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TECHNICAL MEMORANDUM 52
REVISION 4
Pointing Accuracy

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TECHNICAL MEMORANDUM

PROJECT:	NRAO 100 Meter Green Bank Telescope
TECH MEMO NO:	52
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1.0 Introduction and Summary

The purpose of this Tech Memo is to document the system-level pointing accuracy analysis of the NRAO GBT 100-Meter Radio Telescope. As described in the following paragraphs all components and elements contributing to the pointing accuracy have been considered.

The purpose of Revision 3 to this Tech Memo was to incorporate the results of the FEM95 elevation rotating structure analysis and the latest servo control and drive system errors into the pointing accuracy analysis.

Revision 4 corrects some minor ambiguities in the text of the report but does not present any new analytical data. Although the finite element model has since been updated from FEM95 to FEM97, the changes affect only the weight distribution within the structure. Since structural deformations due to gravity do not impact the operational beam pointing accuracy, the results recorded in Revision 3 are still valid.

Results from the analysis indicate that, with the exception of the maximum thermal gradient, the pointing accuracy of the GBT meets the specification requirements. The following conditions are satisfied:

(a) repeatable pointing error (excluding gravity effects) is less than 3 arcminute rss
(b) nonrepeatable pointing error in low frequency operation is less than 7 arcsecond rss without wind or thermal effects
(c) nonrepeatable error is less than 14 arcsecond rss when wind effects are included

2.0 Basis of Analysis

The pointing accuracy error of the GBT is defined as the angular difference between the RF axis of the telescope and the direction corresponding to the azimuth and elevation position commands. In accordance with the GBT specification, the pointing error contributors are categorized as either repeatable or nonrepeatable errors. Repeatable error sources include axes misalignments, gravity distortions, bearing runout and alignment, track deviations, encoder referencing errors, etc. Nonrepeatable pointing errors include distortions due to wind or thermal gradients, bearing nonrepeatability, encoder resolution, encoder accuracy, data conversion error, servo and drive errors, etc. Furthermore, the specification requires that each individual error source contributing to the pointing error be a rms value. If only peak or worst-case errors are identifiable and have time constants less than one minute (such as errors due to wind gusts), the peak errors are to be divided by 2.5 to arrive at a rms value to use in the pointing error calculations. For those peak errors that have time constants longer than one minute and up to several hours (such as those due to thermal effects), the peak errors are to be used as the rms value in the pointing error calculations.

In summarizing the effect of environmental loads and manufacturing limitations on pointing error, it is convenient to divide the errors into components in the elevation direction (ε_Y) and the cross-elevation direction (ε_X) as shown in Figure 2-1. Because of the geometry of the Az-El coordinate system, these error components are related to the axis angle errors by:

$$\varepsilon_X = \varepsilon_A \cos E,$$
$$\varepsilon_Y = \varepsilon_E,$$

where:

ε_A = difference between reference and rf axis azimuth angles,
ε_E = difference between reference and rf axis elevation angles,
E = antenna elevation angle

Error sources that result in fixed azimuth errors have a diminishing effect on space angle error with increasing elevation angle. The combined space angle error (ε) is the vector sum of the elevation and cross-elevation error components.

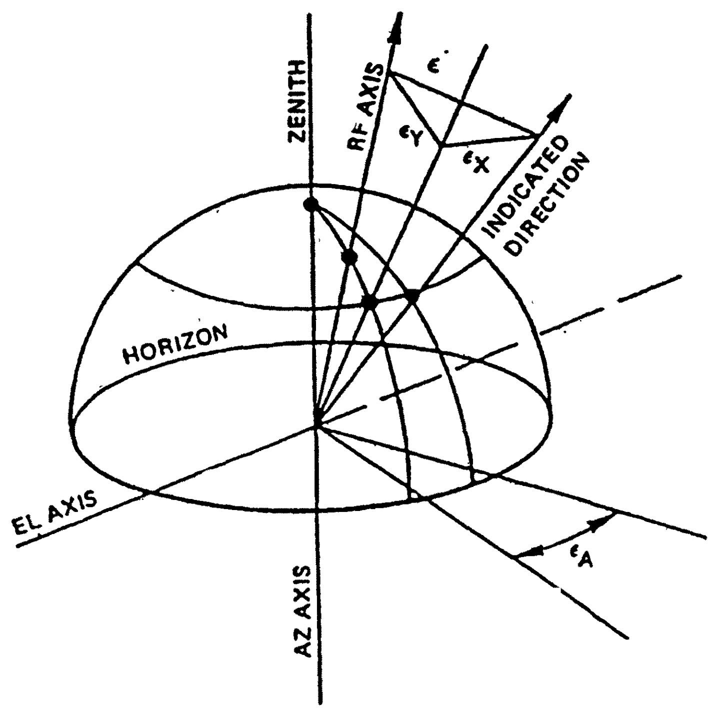

Figure 2-1. Angular Error Components

$$\varepsilon = (\varepsilon_X^2 + \varepsilon_Y^2)^{1/2}$$
$$= (\varepsilon_A^2 \cos^2 E + \varepsilon_E^2)^{1/2}$$

In the pointing error summary below and in the analysis of individual error sources, the error sources are classified by the foregoing conventions.

2.1 Mechanical Alignment Errors

The various axis misalignments are the results of inaccuracies in field alignment and instrumentation procedures and are considered repeatable.

2.1.1 RF/Elevation Axes Orthogonality

Errors can occur in the feed and subreflector alignment procedures and cause misalignment of the RF axis with respect to the elevation data readout and the true elevation axis. The pointing errors due to nonorthogonality of the RF and elevation axes are invariant with time. However, on the GBT, this nonorthogonality will be corrected with the optics positioning mechanisms and there will be no pointing error contribution from this error source.

2.1.2 Elevation/Azimuth Axes Orthogonality

If the elevation axis differs from perpendicularity with the azimuth axis by φ_E, the pointing errors are given by:

$$\varepsilon_X = \varphi_E \sin E,$$
$$\varepsilon_Y = 0$$

The maximum cross-elevation pointing error occurs near zenith while the elevation pointing error is zero throughout the elevation travel range. Based on the field alignment requirement to set the elevation bearings to the correct elevation within ±0.25 inch, φ_E has a maximum value of 60 arcsecond.

2.1.3 Azimuth Axis Verticality

If the azimuth axis deviates by an angle φ_A from vertical, the pointing error components are given by:

$$\varepsilon_X = \varphi_A \sin A' \sin E$$
$$\varepsilon_Y = \varphi_A \cos A'$$

where A' is the azimuth angle measured from a plane containing the vertical axis and the azimuth axis.

The effects of verticality misalignments cannot be compensated since the two pointing error components are not a linear function of the pointing angles. The cross elevation component is a function of both the azimuth and elevation angles and requires a different adjustment for each point of the hemisphere. For the purpose of a conservative pointing accuracy analysis, the maximum value for each elevation angle will be considered. The azimuth track will be aligned level within ±0.020 inch of a true horizontal plane and the azimuth axis will be vertical within 5 arcseconds of the local gravity vector. These pointing errors are greatest in the vicinity of zenith where the pointing error is 5 arcseconds.

2.2 Structural Deformation Errors

The structural deformation contribution to the pointing error is a function of the compliances of the components within the system. Deflections of these components due to wind and thermal loads contribute to the overall pointing error of the system. Initial calibration of the telescope will eliminate the repeatable errors associated with gravity deformations.

Pointing error contributions of the elevation rotating structure are determined by means of computer analysis as described in Tech Memo 43. Deflections of the main reflector surface, subreflector and feed due to various wind and thermal loads are calculated by finite element analysis. A new surface (which minimizes the rf half-path length error) is best-fit to the distorted surface using the NRAO RMS12 computer program. Knowing the best-fit paraboloid (BFP) parameters and the deflections of the subreflector and feed with respect to the BFP axis, the pointing error contribution of the elevation rotating structure can be calculated using the pointing coefficients defined by NRAO[1]. Spreadsheets summarizing the elevation rotating structure pointing errors for both Gregorian and prime focus optics systems are attached as Appendix A. Note that these calculations are based on deformations resulting from a steady 15-mph wind. The resulting pointing errors are factored for the equivalent wind speed of 6 m/s winds gusting to 7 m/s (in accordance with the applicable EIA Standard[2]) in the tables presented in Paragraph 2.5.

