GBT MEMO 103

Division of Concerns in the GBT Pointing Correction System

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INTRODUCTION

This document is a brief description of how the various components of the GBT pointing correction system are expected to be divided between the independent modules in the system. The GBT pointing correction system is sufficiently complex to require that it be broken into smaller parts so that they may be independently designed and built by different groups and people on the project. This is feasible only if the smaller parts can be defined to be independent and are completely specified at the outset of the final design of each module. This is a significant departure from most previous radio telescope pointing correction models where all but a couple of "box offset" terms were lumped into one grand and relatively static pointing solution.

The proposed division of concerns in the pointing system are shown in Figure 1. Each dashed box or solid box on its own is considered to be an independent module for which we need to specify inputs, outputs, and performance expectations.

RULES

In separating the pointing correction tasks, at least two rules must be obeyed:

1. Particular components of the GBT pointing correction must each come from one and only one module in the system. In other words, the addition of a module to the system must not result in a significant change in feedback gain in the pointing correction system for structure deformations already monitored by an existing module. This rule might be relaxed at a later date if we find that there is a significant advantage to a weighted Adder module that can handle correlated corrections from two or more modules.

2. The removal of a module from the system due to failure or by a judgment of the observer/operator must not result in system performance that is significantly worse than it would have been if the system had been designed from the start without the benefit of this module. In practice, this means that, under benign observing conditions, the outputs of all modules except the Traditional Model will be smaller than the expected error limits of the Traditional Model.

DEFINITIONS

This design makes the somewhat arbitrary decision up front that all modules will base their corrections on the Commanded Track of the telescope rather than the actual track. In most cases, the difference between these two tracks will be very small. If a system failure or a large external force such as a wind gust creates a large deviation from the Commanded Track, only those modules that can measure this deviation will respond.

The Commanded Track is a continuous series of directional position vectors and first and second vector derivatives as a function of time which specify the requested track of the telescope's plane wavefront with respect to a local, ground-based coordinate system. The Commanded track is used by the Main Drive Control module as the primary position of the telescope to which the sum of the pointing corrections are added. The Commanded Track is used by all other modules as the independent variable in determining their expected track offsets and by the Ground Reference Laser for acquisition of (1) its retroreflectors and (2) the direction from which its pointing correction is specified. The outputs of all modules are offsets in this same coordinate system with finite derivatives where appropriate. The exact nature of the coordinate system and offsets, as well as the response time and update protocol, will be defined by the creator of the Adder module after negotiation with creators of the other modules.

Adherence to rule 1 above requires that we define precisely what each module is measuring, and rule 2 requires that we define what each module is expected to report as a correction. Below is a short statement of these two definitions for each module in the system that generates a correction . We probably do not have metrologic continuity from the feed phase center to the plane wavefront with the envisioned hardware, but we shall assume that we do. Some "measurements" will imply a known constant or predictable offset from a measurable point on the structure.

In the following paragraphs, the phrase "expected track" is used frequently. It has a specific meaning in each case which is the <u>repeatable</u> position sensor reading(s) as a function of at least one independent variable (usually elevation) under <u>ideal</u> observing conditions. For example, the autocollimator will measure a tilt of the elevation encoder assembly as the antenna is moved from zenith to horizon. This repeatable tilt as a function of antenna elevation is part of the autocollimator's expected track.

<u>Turret Position Module:</u> measures the position of a fiducial point on the active feed assembly with respect to the feed arm reference plane, as defined by the ground referenced laser system; reports the deviation of this point from its expected position in

terms of the resulting offset of the plane wavefront in the ground-based coordinates (Notes 1, 2).

Tertiary Position Module: measures the position of its nominal, virtual phase center with respect to the fiducial point on the active feed assembly; reports nothing because it is assumed to be able to maintain its internal geometry to the accuracy required (Note 3).

Subreflector Position Module: measures the position of the subreflector in its "zero offset" position with respect to the feed arm reference plane as defined by the ground referenced laser system; reports the deviation of this position from its expected track in terms of the resulting offset of the plane wavefront in the ground-based coordinates. (Notes 1, 4).

Prime Focus Position Module: measures the position of a fiducial point on the active feed assembly with respect to the feed arm reference plane, as defined by the ground referenced laser system; reports the deviation of this point from its expected track in terms of the resulting offset of the plane wavefront in the ground-based coordinates (Notes 1, 2).

