TCS3 Project Requirements

Overall goals of TCS3 project is to replace the following equipment:

- LSI II/23 Computer system.
- CCS and MCC Master Control Bus and all QBus Hardware
- Replace the MCC interface panels.
- Forth Software
- TCS support daemons and application software in IRTF workstations as required.

1. Facility Requirement Drivers

1.2 Sky Coverage

Dec Range is -53:05 to +62:07 (deg:min)
HA Range is -05:04 to + 05:04 (hr:min)

1.3 Pointing Accuracy

Slew to an object up to 10 degrees from a known object to +- 2 arc sec (within a cone of 60 degrees from zenith).
Initial slew to any point to +- 10 arc sec (within a cone of 60 degrees from zenith).

1.4 Science Drivers

Four astrophysical research topics shall constitute the primary basis for specifying those requirements that are derived from the prime mission of the IRTF -- conducting state of the art science. These topics are Dark Clouds, Astrometry, Planetary Objects, and Occultation Studies; these topics and the derived requirements are detailed in Appendix A.

Offsetting: ±1 arcsec p-p over 3600 arcsec
±0.1 arcsec p-p over 600 arcsec
±0.1 arcsec p-p over 60 arcsec
±0.1 arcsec p-p over 1 arcsec

p-p = peak-to-peak.

Tracking: ±0.1 arcsec p-p over 600 sec
Nonsidereal rates up to 40 arcsec/sec maximum, with the ability to calculate rates from ephemeris tables

1.6 Velocity and Acceleration

Tracking:
Velocity 400 as/s

Acceleration	1600 as/s^2	
Slewing HA:	SlewEnable	!SlewEnable
Velocity	1600 as/s	400 as/s
Acceleration	1600 as/s	1600 as/s
Slewing Dec:	SlewEnable	!SlewEnable
Velocity	1600 as/s	400 as/s
Accelerations	1600 as/s	1600 as/s

1.7 Implement flexible design to allow for future enhancements. List of possible upgrades:

Remote operations by the Telescope Operator may be desired in the future. This system should be flexible enough to allow modifications for remote operation, if necessary.

2. Computer Hardware Specifications

Equipment Rack - 19" Equipment Rack, 4 post open frame, 30"D x 80.1" H (43U), with wheels.3 fixed shelves, 3 sliding shelves. Include AC Power distribution.
Network Switch – Each rack contains a 12 port, 10/100 switch.
Computer System – Computer system will run the TCS3 software.

- 3 computers systems (Summit, summit spare, lab system).
- All computer system identical in configuration.
- 4 computer monitors (2 for summit, 2 for lab).
- Linux compatible hardware
- Can accommodate either PMAC or DMC 18x0 PCI motor controller.
- Computer configured for Dual Video
- Dual boot with Windows XP and Linux.
- UPS need for computer systems.

Servo Controller – Used on control the HA, Dec, and Dome axis.

- PCI format
- Position range: >1,296,000,000 counts
- Able to interface to T3 custom electronics
- 4 axis of control (HA, Dec, Dome will be targeted).
- Modes of motion: point-to-point, jog
- PID filter with feedforward capabilities.
- 16-bit DAC output
- Inputs from increment encoders and rate tachometers for each axis
- Limit switch inputs.

Lab Motor- A Lab Motor setup is needed to test motor control hardware and software in the lab.

- 2 units (axis) are required to allow testing for HA, and Dec control.

- 2 motors per unit (axis) to mimic the IRTF opposing torque (anti-backlash) design.
- Torque/Current Control servo amplifiers.
- Motor RPM spec: 1200 as/s * 144/1296000 as/rev = 0.13 rps
- Motor-axis spec: 144:1 gear ratio or 9000 arcsec/rev (same as IRTF)
- Increment encoder resolution: 100 counts/arc sec at the load output shaft.
- Design should accommodate up to 40 lbs on axis to provide inertia.
- Implement an adjustable inertia feature; ideally mimic the torque/weight ratio of IRTF.
- Implement an adjustable spring constant mechanism.
- Implement an adjustable friction drag mechanism.
- Provide slew, stop, brake limits switch (Dry contact).

