Telescope Specifications for the Large Binocular Telescope

J. M. Hill, Steward Observatory

Large Binocular Telescope Project
Technical Memo
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Abstract

This document summarizes the various input specifications to the final telescope design. *Will it be finished before the telescope is built? Will it ever be finished?* These specifications include: telescope drives and encoders, enclosure drives, instrument rotators and cable wraps, instrument and telescope utilities. Send corrections, questions and comments to J. Hill.

Distribution

- **ADS** — D. Gallieni, E. Anaclerio (ftp)
- **EIE** — G. Marchiori, G. Rigato, L. Merlo, A. Zanon, L. Giacomel (fax)
- **M3** — D. Mulligan, D. Neff, J. Teran, D. Baumer, M. Fraser (mail)
- **SO** — W. Davison, S. DeRigne, S. Clapp, J. Slagle, S. Schaller, D. Harvey
- **OAA** — P. Salinari, C. Del Vecchio, L. Miglietta, L. Fini (ftp)

Contents

Changes since October 1996

Removed CATV video distribution. Drastically reduced the number of coax cables. Removed Azimuth chilled water. Updated M2 and M3 dimensions for revised back focal distance. Added section on limits of telescope travel. Added section on telescope deflection tolerances. Removed UPS power from F/4 secondary utilities.

Changes since July 1995

Added section on "instrument envelopes" and masses. Added chiller and heating water pipes to "fixed enclosure utilities". Updated requirements for "mirror support air" and "mirror ventilation air". Lowered total AC power estimates. Attempted to clarify limits of azimuth and elevation travel.

Changes since May 1995

Added "maximum observing windspeed" of 80 km/hour to building rotation specifications. Added "compressed air for mirror support" and "mirror ventilation air" to elevation utilities. Reduced electrical service in azimuth utilities since telescope drives use 10 – 20 kVA not 80kVA. Split out listings for tertiary mirrors and laser guide star mirrors. Removed "Bent" from the focal station utilities list and replaced it with "combined".

Changes since August 1994

Additional specs on the instrument rotators have been filled in. UPS power has been added to the on-telescope utilities. Elevation AC power was changed to 480 V assuming some on-board transformers. A list of utilities for the azimuth cable drape has been added. A list of utilities for the rotating section of the enclosure has been added.

Prolog: How specifications live forever

The US Standard railroad gauge (distance between the rails) is 4 feet, 8.5 inches. That's an exceedingly odd number. Why was that gauge used?

Because that's the way they built them in England, and the US railroads were built by English expatriates.

Why did the English people build them like that? Because the first rail lines were built by the same people who built the pre-railroad tramways, and that's the gauge they used.

Why did "they" use that gauge then? Because the people who built the tramways used the same jigs and tools that they used for building wagons, which used that wheel spacing.

Okay! Why did the wagons use that odd wheel spacing? Well, if they tried to use any other spacing the wagons would break on some of the old, long distance roads, because that's the spacing of the old wheel ruts.

So who built these old rutted roads? The first long distance roads in Europe were built by Imperial Rome for the benefit of their legions. The roads have been used ever since. And the ruts? The initial ruts, which everyone else had to match for fear of destroying their wagons, were first made by Roman war chariots. Since the chariots were made for or by Imperial Rome they were all alike in the matter of wheel spacing.

Thus, we have the answer to the original questions. The United State standard railroad gauge of 4 feet, 8.5 inches derives from the original specification (Military Spec) for an Imperial Roman army war chariot. MilSpecs and bureaucracies live forever.

So, the next time you are handed a specification and wonder what horse's ass came up with it, you may be exactly right. Because the Imperial Roman chariots were made to be just wide enough to accommodate the back-ends of two war horses.

Author Unknown

1 Telescope Pointing and Tracking

A study is now underway to optimize the tradeoff between local seeing, pier height and wind-induced motion of the telescope and pier. A discussion on 13JUL94 produced the following error allocation for open-loop telescope tracking errors (tilt):

Total Open Loop Tracking	0.06 arcsec rms
Servo Error Tracking for 5 seconds	0.03 arcsec rms
Telescope Deflections under wind and gravity	0.03 arcsec rms
Pier Deflections under wind and drives	0.03 arcsec rms
Rock Deflection and Enclosure Coupling	0.02 arcsec rms
Primary and Secondary Mirror Supports	0.015 arcsec rms
Instrument Rotator and Guider	0.015 arcsec rms

The following historical section was extracted from Hill (1990, SPIE 1236, 86).