Active Surface Module: measures actuator positions; reports the net effect of all actuator deviations from their expected positions in terms of resulting offset of the plane wavefront in the ground-based coordinates. The pointing correction from this module will be activated only in the absence of a direct measurement of the full surface by the Ground Reference Laser module (Note 1, 7).

Ground Reference Laser Module: measures (1) the position of points (three to many) on the reflector surface with respect to the reference plane on the feed arm and (2) the position of the edge of the reflector surface with respect to the ground; reports offset of the normal to the best-fit plane wavefront from the expected track (Note 5, 6).

Quadrant Detector Module: measures the direction to a point near the top of the feed arm with respect to a plane defined on the structure at the base of the arm; reports the deviation of this direction from its expected track in terms of resulting offset of the plane wavefront in the ground-based coordinates. To satisfy Rule 1, the pointing correction from this module must be turned off when the Ground Reference Laser module is operating in its absolute mode. Since the Quadrant Detector contains higher frequency information than will be available from the laser module, a first order refinement to satisfying Rule 1 would be to add complimentary high and low pass filters to the correction outputs of the Quadrant Detector and Ground Reference Laser modules, respectively. (Note 1).

<u>Autocollimator Module:</u> measures the horizontal position and tilt of the elevation encoder assemblies with respect to the ground based reference; reports the offset of these measurements from their expected track in terms of the resulting offset of the plane wavefront in the ground-based coordinates. To satisfy Rule 1, the pointing correction from this module must be turned off when the Ground Reference Laser module is operating in its absolute mode. Since the Autocollimator contains higher frequency information than will be available from the laser module, a first order refinement to satisfying Rule 1 would be to add complimentary high and low pass filters to the correction outputs of the Autocollimator and Ground Reference Laser modules, respectively. (Note 1).

<u>Traditional Model Module:</u> measures nothing; reports the cumulative effect of all of the expected and repeatable deformations of the structure in terms of the resulting offset of the plane wavefront in the ground-based coordinates. This offset does not include atmospheric refraction which has been removed from the Commanded Track at a higher level in the system. (See text after notes.)

Notes:

1. Under completely benign conditions, this measurement is expected to vary as a function of telescope elevation angle. This expected track will be modeled and included in the Traditional Model correction. Only deviations from this model are to be reported by this module.

2. Feed offsets from the fiducial point are defined not to be part of the pointing correction system (which wants only one "phase center" upon which to base its wavefront calculations). Beam offsets, for purposes such as multi-beaming or beam switching, are considered part of the receiver system.

3. Phase center offsets from nominal are defined not to be part of the pointing correction system (which wants only one "phase center" upon which to base its wavefront calculations). Beam offsets, for purposes such as multi-beaming or beam switching, are considered part of the tertiary and receiver systems.

4. Intentional subreflector offsets from the "zero offset" position for the purpose of beam switching are defined not to be part of the pointing correction system (which wants only one subreflector position upon which to base its wavefront calculations). Intentional subreflector offsets from the "zero offset" position, for the purpose of correcting the pointing, must be subtracted from the reported "zero offset" position. The expected track of the subreflector will largely consist of its position as a function of elevation to maintain optimum aperture efficiency. This motion to achieve optimum aperture efficiency will be directed by a subsystem in the subreflector system but outside of the pointing correction system.

5. The ultimate Ground Reference Laser System will provide an absolute determination of the surface optical axis with respect to the ground and most of the feed arm motion with respect to the optical axis. To make use of these absolute measurements, the Traditional Model must be separable into (1) physical components measured by the laser system and (2) components which are not. The former must be removed from the laser system correction when the laser system is operating in its absolute mode.

6. The Ground Reference Laser System must know where the retroreflectors are to an accuracy of about 20mm (to be specified by the laser group). Either the Commanded Track must be corrected to actual reflector positions by the module, or this module needs to read the Az, El encoders and solve for reflector positions from that. The latter has the advantage of being able to acquire in the absence of a Commanded Track or while the telescope is in progress of getting onto the Commanded Track. This issue is to be resolved as part of the module design.