Compliances of the remaining components of the telescope are determined from structural and mechanical analyses of the components. These compliances include all contributors to displacement and rotation such as the structure, bearings, drives, and foundation and soil. Alidade compliances (which include the compliances of the azimuth wheels and drives) used in these pointing error calculations are taken from Tech Memo 13. Elevation bearing and elevation drive compliances are taken from Tech Memos 17 and 29, respectively. Foundation and soil compliances are taken from Tech Memo 06.

Pointing errors due to wind loads are a function of wind speed and orientation of the antenna relative to the wind direction and include the effects of deflection of the reflector structure, bending and rotation of the pedestal and foundation, and deflections due to mechanical compliances of drives and bearings. Forces and moments on the antenna structure are functions of the wind velocity and the orientation of the antenna relative to the wind. Wind loads used in the calculation of the pointing errors are taken from Tech Memo 15. These loads are factored for the equivalent wind speed of 6 m/s winds gusting to 7 m/s in accordance with the applicable EIA Standard[2]. Detailed calculations of the pointing error contributions of the alidade, elevation bearings and drives, foundation and soil for the various telescope and wind orientations are contained in Appendix B.

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1. Srikanth, S., "Pointing Coefficients for Single Subreflector Optics (Update)," National Radio Astronomy Observatory, Charlottesville, VA, 29 April 1991.

2. --------, "Electrical and Mechanical Characteristics of Earth Station Antennas for Satellite Communications," EIA Standard EIA-411-A, Electronic Industries Association, Washington, DC, September 1986, pg. 3-11.

Pointing errors due to thermal effects are a function of the thermal gradients applied to the components of the alidade and elevation rotating structure and include the effects of the deflections of the reflector backup and feed arm structures. The specific thermal gradient to be applied to the GBT is specified to be 5°C. According to Dr. Lee King of NRAO (in a telephone conversation with Dave Kelley of Loral on 30 September 1991), the gradient is to be applied across the structure dimensional extremes in each of the coordinate axes independently. Thermal gradient pointing errors for the elevation rotating structure are contained in the spreadsheets of Appendix A and those for the alidade are contained in the calculations of Appendix B.

Pointing errors due to structural deformation for a number of telescope and relative wind orientations are tabulated in Paragraph 2.5. Note that the structural deformations due to wind loads are summed prior to combining them with the other errors. The same is true for deformations due to thermal gradients.

2.3 Servo and Drive Errors

Pointing errors due to the servo control and drive systems have been defined by RSi-PCD.[3] These errors are presented in the tables contained in Paragraph 2.5. Note that the pointing error values used in the tables (0.86 arcsecond for elevation and 0.32 arcsecond for azimuth) are based on a 25 January 1993 telephone conversation with Frank Cole of RSi-PCD.

2.4 Miscellaneous Errors

Miscellaneous pointing error contributors include subreflector positioner backlash, elevation and azimuth bearing wobble, encoder accuracy, and encoding system referencing errors. These error sources are addressed in the following paragraphs.

2.4.1 Subreflector Positioner Backlash

Backlash in the subreflector positioning actuator and clevis assemblies can result in nonrepeatable pointing errors under wind loading conditions. These errors occur about the elevation and cross-elevation axes depending upon the orientation of the telescope with respect to the wind and are maxima at either end of the elevation travel. For conservatism, the maximum values are used in the pointing accuracy analysis presented herein. Subreflector rotations due to backlash in the actuator and clevis assemblies are calculated in Tech Memo 46. Applying the pointing coefficients provided by NRAO[1] to these rotations results in the following pointing errors.

ε_X = 0.81 arcsecond for symmetric wind loads
ε_Y = 0.61 arcsecond for asymmetric wind loads

3. --------, "NRAO Green Bank Telescope Servo and Drive Pointing Accuracy," Radiation Systems, Inc, Precision Controls Division, Richardson, TX, October 1992.

2.4.2 Elevation Bearing Wobble

An ideal bearing has a fixed instantaneous axis of rotation; however, in real bearings the axis moves radially and tilts as the bearing rotates. Elevation bearing wobble arises due to variations in the gap between the internal and external races and in the bearing roller diameters and out-of-roundness of the elevation shaft. The magnitude of this wobble is difficult to predict theoretically but it can be estimated by considering tolerance build-up of the various elements. Based on the final design as documented in Tech Memo 17 and assuming the "runouts" occur in a worst case combination, the peak bearing wobble is estimated to be less than 1 arcsecond. WDL has made measurements of the wobble of large bearings and has found that there is a repeatable error component of about this magnitude and a nonrepeatable component that is about 40% of the value of the repeatable portion. Both the repeatable and nonrepeatable pointing error components (φ_{EB}) due to elevation bearing wobble are a maximum at zenith and in the cross-elevation axis vary as the sine of the elevation axis and in the elevation axis are invariant with elevation angle.

$$\varepsilon_X = \varphi_{EB} \sin E$$
$$\varepsilon_Y = \varphi_{EB}$$

2.4.3 Azimuth Bearing Wobble

Azimuth bearing wobble is caused by irregularities in the surface of the azimuth track, out-of-roundness of the azimuth wheels, anomalies in the azimuth wheel bearings, *etc.* Assuming the "runouts" occur in a worst case combination and considering the large diameter of the azimuth track, the magnitude of the peak bearing wobble is estimated to be 1 arcsecond. This is a repeatable error; for conservatism, a nonrepeatable error of 40% of the value will be assumed. The pointing error component (φ_{AB}) due to azimuth bearing wobble is a maximum at zenith and in the cross-elevation axis vary as the sine of the elevation axis and in the elevation axis is invariant with elevation angle.

$$\varepsilon_X = \varphi_{AB} \sin E$$
$$\varepsilon_Y = \varphi_{AB}$$

2.4.4 Encoder Accuracy

Electronic angle encoders that convert the rotations of the respective input shafts to console-mounted digital displays are used to measure the telescope azimuth and elevation axis angles. Peak errors introduced by the encoders themselves (accuracy), encoder resolution and roundoff, and the mechanical couplings delivered with the encoder are defined by RSi-PCD.[4] These errors are presented in the tables contained in Paragraph 2.5.

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4. --------, "NRAO Green Bank Telescope Encoder Accuracy," Radiation Systems, Inc, Precision Controls Division, Richardson, TX, October 1992.

2.4.5 Encoder Coupling

The encoders are coupled to the axes by encoder drive shafts. The errors inherent in the coupling mechanism are nonrepeatable and are not correlated with the encoder errors. The windups of the encoder drive shafts have been calculated; the resulting encoder coupling errors are presented in Tech Memos 41 and 42 for the elevation axis and in Tech Memo 14 for the azimuth axis. The values of these windups are 0.34 arcsecond (Tech Memo 41) plus 0.07 arcsecond (Tech Memo 42) equals 0.41 arcsecond for the elevation axis and 0.686 arcsecond (Tech Memo 14) for the azimuth axis. The 1.41 arcsecond error associated with the 0.3° angular misalignment of the coupling must be added to each axis (see Appendix C). The cross-elevation component of the pointing error (φ_{ENC}) varies with the cosine of the elevation angle while the elevation component is invariant with elevation angle.

$$\varepsilon_X = \varphi_{ENC} \cos E$$
$$\varepsilon_Y = \varphi_{ENC}$$

2.4.6 Encoder Referencing

Repeatable errors (φ_{REF}) can occur in setting the zero positions of the axes encoders. If the zero azimuth readout differs from true north, the azimuth pointing error component varies as the cosine of the elevation angle and no elevation pointing error component occurs. If the zero elevation readout differs from the horizon, the elevation pointing error component is invariant with antenna orientation and no azimuth error occurs. Both azimuth and elevation zero references can be readily aligned to within 10 arcseconds. Hence, the pointing errors are:

$$\varepsilon_X = \varphi_{REF} \cos E$$
$$\varepsilon_Y = \varphi_{REF}$$

2.5 Pointing Error Summary

The repeatable and nonrepeatable system-level pointing accuracies for the various telescope orientations, configurations, and loading conditions are summarized in Tables 2-1 and 2-2, respectively. The component pointing errors are presented for several orientations of the telescope relative to the wind in Tables 2-3 through 2-10 for the Gregorian optics configuration and in Tables 11 through 18 for the prime focus optics configuration. Tables 2-19 and 2-20 contain the pointing errors for both optics configurations for the two worst case thermal loading conditions (*i.e.,* with the sun heating one side of the alidade and with the sun heating the rear face of the alidade, respectively). The pointing errors for both optics configurations without wind or thermal loads are presented in Tables 2-21 and 2-22. In accordance with the GBT specification, these errors are summed in a root-sum-square sense with the structural deformations due to wind loads or thermal gradients being algebraically summed before doing so.