3. T3 Electronics Specifications

- The voltage output to the power amplifiers is removed for the DEC, HA, Dome axis when an emergency or brake lockout condition is active.
- Emergency or brake lockout condition can be overridden via a key switch from the TO panel.
- An emergency condition is defined as follows:
    - Brake limit switch is tripped.
    - Amplifier overload monitor output is active.
    - Emergency stop button is tripped.
    - Facility I/O emergency output is active.
    - Watchdog timer that monitors the TCS computer times out.
    - 1800 as/s over speed condition originating from the motor tachometer.
- A brake lockout condition is defined as follows:
    - Lockout output from the TCS computer.
    - Key switch is in the lockout position.
    - Error output originating from the motor controller card.
- Control of the 115V brake relay is based on the emergency and brake lockout condition.
- The 115V brake relay is enabled via the brake reset switch located on the TO panel.
- The LED indicators present on the TO panel are as follows:
    - Brake On
    - Emergency
    - North Slew
    - North Stop
    - South Slew
    - South Stop
    - East Slew
    - East Stop
    - West Slew
    - West Stop

- Zenith
- Lockout
- Standard
- Horizon Slew
- Horizon Stop

4. Encoders Requirements

Absolute position resolution:	6.0 arcsec.
Incremental position resolution:	0.05 arcsec.
Maximum slew rate:	2000 arcsec/sec on sky
Maximum slew acceleration:	2000 arcsec/sec^2
Environment:	-10 to 50 deg C.
Humidity:	20%-100% Relative Humidity.

Scientific driver require ±0.1 arcsec pointing and tracking accuracy.

The Absolute encoders are needed to define initial position and place a reference star within the field of view of the guide camera (~60 arcsec). Also they are used to calibrate the incremental encoder ratio, is increased accuracy is desired. The project goal is 3.0 arcseconds.

The incremental encoder on the main shaft (bullgear) is the position sensor. We require 0.1 arcseconds position resolution. (10 counts/arcseconds.) The general rule for servo system is that your position sensor should be 5 to 10 times your position specification. The project goal 0.02 arcseconds or 50 counts/arcsecond. (5x position resolution)

The motor tachometer is the velocity sensor. For 0.1 arsec/sec velocity control we require (0.1 as / 2) or 0.05 arcseconds/sec velocity sensor.

2000 as/s = 0.009696 rad/s, the tach generate 16.755161 volts.
Divide by 3.351032 will map +- 2000 as/s to +-5.0 volts.
+- 5 v @ 16bits ADC providesh 0.000153 volts steps
Therefore, tachometer velocity resolution is 2.96e-7 rad/s or 0.061035 as/s.
.

5.1 MCC Replacement

Provide 2 LCD display for TCS control and display. Referred to as Display1 and Display2.
Provide 1 Hardware Panel (referred to as the TO Panel) for TCS control and display.
There devices are to be duplicated at the Hilo lab configuration.

Display1/2 and TO Panel will be in continuous development over the course of the lab development phase. These requirements give the project an initial prototype target. Staff input will allow the displays to evolve through development.

Refreshed GUI at 10 Hz.

5.1.1 Display1 Requirements

Show sidereal time, UTC and Local Time
Show RA, DEC and HA in Target, Mean, Increment Encoder Unit, and Abs Encoder Units.
Show stop/slew/brake limits; zenith indicator; horizontal limits; Emergency indicator; lockout indicator.
Provide shutter control widgets.
Provide Dome control widgets.
Indicated T3 ServoMode with performance data.
Provide various warning indicators.
Provide widgets for Mirror Cover control
Provide widgets for Mirror Support control.
Provide widgets for HA, Dec brake control.
Provide warning indicator.

5.1.2 Display2 Requirements

Display HA motor currents (E, W), and differential current for each axis.
Display Dec motor currents (N, S), and differential current for each axis.
Display Dome motor current (3 motors).
Provide widget to enable/disable dome CW control.
Provide widget to control and view position of the dome counterweight (10 items).
Be able to save a counter weight configuration.
Be able to restore a saved counter weight configuration.
Provide a spare IO window to allow daycrew to view unassigned IO values until new item are integrated into the GUI.