7. With laser ranging of the surface, the surface setting function must be

carefully separated from the pointing function. The same range measurements can serve two purposes (surface setting and pointing correction determination), but the servo loops must be independent since we don't move the surface deliberately to change the pointing. When the surface laser rangers can produce sufficient pointing information due to surface settings, then the pointing error from the surface module is turned off. The Ground Reference Laser module then handles the surface component of the pointing. When there is no surface ranging, the surface module reports pointing errors on the basis of deviations from its open loop model. When the rangers are measuring only a few points on the surface, then a predetermined method is required for the surface module to report pointing errors due only to the surface settings known to the rangers.

COEFFICIENTS

Under benign observing conditions, the coefficients for the Traditional Model for pointing corrections can be determined in the conventional manner of observing source positions all over the sky and doing a best-fit solution to the model. At the same time as the pointing measurements are made, all of the position sensors on the telescope need to be recorded to establish the expected track of each as a function of telescope elevation and possibly azimuth. The expected track of each sensor is then subtracted from its measured position before reporting its pointing correction under less than benign conditions.

Many pointing measurement runs will be done under less than ideal conditions. The quality of the Traditional Model coefficients can be considerably improved in this case by removing the effects of measured deviations from the expected track of each sensor before using the pointing measurements to solve for the coefficients. The sensor expected tracks need to be measured under nearly ideal conditions, or a bit of bootstrapping may be required to satisfy Rule 2 near the beginning of this document.

