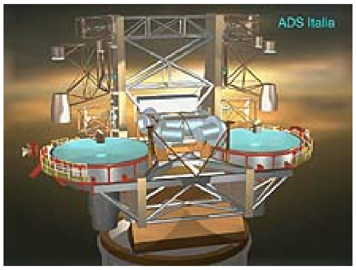

LBT PROJECT
2x8,4m TELESCOPE

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LBT PROJECT

2 X 8,4m OPTICAL TELESCOPE

Instrument Rotator and Cable Chain

Conceptual Design Description

	Signature	Date
Prepared	David Ashby, Robert Meeks	11-Oct-06
Reviewed	Joar Brynnel	11 Oct 06
Approved	Joar Brynnel	11 Oct 06

1. Revision History

Issue	Date	Changes	Responsible
a	11-Oct-06	First Draft	David Ashby

2. Table Of Contents

3. About this document

3.1. Purpose

The purpose of this document is to define the conceptual design of the LBT instrument rotators. The document goes as far as to define select major components such as the motors and encoders but falls short of defining the details of the electronics, software or mechanics. It does however define the basic control strategies to be used.

3.2. Reference Documents

None.

4. Overview

4.1. Scope of Definition

The LBT has ten focal stations equipped with instrument rotators. The two prime focus stations (LBC) are outside of the scope of this document. The remaining focal stations are: left/right direct Gregorian (LDG, RDG), left/right front bent Gregorian (LFBG, RFBG), left/right center bent Gregorian (LCBG, RCBG) and left/right rear bent Gregorian (LRBG, RRBG) focal stations. Because of the requirements of the specific instrument expected to populate these eight focal stations, only the LDG, RDG, LFBG and RFBG will be equipped with rotators at this time.

4.2. Instrument Rotators

All instrument rotators will utilize a counter-torque pair of brushless AC motors. The motors will directly drive the pinion gears which in turn drive the common bull gear around the circumference of the rotator. Each motor will be equipped with a single-turn absolute encoder to control commutation. The absolute motor encoder also produces a high-resolution analog incremental encoder signal from which motor rate will be computed.

Position feedback will be provided by two Inductosyn encoder tapes wrapped around the circumference of the rotator. The two tapes will have slightly different encoder cycle periods so that they act as a vernier scale to encode the absolute rotator angle.

The rotator operates independent of the cable chain within a 5 degree window with respect to the cable chain. Motion outside of the 5 degree window will be inhibited by limit switches and a hard stop between the rotator and cable-chain. There is no restriction on the number of turns the rotator can make. The only travel limits is the operational range of +/-2.5 degrees relative to the cable-chain. Under fault conditions the relative range of motion can be as high as +/-3 degrees.

4.2.1. Instrument Payloads

The mass of LUCIFER (LBT NIR-Spectroscopic Utility with Camera and Integral-Field Unit for Extragalactic Resarch) and its associated AGW unit is expected to be 3500kg. Since this instrument is to be mounted to the front bent Gregorian rotators, it clearly exceeds the specified payload of these rotators. It is anticipated that this will not significantly impact the motor, drive and encoder component selection unless friction is significantly increased as a result of the increased loading on the bearing. This may however impact the mechanical design.

4.3. Cable Wrap Assemblies

The cable wrap assemblies consist of a large bearing with integral gear and two concentric circular trays carrying an off-the-shelf energy chain. The gear and cable chain will be driven by a single brushless AC motor which drives a pinion gear through a gear-box. The cable-chain motor will be equipped with the same absolute encoder used in the rotator motors to encode the commutation angle and motor rate.

Position feedback is provided by an LVDT between the rotator and the cable-chain. The range of travel of the LVDT is +/- 3.0 degrees.

The operating range of travel of the rotator includes the -90 to +450 degrees of the azimuth axis. Motion outside of this envelope will be inhibited by limit switches. The limit switches will be located on a cam which is gear driven by the cable-chain motor so that no flipper-switch is required. The box and cam will accommodate motion of at least -93 to +243 degrees without wrapping.

4.3.1. Utility Requirements

The following table lists the utilities required to be passed through the cable wraps. The large helium lines will limit the minimum bend radius for the wrap. Information is being sought on the requirements for these lines but the minimum radius is believed to be about 400 mm. A bend radius of 500 mm is intended for both the direct and bent Gregorian cable wraps but this depends on availability of space. There seems to be adequate space on the direct Gregorian rotator but interference with other instruments or equipment may restrict the available space on the bent Gregorian rotators.

Table 1 Instrument Utility Requirements

10	**Signal lines**	**6 mm**
2	**Air lines**	**6 mm**
2	**Power cables**	**12 mm**
4	**Coolant lines**	**20 mm**
4	**Helium lines**	**50 mm**

4.3.2. Energy Chain

Because the cable wrap must operate through more than one full rotation, a reverse-bend arrangement is required. Several manufacturers make suitable energy chains and a specific product will be selected based on specific cable and utility requirements. An inner and outer tray are used to guide the energy chain and to constrain its motion.

The list above requires a cross-sectional area of 102 cm^2. Of course this can not be packed solid. If a packing factor of 30% is assumed, the required area in the cable chain is 340 cm^2. Arbitrarily using a width to height ratio of 2:1 requires an energy chain 232 mm wide by 116 mm tall. For conceptual design purposes the nominal size of the energy chain used will be 300 mm by 150 mm. Several commercial products in this size range are available.

4.4. Ventilation

The motors, and to a much lesser extent, the position sensors, produce heat during operation that must be dissipated either through conduction into the structure or through ventilation. The amount of heat is small and the structural mass large enough that conduction alone is probably adequate. But a shroud will enclose the bent Gregorian motors, brakes, and other components and air will be drawn through to ventilate the mechanism. The shroud will have the added benefit of protecting the instrument rotator components from damage during maintenance or mirror coating and protecting the mirror from contamination from grease and other effects from the rotators.