1.1 Strategy for tracking

In the spirit of building a telescope that matches the best atmosphere, the optics support structure is required to track open-loop with a smoothness to match the image motion caused by atmospheric turbulence. The tracking requirements of the telescope are set by two modes of operation. First, image motion should not significantly increase the point spread function during moderate length unguided exposures (minutes). Second, image motion should not degrade the diffraction pattern during rapid readout imaging (speckle, thermal IR imaging, interferometry). The telescope as a system must deal with five types of image motion on various timescales. The most basic motion is the diurnal motion of the sky. Given a stable clock and a good model of the atmosphere, this motion is quite predictable down to the level of a few hundredths of an arcsecond. The next set of motions are caused by flexure, hysteresis, and thermal drift of the telescope structure. Given a stiff steel structure, we can expect deformations of roughly one millimeter or equivalent pointing errors of tens of arcseconds. Systematic pointing variations can be measured as a function of position and temperature and removed from the pointing and tracking error with a lookup table down to the fraction of an arcsecond level. The following section discusses the image motion coming from tilts in the atmospheric wavefront. If the telescope is not in thermal equilibrium, temperature gradients could overwhelm the tabular calibration, but we must maintain equilibrium to preserve seeing. As we look at higher frequency errors we discover wind disturbance of the telescope position and internal torque disturbances. Our primary weapons against windshake are a short focal ratio to reduce wind torque, stiff drives, low wind cross-section and shielding by the dome. Finally we must design the telescope drives and supports to avoid high frequency drive errors and vibrations. These errors are extremely difficult to remove by guiding or other measurements of the focal plane images, and so contribute directly to increasing the image size. Vibrations are also very detrimental to interferometric measurements which require pathlength stability over the characteristic timescale of the atmosphere.

1.2 Atmospheric image motion

The RMS (1D) image motion, $\delta\theta$, induced by the atmosphere is given by:

$$\delta\theta = 0.043 * D^{-1/6} * r_0^{-5/6}\ arcsec$$

where D is the telescope diameter in meters, and $r_0(0.5\mu m)$ is also expressed in meters. For an 8 meter telescope in an $r_0 = 45$ cm atmosphere, we expect 0.06 arcsec rms image motion. For the gaussian case, 0.06 arcsec rms motion would provide a 0.14 arcsec FWHM long-exposure image. Since 0.06 arcsec rms motion is derived by giving the *entire* error budget for wavefront tilt to the mount, we clearly must reach some compromises to allow for telescope – telescope alignment and collimation errors. Unlike image size, image motion is constant with wavelength (neglecting diffraction), because atmospheric phase errors are independent of wavelength. Therefore, these tracking specifications should apply to all wavelengths. In the thermal infrared where the telescope becomes diffraction limited, we must consider the effects of image motion on the diffraction pattern. The minimum image size occurs around 5 microns where r_0 approaches the size of a single 8-meter primary. To meet Marechal's criterion and preserve a Strehl ratio, **S**, of 0.8, again the whole error budget, image motion must remain smaller than 0.031 arcsec rms. This contributes a FWHM image size of 0.074 arcsec. To achieve **S**=0.95 it would be necessary to halve these numbers.

1.3 Guiding

In the absence of wind forces, telescope – telescope alignment is only affected by gravity and thermal effects, which are slow compared to atmospheric motion. These long term drifts are relatively easy to correct by monitoring the positions of the images in the focal plane. Within the linear range of the primary support mechanisms, it should be possible to steer the two primary mirrors into collimation by moving the three (six) hardpoints which locate the mirrors. This seems unusual, but no more so than tilting 2-meter secondaries which are as large as the primaries of today's telescopes.

After we have corrected pointing errors and drifts between the two telescopes, the next challenge for guiding is to remove the slowest parts of the atmospheric image motion to improve the long term image size. To estimate a timescale for the motion, we assume an outer turbulence scale of 100 meters and an upper atmosphere wind velocity of 20 meters/sec. This implies a timescale of up to 5 seconds. Image motions on timescales longer than one second should be correctable with normal guiding (moving the telescope) and tilting the secondaries. This allows us to loosen the tracking specification on longer timescales. The characteristic upper frequency of the atmospheric image motion is set by the pattern speed moving across the aperture. Using a 20 meter/sec wind and an 8 meter aperture we find a frequency of 2.5 Hz. Image motion and telescope motion on timescales longer than 0.1 second should be correctable with rapid guiding with a steering mirror if a sufficiently bright source is available within the isoplanatic region. A goal for rapid guiding would be to reduce net image motion below 0.01 arcsec rms — actually improving on the atmosphere — for frequencies below 10 Hz. Guiding at this level will certainly influence the design of the encoders and servo system, if not the telescope structure. Because the telescope aperture is so much larger than r_0, the improvements in image size from guiding are not as great as they would be for a smaller telescope. In the best seeing, we can expect less than a factor of two improvement. For optical imaging and spectroscopy, where the field-of-view may be much larger than the isoplanatic region in the focal plane, image motion across the field may not be correlated. Differential image motion should not be a problem in the thermal infrared, where the isoplanatic region is roughly the size of the focal plane.

Adaptive optics correction of the wavefront is beyond the scope of this discussion.

1.4 Telescope pointing and tracking specification

Open Loop Pointing	0.30 arcsec rms
Tracking for 1000 seconds	0.10 arcsec rms
Blind Offset up to 1 degree	0.10 arcsec rms
Tracking for 5 seconds	0.03 arcsec rms

The telescope should point to 0.3 arcsec rms at all times (night) with periodic recalibration of the open loop coefficients. The Multiple Mirror Telescope (MMT) already achieves this pointing performance. The telescope should track to 0.1 arcsec rms (1D) for periods up to 1000 seconds. The MMT currently tracks at 0.1 arcsec rms for shorter periods of time. This number also represents the blind offset specification for angular motion less than one degree. The telescope should track to 0.03 arcsec rms for periods up to 5 seconds. The value of 0.03 arcsec rms is somewhat larger than would be calculated from the $r_0 = 150$ cm allowed in the wavefront error budget. This has been allowed because many of the other errors contribute less at large spatial scales. These tracking specifications should apply up to wind speeds of at least 6.7 m/sec (24 km/hour), and performance should degrade gracefully up to the maximum operating wind speed of 22 m/sec (80 km/hour) without exceeding three times the specification. The short timescale specifications imply an effective smoothness of a few microns for the drives and supports. Longer scale variations and temperature effects can presumably be taken out with encoders and look-up tables.