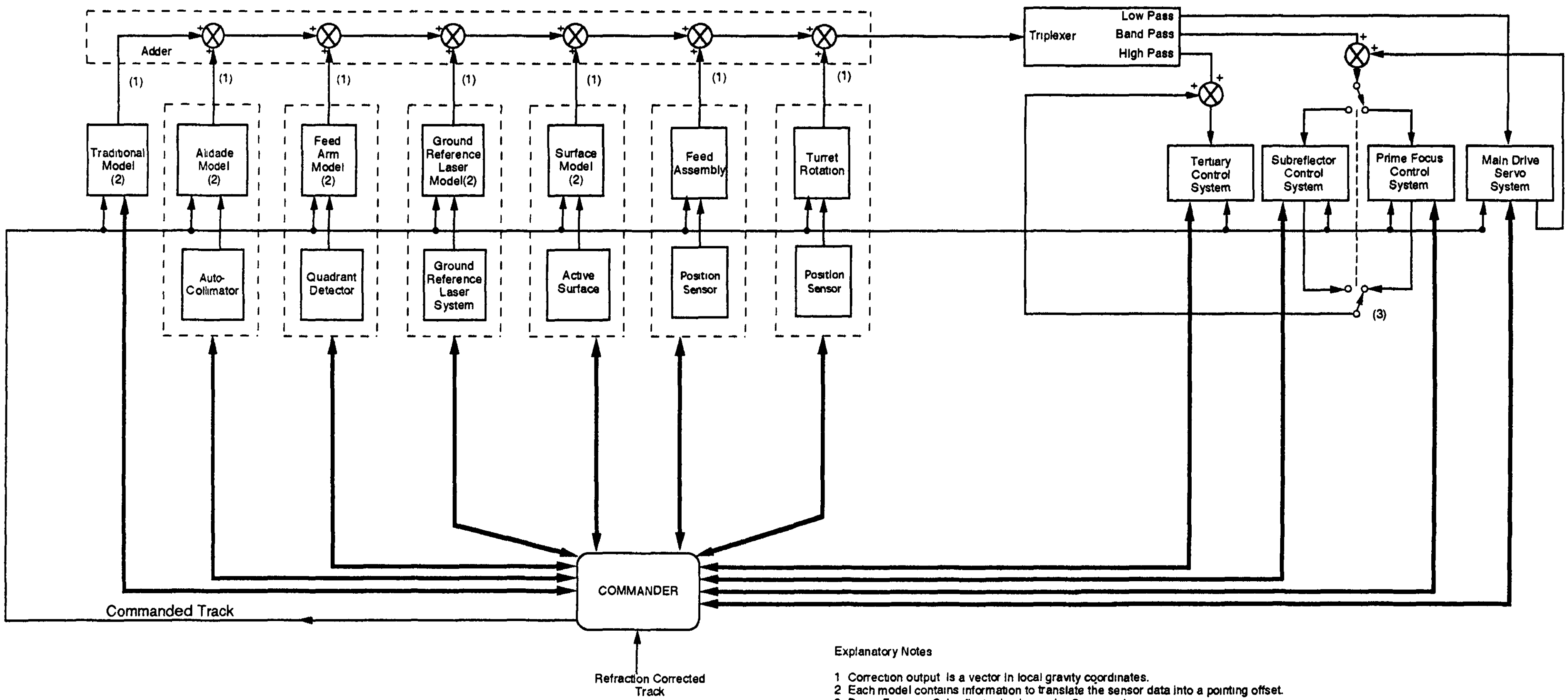
UTILITIES

There are a number of resources available to all modules that are not called out in this document. These include, but are not restricted to, time, power, and Ethernet connections and protocol. A catalog of these utilities with specifications for each must be maintained for the benefit of all module designers.

SHARED RESOURCES

Module dependence is the primary goal in this design. Each module designer should proceed with the assumption that he/she must provide all resources required within a module that are not spelled out as a utility or as an input to this module. Where more than one module is found to be providing the same resource, that resource is a candidate for sharing. If reliability and module independence are not unduly compromised by sharing a common resource, it will be called out in the system as a "shared resource". Three candidates have been suggested so far: (1) the surface laser rangers for pointing and for surface setting, (2) the autocollimator for alidade pointing corrections and possibly for vibration removal in the laser ranges, and (3) Az-El encoders for the main drive control and laser reflector acquisition.

GBT Pointing Correction System



Explanatory Notes

1 Correction output is a vector in local gravity coordinates.
2 Each model contains information to translate the sensor data into a pointing offset.
3 Prime Focus or Subreflector is chosen by Commander.

Module Catalog

Item No. 1

Item Traditional Model

Category Pointing

Subcategory Software

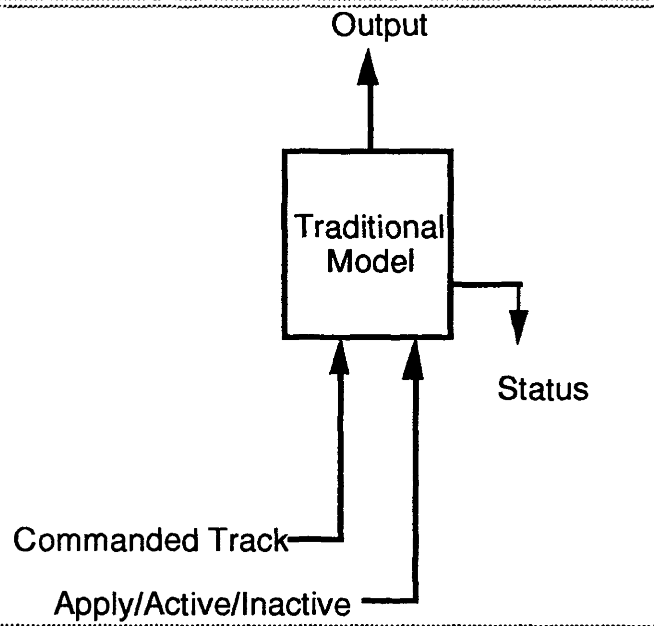
Function

Report pointing correction due to repeatable misalignments in the structure on the basis of a mathematical model with the commanded track as its only independent parameter.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Output corrections are incremental to the commanded track.
2. Output corrections accurate to 7 arc-seconds.
3. Atmospheric correction for refraction is not part of this model.
4. Creator must specify a measurement procedure for determining the model coefficients and be responsible for their maintenance.
5. Output is zero if "Apply" not asserted.
6. Status report list of parameters includes, as a minimum, the calculated correction and whether or not it is valid.

Inputs

Commanded Track

Time

Apply/Active/Inactive

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No. 2

Item Autocollimator & Alidade Model

Category Pointing

Subcategory Hardware & Software

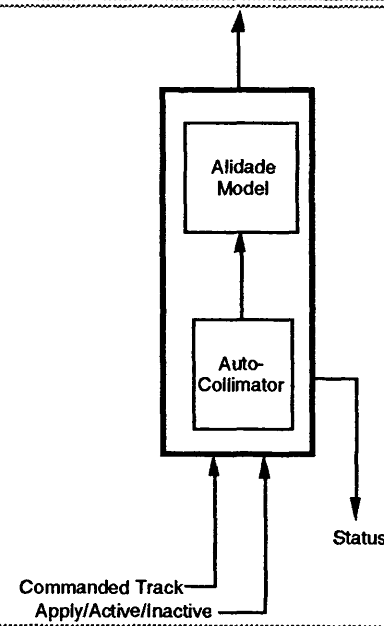
Function

Reports non-repeatable pointing corrections due to alidade deformations and tilts.