5. Bearings and Gears

5.1. Bearings

Large slewing ring bearings are used for the instrument rotator and cable wraps on both the bent and direct Gregorian rotators. These bearings were purchased about 7 years ago and are already installed on the telescope.

The bent Gregorian instrument rotator uses a Kaydon two row angular contact bearing with pitch diameter 1680 mm. The bearing has Buna-N rubber seals set for light or zero contact. The seals are held in place mechanically without adhesives. The balls are about 18 mm diameter and are separated by acetyl strip separators. The ball class is believed to be AFBMA class 24 with about 2 microinches of surface roughness. The bearing stiffnesses are believed to be as given in the table below based on historical information provided by the manufacturer.

Table 2 Bearing Information.

	Direct Gregorian Rotator	**Direct Gregorian Cable Wrap**	**Bent Gregorian Rotator**	**Bent Gregorian Cable Wrap**
Nominal diameter	**2925 mm**	**2925 mm**	**1680 mm**	**1982 mm**
Axial preload	**0.0254to 0.0762 mm**		**0.0254 to 0.0762 mm**	
Starting torque			**24-33 Nm**	
Calculated torque, 2500 lb axial load	**386 Nm**		**386 Nm**	
Axial runout	**0.05 mm**		**0.05 mm**	
Radial runout	**0.03 mm**		**0.03 mm**	**0.03 mm**
Radial stiffness	**3.38 x 109 N/m**		**3.38 x 109 N/m**	**3.38 x 109 N/m**
Axial stiffness	**4.29 x 109 N/m**		**4.29 x 109 N/m**	**4.29 x 109 N/m**
Moment stiffness	**1.27 x 109 Nm/rad**		**1.27 x 109 Nm/rad**	**1.27 x 109 Nm/rad**

With these values, the instrument movements produced by gravity when the optical axis goes from a horizontal orientation to a vertical orientation are 5.8 microns of decenter, 4.6 microns of defocus, and 3.2 arcseconds of tilt. These do not significantly

Additional information including expected frictional torque, runouts, ball class, and stiffness has been requested from Kaydon.

The direct Gregorian instrument rotator also uses a Kaydon two row angular contact bearing but with a pitch diameter of 2925 mm. The bearing is assembled with 0.0254 to 0.0762 mm or axial preload.

Like the bent Gregorian rotator bearing, this bearing also has Buna-N rubber seals set for light or zero contact. The seals are also held in place mechanically with no adhesives. The balls are about 18 mm diameter and are separated by acetyl strip separators. The ball class is believed to be AFBMA class 24 with about 2 microinches of surface roughness. The bearing stiffness are believed to be the same as those given above.

Both bearings are filled with Mobilith SHC 220 grease by the manufacturer. Mobilith SHC 220 uses a synthetic base oil with a lithium complex thickener to provide good lubrication over a wide range of temperatures. The recommended operating temperature range is -40C to +150C which adequately covers the specified operating environment of the LBT.

Both Gregorian instrument rotator bearings have two lubrication points located on the outside diameter of the outer ring of the bearing, 180 degrees apart. These are believed to be currently blocked by other components of the assembly but an attempt will be made to provide access to these by modifying existing components if feasible.

5.2. Gears

All but one of the gears for the instrument rotators and cable chain assemblies have already been purchased. Only the bent Gregorian instrument rotator gear is not already in-house. The gears have the following parameters:

Table 3 Gear parameters.

	Direct Gregorian Rotator	**Direct Gregorian Cable Wrap**	**Bent Gregorian Rotator**	**Bent Gregorian Cable Wrap**
Gear Pair:				
Reduction Ratio	25:1	30:1	23.5:1	
Module	6 mm	6 mm	4 mm	6 mm
Pressure Angle	20 degrees	20 degrees	20 degrees	20 degrees
Rim Gear :				
Pitch Diameter	3300 mm	3600 mm	1880 mm	2136 mm
Number of Teeth	550	600	470	336
Single Tooth Pitch Accuracy	0.011 mm		0.011 mm	
Cumulative Pitch Accuracy	0.032 mm		0.032 mm	
Pinion:				
Pitch Diameter	132 mm	120 mm	80 mm	84
Number of Teeth	22	20	20	20

Pending cost information, the pinions will be integral to the motor shafts to improve rotational stiffness of the drive mechanism. This eliminates any flexibility associated with a joint or coupling. With a 40 mm shaft that is 150 mm long the equivalent rotation stiffness at the motor shaft is found to be 2.322 MNm per radian. If this is too expensive, a compression-type zero-backlash hub may be used instead to attach the pinion to the shaft.

Both of these pinions have enough teeth to be manufactured without undercutting, which weakens the gear. For a gear with pressure angle of 20 degrees, the minimumnumber of teeth required to avoid undercutting is 20. Both the 6 mm and 4 mm modules are standard metric gear modules.

6. Motors and Drives

6.1. Instrument Rotator Motor Requirements

Permanent magnet brushless AC motors are clearly the best choice for this application. The advantages include very low torque ripple, high torque densities and increased reliability over brush-type DC motors. Furthermore, direct drive of the pinions is also preferred to ensure excellent dynamic performance.

In sizing the motors, it is assumed that the counter-torque pair will share the load under high torque conditions. It is assumed that the controller will provide the necessary damping to tolerate the lost motion or backlash associated with the motor torque sign transition.

Table 4 This table illustrates the basic motor requirements.