3.0 Summary and Conclusions

The data presented in the tables of Paragraph 2.5 demonstrate that, with one exception, the three GBT pointing accuracy requirements are met (*i.e.*, with the specified 6 m/s wind gusting to 7 m/s, with the 5°C thermal gradient, or without wind and thermal loads). The out-of-spec condition occurs under a 5° C thermal gradient with the antenna at a 95° elevation angle and the sun at a 270° azimuth. In this condition, the pointing error is 18.9 arcseconds rms versus a 14 arcsecond rms specification. This extreme value is a result of a gradient across the aperture of the antenna and cannot be corrected by substituting different member sizes--it is due solely to the Coefficient of Thermal Expansion of the steel back-up structure and the specified thermal gradient.

TABLE 2-1
Repeatable Pointing Accuracy Summary

			Errors (arcminute rms)		
Elevation	Wind or Sun Azimuth	Loading Condition	Gregorian Optics	Prime Focus Optics	Specification Requirement
5°	0°	None	0.3	0.3	3
5°	180°	Thermal	0.3	0.3	3
5°	270°	Wind	0.3	0.3	3
36°	0°	Wind	0.6	0.6	3
36°	180°	Wind	0.6	0.6	3
66°	0°	Wind	0.9	0.9	3
66°	180°	Wind	0.9	0.9	3
95°	0°	None	1.0	1.0	3
95°	0°	Wind	1.0	1.0	3
95°	180°	Wind	1.0	1.0	3
95°	270°	Wind	1.0	1.0	3
95°	270°	Thermal	1.0	1.0	3

TABLE 2-2
Nonrepeatable Pointing Accuracy Summary

			Errors (arcsecond rms)		
Elevation	Wind or Sun Azimuth	Loading Condition	Gregorian Optics	Prime Focus Optics	Specification Requirement
5°	0°	None	3.4	3.4	7
5°	180°	Thermal	12.3	12.3	14
5°	270°	Wind	5.7	7.8	14
36°	0°	Wind	12.5	10.6	14
36°	180°	Wind	4.7	5.9	14
66°	0°	Wind	4.0	3.8	14
66°	180°	Wind	4.0	4.0	14
95°	0°	None	2.8	2.8	7
95°	0°	Wind	7.7	6.0	14
95°	180°	Wind	4.3	5.6	14
95°	270°	Wind	4.2	6.2	14
95°	270°	Thermal	18.9	18.9	14

APPENDIX A

Elevation Rotating Structure Pointing Errors

TABLE 2-5
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 5°
Thermal Gradient* = N/A

Wind Speed = 6 m/s gusting to 7 m/s
Wind Azimuth = 270°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	5.2	---
o Az Axis Verticality	5.0	---	0.4	---
Structural Deformations				
o Reflector				
- Wind	---	0.1	---	1.8
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	0.1	---	2.6
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	---	---	0.6
o El Bearing Wobble	1.0	0.4	0.1	0.0
o Az Bearing Wobble	1.0	0.4	0.1	0.0
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	2.1
o Encoder Referencing	10.0	---	10.0	---
RSS Subtotals	11.3	2.4	11.3	5.1
Two-Axes Repeatable Error =	0.3 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	5.7 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-4
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 36°
Thermal Gradient* = N/A

Wind Speed = 6 m/s gusting to 7 m/s
Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	35.3	---
o Az Axis Verticality	5.0	---	2.9	---
Structural Deformations				
o Reflector				
- Wind	---	10.5	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	1.5	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	0.8	---	---
o El Bearing Wobble	1.0	0.4	0.6	0.2
o Az Bearing Wobble	1.0	0.4	0.6	0.2
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	1.7
o Encoder Referencing	10.0	---	8.1	---
RSS Subtotals	11.3	12.3	36.3	2.1
Two-Axes Repeatable Error =	0.6 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	12.5 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-5
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 36° | Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A | Wind Azimuth = 180°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	35.3	---
o Az Axis Verticality	5.0	---	2.9	---
Structural Deformations				
o Reflector				
- Wind	---	0.2	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	3.2	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	0.8	---	---
o El Bearing Wobble	1.0	0.4	0.6	0.2
o Az Bearing Wobble	1.0	0.4	0.6	0.2
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	1.7
o Encoder Referencing	10.0	---	8.1	---
RSS Subtotals	11.3	4.2	36.3	2.1
Two-Axes Repeatable Error =	0.6 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	4.7 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-6
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 66°
Thermal Gradient* = N/A

Wind Speed = 6 m/s gusting to 7 m/s
Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	54.8	---
o Az Axis Verticality	5.0	---	4.6	---
Structural Deformations				
o Reflector				
- Wind	---	0.2	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	2.5	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	0.8	---	---
o El Bearing Wobble	1.0	0.4	0.9	0.4
o Az Bearing Wobble	1.0	0.4	0.9	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.9
o Encoder Referencing	10.0	---	4.1	---
RSS Subtotals	11.3	3.7	55.2	1.6
Two-Axes Repeatable Error =	0.9 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	4.0 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-7

NRAO GBT POINTING ACCURACY PREDICTION

Gregorian Configuration

Telescope Elevation = 66°　　Wind Speed = 6 m/s gusting to 7 m/s

Thermal Gradient* = N/A　　Wind Azimuth = 180°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	54.8	---
o Az Axis Verticality	5.0	---	4.6	---
Structural Deformations				
o Reflector				
- Wind	---	0.2	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	2.4	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	0.8	---	---
o El Bearing Wobble	1.0	0.4	0.9	0.4
o Az Bearing Wobble	1.0	0.4	0.9	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.9
o Encoder Referencing	10.0	---	4.1	---
RSS Subtotals	11.3	3.6	55.2	1.6
Two-Axes Repeatable Error =	0.9 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	4.0 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-8
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 95° Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	59.8	---
o Az Axis Verticality	5.0	---	5.0	---
Structural Deformations				
o Reflector				
- Wind	---	3.0	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	4.0	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	0.8	---	---
o El Bearing Wobble	1.0	0.4	1.0	0.4
o Az Bearing Wobble	1.0	0.4	1.0	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.2
o Encoder Referencing	10.0	---	0.9	---
RSS Subtotals	11.3	7.5	60.0	1.4
Two-Axes Repeatable Error =	1.0 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	7.7 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-9
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 95° | Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A | Wind Azimuth = 180°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	59.8	---
o Az Axis Verticality	5.0	---	5.0	---
Structural Deformations				
o Reflector				
- Wind	---	0.6	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	2.5	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	0.8	---	---
o El Bearing Wobble	1.0	0.4	1.0	0.4
o Az Bearing Wobble	1.0	0.4	1.0	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.2
o Encoder Referencing	10.0	---	0.9	---
RSS Subtotals	11.3	4.0	60.0	1.4
Two-Axes Repeatable Error =	1.0 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	4.3 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-10
NRAO GBT POINTING ACCURACY PREDICTION
Gregorian Configuration

Telescope Elevation = 95° Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A Wind Azimuth = 270°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	59.8	---
o Az Axis Verticality	5.0	---	5.0	---
Structural Deformations				
o Reflector				
- Wind	---	0.2	---	2.1
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	0.1	---	1.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o S/R Positioner Backlash	---	---	---	0.6
o El Bearing Wobble	1.0	0.4	1.0	0.4
o Az Bearing Wobble	1.0	0.4	1.0	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.2
o Encoder Referencing	10.0	---	0.9	---
RSS Subtotals	11.3	2.4	60.0	3.4
Two-Axes Repeatable Error =	1.0 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	4.2 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-11
NRAO GBT POINTING ACCURACY PREDICTION
Prime Focus Configuration