Status In Work

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Output corrections are incremental to position described by expected track (the module's "model").
2. Maximum output correction 10 arc-minutes.
3. Output is zero if "Apply" not asserted.
4. Output corrections accurate to 1 arc-second RMS.
5. Creator must specify a measurement procedure for determining the expected track and be responsible for the maintenance of the result.
6. Status report list of parameters includes, as a minimum, the calculated correction and whether or not it is valid.

Inputs

Commanded Track

Time

Apply/Active/Inactive

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No. 3

Item Quadrant Detector & Feed Arm

Category Pointing

Subcategory Hardware & Software

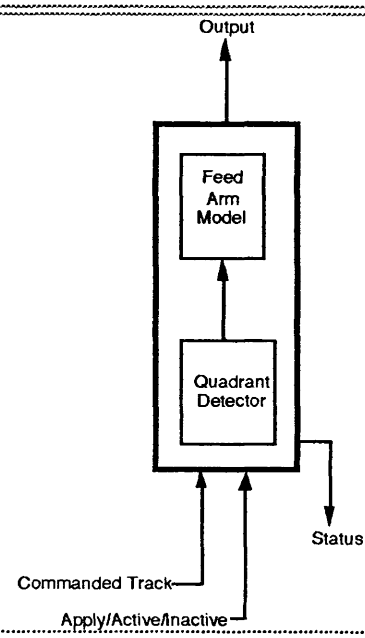
Function

Reports non-repeatable pointing correction due to feedarm deformations.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Output corrections are incremental to position described by expected track (the module's "model").
2. Maximum output correction 10 arc-min.
3. Output corrections accurate to 1 arc-sec RMS.
4. Status report list of parameters includes, as a minimum, the calculated correction and whether or not it is valid.
5. Creator must specify a measurement procedure for determining the expected track and be responsible for the maintenance of the result.
6. Output is zero if "Apply" not asserted.

Inputs

Time

Commanded Track

Apply/Active/Inactive

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No. 4

Item Ground Reference Laser System

Category Pointing

Subcategory Hardware & Software

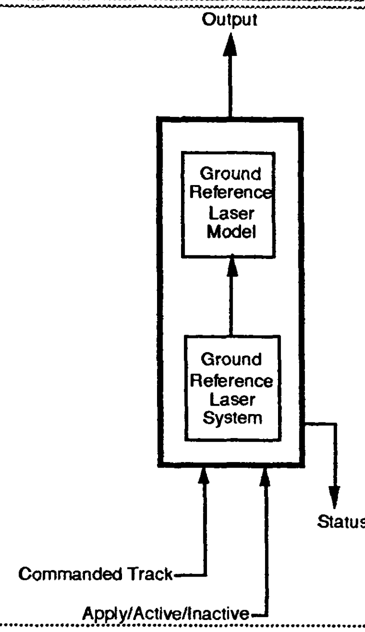
Function

Report non-repeatable pointing correction due to misalignment of the antenna surface and feed support arm with respect to the ground.

Status In Work

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Given axis positions accurate to 10 arc-mins. for retro-reflector acquisition purposes.
2. Output corrections are incremental to commanded track.
3. Maximum output correction 1 degree.
4. Output corrections accurate to 1 arc-sec RMS.
5. Status report list of parameters includes, as a minimum, the calculated correction and whether or not it is valid.
6.Creator must specify a measurement procedure for determining the expected track and be responsible for the maintenance of the result.
7. Output is zero if "Apply" not asserted.

