GNIRS PRE-FABRICATION REVIEW
May 11-12, 2000

Presentation Preliminary Draft
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GNIRS Pre-Fabrication Review

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GNIRS Pre-Fabrication Review

Section I

Introduction and Overview
GNIRS Staff

- Project management
  - N. Gaughan, PM
  - D. Eklund, PA
  - M. Bowersock, AA
- Project scientist(s)
  - J. Elias, PS
  - D. Joyce, PSS
  - B. Gregory, PSS
- Electrical - J. Penegor, Sr. EE
- SW – R. Wolff, Sr. Prog
- Mechanical
  - G. Muller, Sr. ME
  - E. Hileman, Sr. ME
  - L. Goble, Sr. ME
- Design Drafting
  - J. Andrew, Sr. TA
  - D. Rosin, DT
  - E. Downey, DT
  - R. Robles, DT
- Procurement – A. Davis, TA
- IM – J. Stein, Sr. IM
Introduction

• Welcome
• Orientation
• Agenda
• Staff introductions
  – Reviewers, visitors
  – GNIRS Project
    • PM, PS, ME, EE, SW, DT, Proc, IM
• Overview of the presentation
Overview of the presentation

• We will start with the current status of the project including an overview of the project schedule, summaries of the bench design and prototyping efforts, and progress on mechanism design and software.
• The risk reduction effort is being conducted to prove the design approaches of our two types of mechanism drives, and camera lens mounting.
• Optical bench design will discuss the solid models of the three main components of the bench: Pre-Slit, Post-Slit, and OIWFS.
• Both thermal and structural analysis of these solid models are in process. We will present preliminary results of these analyses.
• The software section will cover the software plan and software development in general.
• The management section will discuss the project schedule in detail, progress, costs, and procurement.
Overview of the Presentation

- Current status of the project
- Project overview
- Risk Reduction effort
- Optical bench design and analysis
- Software
- Management
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Review Purpose

• Assess if optical bench design will meet deflection requirement
• Review risk reduction results and assess how these results couple into the actual design
• Review scope of software effort and assess if it will meet project requirements
# Agenda

**May 11:**

<table>
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<th>Time</th>
<th>Subject</th>
<th>Presenter</th>
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<td>0830</td>
<td>Introduction, opening statements</td>
<td>Sidney/Neil</td>
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<td>0900</td>
<td>Technical presentation</td>
<td>Jay</td>
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<td>introduction and overview</td>
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<td>0940</td>
<td>Break</td>
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<td>1000</td>
<td>Requirements overview</td>
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<td>Risk Reduction overview</td>
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<td>1045</td>
<td>Bench Design</td>
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<td>- Detail description</td>
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<td>- Analysis</td>
<td>Ed/Gary</td>
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<td>- Fab issues</td>
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<td>1200</td>
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<td>1300</td>
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Agenda

• Order of presentations
• Breaks
• Lunch plans
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Orientation and Overview

• Wall charts and posters
• Work stations
  – Demos of solid models of benches and other components
  – Manned during breaks
• Progress overview
  – Project plan
  – Status
  – Projections
Project Status

• Systems engineering
  – Prototyping of mechanism drives
    • Rotary drive
    • Linear drive
    • Optical mount prototype
  – Cold motor testing
  – IFU ICD
  – Bench 3D solid model design
  – Designs are for analysis (not production)
  – 3 separate benches involved

• Bench analysis
  – Structural analysis
  – Thermal analysis
Project Status

• Software
  – Software Plan
  – Component controller

• Overall project
Project Plan Components and Phases

• Systems Engineering effort
  – Prototyping
  – Structural and thermal analysis
• Bench Design design and fab
  – Pre-slit bench
  – Post-slit bench
  – OIWFS bench
• Mechanism design and fab
• Fixed Assemblies design and fab
• Electronics design and fab
• Software design, code and test/debug
• Integration and test
Project Plan
GNIRS Pre-Fabrication Review

Section II
Configuration Overview
Overview

- Critical Requirements
- Configuration Overview
- Risk Reduction
Critical Requirements Identified