Telescope Elevation = 5° | Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A | Wind Azimuth = 270°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	5.2	---
o Az Axis Verticality	5.0	---	0.4	---
Structural Deformations				
o Reflector				
- Wind	---	0.1	---	4.3
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	0.1	---	2.6
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.1	0.0
o Az Bearing Wobble	1.0	0.4	0.1	0.0
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	2.1
o Encoder Referencing	10.0	---	10.0	---
RSS Subtotals	11.3	2.4	11.3	7.4
Two-Axes Repeatable Error =	0.3 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	7.8 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-12
NRAO GBT POINTING ACCURACY PREDICTION
Prime Focus Configuration

Telescope Elevation = 36° | Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A | Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	35.3	---
o Az Axis Verticality	5.0	---	2.9	---
Structural Deformations				
o Reflector				
- Wind	---	8.6	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	1.5	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.6	0.2
o Az Bearing Wobble	1.0	0.4	0.6	0.2
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	1.7
o Encoder Referencing	10.0	---	8.1	---
RSS Subtotals	11.3	10.4	36.3	2.1
Two-Axes Repeatable Error =	0.6 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	10.6 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-13

NRAO GBT POINTING ACCURACY PREDICTION

Prime Focus Configuration

Telescope Elevation = 36° | Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A | Wind Azimuth = 180°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	35.3	---
o Az Axis Verticality	5.0	---	2.9	---
Structural Deformations				
o Reflector				
- Wind	---	1.7	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	3.2	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.6	0.2
o Az Bearing Wobble	1.0	0.4	0.6	0.2
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	1.7
o Encoder Referencing	10.0	---	8.1	---
RSS Subtotals	11.3	5.5	36.3	2.1
Two-Axes Repeatable Error =	0.6 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	5.9 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-14
NRAO GBT POINTING ACCURACY PREDICTION
Prime Focus Configuration

Telescope Elevation = 66°
Thermal Gradient* = N/A

Wind Speed = 6 m/s gusting to 7 m/s
Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	54.8	---
o Az Axis Verticality	5.0	---	4.6	---
Structural Deformations				
o Reflector				
- Wind	---	0.0	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	2.5	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.9	0.4
o Az Bearing Wobble	1.0	0.4	0.9	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.9
o Encoder Referencing	10.0	---	4.1	---
RSS Subtotals	11.3	3.5	55.2	1.6
Two-Axes Repeatable Error =	0.9 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	3.8 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-15
NRAO GBT POINTING ACCURACY PREDICTION
Prime Focus Configuration

Telescope Elevation = 66° Wind Speed = 6 m/s gusting to 7 m/s
Thermal Gradient* = N/A Wind Azimuth = 180°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	54.8	---
o Az Axis Verticality	5.0	---	4.6	---
Structural Deformations				
o Reflector				
- Wind	---	0.3	---	0.0
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	2.4	---	0.0
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	0.0	---	0.0
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.9	0.4
o Az Bearing Wobble	1.0	0.4	0.9	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.9
o Encoder Referencing	10.0	---	4.1	---
RSS Subtotals	11.3	3.7	55.2	1.6
Two-Axes Repeatable Error =	0.9 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	4.0 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-19
NRAO GBT POINTING ACCURACY PREDICTION
Either Configuration

Telescope Elevation = 95°
Thermal Gradient* = 5°C

Wind Speed = N/A
Sun Azimuth = 270°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	59.8	---
o Az Axis Verticality	5.0	---	5.0	---
Structural Deformations				
o Reflector				
- Wind	---	---	---	---
- Thermal Gradient	---	0.0	---	16.3
o Alidade				
- Wind	---	---	---	---
- Thermal Gradient	---	---	---	2.4
o Foundation				
- Wind	---	---	---	---
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	1.0	0.4
o Az Bearing Wobble	1.0	0.4	1.0	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.2
o Encoder Referencing	10.0	---	0.9	---
RSS Subtotals	11.3	2.4	60.0	18.8
Two-Axes Repeatable Error =	1.0 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	18.9 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-20

NRAO GBT POINTING ACCURACY PREDICTION

Either Configuration

Telescope Elevation = 5°　　　　Wind Speed = N/A

Thermal Gradient* = 5°C　　　　Sun Azimuth = 180°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	5.2	---
o Az Axis Verticality	5.0	---	0.4	---
Structural Deformations				
o Reflector				
- Wind	---	---	---	---
- Thermal Gradient	---	0.3	---	---
o Alidade				
- Wind	---	---	---	---
- Thermal Gradient	---	11.5	---	---
o Foundation				
- Wind	---	---	---	---
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.1	0.0
o Az Bearing Wobble	1.0	0.4	0.1	0.0
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	2.1
o Encoder Referencing	10.0	---	10.0	---
RSS Subtotals	11.3	12.1	11.3	2.4
Two-Axes Repeatable Error =	0.3 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	12.3 arcsecond rss		Reqm't = 14 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-21
NRAO GBT POINTING ACCURACY PREDICTION
Either Configuration

Telescope Elevation = 95° — Wind Speed = 0 m/s
Thermal Gradient* = 0°C — Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	59.8	---
o Az Axis Verticality	5.0	---	5.0	---
Structural Deformations				
o Reflector				
- Wind	---	---	---	---
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	---	---	---
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	---	---	---
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	1.0	0.4
o Az Bearing Wobble	1.0	0.4	1.0	0.4
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	0.2
o Encoder Referencing	10.0	---	0.9	---
RSS Subtotals	11.3	2.4	60.0	1.4
Two-Axes Repeatable Error =	1.0 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	2.8 arcsecond rss		Reqm't = 7 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

TABLE 2-22

NRAO GBT POINTING ACCURACY PREDICTION

Either Configuration

Telescope Elevation = 5°
Thermal Gradient* = 0°C

Wind Speed = 0 m/s
Wind Azimuth = 0°

Error Sources	El Errors (arcsecond)		X-El Errors (arcsecond)	
	Repeatable	Nonrepeatable	Repeatable	Nonrepeatable
Mechanical Alignments				
o RF/El Axes Orthogonality	0.0	---	0.0	---
o El/Az Axes Orthogonality	0.0	---	5.2	---
o Az Axis Verticality	5.0	---	0.4	---
Structural Deformations				
o Reflector				
- Wind	---	---	---	---
- Thermal Gradient	---	---	---	---
o Alidade				
- Wind	---	---	---	---
- Thermal Gradient	---	---	---	---
o Foundation				
- Wind	---	---	---	---
Servo and Drive	---	0.9	---	0.3
Miscellaneous				
o El Bearing Wobble	1.0	0.4	0.1	0.0
o Az Bearing Wobble	1.0	0.4	0.1	0.0
o Encoder Accuracy	---	1.2	---	1.2
o Encoder Coupling	---	1.8	---	2.1
o Encoder Referencing	10.0	---	-10.0	---
RSS Subtotals	11.3	2.4	11.3	2.4
Two-Axes Repeatable Error =	0.3 arcminute rss		Reqm't = 3 arcminute rss	
Two-Axes Nonrepeatable Error =	3.4 arcsecond rss		Reqm't = 7 arcsecond rss	

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* Across minimum dimension of entire telescope in orientation shown

NRAO GBT MODEL95 POINTING ERROR - GREGORIAN FEED 30-Sep-93

THERMAL Y

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	-8.0570E-01	18.623
PARABOLA +Z SHIFT	-0.0092	-6.5660E-02	1.534
PARABOLA X ROTATIO	1.549	-1.3730E-04	-21.268
S/R +Y SHIFT	0.0141	-1.4796E-01	-5.299
S/R +Z SHIFT	0.0103	-3.5434E-02	-0.927
S/R X ROTATION	0.1504	4.8383E-05	0.728
FEED +Y SHIFT	-0.0051	-1.2145E-01	1.573
FEED +Z SHIFT	-0.0012	-3.3417E-02	0.102
FOCAL LENGTH CHANG	-0.0092	-2.1830E-01	5.101
TOTAL (ARC SEC)			0.345