Rotator Requirements:	**Direct Gregorian**	**Bent Gregorian**
Gear Ratio	25:1	23.5:1
Max Moment Of Inertia	7900 kg m^2	2000 kg m^2
Max Frictional Torque	400 Nm	300 Nm
Max Rotator Rate	5.0 deg/sec	5.0 deg/sec
Max Acceleration	0.3 deg/sec^2	0.3 deg/sec^2
Max Imbalance Torque	3000 Nm	2000 Nm
Minimum Bias Torque	440 Nm	330 Nm
Motor Size Requirements		
Motor Torque	69.6 Nm	50.0 Nm
Max Motor Rate	20.83 rpm / 2.18 rad/sec	19.60 rpm / 2.05 rad/sec

Because the basic requirements for both the bent and direct Gregorian rotators are so similar, the same motor should be considered for both.

6.1.1. Motor Selection

The motor selected for both the direct and bent Gregorian rotators is the Kollmorgen Danaher D103M. In addition to the basic requirements illustrated in Table 2, power dissipation and winding temperature are both key points for consideration.

The D103M motor is the smallest of the Kollmorgen Danaher Goldline series capable of directly driving the pinion gears on both Instrument Rotator configurations. The motor is not ideal for this application in that it is capable of delivering full torque at speed in excess of five times the requirement. An added gear ratio of 5:1 could be added to improve the efficiency. The inertial imbalance is 44.8 for the direct Gregorian and 20.7 for the bent Gregorian rotators. This is of little concern unless the mounting of the motor is particularly soft. In comparison, the elevation axis inertial imbalance is 280. Insulation and forced air ventilation will be required to mask the elevated winding temperature.

Table 5 The motor selected for both the bend and direct Gregorian rotators is the D103M. This table illustrates how this motor compares to others in the same family.

Model:	**D081M**	**D083M**	**D103M**	**D143M**
Peak Torque	51.0 N m	160 N m	305 N m	1341 N m
Continuous Torque	17.6 N m	50.4 N m	115 N m	339 N m
Rated Speed	500 rpm	250 rpm	120 rpm	60 rpm
Rotor Inertia	0.0144 kg m^2	0.0301 kg m^2	0.175 kg m^2	0.542 kg m^2
Mass	17.9 kg	28.8 kg	60.8 kg	146 kg
Diameter	218 mm	218 mm	284 mm	362 mm
Length	149 mm	210 mm	251 mm	343 mm

6.1.2. Power Simulations

Power consumption and dissipation cannot be computed without assuming some sort of torque bias method. This Gaussian torque bias function is used in the power consumption and dissipation simulations. A peak torque bias of about 15% is expected to be sufficient to overcome the rotator and motor bearing friction. It is assumed that the motors are properly aligned so that no additional torque is required to stiffen the motor-to-rotator stiffness.

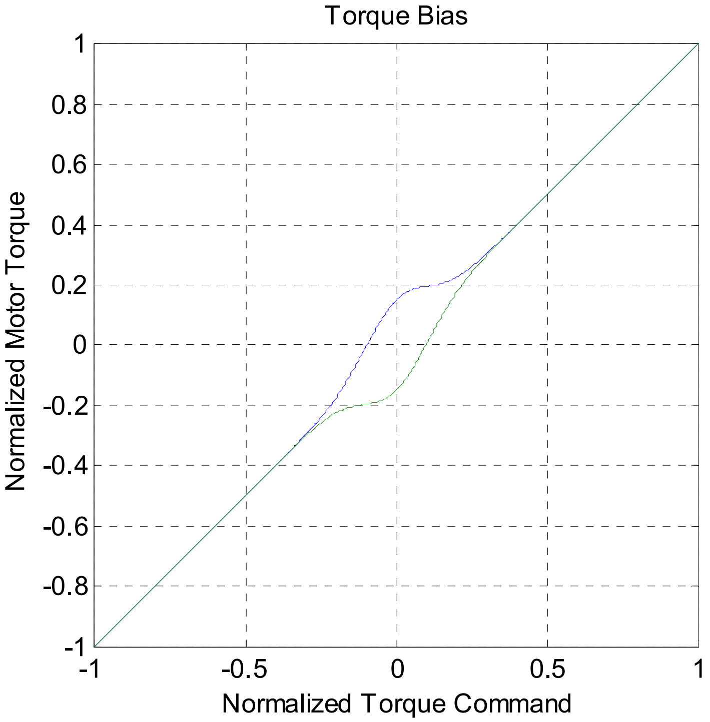

Figure 1 The torque bias method used will impact the sizing of the motors. It is assumed that the torque bias will fade under high torque demand. This figure illustrates the Gaussian torque bias function used in the simulations.

The goal of the power simulation was to understand drive power requirements, regeneration requirements, motor power dissipation and motor winding temperatures. Simulation results indicate satisfactory thermal performance though they do indicate the need to mask the elevated motor winding temperature through insulation and forced air ventilation. The simulation results also indicate a need to dissipate regenerated energy. The power simulation results are illustrated in Table 6.

Table 6 Thermal simulation results for the Bent Gregorian Instrument Rotator using D103M motors directly driving the pinion. The minimum expected counter-torque is applied and the controller is designed with load-sharing capability. Non-linear friction is included in the simulation which has a significant impact on the heat load under the low imbalance torque condition.