• Gravity deflection - 3 requirements (from RR review and before) list - 2 affect bench
  – OIWFS maintains object on slit (12 microns (0.02 arcsec) motion in 1 hour)
  – Spectrum (slit image) doesn’t move on detector (0.1 pixel=2.7 microns in hour)
  – Secondary image motion at cold stop +/-1% overall (less stringent but involves interface to warm structure and to ISS)

• Thermal performance
  – Cool-down time (Maximum 4 days)
  – Temperature gradients (preservation on alignment, several degrees OK)
  – Temperature variations (limit flexure, defocus - need <1 K)

• Mechanism performance
  – Repeatability (10 pixels for reconfigurations, 0.1 pixels for acquisition)
  – Flexure (0.1 pixel pixel, includes mechanism “play”)
  – Thermal (cooling time constant, heating from motor/drive)

• Opto-mechanical performance
  – Lens cooling
  – Lens positioning (stability under thermal cycling within tolerances)
  – Lens stresses (500 psi or less)
Critical Requirements Identified

• Gravity Deflection
• Thermal Performance
• Mechanism Performance
• Opto-mechanical performance
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Risk Reduction - Overview

• What are the risks?
• How did we address them?
## Risk Mitigation Table

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<th>Item</th>
<th>Areas of Concern</th>
<th>Impact</th>
<th>7/99 Risk Level</th>
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<th>Mitigation Plan</th>
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<td>- Long Cool Down Time</td>
<td>LOW</td>
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<td>Central Positioning of Cryocoolers</td>
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<td>LN2 Precool</td>
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<td>Active Thermal Bench Control</td>
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<td>Reduced Cold Mass</td>
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<td>- Temperature Gradients</td>
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<td>Central Positioning of Cryocoolers</td>
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<td></td>
<td>and Stability</td>
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<td>Active Radiation Shield</td>
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<td>Minimize Bolted Joints</td>
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<td>Ability to Cold Strap Cryomotors</td>
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<td>- Optical Alignment</td>
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<td>Cleaner Optical Design (fewer folds)</td>
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<td>Modular Mechanisms</td>
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<td>Sub-system Alignment outside GNIRS</td>
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<td>Simplified Alignment Procedure</td>
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<td>- Diamond Turned Mirrors</td>
<td>MEDIUM</td>
<td>LOW</td>
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<td>Now only 3 Diamond Turned Mirrors</td>
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<td>Glass Substrate or Replica Flat Mirrors</td>
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<td>Radiation Shield Gaps</td>
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<td>Internal Motors (no feedthroughs)</td>
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<td>Spectrograph Completely Enclosed by Bench Structure</td>
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<td>Handling</td>
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<td>Instrument Conforms to Gemini Interfaces</td>
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<td>OWFS</td>
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<td>Now Essentially Independent Module</td>
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<td>Use IfA Layout (except 2 fold mirrors)</td>
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<td>Operational Alternatives with PWFS</td>
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<td>NRII tests show no major problems</td>
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<td>ICD Nearing Completion</td>
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<td>Assembly</td>
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<td>LOW</td>
<td>Repackaged as Self-Contained Units, Install in Slit Mechanism</td>
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<td>Performance</td>
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<td>Only IFU Operation Affected/Risk should change after IFU CDR</td>
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<td>Cold Test of Critical Functions on Prototype</td>
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<td></td>
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<td>(cooldown, torque, repeatability, absolute positioning, flexure)</td>
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<td>Cold Test Completed Mechanism</td>
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<td>Instrument Can be Tested Without Gemini Software</td>
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Risk Reduction Plan

• Systems Engineering: Systems approach used to identify areas of risk (some help from review committees!) and isolate specific issues.
• Prototypes vs. analysis: Identify those issues where analysis provides good answers as opposed to those where prototyping is better. Example: use FEA for rigid structures (bench), but need prototypes to model situations where contact properties dominate effects (turrets).
• Test Plans and Procedures: Prototype work designed to answer specific questions, need focussed test plan to ensure that questions are thoroughly investigated, avoid wasted effort.
• Results Applied to Design: Experience with prototypes may show that a design works “as is”. May also suggest design improvements, but these are implemented only if the design would not meet requirements otherwise or redesign leads to faster schedule or lower cost.
• Prototype does not need rework to meet requirements if design change to meet requirements involves minimal risk.
Risk Reduction Plan