THERMAL Z

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	-7.3760E-01	17.049
PARABOLA +Z SHIFT	-0.0092	-5.2980E-02	1.238
PARABOLA X ROTATIO	1.549	-1.0530E-04	-16.311
S/R +Y SHIFT	0.0141	-1.4378E-01	-5.149
S/R +Z SHIFT	0.0103	6.2052E-02	1.623
S/R X ROTATION	0.1504	1.9781E-05	0.297
FEED +Y SHIFT	-0.0051	-1.2061E-01	1.562
FEED +Z SHIFT	-0.0012	3.7947E-02	-0.116
FOCAL LENGTH CHANG	-0.0092	6.6250E-02	-1.548
TOTAL (ARC SEC)			-2.792

WIND LOAD CASE 2

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	6.9810E-01	-16.136
PARABOLA +Z SHIFT	-0.0092	3.6310E-03	-0.085
PARABOLA X ROTATIO	1.549	1.8310E-04	28.362
S/R +Y SHIFT	0.0141	-1.0648E-02	-0.381
S/R +Z SHIFT	0.0103	-2.0129E-02	-0.527
S/R X ROTATION	0.1504	-5.1042E-05	-0.768
FEED +Y SHIFT	-0.0051	-6.8400E-03	0.089
FEED +Z SHIFT	-0.0012	-1.9083E-03	0.006
FOCAL LENGTH CHANG	-0.0092	7.2200E-01	-16.872
TOTAL (ARC SEC)			-13.018

NRAO GBT MODEL95 POINTING ERROR - GREGORIAN FEED 30-Sep-93

WIND LOAD CASE 3

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	1.5520E-01	-3.587
PARABOLA +Z SHIFT	-0.0092	8.9330E-02	-2.087
PARABOLA X ROTATIO	1.549	-8.6180E-06	-1.335
S/R +Y SHIFT	0.0141	1.8028E-01	6.457
S/R +Z SHIFT	0.0103	1.0926E-01	2.859
S/R X ROTATION	0.1504	-7.2910E-07	-0.011
FEED +Y SHIFT	-0.0051	1.4603E-01	-1.892
FEED +Z SHIFT	-0.0012	8.5554E-02	-0.261
FOCAL LENGTH CHANG	-0.0092	2.1770E-03	-0.051
TOTAL (ARC SEC)			0.188

WIND LOAD CASE 4

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	2.4240E-01	-5.603
PARABOLA +Z SHIFT	-0.0092	-5.6920E-02	1.330
PARABOLA X ROTATIO	1.549	7.9360E-05	12.293
S/R +Y SHIFT	0.0141	-2.3176E-01	-8.300
S/R +Z SHIFT	0.0103	-7.9673E-02	-2.084
S/R X ROTATION	0.1504	8.4145E-05	1.266
FEED +Y SHIFT	-0.0051	-1.7841E-01	2.311
FEED +Z SHIFT	-0.0012	-7.3203E-02	0.223
FOCAL LENGTH CHANG	-0.0092	5.7070E-02	-1.334
TOTAL (ARC SEC)			0.209

WIND LOAD CASE 5

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	-3.6510E-02	0.844
PARABOLA +Z SHIFT	-0.0092	6.6360E-02	-1.551
PARABOLA X ROTATIO	1.549	-4.0070E-05	-6.207
S/R +Y SHIFT	0.0141	2.3001E-01	8.237
S/R +Z SHIFT	0.0103	7.9003E-02	2.067
S/R X ROTATION	0.1504	-8.6098E-05	-1.295
FEED +Y SHIFT	-0.0051	1.7510E-01	-2.268
FEED +Z SHIFT	-0.0012	7.2609E-02	-0.221
FOCAL LENGTH CHANG	-0.0092	-2.0800E-02	0.486
TOTAL (ARC SEC)			0.190

NRAO GBT MODEL95 POINTING ERROR - GREGORIAN FEED 30-Sep-93

WIND LOAD CASE 6

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	4.7310E-01	-10.935
PARABOLA +Z SHIFT	-0.0092	-5.1280E-02	1.198
PARABOLA X ROTATIO	1.549	1.2630E-04	19.564
S/R +Y SHIFT	0.0141	-2.6190E-01	-9.380
S/R +Z SHIFT	0.0103	-6.4228E-02	-1.680
S/R X ROTATION	0.1504	1.4699E-04	2.211
FEED +Y SHIFT	-0.0051	-1.9685E-01	2.550
FEED +Z SHIFT	-0.0012	-7.0047E-02	0.214
FOCAL LENGTH CHANG	-0.0092	8.2170E-02	-1.920
TOTAL (ARC SEC)			3.756

WIND LOAD CASE 8

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	6.4210E-01	-14.842
PARABOLA +Z SHIFT	-0.0092	9.3470E-03	-0.218
PARABOLA X ROTATIO	1.549	1.6650E-04	25.791
S/R +Y SHIFT	0.0141	2.8803E-01	10.316
S/R +Z SHIFT	0.0103	6.2264E-02	1.629
S/R X ROTATION	0.1504	-1.5138E-04	-2.277
FEED +Y SHIFT	-0.0051	2.1976E-01	-2.847
FEED +Z SHIFT	-0.0012	6.6614E-02	-0.203
FOCAL LENGTH CHANG	-0.0092	7.2700E-01	-16.989
TOTAL (ARC SEC)			0.743

NRAO GBT MODEL 95 POINTING ERROR - GREGORIAN FEED 30-Sep-93

X-DIR THERMAL

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/RAD)	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)	Y-AXIS P/E (1.E-5 RAD)
PARABOLA +X SHIFT	0.013	-2.2100E-01		-7.297
PARABOLA +Y SHIFT	-0.0091	4.8530E-05	-0.001	
PARABOLA +Z SHIFT	-0.0092	1.1050E-06	-0.000	
PARABOLA X ROTATIO	1.549	1.0500E-08	0.002	
PARABOLA Y ROTATIO	1.771	2.2910E-05		4.057
S/R +X SHIFT	-0.0183	-3.9947E-01		18.568
S/R +Y SHIFT	0.0141	0.0000E+00	0.000	
S/R +Z SHIFT	0.0103	0.0000E+00	0.000	
S/R X ROTATION	0.1504	0.0000E+00	0.000	
S/R Y ROTATION	0.1336	-3.5594E-04		-4.755
FEED +X SHIFT	0.0051	-2.2899E-01		-2.966
FEED +Y SHIFT	-0.0051	0.0000E+00	0.000	
FEED +Z SHIFT	-0.0012	0.0000E+00	0.000	
FOCAL LENGTH CHANG	-0.0092	2.0200E-05	-0.000	
TOTAL (ARC SEC)			0.000	15.690

WIND LOAD CASE 1 - EL= 5, AZ= 270

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/RAD)	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)	Y-AXIS P/E (1.E-5 RAD)
PARABOLA +X SHIFT	0.013	2.5680E-01		8.480
PARABOLA +Y SHIFT	-0.0091	-5.9080E-02	1.366	
PARABOLA +Z SHIFT	-0.0092	5.5940E-04	-0.013	
PARABOLA X ROTATIO	1.549	-1.5770E-05	-2.443	
PARABOLA Y ROTATIO	1.771	-1.6420E-04		-29.080
S/R +X SHIFT	-0.0183	-5.6909E-01		26.452
S/R +Y SHIFT	0.0141	-2.8386E-03	-0.102	
S/R +Z SHIFT	0.0103	-4.7617E-04	-0.012	
S/R X ROTATION	0.1504	6.6600E-07	0.010	
S/R Y ROTATION	0.1336	-4.1401E-05		-0.553
FEED +X SHIFT	0.0051	-4.9361E-01		-6.394
FEED +Y SHIFT	-0.0051	-2.4496E-03	0.032	
FEED +Z SHIFT	-0.0012	-3.9189E-04	0.001	
FOCAL LENGTH CHANG	-0.0092	-5.2360E-02	1.224	
TOTAL (ARC SEC)			0.128	-2.259