1.5 Telescope encoder specifications

The fundamental encoder specifications are derived from the telescope tracking specifications listed above. We expect to have an encoder on the azimuth platform and one encoder on each of the two elevation C-rings. Additional encoders will be located on the instrument rotators etc.. Environmental parameters are listed consistent with the general telescope specifications.

We would like an angular resolution of at least 27 bits (1 part in 2^{27}) with 28 bits as a desirable goal. We have dropped the 0.01 arcsec tracking requirement discussed previously, although we will still need 27 bit encoding to meet the 0.03 arcsec requirement. Some assumptions about the servo system have been used to decide between 26 and 28 bits.

1.5.1 Overall telescope encoder specifications

Angular Resolution	0.01 arcsec (27 bits, minimum) 0.005 arcsec (28 bits, goal)
Linearity	0.03% on scales of 1 arcminute (0.02 arcsec) 0.005% on scales of 1 degree (0.2 arcsec)
Repeatability	0.02 arcsec, over 1000 seconds 0.05 arcsec, long term
Angular Velocity	0.0 to 1.5 degrees $\sec^{-1}$
Azimuth Range	± 270 degrees
Elevation Range	2 x 95 degrees

1.5.2 Telescope encoder environmental specifications

Using the encoder in a typical mountaintop environment, we have the following general environmental requirements. It would also be prudent if the encoder tape were tolerant of hydraulic oil from the nearby hydrostatic bearings of the telescope.

Storage Temperature	–30 to +50 °C
Operating Temperature	–20 to +25 °C (following ambient temperature)
Storage Pressure	500 to 760 Torr
Operating Pressure	500 to 600 Torr
Storage Humidity	5 to 80%
Operating Humidity	5 to 95%
Mounting Surface	steel

1.5.3 Derived telescope encoder specifications

Assuming a strip encoder mounted on a 14 meter diameter cylinder we may derive the following subsidiary specifications. Each elevation C-ring would use half a circumference strip. From the angular encoder specs, we can derive some corresponding linear specs for the tape encoders. These linear specs are listed in the table below. The linearity requirements come from the desire to track smoothly for short periods of time without reference to the sky. Large scale non-linearities in the encoder are of little importance as they will be calibrated out along with telescope flexure and other similar effects. The maximum bit rate or maximum linear velocity indicates how fast the bits on the encoder need to pass by without getting lost. The minimum update rate indicates how often we want to feed position and velocity information to our control system.

The actual encoder mounting diameters are closer to 13 meters, but these tables have not been updated to reflect that change.

Tape Length	44 meters (azimuth circumference) 2 x 22 meters (elevation length) (need not be a single tape segment)
Linear Resolution	0.33 μm (27 bits) 0.16 μm (28 bits)
Linearity	0.03% on scales of 0.002 meters 0.005% on scales of 0.12 meters
Repeatability	0.6 microns, over 1000 seconds 1.5 microns, long term
Maximum Linear Velocity	0.18 meters sec^{-1} (1.5 degrees sec^{-1})
Maximum Bit Rate	560 kHz (27 bits) 1118 kHz (28 bits)
Minimum Update Rate	250 Hz
Coefficient of Thermal Expansion	$\sim$ steel
Computer Interface	VME board
Number of Read Heads per Axis	4 azimuth, 2 x 2 elevation

1.5.4 Farrand encoders

The actual encoders purchased in 1995 are Farrand Inductosyn tapes with a physical pitch of 0.1 inches (2.54 mm). With nominal 14-bit interpolation, this is reduced to a linear resolution of 0.155 μm. The diameter of the azimuth mounting surface is 13130 mm. The equivalent diameter of the elevation mounting surfaces is 12960 mm.

1.6 Limits of Elevation and Azimuth travel

The following description of the telescope azimuth and elevation limits is extracted from an email discussion in October 1996.

First, let us specify that the brakes of both the telescope and the enclosure are sized so that they can stop from the full slew velocity of 1.5 $deg\ sec^{-1}$ in a distance of no more than 2 degrees AND no less than 1 degree. Note that stopping by brakes produces a deceleration which is 2 - 4 times larger than that available from the motors; i.e. the brakes are stronger than the motors.

Second, we will agree to move the bumpers back a small distance behind the final limit switch for elegance if not necessity.

Third, we will specify the position of a software limit which causes the control system to reduce the allowed maximum velocity to a smaller value (perhaps 0.3 $deg\ sec^{-1}$?). This software limit could have more than a single step, but the principle is the same. In the case of the enclosure with respect to the telescope, the software limit will refer to relative velocity.

Fourth, as before we ask bumpers/dampers which stop the full slew motion in a distance of 1 degree. If the bumpers need additional distance for engineering reasons, we can engage them slightly sooner. Because the 270 degree rotation of the enclosure has no bumpers, we've added some extra angle for the emergency stopping distance. (In the table below, ±277 degrees is the position by which the enclosure should certainly have stopped after the final limit switch. Then there are 3 degrees more before the cable chain is damaged.)