• Systems Engineering
• Prototypes vs. Analysis
• Test Plan and Procedures
• Results Applied to Design
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Risk Reduction Plan

5 Areas Involved
• Flexure Analysis
• Thermal Analysis
• Mechanical Prototypes
• Systems Approach to Design
• Early Procurement
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Optical Bench Design

Agenda

• Design Overview
• Pre-Slit Bench Assembly
• Post-Slit Bench Assembly
• OIWFS Bench Assembly
• Fabrication Issues
• Example of systems approach to design
Bench Configuration Overview

• Bench structure comprises
  – Pre-slit bench (pick-off mirror to and including slit/IFU)
  – Post-slit bench (from slit to detector)
  – OIWFS bench (field lens to OIWFS detector)

• Mechanisms/optical assemblies
  – Offner relay (includes pick-off mirror)
  – Filter wheels
  – Slit/IFU slide and Decker assembly
  – Collimator
  – Acquisition mirror
  – Prism turret
  – Grating turret
  – Camera turret
  – Long camera external fold mirrors
  – Detector mount/focus stage
Pre-Fab Review

Configuration Overview

Red ray: Spectrograph
Blue ray: On Instrument Wave Front Sensor
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Configuration Overview

Red ray: Spectrograph
Blue ray: On Instrument Wave Front Sensor
Exploded view of bench structure

- All bench structure machined from single billet.
- Bench structure designed for ease of fabrication.
- Machining techniques considered during design process.
  - Pocket depth to tool diameter ratios, radiused pockets, etc
- Stiffness obtained when components are fastened together.
Exploded view of bench structure

- Wavefront Sensor Bench
- Collimator Cover
- Top Bench Hogout
- Bottom Bench Hogout
- Bottom Camera Cover
- Long Camera Fold Mirror Housing
- Top Camera Cover
- Pre-slit Bench Rear Housing
- Pre-slit Bench Front Housing
- Offner Assembly
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Bench Design Drivers

• Stiffness
  – Minimize deflections

• Weight
  – Goal: Minimize weight of cold bench for minimal cool-down cycle
  – Weight budget

• Envelope
  – Fit within Gemini instrument envelope

• Mechanism access
  – Modular mechanisms for ease of installation/removal
  – Mechanisms accessible without disassembly of bench

• Motor access
  – Cold strapping, wiring
  – External to light tight bench

• Fabrication
  – Use proven technologies, minimize risk, optimize schedule

• Minimize bolted joints
  – Optimal thermal conductivity, control tolerances, homogeneous structure
## GNIRS Weight Budget

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<th>Pre-Fab Review May, 2000</th>
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<td>GNIRS Final Assy</td>
<td>2000 Kg</td>
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<td>Optical Bench (Cold)</td>
<td>700 Kg</td>
<td>698 Kg</td>
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<tr>
<td>Pre-slit Bench</td>
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<td>204 Kg</td>
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<tr>
<td>Post-Slit Bench</td>
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<td>412 Kg</td>
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<tr>
<td>OIWFS Bench</td>
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<td>82 Kg</td>
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Bench Design Philosophy

• Use 3D ray traces to drive mechanism/optics locations.
• Design bench structure/interfaces around mechanisms/optics.
• Put structure where the load path is.
• Use best engineering judgement to optimize bench design prior to analysis.
  – Minimize number of iterations during analysis.
Mechanism Interface Design Philosophy

- Control interfaces using parametric design.
  - Example: Using tool bodies

- Support axles of rotary mechanisms at both ends for maximum stiffness.

- Use dowel pins or locating surfaces for repeatable installation of mechanisms.

- Use captive screws to fasten mechanisms to bench.

- Use threaded inserts on all bench to mechanism interfaces.
Using parametric tool bodies

• A tool body is a positive shape that gets Boolean subtracted from another shape to produce a negative of that shape.

• Parametric: Change the dimensions on the tool body and all instances of that tool body will update.