5.1.3 TO Panel Requirements

Form Factor approx 14W x 15H x 8D.
30 ft. cable from T3 Electronic rack.
Provides direct hardware control directly to T3 Electronics
Computer Control (ON=computer doing servo, OFF=brake lock condition).
Limit Override (ON=ignore limits; OFF=use limit inputs)
Emergency Stop (Push to Enable Emergency)
Emergency Reset (To Display emergency)
Telescope Brake Control (Switch + Enable button; LED to indicate ON).
LED to indicate Slew, Stop, Brake Limit for N, S, E, W. (3 x 4 = 12 inputs)
LED to indicate Zenith

LED to indicate Horizon Limit (2 TCS inputs)
LED to indicate Emergency condition on Safety Circuit
LED to indicated BrakeLockOut condition on Safety Circuit

6. Facility IO Requirements

The bulk of the IO signal coming into the current MCC will be replaced with an off-the-shelf IO hardware. The facility IO is intended for non-realtime IO. The following general requirements are established.

- 10 Hz update rates
- Additional IO can be easily added.
- Widely used in Industrial Automation
- Wide variety of the IO options.
- Ethernet based interface

7. Software Requirements

- Maintain position table. Data item for position table to evolve per TO and scientific staff input. Basic information includes:
    - RA, Dec base position in Time, Degrees
    - RA, Dec rate in as/s
    - 2 user offset (beam, user) in as/s. Total offset limited to 600 as/s.
    - scan offset to include RA, Dec offset, and desired rate(as/s)
- Calculate Target (RA, Dec) to mount (HA, Dec) coordinates at minimum rate of 10 Hz.
- Monitor and set Facility IO hardware at a minimum rate of 10 Hz.
- Pointing Correction
    - Develop procedure to collect pointing data for TPOINT utility.
    - Apply TPOINT pointing corrections for equatorial mount.
    - Allow user modification of TPOINT IH and ID coefficients in real-time.
    - Suggested, but not required: Nightly adjustments to CH coefficients.
- Provide network based communication for instrumentation and guiders using TCP/IP.
- Provide source code for visitor instrumentations that allow socket communication to TCS. Visitor computer must support the Berkley socket API (All UNIX-like systems, and windows after Win98 support this API).
- Develop GUI to display similar data item provide by TCS1 MCC. Data item and format to evolve per TO and staff input.
- Develop Remote observation GUI for remove observers similar to tcs1_status.
- Develop a TO GUI interface.
- Allow any GUI to be remotely exported using the internet.
- TCS mode for servo should include: tracking, slewing, direct motor position, and Jog.
- Diagnostics and Utilities
    - Procedure to calculate Encoder Rations.

- Safety Related
    - Trigger Safety Circuit Watch Dog Timer at 10 Hz.
    - Monitor ABS vs INC. Enable BrakeLock on ABS-INC > 2 deg.
    - Monitor Speed. Enable BrakeLock on speed > 25000 as/s.
    - Enable BrakeLock for ServoPosExceedLimit (Commanded vs Encoder position) > 2 deg.
    - Software HA and Dec Limits are default to SLEW Limits, but can be adjust up to STOP Limit. Software limits can be disabled by tcs3 command.

Appendix A – Science Drivers

1) Dark Clouds

Studying embedded sources in dark clouds is an important topic of research in the field of star formation and evolution. Spectroscopy is becoming increasing important for these objects because spectral line analysis provides a detailed understanding of the processes and physics involved in forming stars and planetary systems. Typically, many embedded sources are not detectable except in the infrared, so visible light, telescope acquisition cameras are not useful in properly positioning the source onto the science instrument. In order to position a source onto a spectrometer slit, the telescope has to offset from a bright, nearby offset star. Once the object is centered on the slit, it must remain centered during the duration of the integration time. To get a good estimate of the sky flux and to help in calibrating the data, the telescope is usually nodded in the direction of the slit length so the object appears at two different positions on the slit. Finally, a source can be mapped by stepping the slit across the source by 1 slit width and/or 1 slit length, thus creating a 3 dimensional data cube. Clouds are typically about 10 arcminutes in size, slit widths and lengths are about 0.5 and 60 arcseconds, respectively, and integration times are up to about 600 seconds.

Therefore, the telescope must: 1) offset to ±0.1 arcsec p-p over a distance of 600 arcsec (source acquisition), 2) offset to ±0.1 arcsec p-p over 60 arcsec (mapping), 3) nod in the slit length direction to ±0.1 arcsec p-p over 60 arcsec, 4) offset to ±0.1 over 1 arcsec, and 5) track to ±0.1 arcsec p-p over a 600 sec interval.