Rate	Counter-Torque (N*m)	Imbalance Torque (N*m)	Motor1 / 2 Drive Power (W)	Motor1 / 2 Heat Load (W)	Motor1 / 2 Temperature Rise (ºC)
Tracking					
15 as/s	370	0	11.7 / 0.8	11.7 / 0.8	3.0 / 0.2
15 as/s	370	-100	13.8 / 0.3	13.8 / 0.3	3.5 / 0.1
15 as/s	370	-500	23.8 / 0.3	23.8 / 0.3	6.0 / 0.1
15 as/s	370	-1000	40.2 / 4.2	40.3 / 4.2	10.2 / 1.1
15 as/s	370	-2000	85.8 / 24.6	85.7 / 24.6	21.0 / 6.2
Slewing					
5 deg/s	370	0	71.1 / -7.3	14.4 / 0.3	3.6 / 0.1

5 deg/s	370	100	64.6 / -11.3	12.3 / 0.6	3.1 / 0.2
5 deg/s	370	500	40.3 / -25.5	5.4 / 3.9	1.4 / 1.0
5 deg/s	370	1000	13.8 / -39.5	0.8 / 11.7	0.2 / 3.0
5 deg/s	370	2000	-26.4 / **-54.6**	4.2 / 40.3	1.1 / 10.2
5 deg/s	370	-100	77.8 / -3.1	16.7 / 0.0	4.2 / 0.0
5 deg/s	370	-500	106 / 15.2	27.6 / 0.9	7.0 / 0.2
5 deg/s	370	-1000	145 / 41.9	45.1 / 5.8	11.4 / 1.5
5 deg/s	370	-2000	**237** / 108	92.8 / 28.5	23.5 / 7.2

6.1.3. Dynamic Simulation

In order to specify the required motor mounting stiffness, a dynamic simulation was performed. The simulation revealed that in order for the first eigen frequency to exceed 10.0 Hz, the drive stiffness should exceed $8x10^3$ Nm/radian for the bent Gregorian rotators and $16x10^3$ Nm/radian for the direct Gregorian rotator. The drive stiffness is the equivalent torsional stiffness including all flexible coupling modes between the motors and the rotator bearing. Figures 2 and 3 illustrate the simulation results using the minimum drive stiffness.

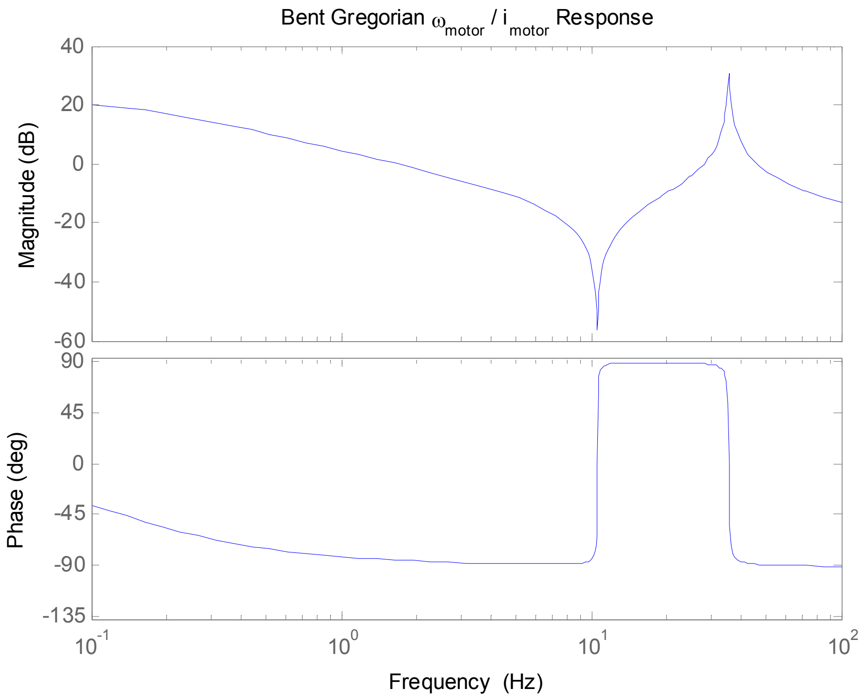

Figure 2 This figure illustrates the anticipated angular velocity response of the bent Gregorian rotator built with the D103 motors mounted with an effective stiffness of $8x10^3$ Nm/radian.

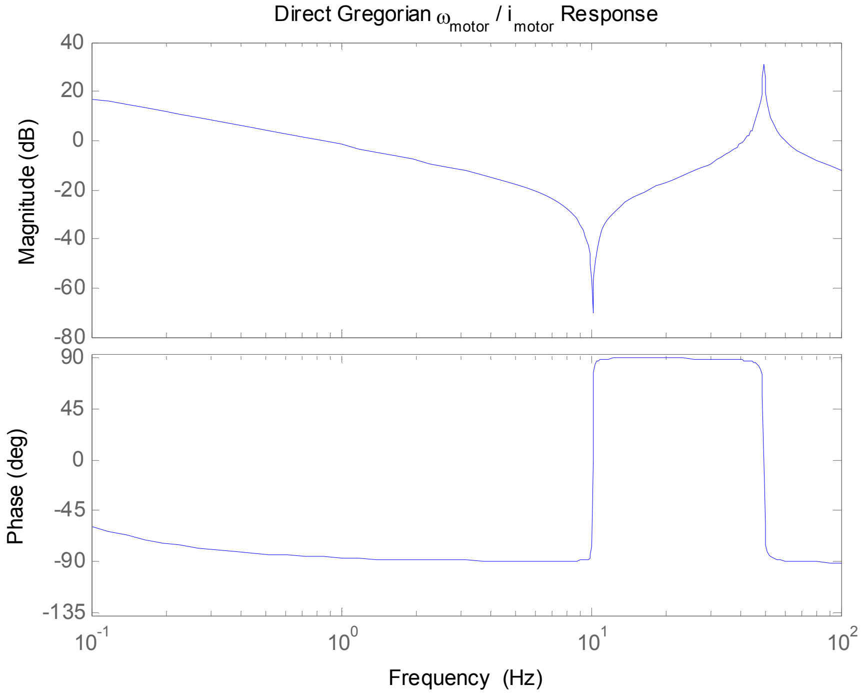

Figure 3 This figure illustrates the anticipated angular velocity response of the bent Gregorian rotator built with the D103 motors mounted with an effective stiffness of 16x10^3 Nm/radian.