• Effective method of controlling interface accuracy between mechanisms and bench.
Using parametric tool bodies

- Mechanism
- Tool body
- Bench structure
- Boolean subtract tool body from bench
- Mechanism interfaces properly with bench
Pre-Slit Bench Assembly

- Pick off mirror
- Offner relay
- Filter wheel
- Decker slide
- Slit & IFU slide
Pre-Fab Review

Pre-Slit Bench Assembly
Pre-Slit Bench Assembly

- Fore-optics mirror access through covers.
- Filter access achieved by removing filter wheel assembly.
- Slit module and IFU module access achieved by driving slit slide to access port and removing covers.
- Decker slide has no serviceable parts.
Pre-Slit Bench Assembly

Design Features

- Component accessibility without disassembly
  - Fore optics Mirrors
  - Filter wheel
  - Slit module
  - IFU modules

- Drive motors mounted externally
  - External to light tight bench

- Modular design
  - Removable as an assembly
Post-Slit Bench Assembly

- Collimator mirror: Mount is integral part of post-slit bench
- Acquisition mirror: Mounts from bottom of post-slit bench
- Prism turret: Mounts to bottom of post-slit bench
- Grating turret: Mounts to side of post-slit bench
- Camera turret: Post-slit bench is support housing
- Long camera fold mirror housing
- Detector/focus mechanism: Mounts to side of post-slit bench
Post-Slit Bench Assembly
Post-Slit Bench Assembly

• Remove covers to access components
Post-Slit Bench Assembly

Design Features

• Component accessibility without disassembly
  – Collimator mirror
  – Acquisition mirror
  – Prism turret
  – Grating turret
  – Camera turret
  – Detector
  – Camera fold mirrors

• Drive motors mounted externally
  – External to light tight bench

• Good thermal conductivity by minimizing bolted joints
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OIWFS Bench Assembly

• Wave front sensor bench hog out and field lens support tube
• Modular: Bolt in IFA hardware and align separately
• OIWFS bolts to post-slit bench only
• Field lens support tube clamped to post-slit bench
• No mechanical connections to pre-slit bench
• Labyrinth light seal between field lens support tube and pre-slit bench
OIWFS Bench Assembly

Design Features

• Modular design
  – Align wave front sensor independently of spectrograph
• Mechanically interfaces with post-slit bench only
• Use IFA components
  – Field lens
  – Combo lens mount
  – Gimbal mirror
  – Filter wheel
  – Detector/focus mechanism
• Interfaces to IFA supplied components are according to ICD
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Fabrication Issues (1)

Design Considerations/Conclusions

• Investigated Castings, Hog-outs, Weldments
• Rejected Castings
  – CTE mismatches between cast and machined components
• Rejected Weldments
  – Requires many welding fixtures
  – Warping issues
• Selected Hog-outs
  – Uniform CTE’s
  – Utilize CNC machining techniques
  – Less fixturing, more expeditious
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Fabrication Issues (2)

Minimize fabrication risks

• CNC machine and stress relieve critical components.
  – Reliable, known, technology has been used extensively at NOAO.
  – Use uphill quench technique
  – Tool paths defined by 2D drawing or 3D solid models.

• Fabricate all critical parts from a single billet.
  – Ensure material uniformity

• Vendor qualification.
Machine critical structure from one billet

• Rough machine, stress relieve and anodize, final machine
• Orient critical components in same direction on billet for uniformity
• Witness samples taken on both ends of billet to verify uniformity of billet
Machine critical structure from one billet

- Material: 6061-T6 Aluminum
- Largest component duplicated in layout for contingencies
- CTE measurements on witness samples
  - Characterize CTE in 3 axes at 2 locations
- Material has been purchased
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Procurement

• 1 FTE assigned to procurement
• Purchasing parts
• Tracking parts through fabrication
• Inventory control
• Vendor qualification
• Inspection
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Systems approach to design
3:1 Drive Motor Module

Requirements
• Standardize on one motor
• Common electrical connections
• Motors to be thermally isolated
• All motors to be light sealed from bench
• Common interface with mechanisms/bench
• Ease of installation, alignment, removal
3:1 Drive Motor Module

Used on:

• Decker slide
• Slit slide
• Prism turret
• Grating turret
• Camera turret
• Detector focus drive
3:1 Drive Motor Module

- Modular Design
  - remove complete assy if motor fails
- Easy to remove & install
  - captive screws, locates on mechanism shaft
- Light tight design
  - labyrinth feed through shaft
  - stepped seal around housing
- Motor thermally isolated
  - G10 standoffs
  - thermal resistance through gear teeth
  - motor strapped to thermal bus
- Use on 6 mechanisms
- 3:1 Spur gear reduction
  - Initial reduction to mechanisms
Cold Bench Assembly Rigidity Requirements:

- Image de-center at detector due to flexure between slit and detector to be < 2.7 micron (0.000107") during 1 hour.