Inputs

Time

Commanded Track

Environmentals (T,p,RH)

Apply/Active/Inactive

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

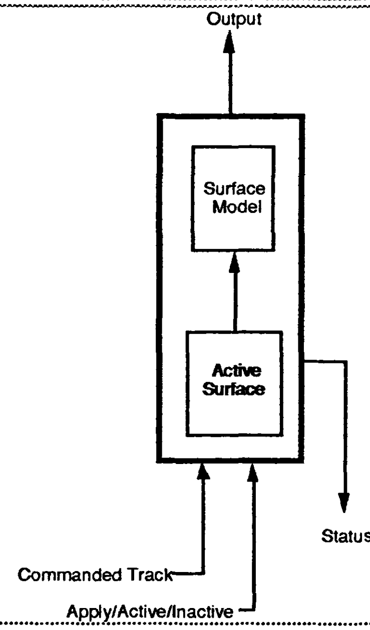
Module Catalog

Item No.
5

Item
Active Surface

Category
Pointing

Subcategory
Hardware & Software



Function

Reports pointing correction due to surface settings that are different from expected

Status Not Started

Comments

Traditional model assumes that surface optimization is active. Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.

Specs:

1. Output corrections are incremental to position described by expected track.
2. Maximum output correction 1 arc-min.
3. Output corrections accurate to 0.3 arc-sec RMS.
4. Output is zero if "Apply" not asserted.
5. Creator must specify a measurement procedure for determining the expected track and be responsible for the maintenance of the result.

Inputs

Time

Commanded Track

Status

Apply/Active/Inactive

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No.
6

Item
Feedhorn Rotation Control System

Category
Pointing

Subcategory
Hardware & Software

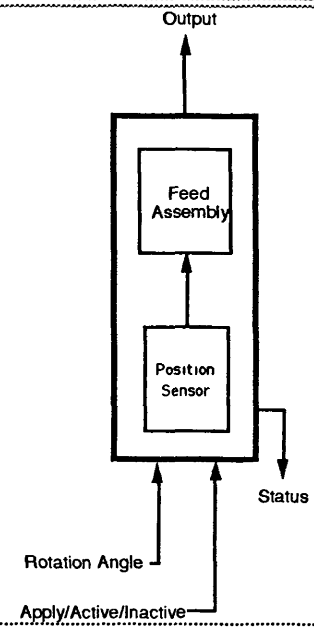
Function

To provide pointing corrections to pointing errors caused by motion of the fiducial point as a function of feed assembly rotation.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Maximum output correction 1 arc-min.
2. Output corrections accurate to 0.3 arc-sec RMS.
3. Output is zero if "Apply" not asserted.
4. Creator must specify a measurement procedure for determining the pointing correction as function of rotation angle and be responsible for the maintenance of the result.

Inputs

Time

Rotation Angle

Apply/Active/Inactive

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

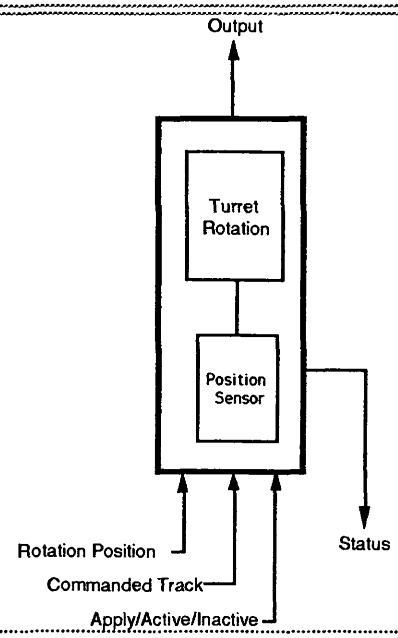
Module Catalog

Item No. 7

Item Turret Rotation Control System

Category Pointing

Subcategory Hardware & Software



Function

Move active feed assembly into position and report pointing correction due to measured misalignment of feed assembly fiducial point.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.

Specs:

2. Output corrections are incremental to the setting of the feed assembly position
3. Maximum output correction 10 arc-min.
4. Output corrections accurate to 0.3 arc-sec RMS.
5. Output is zero if "Apply" not asserted.
6. Creator must specify a measurement procedure for determining the pointing correction as a function of feed assembly selection and be responsible for the maintenance of the result.