6.1.4. Motor Encoder Performance

If optical motor encoders are used, high resolution is essential to ensure robust rate feedback at low speed. Resolvers can be desirable for low speed applications because a continuous analog rate feedback can generated by common resolver-to-digital converters.

As a rule of thumb, the on-sky resolution of the rate feedback should be at least as good as that of the main axes. The main axes utilize rate feedback which is synthesized from incremental quadrature motor encoder signals. The on-sky resolution of the main axis motor encoders is 3 mas.

Table 7 This table illustrates the motor encoder requirements.

Rotator:	**Direct Gregorian**	**Bent Gregorian**
	Relevant Telescope Specifications	
Plate Scale	0.600 mm/arcsec	
Field Radius	0.25 degrees	0.1 degrees
Gear Ratio	25:1	23.5:1
Az Motor Encoder Resolution	3 mas	
	Motor Encoding Requirements	
Resolution	0.69 arcsec / 21-bits per rotation	1.7 arcsec / 20-bits per revolution

The 103M motor is available with the Heidenhain EnDat ECN 113 single-turn absolute encoder. The 103A is a resolver version of the 103M. Absolute encoding of the shaft position allows direct commutation control without an initialization sequence.

In addition to the EnDat 13-bit absolute position, the ECN 113 also outputs 2048 cycle per rev analog incremental encoder signals. Combined with an interpolation factor of 256, the encoder is capable of delivering 21-bit performance. This gives a rotator resolution of over 26-bits, far exceeding the requirement.

6.1.5. Motor Drive Selection

Tentatively, the drive selected for the instrument rotator is the Kollmorgen Danaher SERVOSTAR CD 10 amp (CB-10-5-6-0), with the CS-SS-S3HA1HE-xx cable set. The relevant features are:

- Analog Torque Command
- EnDat Direct Commutation Control
- Integrated 256x Encoder Interpolator with A/B quadrature output
- Direct 208 3-Phase input
- External 24VDC Logic Power.

The decision to select this drive will depend on the detailed electronics design.

One known disadvantage in using this drive is the lack of a separate DC bus that can be shared between the pair of rotator drives. This forces one of the drives to be in regeneration mode under slew conditions. This emphasizes the need for an external regeneration shunt load such as the Kollmorgen Danaher ERH-26.

6.1.6. Motor Mounts

The existing interfaces on the ISS are not adequate for mounting the larger motors required for the bent Gregorian rotator. New mounts will be required and it is important that these be adequately stiff to ensure the control system performs properly. Because it is infeasible to machine a flat interface into the existing ISS, the motor mounts will bolt directly to the painted ISS surface and will incorporate internal adjustments to accurately align the pinion to the rim gear and then rigidly lock the adjustment.

The direct Gregorian motors were intended to mount to “ears” attached to the rotating part of the bearing. The motors then crawl around on the gear to move the instrument rotator. The same principle will be used but the existing ears are machined for different motors so they will require replacement.

6.2. Cable Chain Motor Requirements

*** TBD ***

6.2.1. Motor and Gearbox Selection

*** TBD ***

6.2.2. Motor Encoder

The same Heidenhain ECN 113 encoder used in the instrument rotator motors will be used in the cable chain motor. The encoder will be used to provide both absolute commutation phase and high resolution rate feedback.

6.2.3. Motor Drive Selection

*** TBD ***

6.2.4. Motor Mounts

The bent Gregorian cable chain motors will be mounted using a standoff that attaches to the existing mounting location. An inline gearbox will probably fit inside the standoff. If a suitable gearbox can not befound, a right angle gearbox may also be used.

7. Position Encoding

7.1. Instrument Rotator Position Encoding

Table 8 This table illustrates the basic requirements of the rotator position encoders.

Rotator:	**Direct Gregorian**	**Bent Gregorian**
Relevant Telescope Specifications		
Plate Scale	0.60 mm/arcsec	
Field Radius	0.25 degrees	0.1 degrees
On-Sky Short Term Accuracy	10 mas	
Range	-90 to +270 degrees	
Az/El Encoder Resolution	5 mas	
Rotator Position Encoding Requirements		
Short Term Accuracy	2.3 arcsec	5.7 arcsec
Resolution	1.1 arcsec / 21-bits per rotation	2.9 arcsec / 19-bits per revolution

7.1.1. Position Encoder Selection

Early conceptual designs utilized pick-off gears to encode the absolute position of the rotator. It does not appear that the above accuracy can be met through this method. Clearly, the simplest solution is to use a tape encoder wrapped around a surface near the rotator bearings. Optical tape is a potential solution, though the resulting resolution is excessive and the cost is very high. An alternative solution is to use an Inductosyn tape. The Inductosyn has the additional advantage in that it does not require a light baffle. By using two Inductosyn tapes with slightly different cycle pitches, the absolute rotator angle can be determined. This is done by taking the difference in the two interpolation angles to determine the absolute interpolation cycle count.

7.1.2. Inductosyn Performance

The analysis assumes a resolver-to-digital converter such as the Analog Devices AD2S83 is used. This device will provide both an absolute cycle phase vector and an analog rate feedback signal. The analog rate feedback signal is continuous and thus is very useful at low speeds.

Table 9 This table illustrates the anticipated performance of the inductosyn encoders.