The revised table:

Elevation Limit Description	Low Elevation	High Elevation
Over-travel Damage	–4.0 degrees	+94.0 degrees
Bumpers compressed (approx)	–3.5 degrees	+93.5 degrees
Clear Travel (bumpers engage)	–2.5 degrees	+92.5 degrees
Final Emergency Limit Switch	–2.0 degrees	+92.0 degrees
Initial Proximity Limit Switch	–0.2 degrees	+90.2 degrees
Normal Operation Range	0.0 degrees	+90.0 degrees
Software Low Velocity Zone	2.0 degrees	+88.0 degrees
Azimuth Limit Description	**Az wrt/Enclosure**	**Enclosure Absolute**
Over-travel Damage	±4.0 degrees	±280 degrees
Bumpers compressed (approx)	±3.5 degrees	N/A
Clear Travel (bumpers engage)	±2.5 degrees	N/A
Final Emergency Limit Switches	±2.0 degrees	±273 degrees
Initial Proximity Limit Switches	±1.0 degrees	±270.2 degrees
Normal Operation Position	~0.0 degrees	±270 degrees
Software Low Velocity Zone	N/A	±270 degrees

Limit switch responses We have written the above assuming that the telescope and the enclosure are always able to move in their normal operating ranges without encountering any limit switches. Just beyond the normal operating range an initial proximity limit switch is encountered which serves as a warning to the control system that there is a problem. Upon sensing the initial limit switch, the control system immediately commands the telescope and/or enclosure to zero velocity under software or firmware control.

If the system does not heed the initial proximity limit, a second final limit switch disables the drives and applies the brakes in hardware just before the bumper is engaged. Even if the final limit switch fails, the bumpers are able to stop the telescope before reaching the ends of their travel.

If everything fails, damage to the cables and/or the steel structure will occur when a travel of 4 degrees occurs. Hopefully this condition is only hypothetical.

The instrument rotators/derotators and cable chains should have the approximately the same ranges as the enclosure absolute motion, but in reality they have slightly less travel than the enclosure absolute angles listed above.

In this scheme, pressing the emergency stop button cuts power to the drives, applies the brakes of both telescope and enclosure, and cuts power to the hydrostatic pads and other systems. The telescope should have stopped moving before the hydraulic accumulator drains down.

Azimuth brakes There is another debate about whether strong (as specified above) brakes are needed on the azimuth of the telescope. The MMT has disabled their original telescope azimuth brakes to avoid problems with the enclosure backdriving the telescope against its drives and brakes. I suggest that we need the telescope azimuth brakes for the pre-erection and we can decide whether to disable them later. Apparently the teeth of the gears are strong enough to withstand this backdrive force.

The previous calculation of the space necessary to stop the telescope at full slew velocity: Vmax=1.5 $deg\ sec^{-1}$ had:

Stopping Distance	Maximum Deceleration	Stopping Time
1.0 deg	dw/dt = 1.125 $deg\ sec^{-2}$	t = 1.33 sec
1.5 deg	dw/dt = 0.750 $deg\ sec^{-2}$	t = 2.00 sec
2.0 deg	dw/dt = 0.5625 $deg\ sec^{-2}$	t = 2.66 sec
3.75 deg	dw/dt = 0.300 $deg\ sec^{-2}$	t = 5.0 sec

If we consider to reduce the full slew velocity down to ~ 1 $deg\ sec^{-1}$ having the same maximum deceleration of 0.3 $deg\ sec^{-2}$ we can stop in 1.5 - 2 degrees. In any case considering the highest deceleration we have in the previous calculations we have on the mirror just a fraction of the 1.3g allowable load.

1.7 Instrument rotator specifications

1.7.1 Gregorian F/15 instrument rotator specifications

Angular Resolution	1.24 arcsec (20 bits)
Resolution on Sky	0.005 arcsec ($R_{field} = 0.25\ degree$)
Linear Resolution	9.0 μm (20 bits, $R_{bearing} = 1.5\ m$)
Linearity	0.01%
Angular Velocity	0.0 to 1.5 degrees $\sec^{-1}$
Angular Acceleration	0.0 to 0.3 degrees $\sec^{-2}$
Rotation Range	± 270 degrees (±280 degrees clearance)
Maximum Torque	3000 N m

1.7.2 Cassegrain F/4 instrument rotator specifications

Angular Resolution	1.24 arcsec (20 bits)
Resolution on Sky	0.01 arcsec ($R_{field} = 0.5\ degree$)
Linear Resolution	5 μm (20 bits, $R_{bearing} \sim 0.8\ m$)
Linearity	0.01%
Angular Velocity	0.0 to 1.5 degrees $\sec^{-1}$
Angular Acceleration	0.0 to 0.3 degrees $\sec^{-2}$
Rotation Range	± 270 degrees
Maximum Torque	2000 N m

1.7.3 Combined F/15 and Nasmyth instrument rotator specifications

Angular Resolution	2.5 arcsec (19 bits)
Resolution on Sky	0.005 arcsec (R=0.1 degree)
Linear Resolution	11 μm (19 bits, $R_{bearing} = 0.9\ m$)
Linearity	0.01%
Angular Velocity	0.0 to 1.5 degrees $\sec^{-1}$
Angular Acceleration	0.0 to 0.3 degrees $\sec^{-2}$
Rotation Range	± 240 degrees (±250 degrees clearance)
Maximum Torque	2000 N m

The rotation range of the front and back combined focus rotators is limited by the cable chains to a maximum of 250 degrees.