Inputs

Rotation angle or position of the turret
Apply/Active/Inactive

Time

Commanded Track

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No. 8

Item Tertiary Control System

Category Pointing

Subcategory Hardware & Software

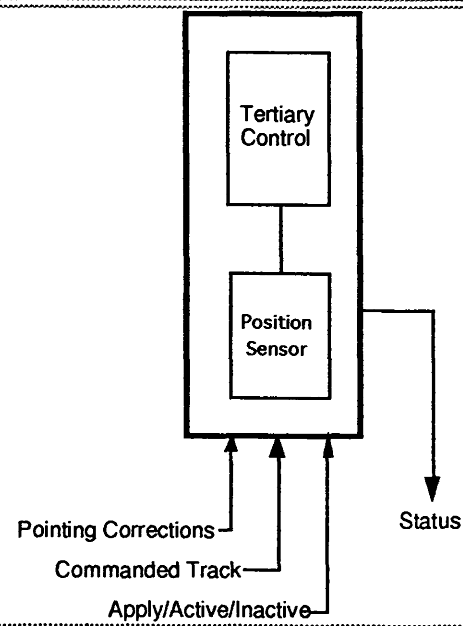
Function

Control the position of the Tertiary Mirror for rapid pointing correction.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Holds commanded position plus pointing correction of virtual phase center to 0.3 arc-sec RMS.
2. Other movements may be required (e.g. beam switching).

Inputs

Time

Commanded Track

Apply/Active/Inactive

Pointing Correction (High pass output of Triplexer)

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

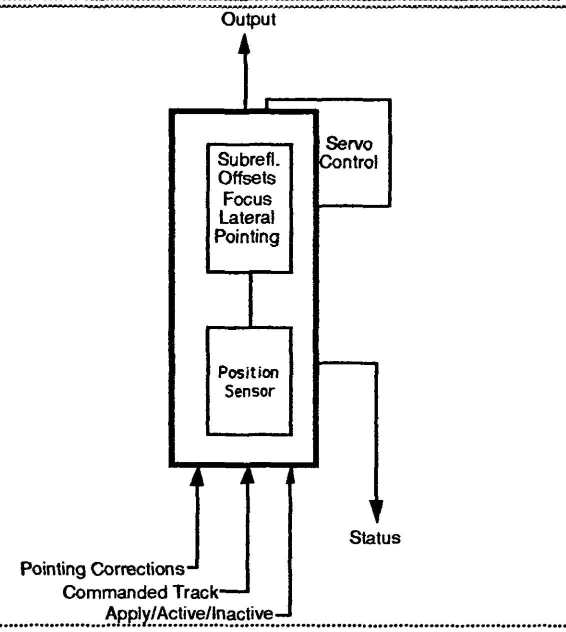
Module Catalog

Item No. 9

Item Subreflector Control System

Category Pointing

Subcategory Hardware & Software



Function

Control the position of the Subreflector for medium speed pointing correction. Report pointing correction due to uncompensated alignment errors.

Status Not Started

Comments

Traditional model assumes that gain optimization is active.

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.

Specs:

1. Output corrections are incremental to position described by expected track.
2. Maximum output correction 10 arc-mins.
3. Output corrections accurate to 0.3 arc-sec RMS.
4. Output is zero of "Apply" is not asserted.
5. Creator must specify a measurement procedure for determining the expected track and be responsible for the maintenance of the result.
6. Other motions may be required (e.g. slow focus tracking, nutations)
7. The output corrections cannot be implemented without an independent measurement system to determine the expected track.

Inputs

Time

Commanded Track

Apply/Active/Inactive

Pointing Correction(Band pass output of triplexer)

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No. 10

Item Prime Focus Control System

Category Pointing

Subcategory Hardware & Software

Function

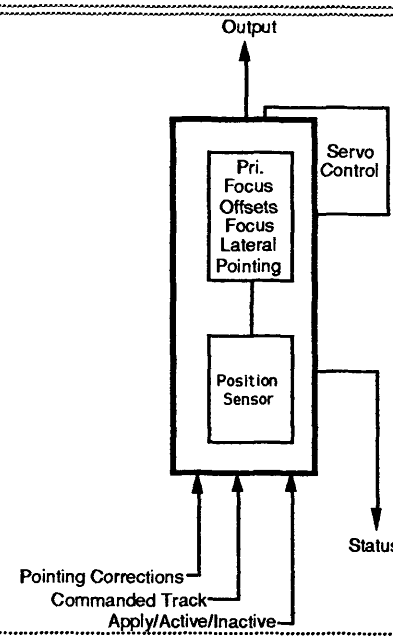
Controls the position of the Prime Focus Box for medium speed pointing correction. Report pointing correction due to uncompensated alignment errors.