	Direct Gregorian	Bent Gregorian
Tape Length	10.4 m	5.9 m
Cycle Period	2.54 mm	2.54 mm
Resolution	5.0 µm	11 µm
Minimum Interpolation Factor	512 (9-bits)	226 (8-bits)
Slew Frequency (1.5 / 15 deg/sec)	17.1 / 171 Hz	9.68 / 96.8 Hz
Max AD2S83 Interpolation Factor	14 / 12-bits	16 / 12-bits
Max AD2S83 Resolution	19 / 77 mas	8.5 / 136 mas
AD2S83 Rate Feedback Sensitivity	0.39 / 0.098 mV/arcsec/sec	0.89 / 0.056 mV/arcsec/sec

As stated above, it is possible to encode the position absolutely by using two tapes. The two tapes would have a slightly different cycle pitch. By taking the difference between the to interpolation angles, the cycle count can be derived. To effectively use this technique, the interpolation factor must be at least 12-bits due to the length of the tape. An additional switch must be used to encode rotation count. This wrap phase switch will be integrated into cable chain limit switches. It will flip state at a cable chain angle of 225 degrees.

Position encoding is expected to be performed seamlessly by butting the ends of the inductosyn together.

7.1.3. Encoder Read Head Mounts

The Inductosyn tapes must be of small enough diameter to clear the motors and other equipment. This places them well inboard of the rim gear and means that the mount for the read heads must reach far across the gear. This could be done with a cantilevered mount but it is likely that the mount can be made stiffer by using a beam to span across the gear to hold the read heads in position. This is the current plan pending analysis. Fine adjustment and positioning of the heads will be accomplished by mounting each head on an adjustment mechanism providing steering, tilt and spacing adjustment. Other adjustment degrees of freedom can also be included if required but are not expected to be necessary at this time.

7.2. Cable Chain Position Encoding

The encoding of the cable-chain position will be done using an LVDT. Because the LVDT will be located a significant distance from the control electronics, the demodulator will be located in the tree house rather than integrated into the LVDT itself. The LVDT will encode the relative angle between the cable chain and the instrument rotator. The required range of the LVDT is +/-3.0 degrees. This corresponds to 17 cm of travel for the direct Gregorian cable chains and about 11 cm of travel for the bent Gregorian cable chains. If the LVDT is digitized at 14-bits at the drive, this will correspond to 0.66 arcsecond resolution which is more than sufficient.

The long travel of the LVDTs requires that substantial sideways motion be accommodated. A simple method for allowing this motion is to pivot the LVDT on its mount but other approaches are also under consideration. This is not considered a high-risk area.

8. Control System

8.1. Control Hardware Topography

Control of the instrument rotators will be handled by the MCSPU, the same Compact PCI Linux computer that controls the azimuth and elevation axes of the telescope. The MCSPU will be augmented with additional Bittware Reef boards to accommodate the new tasks. The Reef boards integrate an Analog Devices ADSP21160 DSP and a Xilinx Virtex II FPGA onto a PMC board that can easily be integrated into compact PCI cassis. The control loop will be closed in the DSP and the FPGA will be used to interface to a SERDES device which will facilitate communicate with the interface electronics through fiber-optic connections. One Reef board will control two rotators and associated cable chains through two fibers.

The drives interlock hardware and SERDES communication hardware will be located on the elevation axis of the telescope in the upper right tree house. The MCSPU is located in the auxiliary control room.

The cable chain control loop will be closed locally in the tree house by the cable chain servo amplifier using the analog feedback from the LVDT defined in section 10. The position command will be supplied remotely through the SERDES interface.

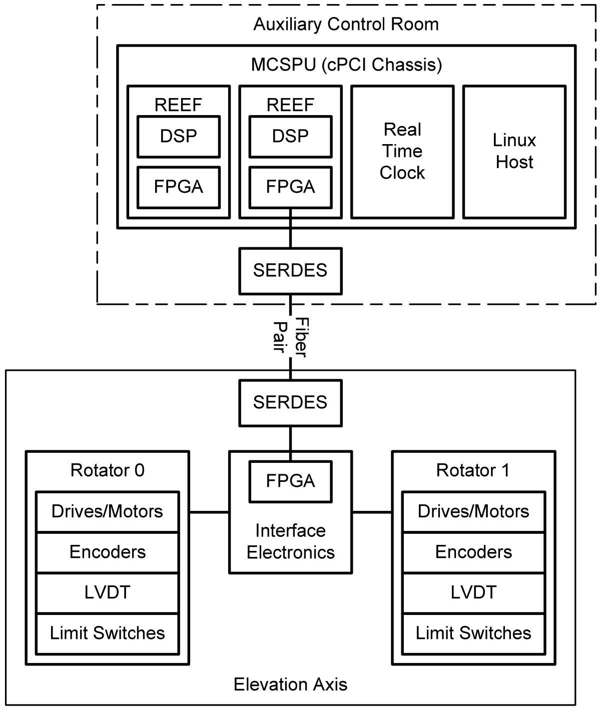

Figure 4 Control Hardware Topography

8.2. Control Software Topography

Rotator control will be integrated into the existing software that controls the main axes of the telescope. Much of the same software will be reused to minimize the software development effort. Trajectory commands will take the form of an N^{th} order polynomial in time consistent with the azimuth and elevation trajectory format. The trajectory will be supplied by PCS to the MCSControl process running on the MCSPU Linux host processor. Non-trajectory related status and control functionality will be integrated into the MCS subsystem. MCSControl then communicates via the PCI bus with the real time control (RTControl) process running on the Reef board DSP. RTControl and Servo which both run on the Reef board DSP control the hardware through the FPGA. Telemetry from the servo, RTcontrol and MCSControl will be delivered to the TEL subsystem via Ethernet.