1.8 Telescope drive specifications

maximum angular velocity	1.5 $degrees\ sec^{-1}$ (0.026 $rad\ sec^{-1}$)
maximum angular acceleration	0.3 $degrees\ sec^{-2}$ (0.005 $rad\ sec^{-2}$)
maximum azimuth rotation	±270 degrees from South
maximum elevation rotation	95 degrees
maximum operating windspeed	80 km/hour (22 m/sec, 50 mph)
zenith blindspot radius	$<$ 20 arcminutes
maximum azimuth torque	80000 N m (continuous)
maximum elevation torque	80000 N m (continuous)
maximum instantaneous torque	160000 N m

The telescope shall be able to achieve a maximum angular velocity in each axis of 1.5 $degrees\ second^{-1}$. The maximum acceleration shall be 0.3 $degrees\ second^{-2}$. These parameters and a 10 Hz telescope will allow a 1 arcminute offset in 0.6 seconds, a 1 degree offset in 4 seconds, and a 90 degree slew in 70 seconds. Motions less than about 7.5 degrees are acceleration limited. It is desirable to have a "no-track" cone no larger than 0.7 degree in diameter at the zenith (peak angular velocity = 0.58 $degrees\ sec^{-1}$). These velocity specifications are not intended to substantially impact the design or cost of a telescope which can meet the tracking goals.

1.9 Building drive specifications

1.9.1 Building rotation drive specifications

maximum angular velocity	1.0 $degrees\ sec^{-1}$
maximum angular acceleration	0.2 $degrees\ sec^{-2}$
maximum azimuth rotation	±270 degrees from South
maximum observing windspeed	80 km/hour (50 mph)
survival windspeed open	150 km/hour (90 mph)
maximum operating windspeed	120 km/hour (75 mph)
survival windspeed closed	225 km/hour gust (135 mph)
clearance on telescope rotation	± 2 degrees
tracking of telescope	± 15 arcminutes

The drive specifications for the co-rotating building enable it to follow the telescope and provide protection from foul weather. *Maximum velocity and acceleration were revised July 1994.* See also the limits of travel discussed in a previous section.

1.9.2 Building shutter specifications

maximum operating windspeed	120 km/hour (75 mph)
survival windspeed open	150 km/hour (90 mph)
survival windspeed closed	225 km/hour gust (135 mph)
clear aperture	10.4 meters (1 – 89 degrees)
opening / closing time	less than 2 minutes per shutter

Shutter aperture width calculation comes from Tech Memo UA-91-02.

2 Telescope Utilities

2.1 Cable wrap contents

This section summarizes the cable wrap allotments for utilities to pass through the instrument rotators. This list came from discussions at the LBT Engineering meeting on June 3, 1993. The previous version of this list came from discussions held on November 20, 1990 (see UA-91-02). Cable wrap contents for the large Gregorian/Cassegrain instrument rotators are listed in rough order of priority. A subset of these cables will be used for the bent Cassegrain and interferometric focal stations. When a bore is specified, it refers to the section through the instrument rotator, not to long runs on or off the telescope. If cable wrap design becomes too difficult on the instrument rotators, then some of these cables might be derotated directly from the instrument. An important question still to be answered is: Where on the rotating part will all this stuff terminate?

The instrument "cable wraps" are more correctly called "cable chains".

2.1.1 Gregorian F/15 instrument utilities

OPTICAL FIBER PAIRS 10 fiber pairs (6 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), 7kVA continuous/10kVA surge, (208VAC, 60 Hz)
This will provide heavy power for instrument package – fans, pumps, cameras, etc.

UPS POWER 1-phase (3 wires), 3kVA continuous, (120VAC, 60 Hz)
This will provide control power for instrument package – microcomputers, electronics, etc.

PURGE GAS 60 psi (0.42 MPa), 10 cfm (maximum flow), dry nitrogen (input only)
Used to purge dewar windows, instrument volume, etc.

COOLANT 100 psi (0.7 MPa) maximum pressure, 5kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options) Used to regulate instrument to ambient and scavenge waste heat.

TWISTED PAIRS 30 shielded twisted pairs (one to three cables)
Miscellaneous usefulness.

COAXIAL CABLES eight 75-ohm coax cables, eight 50-ohm coax cables
(mounted with isolated shields) Miscellaneous usefulness.
Belden Trade Number 9231

TELEPHONE Just a phone line. (4, 20 gauge conductors)

HIGH PRESSURE HELIUM GAS 300 psi (2.1 MPa),
two 12 mm bore lines (in and out)
Used for supply to cryocoolers. (still considered optional)

MISC. two 5 cm flexible conduits (empty)
Used for whatever we haven't thought of.

HELIUM RECOVERY 2.5 cm bore vacuum line,
(Low vacuum line can be simple PVC pipe.)
Used to recover helium gas from pumped LHe dewars.

GENERAL VACUUM 2.5 cm bore vacuum line,
Used for pumping LN2 and general purpose vacuum.

Available 1 x 2 places on the telescope.