NRAO GBT MODEL 95 POINTING ERROR - GREGORIAN FEED 30-Sep-93

WIND LOAD CASE 7 - EL= 95, AZ= 270

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/RAD)	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)	Y-AXIS P/E (1.E-5 RAD)
PARABOLA +X SHIFT	0.013	2.8150E-01	-	9.295
PARABOLA +Y SHIFT	-0.0091	-5.9670E-02	1.379	
PARABOLA +Z SHIFT	-0.0092	-1.1510E-03	0.027	
PARABOLA X ROTATIO	1.549	-1.4930E-05	-2.313	
PARABOLA Y ROTATIO	1.771	-1.6690E-04		-29.558
S/R +X SHIFT	-0.0183	-5.5515E-01		25.804
S/R +Y SHIFT	0.0141	-5.5658E-03	-0.199	
S/R +Z SHIFT	0.0103	-2.3608E-03	-0.062	
S/R X ROTATION	0.1504	1.5504E-06	0.023	
S/R Y ROTATION	0.1336	-4.1733E-05		-0.558
FEED +X SHIFT	0.0051	-4.7985E-01		-6.216
FEED +Y SHIFT	-0.0051	-4.6635E-03	0.060	
FEED +Z SHIFT	-0.0012	-2.1643E-03	0.007	
FOCAL LENGTH CHANG	-0.0092	-5.2470E-02	1.226	
TOTAL (ARC SEC)			0.307	-2.541

NRAO GBT MODEL95 POINTING ERROR - PRIME FOCUS F 30-Sep-93

THERMAL Y

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	-8.0570E-01	18.623
PARABOLA +Z SHIFT	-0.0092	-6.5660E-02	1.534
PARABOLA X ROTATI	1.549	-1.3730E-04	-21.268
FEED +Y SHIFT	0.0091	-1.4043E-01	-3.246
FEED +Z SHIFT	0.0092	-3.1692E-02	-0.741
FOCAL LENGTH CHA	-0.0092	-2.1830E-01	5.101
TOTAL (ARC SEC)			0.009

THERMAL Z

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	-7.3760E-01	17.049
PARABOLA +Z SHIFT	-0.0092	-5.2980E-02	1.238
PARABOLA X ROTATI	1.549	-1.0530E-04	-16.311
FEED +Y SHIFT	0.0091	-1.2901E-01	-2.982
FEED +Z SHIFT	0.0092	2.4614E-02	0.575
FOCAL LENGTH CHA	-0.0092	6.6250E-02	-1.548
TOTAL (ARC SEC)			-4.082

WIND LOAD CASE 2
(EL= 36°/Az=0°)

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	6.9810E-01	-16.136
PARABOLA +Z SHIFT	-0.0092	3.6310E-03	-0.085
PARABOLA X ROTATI	1.549	1.8310E-04	28.362
FEED +Y SHIFT	0.0091	-1.1432E-02	-0.264
FEED +Z SHIFT	0.0092	-5.9479E-03	-0.139
FOCAL LENGTH CHA	-0.0092	7.2200E-01	-16.872
TOTAL (ARC SEC)			-10.589

NRAO GBT MODEL95 POINTING ERROR - PRIME FOCUS F 30-Sep-93

WIND LOAD CASE 3
(EL=36°/AZ=180°)

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	1.5520E-01	-3.587
PARABOLA +Z SHIFT	-0.0092	8.9330E-02	-2.087
PARABOLA X ROTATI	1.549	-8.6180E-06	-1.335
FEED +Y SHIFT	0.0091	1.7418E-01	4.026
FEED +Z SHIFT	0.0092	8.6812E-02	2.029
FOCAL LENGTH CHA	-0.0092	2.1770E-03	-0.051
TOTAL (ARC SEC)			-2.075

WIND LOAD CASE 4
(EL=60°/AZ=0°)

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	2.4240E-01	-5.603
PARABOLA +Z SHIFT	-0.0092	-5.6920E-02	1.330
PARABOLA X ROTATI	1.549	7.9360E-05	12.293
FEED +Y SHIFT	0.0091	-2.1916E-01	-5.066
FEED +Z SHIFT	0.0092	-6.9533E-02	-1.625
FOCAL LENGTH CHA	-0.0092	5.7070E-02	-1.334
TOTAL (ARC SEC)			-0.008

WIND LOAD CASE 5
(EL=60°/AZ=180°)

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	-3.6510E-02	0.844
PARABOLA +Z SHIFT	-0.0092	6.6360E-02	-1.551
PARABOLA X ROTATI	1.549	-4.0070E-05	-6.207
FEED +Y SHIFT	0.0091	2.1712E-01	5.019
FEED +Z SHIFT	0.0092	6.8395E-02	1.598
FOCAL LENGTH CHA	-0.0092	-2.0800E-02	0.486
TOTAL (ARC SEC)			0.390

NRAO GBT MODEL95 POINTING ERROR - PRIME FOCUS F 30-Sep-93

WIND LOAD CASE 6
(EL=95°/Az=0°)

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	4.7310E-01	-10.935
PARABOLA +Z SHIFT	-0.0092	-5.1280E-02	1.198
PARABOLA X ROTATI	1.549	1.2630E-04	19.564
FEED +Y SHIFT	0.0091	-2.4558E-01	-5.676
FEED +Z SHIFT	0.0092	-6.3143E-02	-1.476
FOCAL LENGTH CHA	-0.0092	8.2170E-02	-1.920
TOTAL (ARC SEC)			1.557

WIND LOAD CASE 8
(EL=95°/Az=180°)

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/R	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)
PARABOLA +Y SHIFT	-0.0091	6.4210E-01	-14.842
PARABOLA +Z SHIFT	-0.0092	9.3470E-03	-0.218
PARABOLA X ROTATI	1.549	1.6650E-04	25.791
FEED +Y SHIFT	0.0091	2.7124E-01	6.269
FEED +Z SHIFT	0.0092	5.9175E-02	1.383
FOCAL LENGTH CHA	-0.0092	7.2700E-01	-16.989
TOTAL (ARC SEC)			2.876

NRAO GBT MODEL 95 POINTING ERROR - PRIME FOCUS FEED 30-Sep-93

X-DIR THERMAL

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/RAD)	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)	Y-AXIS P/E (1.E-5 RAD)
PARABOLA +X SHIFT	0.013	-2.2100E-01		-7.297
PARABOLA +Y SHIFT	-0.0091	4.8530E-05	-0.001	
PARABOLA +Z SHIFT	-0.0092	1.1050E-06	-0.000	
PARABOLA X ROTATIO	1.549	1.0500E-08	0.002	
PARABOLA Y ROTATIO	1.771	2.2910E-05		4.057
FEED +X SHIFT	-0.013	-3.3760E-01		11.148
FEED +Y SHIFT	0.0091	0.0000E+00	0.000	
FEED +Z SHIFT	0.0092	0.0000E+00	0.000	
FOCAL LENGTH CHANG	-0.0092	2.0200E-05	-0.000	
TOTAL (ARC SEC)			0.000	16.310

WIND LOAD CASE 1 - EL= 5, AZ= 270

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/RAD)	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)	Y-AXIS P/E (1.E-5 RAD)
PARABOLA +X SHIFT	0.013	2.5680E-01		8.480
PARABOLA +Y SHIFT	-0.0091	-5.9080E-02	1.366	
PARABOLA +Z SHIFT	-0.0092	5.5940E-04	-0.013	
PARABOLA X ROTATIO	1.549	-1.5770E-05	-2.443	
PARABOLA Y ROTATIO	1.771	-1.6420E-04		-29.080
FEED +X SHIFT	-0.013	-5.4530E-01		18.006
FEED +Y SHIFT	0.0091	-2.7498E-03	-0.064	
FEED +Z SHIFT	0.0092	-3.7354E-04	-0.009	
FOCAL LENGTH CHANG	-0.0092	-5.2360E-02	1.224	
TOTAL (ARC SEC)			0.126	-5.352

WIND LOAD CASE 7 - EL= 95, AZ= 270

ERROR SOURCE	P/E COEFF. (RAD/M,RAD/RAD)	DEFLECTIONS (RAD,IN)	X-AXIS P/E (1.E-5 RAD)	Y-AXIS P/E (1.E-5 RAD)
PARABOLA +X SHIFT	0.013	2.8150E-01		9.295
PARABOLA +Y SHIFT	-0.0091	-5.9670E-02	1.379	
PARABOLA +Z SHIFT	-0.0092	-1.1510E-03	0.027	
PARABOLA X ROTATIO	1.549	-1.4930E-05	-2.313	
PARABOLA Y ROTATIO	1.771	-1.6690E-04		-29.558
FEED +X SHIFT	-0.013	-5.3143E-01		17.548
FEED +Y SHIFT	0.0091	-5.3588E-03	-0.124	
FEED +Z SHIFT	0.0092	-2.1247E-03	-0.050	
FOCAL LENGTH CHANG	-0.0092	-5.2470E-02	1.226	
TOTAL (ARC SEC)			0.301	-5.600

APPENDIX B

Alidade and Foundation Pointing Errors

WIND LOADS

THE FOLLOWING WIND LOADS FROM TECH MEMO 15 ARE USED TO CALCULATE THE POINTING ERROR CONTRIBUTIONS OF THE ALIDADE, ELEVATION BEARINGS AND DRIVES, AND FOUNDATION. FOR CONVENIENCE WIND LOADS ARE FACTORED TO 15 mi/h FROM THE 50 mi/h VALUE USED IN TM 15.