Status Not Started

Comments

Traditional model assumes that gain optimization is active.

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Output corrections are incremental to position described by expected track.
2 Maximum output correction 1 degree.
3. Output corrections accurate to 1 arc-sec RMS.
4. Output is zero if "Apply" not asserted.
5. Creator must specify a measurement procedure for determining the expected track and be responsible for the maintenance of the result.
6. The output correction cannot be implemented without an independent measurement system to determine the expected track.

Inputs

Time

Commanded Track

Apply/Active/Inactive

Pointing Correction(Band pass output of triplexer)

Outputs

Pointing correction vector in the protocol specified by the Adder.

Status

Module Catalog

Item No. 11

Item Main Drive Servo System

Category Pointing

Subcategory Hardware & Software

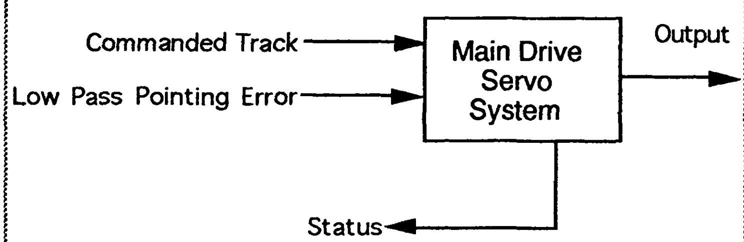
Function

Maintain the antenna position on a track that causes the encoder readings to equal the sum of the commanded track and the low-pass component of the pointing correction.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

Specsifications will be set in close coordination with RSI/PCD.

Inputs

Low Pass output from Triplexer

Commanded Track

Time

Outputs

Az & El Motion

Status

Pointing correction vector in the protocol specified by the Adder.

Module Catalog

Item No. 12

Item Triplexer

Category Pointing

Subcategory Software Only

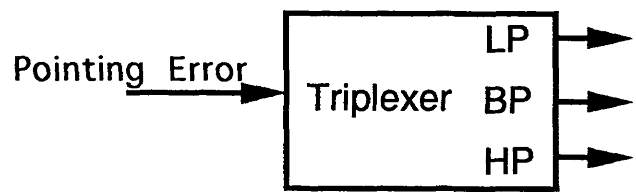
Function

Distribute the pointing correction to the Main Drive, Subreflector, Prime Focus, and Tertiary according to their response speeds.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

1. Input-to-Output phase and amplitude transfer functions must be stable and consistent with stability of any servo loop in which it is included.

2. Sum of three outputs must equal the input.

3. Filter cutoffs must be consistent with the driven control systems.

Inputs

Total Pointing Correction from Adder

Outputs

Pointing correction vector in the protocol specified by the Adder.

Module Catalog

Item No.
13

Item
Adder

Category
Pointing

Subcategory
Software Only

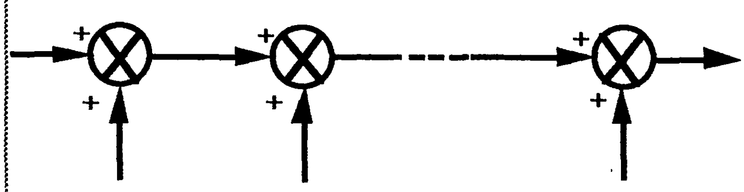
Function

Add all vector corrections to the commanded track vector and send the result to the pointing correction triplexer.

Status Not Started

Comments

Coefficients for this module contain information only on those parts of the structure that have been specifically assigned to this model and to no other modules. See the description of how the structure components are to be assigned to various modules.



Specs:

Must provide an input-to-output response time that is short enough to cause an insignificant distortion of any of the servo loops in which it is involved.

Inputs

All pointing module output vector corrections.

Outputs

Total pointing correction

Module Catalog

Item No.
14

Item
Commander

Category
Pointing

Subcategory
Software

Function

Monitors status of all modules and enables modules based on Monitor & Control configuration requests.

Status Not Started

Comments

Specs:

1. Enables modules based on status report from modules and requested configuration.

2. Can disable modules based on detected problems, malfunctions, or status reports.

Inputs

Commanded Track

Module Status

Monitor & Control requests

Outputs

Apply/Active/Inactive

Commanded Track

Monitor & Control dialog