2.1.2 Central combined instrument utilities

OPTICAL FIBER PAIRS 10 fiber pairs (6 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), 4kVA continuous/6kVA surge, (208VAC, 60 Hz)
This will provide heavy power for instrument package – fans, pumps, cameras, etc.

UPS POWER 1-phase (3 wires), 2kVA continuous, (120VAC, 60 Hz)
This will provide control power for instrument package – microcomputers, electronics, etc.

PURGE GAS 60 psi (0.42 MPa), 10 cfm (maximum flow), dry nitrogen (input only)
Used to purge dewar windows, instrument volume, etc.

COOLANT 100 psi (0.7 MPa) maximum pressure, 3kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options) Used to regulate instrument to ambient and scavenge waste heat.

TWISTED PAIRS 20 shielded twisted pairs (one to two cables)
Miscellaneous usefulness.

COAXIAL CABLES five 75-ohm coax cables, five 50-ohm coax cables
(mounted with isolated shields) Miscellaneous usefulness.
Belden Trade Number 9231

Available up to 3 x 2 places on the telescope.

2.1.3 F4 instrument utilities

OPTICAL FIBER PAIRS 10 fiber pairs (6 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), 4kVA continuous/6kVA surge, (208VAC, 60 Hz)
This will provide heavy power for instrument package – fans, pumps, cameras, etc.

UPS POWER 1-phase (3 wires), 2kVA continuous, (120VAC, 60 Hz)
This will provide control power for instrument package – microcomputers, electronics, etc.

PURGE GAS 60 psi (0.42 MPa), 10 cfm (maximum flow), dry nitrogen (input only)
Used to purge dewar windows, instrument volume, etc.

COOLANT 100 psi (0.7 MPa) maximum pressure, 3kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options) Used to regulate instrument to ambient and scavenge waste heat.

TWISTED PAIRS 20 shielded twisted pairs (one to two cables)
Miscellaneous usefulness.

COAXIAL CABLES five 75-ohm coax cables, five 50-ohm coax cables
(mounted with isolated shields) Miscellaneous usefulness.
Belden Trade Number 9231

Available up to 1 x 2 places on the telescope.

2.2 Auxiliary optics utilities

2.2.1 F/15 secondary utilities

Available 1 x 2 places on the telescope.

Adaptive F/15 utilities

Chopping F/15 utilities

Laser mirror utilities

OPTICAL FIBER PAIRS 3 fiber pairs (2 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), 1kVA continuous/1.5kVA surge, (208VAC, 60 Hz)

COOLANT 100 psi (0.7 MPa) maximum pressure, 0.5kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options) Used to regulate mirror to ambient and scavenge waste heat.

TWISTED PAIRS 5 shielded twisted pairs (one cable)
Miscellaneous usefulness.

Available 1 x 2 places on the telescope. (signals and power may be routed to electronics enclosure.)

2.2.2 Tertiary mirror utilities

OPTICAL FIBER PAIRS 3 fiber pairs (2 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), 1kVA continuous/1.5kVA surge, (208VAC, 60 Hz)

COOLANT 100 psi (0.7 MPa) maximum pressure, 0.5kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options) Used to regulate mirror to ambient and scavenge waste heat.

TWISTED PAIRS 5 shielded twisted pairs (one cable)
Miscellaneous usefulness.

Available 1 x 2 places on the telescope. (signals and power may be routed to electronics enclosure.)

2.2.3 F/4 secondary utilities

OPTICAL FIBER PAIRS 3 fiber pairs (2 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), 1kVA continuous/1.5kVA surge, (208VAC, 60 Hz)
This will provide heavy power for mirror support cell, etc.

COOLANT 100 psi (0.7 MPa) maximum pressure, 1kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options) Used to regulate mirror to ambient and scavenge waste heat.

TWISTED PAIRS 5 shielded twisted pairs (one cable)
Miscellaneous usefulness.

COAXIAL CABLES two 50-ohm coax cables
(mounted with isolated shields) Miscellaneous usefulness.
Belden Trade Number 9231

Available 1 x 2 places on the telescope.

2.3 On-Telescope utilities

2.3.1 Elevation utilities

This is the first cut at the utility requirements for everything on-board the elevation structure. These utilities travel through the elevation cable drapes onto the telescope. This should be a superset of the above instrument and secondary utilities. This table represents the combination of the two elevation cable drapes on the left and right sides of the telescope.

OPTICAL FIBER PAIRS 20 fiber pairs (12 active pairs plus spares)
These will be used for telescope control network, instrument control network, and instrument data links.

AC POWER 3-phase (5 wires), ~30 kVA continuous/ 40 kVA surge, (480VAC, 60 Hz)
Isolation/stepdown transformers on the telescope should isolate various subsystems. 10 kVA of this power will supply an on-telescope UPS (single phase?).

PURGE GAS 60 psi (0.42 MPa), 100 cfm (maximum flow), dry nitrogen (input only)
Used to purge dewar windows, instrument volume, etc.

COOLANT 100 psi (0.7 MPa) maximum pressure, 30 kW capacity to give 2 degC rise, 2 uninsulated lines
(probably propylene glycol/water, consider other options)

TWISTED PAIRS 20 shielded twisted pairs (two cables)
Miscellaneous usefulness.