FOR EL = 36° & AZ = 0° (USE EL = 30° & AZ = 0°)

$F_Y = (-683 \cdot 10^3)(0.09) = -6.15 \cdot 10^4$ lb.

$M_Y = (-52.6 \cdot 10^6)(0.09)(12) = -5.68 \cdot 10^7$ in·lb

FOR EL = 95° & AZ = 180° (USE EL = 90° & AZ = 180°)

$F_Y = (433 \cdot 10^3)(0.09) = 3.90 \cdot 10^4$ lb

$M_X = (-9.69 \cdot 10^6)(0.09)(12) = -1.05 \cdot 10^7$ in·lb

FOR EL = 5° & AZ = 270° (USE EL = 0° & AZ = 90°)

$F_Y = (-142 \cdot 10^3)(0.09) = -1.28 \cdot 10^4$ lb

$M_X = (-5.65 \cdot 10^6)(0.09)(12) = -6.10 \cdot 10^6$ in·lb

$M_Z = (-3.62 \cdot 10^7)(0.09)(12) = -3.91 \cdot 10^7$ in·lb

FOR EL = 95° & AZ = 270° (USE EL = 90° & AZ = 90°)

$F_X = (399 \cdot 10^3)(0.09) = 3.59 \cdot 10^4$ lb

$F_Y = (89 \cdot 10^3)(0.09) = 8.01 \cdot 10^3$ lb

$M_X = (5.92 \cdot 10^6)(0.09)(12) = 6.39 \cdot 10^6$ in·lb

$M_Y = (2.56 \cdot 10^7)(0.09)(12) = 2.77 \cdot 10^7$ in·lb

FOR EL = 36° & AZ = 180° (USE EL = 30° & AZ = 180°)

$F_Y = (500 \cdot 10^3)(0.09) = 4.50 \cdot 10^4$ lb

$M_X = (-1.48 \cdot 10^7)(0.09)(12) = -1.60 \cdot 10^7$ in·lb

WIND LOADS (CONT'D)

FOR EL=95° & AZ=0° (USE EL=90° & AZ=0°)

$F_Y = (-417\cdot10^3)(0.09) = -3.75\cdot10^4$ lb

$M_X = (3.07\cdot10^7)(0.09)(12) = 3.12\cdot10^7$ in-lb

FOR EL=66° & AZ=0° (USE EL=60° & AZ=0°)

$F_Y = (-307\cdot10^3)(0.09) = -2.76\cdot10^4$ lb

$M_X = (1.56\cdot10^7)(0.09)(12) = 1.69\cdot10^7$ in-lb

FOR EL=66° & AZ=180° (USE EL=60° & AZ=180°)

$F_Y = (356\cdot10^3)(0.09) = 3.20\cdot10^4$ lb

$M_X = (-1.22\cdot10^7)(0.09)(12) = -1.32\cdot10^7$ in-lb

COMPLIANCES

ALIDADE INCLUDING AZ WHEELS AND DRIVES (FROM TECH MEMO 13)

$\theta_X^P = 2.6\cdot10^{-10}$ rad/lb

$\theta_X^M = 0.3\cdot10^{-12}$ rad/in-lb

$\theta_Y^P = 0.4\cdot10^{-10}$ rad/lb

$\theta_Y^M = 0.14\cdot10^{-12}$ rad/in-lb

$\theta_Z^M = 0.5\cdot10^{-12}$ rad/in-lb

Housing: $1.55\cdot10^{-8}$ in/lb
Brg: $0.59\cdot10^{-8}$ in/lb

ELEVATION BEARINGS CONVERTED TO ON-AXIS ROTATIONS (FROM TM17 & TM 28)

$\theta_X^P = \delta_R^P/(2)(1130) = 2.1\cdot10^{-8}/(2)(1130) = 9.29\cdot10^{-12}$ rad/lb

$\theta_Y^M = \delta_Z^P/(1746)^2 = 0.47\cdot10^{-8}/(1746)^2 = 1.54\cdot10^{-15}$ rad/in-lb

ELEVATION DRIVES (FROM TECH MEMO 29)

$\theta_X^M = 0.15\cdot10^{-12}$ rad/in-lb

FOUNDATION INCLUDING SOIL (FROM TECH MEMO 06)

$\theta_X^M = \theta_Y^M = 9.13\cdot10^{-16}$ rad/in-lb

$\theta_Z^M = 7.72\cdot10^{-16}$ rad/in-lb

COMPLIANCES (CONT'D)

ALIDADE INCLUDING ELEVATION BEARINGS AND DRIVES

$\theta_X^P = 2.69 \cdot 10^{-10}$ rad/lb

$\theta_X^M = 0.45 \cdot 10^{-12}$ rad/in·lb

$\theta_Y^P = 10.6 \cdot 10^{-10}$ rad/lb

$\theta_Y^M = 0.14 \cdot 10^{-12}$ rad/in·lb

$\theta_Z^M = 0.5 \cdot 10^{-12}$ rad/in·lb

POINTING ERRORS

FOR EL = 36° & AZ = 0°

ALIDADE CONTRIBUTION

$PE_X^P = -\theta_X^P F_Y = -(2.69 \cdot 10^{-10})(-6.15 \cdot 10^4) = 3.41$ arcsec

$PE_X^M = \theta_X^M M_X = (0.45 \cdot 10^{-12})(-5.68 \cdot 10^7) = -5.27$ arcsec

$PE_X = -1.86$ arcsec

FOUNDATION CONTRIBUTION

$M_X = -5.68 \cdot 10^7 - (1900)(-6.15 \cdot 10^4) = 6.01 \cdot 10^7$ in·lb

$PE_X = \theta_X^M M_Y = (9.13 \cdot 10^{-16})(6.01 \cdot 10^7) = 0.01$ arcsec

FOR EL = 95° & AZ = 180°

ALIDADE CONTRIBUTION

$PE_X^P = -\theta_X^P F_Y = -(2.69 \cdot 10^{-10})(3.90 \cdot 10^4) = -2.16$ arcsec

$PE_X^M = \theta_X^M M_X = (0.45 \cdot 10^{-12})(-1.05 \cdot 10^7) = -0.97$ arcsec

$PE_X = -3.13$ arcsec

FOUNDATION CONTRIBUTION

$M_X = -1.05 \cdot 10^7 - (1900)(3.90 \cdot 10^4) = -8.46 \cdot 10^7$ in·lb

$PE_X = \theta_X^M M_X = (9.13 \cdot 10^{-16})(-8.46 \cdot 10^7) = -0.02$ arcsec

POINTING ERRORS (CONT'D)

FOR EL = 5° & AZ = 270°

ALIDADE CONTRIBUTION

$PE_x^P = -\theta_x^P F_y = -(2.69 \cdot 10^{-10})(-1.28 \cdot 10^4) = 0.71$ arc sec

$PE_x^M = \theta_x^M M_x = (0.45 \cdot 10^{-12})(-6.10 \cdot 10^6) = -0.56$ arc sec