2) Astrometry of Isolated Sources in Dark Regions

Understanding the morphology and position of a source can involve accurate astrometry. The positional center of an object, particularly objects in highly obscured regions like star formation regions and nuclei of galaxies, will spatially shift as a function of wavelength. The typical method for determining positions is to offset from an infrared-bright, nearby, fiducially centered star to the object of interest then back to a star, This offset procedure can be repeated many times and with a set of stars to get positions to about ±0.1 arcsec.

Therefore, the telescope must: 1) offset to ±1 arcsec p-p over 3600 arcsec, and 2) track to ±0.3 arcsec p-p over 60 sec.

3) Planetary Objects

Observing planetary objects is the prime mission objective for the IRTF. These objects move at time-variable, nonsidereal rates. Typically an observation requires offsetting from one planetary object to another (e.g. between moons).

Therefore, the telescope must 1) offset to ±0.1 arcsec p-p over 600 arcsec, 2) track to ±0.1 arcsec p-p over 600 sec at time variable, nonsidereal rates up to 40 arcsec/sec maximum, and 3) use ephemeris tables to calculate the instantaneous position of the target and the proper tracking rates.

4) Occultation Studies

Occultation studies are an important observing technique for obtaining high spatial resolution information of objects like planetary ring systems and atmospheres. Having a precise and accurate time standard is paramount.

Therefore, the control system must provide a GPS time standard to the observer.

Appendix B – TCS2 specification (Dated 9/7/90). This information obtained from Ev Irwin in the 8/2003 TCS3 Conceptual Design Review.

1.2 SYSTEM SPECIFICATION (summary of present specifications) 9/7/90

1.2.1 Sky Coverage
-56 degrees 45 sec to +67 degrees in declination
5 hours 0 minutes East or West in hour angle

1.2.2 Pointing Accuracy
Point to an object up to 10 degrees from a known object to ±2 arc sec (within a cone of 60 degrees from zenith) under computer control.
Point to an object up to 10 degrees from a known object to ±10 arc sec under manual control.

1.2.3 Tracking
± 2 arc sec per hour under computer control.
short term RMS error of ±0.1.(Within a cone of 60 degrees from zenith)

1.2.4 Repeatability
Return to previously acquired object within:
±2 arc sec after 24 hours under computer control.
±5 arc sec after 24 hours under manual control

1.2.5 Offsetting
Accuracy of less than or equal to 1 arc sec for offsets less than 1 degree.

1.2.6 Scanning
For a 10 arcsec move: Total Time= 1 sec, Damping Time= 0.5 sec
For a 2 arcmin move: Total Time= 2.5 sec, Damping Time= 0.5 sec

1.2.7 Chopping Secondary
collimation, focusing, space chopping
direction: ± 90degrees from the N-S direction
amplitude: 0 to 6 arc minutes
frequency: 0 to 40Hz
waveform: trapezoidal w/variable rise time
performance:

1.2.8 Computer Control
Display HA and dec
Calculate and display RA and air mass
Display dome position, shutter position, focus position, current track & guide rates
Display sidereal time, UT and HST
Correct telescope pointing and tracking for atmospheric refraction at a set wavelength and for telescope flexure
Control of dome and shutter(?)

1.2.9 Manual Control
a manual analog drive and control system
dome and shutter control
slewing, guiding and tracking at variable rates
display of RA and declination

1.2.10 Automatic Mode
correction for precession, nutation, and aberration for current epoch
scanning patterns
blind offsetting

Appendix C – Telescope Information

1. Telescope Travel Limits

	Slew	Stop	Brake
South (deg:mm)	-53:05	-56:35	-59:19
North (deg:mm)	62:07	66:54	69:19
East (hr:mm)	-05:26	-05.37	-05:57
West (hr:mm)	05:27	+05:57	unknown

Ref: http://irtfweb.ifa.hawaii.edu/irtf/tcs3/history/0309/030905_koenig_tcs_limits_email.txt

Note DayCrew routine operation outside the limits
Dec-South require positioning at -59:59 for top-end access.

HorSlew Limit about 70.75 deg; HorStop limit is about 77 deg.

