rotation about vertex.
ΔS	is subreflector lateral translation.
ΔX	is prime focus feed translation.
$\Delta\alpha$	is parabola rotation.

Tracking Stability

Prime Focus Feed Lateral, so that error is within ± HPBW/20 at $\lambda = 6$ cm (HPBW = 2.4 arc min)

=> $\Delta X < \pm 2.2$ mm = ± 0.087"

at

$\lambda = 15$ cm, $\Delta X \leq \pm 5.6$ mm = ± 0.22"

<u>M1:</u> Error < ± HPBW/20 @ $\lambda = 3$ cm (HPBW = 1.2 arc min)

Allow 1/3 of 1.2/20 arc min to each.

=> $\Delta\theta_{FS} = \Delta\theta_{SR} = \Delta\theta_{ST} < 0.020$ arc min (1.2 arc sec)

=> $\Delta X_S < \pm 0.11$ cm = ± 1.1 mm = ± 0.04" (Feed Translation)

$\Delta\beta < \pm 8$ arc sec (Subreflector Rotation)

$\Delta S < \pm 0.03$ cm = ± 0.3 mm = ± 0.012" (Subreflector Translation)

<u>M2:</u> Error < ± HPBW/10 @ $\lambda = 3$ mm (100 GHz) HPBW = 7.2 arc sec

Allow 1/3 of 7.2/10 arc sec to each

=> Tol = 0.24 arc sec = 0.004 arc min

=> $\Delta X_S \leq \pm 0.04$ cm = ± 0.4 mm = ± 0.016"

$\Delta\beta \leq \pm 3$ arc sec

$\Delta S \leq \pm 0.06$ mm = ± 0.002"

at $\lambda = 7$ mm (43 GHz) HPBW = 16.9 arc sec

$\Delta X_S \leq \pm 0.9$ mm = ± 0.037"

$\Delta\beta \leq \pm 7$ arc sec

$\Delta S \leq \pm 0.15$ mm = ± 0.006"

To nutate beam ± 10 arc min with M2

By Feed Translation: $\Delta X_S = \pm 10/0.10 = \pm 100$ cm = 39"

By Subreflector Rotation: $\Delta\beta = \pm 10/0.08 = \pm 125$ arc min = ± 2°

By Subreflector Translation: $\Delta S = \pm 10/0.64 = \pm 16$ CM = ± 6"

Registration

Prime Focus

$\Delta\theta/\Delta X = 1.34\ BW/\lambda$

Registration : within $\pm$ 0.5 HPBW

$\Rightarrow \Delta X \leq \pm 0.37\ \lambda$

@ $\lambda = 15$ cm (2 GHz); $\Delta X \leq \pm 5.6$ cm $= \pm 2.2''$

@ $\lambda = 6$ cm (5 GHz); $\Delta X \leq \pm 2.2$ cm $= \pm 0.87''$

Subreflector Translation

Registration: within $\pm$ 0.5 HPBW

M1: $\Delta\theta/\Delta S = 1.7\ BW/\lambda \Rightarrow \Delta S \leq \pm 0.3\ \lambda$

@ $\lambda = 3$ cm (10 GHz), $\Delta S \leq \pm 9$ mm $= \pm 0.35''$

M2: $\Delta\theta/\Delta S = 1.6\ BW/\lambda \Rightarrow \Delta S \leq \pm 0.3\ \lambda$

@ $\lambda = 7$ mm (43 GHz), $\Delta S < \pm 2.1$ mm $= \pm 0.08''$

@ $\lambda = 3$ mm (100 GHz), $\Delta S < \pm 0.9$ mm $= \pm 0.035''$