COAXIAL CABLES 6 75-ohm coax cables, 4 50-ohm coax cables
(mounted with isolated shields) Miscellaneous usefulness.
Belden Trade Number 9231

TELEPHONE Just a phone line. (4, 20 gauge conductors)

HIGH PRESSURE HELIUM GAS 300 psi (2.1 MPa),
two 25 mm bore lines (in and out)
Used for supply to cryocoolers. (still considered optional)

MISC. eight 5 cm flexible conduits (empty)
Used for whatever we haven't thought of.

HELIUM RECOVERY 10 cm bore vacuum line.
(Low vacuum line can be simple PVC pipe.)

GENERAL VACUUM 10 cm bore vacuum line.

MIRROR SUPPORT AIR 120 – 140 psi (0.84 – 1.0 MPa),
clean dry compressed air, 80 – 120 SCFM
(40 SCFM continuous for each 8.4m mirror)
(60 SCFM peak for up to 2 minutes for each 8.4m mirror)
Last revised September 1995, see UA-95-02, "Mirror Support II/R" for additional discussion.

MIRROR VENTILATION AIR 1.75 psi (0.12 Bar) at the cell, 1.62 psi at the jet ejectors,
2800 liters/sec (1400 liters/sec per mirror), 2 x 70 cm diameter ducts.

EQUIPOTENTIAL CABLES for lightning protection

2.3.2 Azimuth utilities

This is the first cut at the utility requirements for everything on-board the azimuth platform. These utilities travel across the azimuth cable bridge onto the telescope.

OPTICAL FIBER PAIRS 4 fiber pairs (2 active pairs plus spares)
These will be used for telescope control network.

AC POWER 3-phase (5 wires), 25 kVA continuous/ 35 kVA surge, (480 VAC, 60 Hz)

TWISTED PAIRS 10 shielded twisted pairs (two to six cables)
Miscellaneous usefulness.

TELEPHONE Just a phone line. (4, 20 gauge conductors)

MISC. two 5 cm flexible conduits (empty)
Used for whatever we haven't thought of.

COMPRESSED AIR 120 – 140 psi (0.84 – 1.0 MPa),
clean dry compressed air for pneumatic brakes TBD SCFM

HYDROSTATIC BEARING SYSTEM Pipes and Cables for the Telescope Hydrostatic Bearing System

EQUIPOTENTIAL CABLE for lightning protection

3 Optics

3.1 Wavefront specifications

See the separate LBT Tech Memo UA-94-01 “Error Budget and Wavefront Specifications for Primary and Secondary Mirrors” for additional details.

3.2 Primary mirror dimensions

- Number of Primary Mirrors: 2
- Primary Spacing: 14.417 meters center-to-center
- Primary Glass Diameter: 8.417 meters
- Primary Clear Aperture: 8.408 meters
- Primary Focal Length: 9.600 meters
- Primary Focal Ratio: F/1.142
- Central Hole Glass Diameter: 0.889 meters
- Central Hole Clear Aperture: 0.898 meters
- Primary Figure: parabolic
- Primary Construction
  - cast borosilicate honeycomb
  - 28 mm faceplate thickness
  - edge thickness 894 mm, plano-concave
- Primary Mirror Mass: approximately 15.6 metric tons each

These dimensions are from the January 1993 LBT Tech Memo UA-93-01 entitled “1993 Baseline Telescope Description”. See the separate memo “Dimensions for Large Borosilicate Honeycomb Mirrors” from the Mirror Lab for additional details.

3.3 Secondary and tertiary dimensions

3.3.1 optical Cassegrain, ~ F/3.8 (naked)

- interchange: swing arm
- mirror diameter: ~ 1.25 m
- field-of-view: 60 arcminutes (corrected)
- baffle diameter: ~ 2.8 m
- asphere: TBD
- back focal distance: –3.6 m

3.3.2 infrared Gregorian, F/15

- interchange: swing arm
- mirror diameter: 0.911 m (undersized secondary)
- infrared field-of-view: 4 arcminutes (unvignetted at primary)
- optical field-of-view: ~10 arcminutes (vignetted at secondary)
- asphere: –0.7328
- focal length: 0.9871 m
- focal ratio of full-aperture parent: F/14.7204
- back focal distance: 3.050 m

3.3.3 tertiary flats (2)

- interchange: swing arm
- major axis diameter: 63.8 cm (not corrected for offset)
- 45 degrees
- minor axis diameter: 54 cm (45 cm minimum)
- location: 2.25 m above primary vertex
- F/15 field-of-view: 8 x 4 arcminutes (before tertiary vignettes)

3.3.4 beam combination optics

- lateral offset: 3.5 m

3.3.5 laser guide star projector

- beam diameter: 0.55 m
- source laser(s) mounted inside pier
- flat relay mirrors near the azimuth/elevation intersection
- beam expanders mounted on elevation structure
- final flat mirrors mounted above F/15 secondaries

3.4 Telescope deflection tolerances

These tolerances are intended to say what is required from the perspective of the optics and the astronomer. I have not worried about any special tolerances imposed by the steel structure, hydrostatic bearings and similar systems. *(from a March 1996 email)*