2. Acceleration and Velocity

Tracking

	HA	Dec
Max Velocity	449 as/s	518 as/s
Max Acceleration	1280 as/s*s	1722 as/s*s

Ref: http://irtfweb.ifa.hawaii.edu/irtf/tcs3/history/0312/Testdata2

Slew Enable = ON

	HA	Dec
Max Velocity	1820 as/s	2026 as/s
Max Acceleration	1530 as/s*s	1771 as/s*s

Ref: http://irtfweb.ifa.hawaii.edu/irtf/tcs3/history/0312/Testdata1
Tests by Lars indicates HA 2025 as/a, Dec 1620 as/s (see history/0309)

Slew Enable = OFF

	HA	Dec
Max Velocity	Est. 484 as/s	Est. 415 as/s
Max Acceleration	N/A	N/A

Ref: http://irtfweb.ifa.hawaii.edu/irtf/tcs3/history/0401

TAC Information:

INLAND TG-5714C DC Tachometer
Voltage output: 12 volts per radian/sec
Max Speed 3.6 radians/sec

Max terminal volts: 43.2 volts
Armature resistance: 325
Inductance: 1 milihenry
Operation above 10 milivolt output.

Volts2Radians is (5.0 / 12.0 / 144.0) = 0.0028935
Radians2Volts is (144.0 * 12.0 / 5.0) = 345.6
V = R * 345.6

144:1 gear ratio * 12 volts / rad/sec / 5.0 voltage divider circuit)

3. Wind Buffering – Operational guidelines for the summit is to close the dome with wind speed is > 45mph. Personnel evacuate the facility at wind speed > 65 mph.

4. DOME Operations –

Mapping of barcode value to azimuth:

Dir	Azimuth	Barcode
N	0	342
E	90	1696
S	180	1243

Notes:

- Barcode provides 0.2 deg of resolution. Original gray code only has about 0.7 deg of resolution.
- A D/A controls the speed.
- A joystick is using for manual position.
- Current TCS check a adjust position every 100 sec. (keep within 2 degrees).
- Dome brakes exist, must be disable/enable after every move.
- The slit vignettes at roughly 3 deg from zenith.
- Speed about 1.5 deg per seconds. (60 sec. for 90 deg. of travel).

Description of TCS1 Dome Operations:

```
Date: Tue, 18 May 2004 13:17:18 -1000 (HST)
From: George Koenig <koenig@duke.ifa.hawaii.edu>
To: Tony Denault <denault@jeans.ifa.hawaii.edu>
Cc: George Koenig <koenig@jeans.ifa.hawaii.edu>
Subject: Re: dome speed

Hi Tony,
The dome drive presently has 4 modes of operation.
  Auto-mode uses the computer interface to drive it via a d/a chip.
I don't readly find any reference to how the computer software is setup
so you'll probably need to talk to Jim about that.  I'm pretty sure he
does a ramp up / ramp down.  As far as the speed, Fred may be able to
tell from the miller intergrator on the schematic.  Actual speed is
dependant on the state of the dome alignment and the tachometer settings
on the power amps.
  Manual-mode has 3 sub modes.
```

```
Joystick, sliding potentiomoter, and handpaddle pushbuttons using a
fixed resistance rate. As was talked about in the past, we need to
maintain some form of remote control to use a handpaddle from the
mezzaninne for servicing the dome and crane operations.
  We have also incorporated a lockout to disable the 3 dome power amps so
when the heat trace cables are connected the dome drive is inoperative.
This lockout would also need to be included with the new TCS and I think
Fred had an idea for it.
  The electronic schematic would be on dwg. #710-254
thanks,
-george
```


```
George Koenig  ~  Observatory Superintendent  ~  NASA Infrared Telescope
Institute for Astronomy  ~  640 N. A'ohoku Pl. Rm.209  ~  Hilo, HI 96720
              808-974-4209  ~  koenig@irtf.ifa.hawaii.edu
```

Document Sign Off

The requirement specifications contained in this document have been reviewed and agreed upon.

Tony Denault, T3 Project Manager ______________________________

Alan Tokunaga, IRTF Division Chief ______________________________

Peter Onaka, IRTF Chief Engineer ______________________________

George Koenig, IRTF Superintendent ______________________________