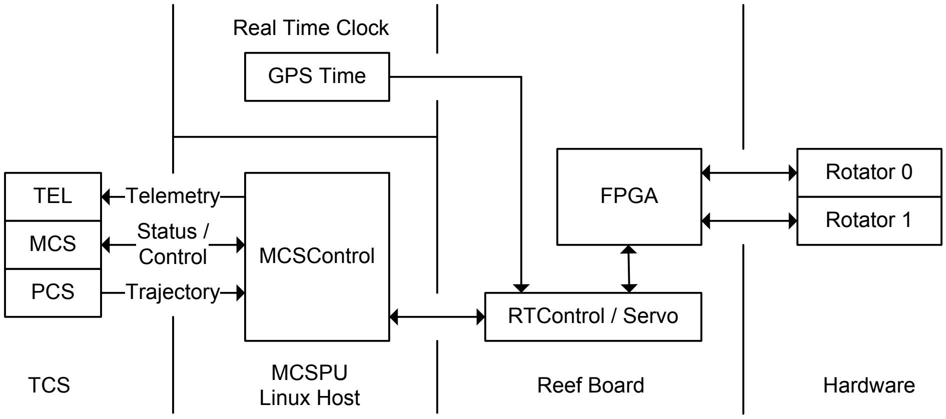

Figure 5 Software topography

8.3. Signals Definitions

The signals defined here are intended to reflect the data that will be serialized for delivery over the fiber connection to and from the DSP. Since one fiber connection will control two rotators, the signals are duplicated two fold. Signals in yellow represent high speed signals required to close the control loop in the DSP. Additional signals will likely be added to aid in monitoring the drives. A great deal of data is available though the drive serial ports that may be useful for monitoring the system. Additionally, data specific to the communication control must also be added.

	Direction	**Type**	**Note**
	Instrument Rotator Signals		
MCR Status	Input	Discrete	Master Control Relay Status
Power Enable	Output	Discrete	Contactor Control
Power Monitor	Input	Discrete	AC Drive Power Monitor
Amplifier Enable	Output	Discrete	Enables both amplifiers
Amplifier Fault Clear	Output	Discrete	Reset Amplifier Fault State
Amplifier 0 Status 0	Input	Discrete	Over Voltage
Amplifier 0 Status 1	Input	Discrete	Over Temperature
Amplifier 0 Status 2	Input	Discrete	Over Speed
Amplifier 0 Status 3	Input	Discrete	TBD
Amplifier 1 Status 0	Input	Discrete	Over Voltage
Amplifier 1 Status 1	Input	Discrete	Over Temperature
Amplifier 1 Status 2	Input	Discrete	Over Speed
Amplifier 1 Status 3	Input	Discrete	TBD
Current Command 0	Output	Analog	Quadrature Current Command
Current Monitor 0	Input	Analog	Quadrature Current Monitor
Motor Temperature 0	Input	Analog	External Thermister?
Current Command 1	Output	Analog	Quadrature Current Command
Current Monitor 1	Input	Analog	Quadrature Current Monitor
Motor Temperature 1	Input	Analog	External Thermister?
Brake 0 Release	Output	Discrete	Pneumatic Solenoid Valve Command
Brake 0 Monitor	Input	Discrete	Proximity Switch on Brake
Brake 1 Monitor	Input	Discrete	“
CCW Emergency Limit	Input	Discrete	-2.7 Degrees Relative Monitor
CCW Proximity Limit	Input	Discrete	-2.6 Degrees Relative
CCW Limit Override Monitor	Input	Discrete	CCW Limit Override Switch
CW Proximity Limit	Input	Discrete	+2.6 Degrees Relative
CW Emergency Limit	Input	Discrete	+2.7 Degrees Relative Monitor

CW Limit Override Monitor	Input	Diecrete	CW Limit Override Switch
Motor 0 Encoder A	Input	Discrete	High Speed Motor Encoder Signals
Motor 0 Encoder B	Input	Discrete	“
Motor 0 Encoder X	Input	Discrete	“
Motor 1 Encoder A	Input	Discrete	“
Motor 1 Encoder B	Input	Discrete	“
Motor 1 Encoder X	Input	Discrete	“
Strip Encoder Angle 00	Input	16-bits	Absolute Interpolation Angle
Strip Encoder Angle 01	Input	16-bits	“
Strip Encoder Angle 10	Input	16-bits	“
Strip Encoder Angle 11	Input	16-bits	“
Strip Encoder A0	Input	Discrete	High Speed Strip Encoder Signals
Strip Encoder B0	Input	Discrete	“
Strip Encoder A1	Input	Discrete	“
Strip Encoder B1	Input	Discrete	“
Strip Encoder A2	Input	Discrete	“
Strip Encoder B2	Input	Discrete	“
Strip Encoder A3	Input	Discrete	“
Strip Encoder B3	Input	Discrete	“
Cable Chain Signals			
MCR Status	Input	Discrete	Master Control Relay Status
Power Enable	Output	Discrete	Contactor Control
Power Monitor	Input	Discrete	AC Drive Power Monitor
Enable	Output	Discrete	Servo Amplifier Enable
Amplifier Fault Clear	Output	Discrete	Reset Amplifier Fault State
Amplifier Status 0	Input	Discrete	Over Voltage
Amplifier Status 1	Input	Discrete	Over Temperature
Amplifier Status 2	Input	Discrete	Over Speed
Amplifier Status 3	Input	Discrete	TBD
Current Monitor	Input	Analog	Quadrature Current Monitor
Motor Temperature	Input	Analog	
Position Command	Output	Analog	Command to Servo Amplifier
Position Monitor	Input	Analog	LVDT Monitor
Brake Release	Output	Discrete	Pneumatic Solenoid Valve Command
Brake Monitor	Input	Discrete	Proximity Switch on Break
CCW Emergency Limit	Input	Discrete	-92 Degrees Absolute Monitor
CCW Proximity Limit	Input	Discrete	-91 Degrees Absolute
CCW Limit Override Monitor	Input	Discrete	CCW Limit Override Switch
CW Proximity Limit	Input	Discrete	+541 Degrees Absolute
CW Emergency Limit	Input	Discrete	+542 Degrees Absolute Monitor
CW Limit Override Monitor	Input	Diecrete	CW Limit Override Switch
Wrap Phase	Input	Discrete	Flips State at +225 Degrees Absolute
Common Signals			
EStop Status	Input	Discrete	Emergency Stop Status
Lockout Status	Input	Discrete	Rotator/Cable Chain Lockout Status
Watchdog Output	Output	Discrete	Watchdog Loop
Watchdog Input	Input	Discrete	“
Air Supply Pressure	Input	Analog	
Analog 0	Input	Analog	Unassigned Analog Sensor
Analog 1	Input	Analog	Unassigned Analog Sensor
Analog 2	Input	Analog	Unassigned Analog Sensor
Analog 3	Input	Analog	Unassigned Analog Sensor