- Azimuth Axis Vertical: ±1 arcminute
- Elevation Axis Perpendicular to Azimuth: ±1 arcminute
- Optical Axis Perpendicular to Elevation: ±1 arcminute
  (Optical axis is defined as the mean pointing of the two Gregorian rotators.)
- Both Gregorian Rotators Parallel: ±0.5 arcminute (zenith)
  (with primary mirrors installed) ±1 arcminute (horizon)
- Other Instrument Rotators (central) Parallel: ±0.5 arcminute (zenith)
  ±1 arcminute (horizon)
  (I've ignored the internal tolerances of the F/4 swing arm which are TBD.)
- Average Plane of M1 Cell Parallel to Gregorian: ±0.5 mm across cell
  (Still to be defined how we measure the average plane of the cells.)
- Coplanarity of the Gregorian Rotators: ±1.0 mm
  (Also implies a certain coplanarity of M1 Cells.)
- Average Plane of M1 Cell Spacing to Gregorian: ±0.5 mm
  (Z-direction) (This assumes that +-20 mm adjustments in the focal plane position to correct errors in the M1 or M2 aspheres are done at the instrument mounting flange rather than at the rotator bearing.)
- Separation of the Two Optical Axes: ±2.0 mm
  (M1 Mirror Cell separation in X direction)
- Front-Back alignment of the Two Optical Axes: ±1.0 mm
- Swing arm spiders aligned to the Gregorian Axes: ±1.0 mm
  (Presumably by adjustments at the attachment points.)

4 Enclosure

4.1 Outside enclosure utilities

This is the first cut at the utilities required from outside the enclosure. These utilities come up the road through the utility trench from the utility building.

OPTICAL FIBER PAIRS 10 fiber pairs (6 active pairs plus spares)
These will be used for ethernet, telephone and data links.

AC POWER 3-phase (4 wires), ~700 kVA continuous / 900 kVA surge,
(25 kVAC, 60 Hz)
(Utility trench includes spare conduits for power wiring.)

PROPANE GAS Used for emergency heating and shop area heating?
2-inch HDPE line.

COOLANT WATER 200 psi (1.4 MPa) maximum pressure,
500 kW capacity to give 10 degC rise,
2, 4-inch insulated lines (separated)
Used for waste heat dump to chiller. (glycol/water)

HEATING WATER 200 psi (1.4 MPa) maximum pressure,
100 kW capacity,
2, 2-inch insulated lines
Used for heating enclosure with waste heat from generators. (glycol/water)

TELEPHONE Used for telecommunications. 2 - 5 lines (TBD)

WATER Potable water for the living facilities.
3-inch PVC line.

FIRE PROTECTION External emergency fire water.
6-inch PVC line.

SEWAGE Only to the local vault under the parking lot.

SPARE CONDUITS

4.2 Rotating enclosure utilities

This is the first cut at the utilities required from the fixed to the rotating enclosure. These are the utilities that go through the enclosure cable chain between the fixed and rotating sections of the enclosure.

AC POWER 3-phase (5 wires), ~400 kVA continuous/ 500 kVA surge, (4160 VAC, 60 Hz)

MAIN COOLANT 200 psi (1.4 MPa) maximum pressure, 300 kW capacity to give 10 degC rise,
2, xx-inch insulated lines
Used for waste heat dump to chiller. (glycol/water)

AUXILIARY COOLANT 200 psi (1.4 MPa) maximum pressure, 120 kW capacity to give xx degC rise,
2, xx-inch insulated lines
Used for daytime chamber conditioning. (glycol/water)

FIRE PROTECTION Empty fire hose.

OPTICAL FIBER PAIRS 20 fiber pairs (12 active pairs plus spares)
These will be used for ethernet, telephone, data and interlock links.

TELEPHONE Used for telecommunications. 2 - 5 lines (TBD)

GROUND CABLE (depends on details of electrical grounding/equipotential system.)

SPARE CONDUITS

5 Instrument Envelopes

These instrument dimensions were previously specified in LBT Technical Memo UA-93-01, "1993 Baseline Telescope Description". I've now updated them to be consistent with the final design. These are nominal dimensions. Refer to the design drawings for specific details and precise dimensions.

- Gregorian F/15
    - flange to focal plane: 0.080 m / 0.610 m
    - rotator outside diameter: 3.050 m
    - rotator bolt circle: 2.850 m (48 holes)
    - instrument bolt circle diameter: 3.110 m (locking devices)
    - rotator inside clearance: 2.250 m (guide space 0.97 m above flange)
    - instrument length: 4.2 m / 3.8 m (3.7 m below focal plane)
    - instrument diameter: 3.0 m (2.4 m on lower 1.5 m)
    - maximum instrument plus AGW weight: 3.5 tons
- Bent F/15 (a.k.a. Nasmyth or Combined)
    - flange to focal plane: 0.080 m
    - rotator outside diameter: 1.8 m
    - instrument bolt circle diameter: 1.460 m (24 holes)
    - rotator inside clearance: 1.390 m (guide space until primary edge)
    - instrument length: 1.9 m (to centerline at Nasmyth)
    - instrument diameter: 2.0 m (4.0 m over limited angle at Nasmyth)
    - maximum instrument plus AGW weight: 2 tons
- Trapped F/4
    - flange to focal plane: TBD
    - rotator diameter: TBD
    - instrument bolt circle diameter:
    - rotator inside clearance: TBD
    - instrument length: 0.9 m
    - instrument diameter: 1.8 m
    - maximum instrument weight: TBD