$PE_x = 0.15$ arc sec

$PE_z = \theta_z^M M_z = (0.5 \cdot 10^{-12})(-3.91 \cdot 10^7) = -3.23$ arc sec

FOUNDATION CONTRIBUTION

$M_x = -6.10 \cdot 10^6 - (1900)(-1.28 \cdot 10^4) = 1.82 \cdot 10^7$ in·lb

$PE_x = \theta_x^M M = (9.13 \cdot 10^{-16})(1.82 \cdot 10^7) = 0.003$ arc sec

$PE_z = \theta_z^M M = (7.72 \cdot 10^{-16})(-3.91 \cdot 10^7) = -0.01$ arc sec

FOR EL = 95 & AZ = 270°

ALIDADE CONTRIBUTION

$PE_x^P = -\theta_x^P F_y = -(2.69 \cdot 10^{-10})(8.01 \cdot 10^3) = -0.44$ arc sec

$PE_x^M = \theta_x^M M_x = (0.45 \cdot 10^{-12})(6.39 \cdot 10^6) = 0.59$ arc sec

$PE_x = 0.15$ arc sec

$PE_y^P = \theta_y^P F_x = (0.6 \cdot 10^{-10})(3.59 \cdot 10^4) = 0.44$ arc sec

$PE_y^M = \theta_y^M M_y = (0.14 \cdot 10^{-12})(2.77 \cdot 10^7) = 0.80$ arc sec

$PE_y = 1.24$ arc sec

FOUNDATION CONTRIBUTION

$M_x = 6.39 \cdot 10^6 - (1900)(8.01 \cdot 10^3) = -8.83 \cdot 10^6$ in·lb

$M_y = 2.77 \cdot 10^7 + (1900)(3.59 \cdot 10^4) = 9.59 \cdot 10^7$ in·lb

$PE_x = \theta_x^M M_y = (9.13 \cdot 10^{-16})(-8.83 \cdot 10^6) = -0.001$ arc sec

$PE_y = \theta_y^M M_y = (9.13 \cdot 10^{-16})(9.59 \cdot 10^7) = 0.02$ arc sec

POINTING ERRORS (CONT'D)

FOR EL = 36° & AZ = 180°

ALIDADE CONTRIBUTION

$PE_x^P = -\theta_x^P F_y = -(2.69\cdot10^{-10})(4.5\cdot10^4) = -2.50$ arc sec

$PE_x^M = \theta_x^M M_x = (0.45\cdot10^{-12})(-1.6\cdot10^7) = -1.49$ arc sec

$PE_x = -3.99$ arc sec

FOUNDATION CONTRIBUTION

$M_x = -1.60\cdot10^7 - (1900)(4.5\cdot10^4) = -1.02\cdot10^8$ in·lb

$PE_x = \theta_x^M M_x = (9.13\cdot10^{-16})(-1.02\cdot10^8) = -0.02$ arc sec

FOR EL = 95° & AZ = 0°

ALIDADE CONTRIBUTION

$PE_x^P = -\theta_x^P F_y = -(2.69\cdot10^{-10})(-3.75\cdot10^4) = 2.08$ arc sec

$PE_x^M = \theta_x^M M_x = (0.45\cdot10^{-12})(3.17\cdot10^7) = 2.90$ arc sec

$PE_x = 4.98$ arc sec

FOUNDATION CONTRIBUTION

$M_x = 3.17\cdot10^7 - (1900)(-3.75\cdot10^4) = 1.03\cdot10^8$ in·lb

$PE_x = \theta_x^M M_x = (9.13\cdot10^{-16})(1.03\cdot10^8) = 0.02$ arc sec

FOR EL = 64° & AZ = 0°

ALIDADE CONTRIBUTION

$PE_x^P = -\theta_x^P F_y = -(2.69\cdot10^{-10})(-2.76\cdot10^4) = 1.53$ arc sec

$PE_x^M = \theta_x^M M_x = (0.45\cdot10^{-12})(1.69\cdot10^7) = 1.57$ arc sec

$PE_x = 3.10$ arc sec

FOUNDATION CONTRIBUTION

$M_x = 1.69\cdot10^7 - (1900)(-2.76\cdot10^4) = 6.93\cdot10^7$ in·lb

POINTING ERRORS (CONT'D)

FOR EL = 66° & AZ = 180°

ALIDADE CONTRIBUTION

$PE_X^P = -\theta_X^P F_y = -(2.69 \cdot 10^{-10})(3.2 \cdot 10^4) = -1.78$ arcsec

$PE_X^M = \theta_X^M M_X = (0.45 \cdot 10^{-12})(-1.32 \cdot 10^7) = -1.23$ arcsec

$PE_X = -3.01$ arc sec

FOUNDATION CONTRIBUTION

$M_X = -1.32 \cdot 10^7 - (1900)(3.2 \cdot 10^4) = -7.4 \cdot 10^7$ in·lb

$PE_X = \theta_X^M M_X = (9.13 \cdot 10^{-16})(-7.4 \cdot 10^7) = -0.01$ arc sec

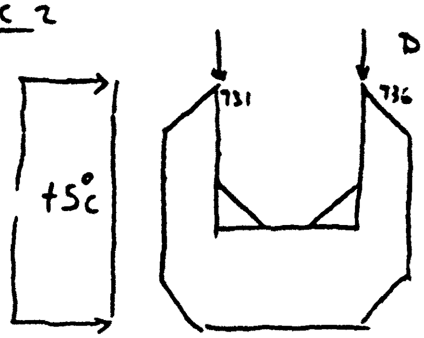
GBT ALIDADE

10/8/9? WJS

DL + THERMAL

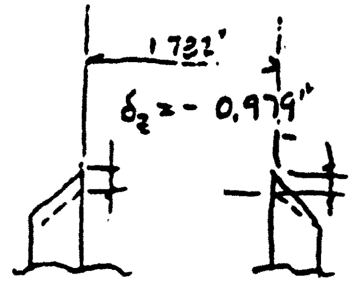
REF ALD61.OUT

LC 2



DL = 9.60×10^6 LB

4.80×10^6 /BRG

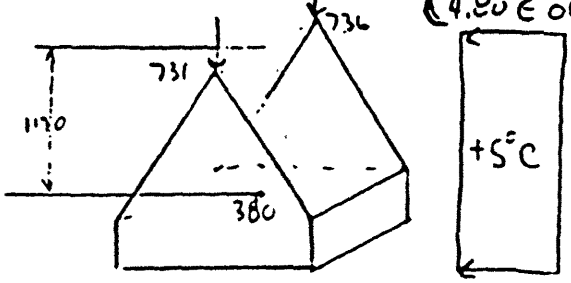


$$\theta_y = \frac{1.000 - .979}{1782} = 1.18\ E-05\ RAD/5°C$$

LC 3

DL = 9.60 E 06 LB

(4.80 E 06/BRG)



δ_y @ 731 : -8.57 E-02

@ 736 : -8.88 E-02 } Av = -8.73 E-02 = .0873

@ 380 : -2.22 E-03

= .00222

$$\theta_x = \frac{.0873 - .0022}{1170} = 5.58\ E-05\ RAD/5$$

APPENDIX C

Encoder Coupling Misalignment Error

UNIT NAME:	AZ/EL ENCODER
PART NUMBER:	90-001-4004-01
MECHANICAL DIMENSIONS:	REFER TO FOLLOWING FIGURE
WEIGHT:	12 LBS. MAX
MECHANICAL INTERFACE:	
STARTING TORQUE:	4 Oz-In MAX
RUNNING TORQUE:	3 Oz-In MAX
MAX COMPRESSION: (AXIAL)	15 LBS.
MAX RADIAL LOAD:	10 LBS.
WITH COUPLING (SURVIVAL, ACCURACY, REPEATABLE):	
ANGULAR MISALIGNMENT:	0.80°, 0.01°, 0.3° = ε
PARALLEL MISALIGNMENT:	0.07", 0.004", 0.015"
END FLOAT:	0.030", 0.002", 0.015"
POWER REQUIREMENTS:	SUPPLIED BY ENCODER POWER UNIT
	+5 VDC, ±5%, 1.5A
	+15 VDC, ±5%, 200 mA
	-15 VDC, ±5%, 200 mA
ENVIRONMENT:	OUTDOOR, NO DIRECT RAIN
TEMPERATURE RANGE:	
OPERATIONAL:	-40° TO 75° C (-40° TO 167° F)
STORAGE:	-40° TO 85° C (-40° TO 185° F)
HUMIDITY RANGE:	
OPERATIONAL:	100% CONDENSING
STORAGE:	100%