8.4. Instrument Rotator Position Control

Position and rate control of the instrument rotators will be handled by the DSP located on the Reef board in the MCSPU chassis. This position controller will accept N^{th} order trajectory polynomials from MCSControl running on the MCSPU host processor. The trajectory will be evaluated using the local real time clock and the DSP will generate torque commands for the drives. These torque commands will be serialized for transport to the drives located on the elevation axis in the upper right tree house. Encoder and general status will also be serialized for transport to the DSP. This puts a significant burden on the communication link between the DSP and the rotator electronics.

8.5. Cable Chain Position Control

The position of the cable chain will be controlled by the electronics located in the tree house. Because the position feedback is analog, a PI controller external to the servo drive may be necessary if the servo drive does not support analog position feedback.

8.6. Power Control

The drive power will be individually controlled under software control to minimize heat loading in the tree house. Local power control and lockouts will override the software control of the power.

9. Brakes, Stops, and Limits

9.1. Instrument Rotator Limit Switches

A total of four switches will be used to limit the range of motion of the instrument rotator. Two proximity limit switches located at -2.6 and +2.6 degrees relative to the cable chain will be used as directional enables for the servo software. A second set of switches will be located at -2.7 and +2.7 degrees relative to the cable chain. Triggering these mechanical limit switches will interrupt the rotator drive power though relay logic only. Recovery from this latched state requires local intervention.

9.2. Cable Chain Limit Switches

Over-travel of the cable chain will be prevented using four limit switches. Two of the switches will be proximity-type switches positioned at -91 and 541 degrees. These switches will be used as direction enable inputs in the cable-chain drive. The second set of switches will be located at -92 and +542 degrees. These are mechanical switches that will interrupt the power to the cable-chain drive. Once triggered, the cable chain drive will be latched off using relay logic. Local intervention will be required to recover from this state.

One additional switch will be used to indicate the wrap phase. This switch will be required to identify which wrap the rotator is on during initialization.

The cable chain limit switch cam will be gearbox driven so that no flipper is required. This gearbox will be driven by the cable chain motor directly.

9.3. Relative Rotation Bumpers

Mechanical bumpers will be implemented between the rotator and cable chain. The rotator will first contact the bumper at 2.7 degrees and compress to 3.0 degrees. This gives a total range of motion of -3.0 to +3.0 degrees relative to the cable chain.

9.4. Brakes

Each instrument rotator and cable chain will be equipped with fail-safe brakes. The brakes will each be equipped with state feedback. The fail-safe brakes will be pneumatically operated because the power needed to operate electric brakes is prohibitively high. The solenoid valves will be located in the tree house with the electronics. Because the brakes are pneumatic, the supply air pressure is required.

9.4.1. Selection

An MWM pneumatic negative single disk brake will be used to lock rotator moment when power is removed. Pneumatic brakes were selected to minimize heat generation during operation. These particular brakes were selected because they are similar to the brakes used elsewhere on the telescope and because they are designed to operate dry, without oil in the air supply. This reduces the chance of contamination of the mirror or other surfaces with oil.

The brake sselected must be capable of resisting the full motor torque.

9.4.2. Mounting

The physical space between the instrument support structure and the mirror cell flange makes it undesirable (and possibly impossible) to mount the brakes on the motor shafts of the bent Gregorian rotators. If mounted to the motor shafts the brakes would extend over the mirror cell flange and potentially interfere with the vacuum flange. Because of this issue, the brakes will be mounted separately and engage the large gear through separate pinions. The spot faced interface on the inside (mirror-facing) surface of the ISS frame will be used for attaching and locating the brake assembly. A single brake will be used for the bent Gregorian rotator.

The direct Gregorian rotator has adequate axial space and does not have the same requirements for telescope maintenance as the bent Gregorian rotator. Two brakes will be used mounted directly on the motor shafts for the direct Gregorian rotator.

9.5. Emergency Stop

All cable chains and instrument rotators will respond to the LBT Emergency Stop System (EStop). An EStop will cause the drive and solenoid brake valve power to be interrupted. This functionality will be provided using relay-logic only. Recovery from an EStop will require local intervention.

9.6. Lockouts

A lockout will be provided for the rotators. This will be a key-operated system that will utilize relay logic to interrupt drive power and brake control. In series with the lockout logic will be a set of contacts that will be made available to the instrument. These contacts can be used to facilitate instrument specific lockout conditions.

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