- Differential flexure between OIWFS and spectograph slit shall not cause image decenter at slit > than 12 micron (0.000472") in 1 hour.
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Analysis Tools

- MSC Nastran Finite Element Analysis to determine structural deformation under gravity loads.

- ZEMAX Optical Analysis package for structural to optical influence matrix.

- MathCad document synthesizing results of the two.
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FEA methodology

• For expediency, use tetrahedral meshing from imported solids created in mechanical desktop.
  – Ran test cases to determine accuracy of tetrahedral mesh vs. mesh of plate elements.
  – Compare model sizes, estimate solve time.

• Merge nodes at bolted interface surfaces.
  – Ensure design incorporates sufficient fasteners.
Tetrahedral mesh vs. plate mesh performance

- Comparison of 12”x12”x1/4” and 18”x6”x1/4” aluminum plates with 1/4” element size.

- Transversely loaded plate: deflection agrees within 1% between models and with theoretical solution. DOF = 149,284 for tetrahedral, DOF = 25,091 for plate

- Shear deformed plate: deflection agrees within 1%. 

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Pre-Fab Review

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FEA model of Cold Bench Assembly

- Constrained along three faces.
- Load cases are gravity in X, Y, Z directions.
- Model size: ______ nodes, ______ elements, ______ DOF.
- Solve time: ___ hours
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Bench Assembly Deformed Shape

- Load Case: -1 g in the Y direction.
- Plotted Scale multiplier = x1000
- Plotted Units: Inches
- .0001” = 2.54 microns
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Image De-center at Detector due to Unit Gravity Loading:

- 1 G in the $X$ direction = ______ microns.
- 1 G in the $Y$ direction = ______ microns.
- 1 G in the $Z$ direction = ______ microns.
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Thermal Analysis

• Passive Design Optimizes Thermal Performance
• Bench Thermal Control Provided
• Extensive Analysis Not Required
Thermal Design

[Facing Page]
The design minimizes impact of thermal requirements on structure.
• During cool-down, most of the heat is removed by the pre-cool system, which is routed so that thermal paths from the structure and mechanisms to the pre-cool attachment points are short (~50 cm or less).
• During operation (steady state), the design minimizes heat input into the bench and heat flow through the bench. Heat flow is through the active radiation shield (radiation loads) or through cold-strapping (motors, cold-stationing of wires). Dominant source of heat input into bench should be radiation through dewar window.
• Thermal control of bench allows bench temperature to be stable even with varying loads into cryo-coolers.
• Extensive analysis is not required since the design minimizes the heat input into the bench, so that gradients or variations in gradients will be very small.
Thermal Design

Design minimizes impact of thermal requirements on structure

- Cool-down time
- Temperature gradients
- Temperature stability
Thermal Analysis

Facing Page

Cool-down time <4 days is met by design, limited analysis needed to demonstrate this. Cold mass budget has been stable over past 10 months.

• Liquid nitrogen pre-cool system cools to approximately 80K; routing provides short thermal paths for structure; bench structure design thus constrained by flexure requirements only.
• 4 cryocooler heads provide cooling power to get from 80K to 60K rapidly.
• Bench temperature control allows rapid stabilization of bench temperature at nominal value, avoid long cooling “tail” common with cryocoolers.
Thermal Analysis

Cool-down time <4 days
• Liquid nitrogen pre-cool system
• 4 cryocooler heads
• Bench temperature control
Thermal Analysis

Facing Page

Gradients are limited by design, only limited analysis needed to demonstrate this. Note that requirement to limit *temperature gradient variations* is more stringent than limitations on either temperature stability or temperature gradients – see next item.

• Gradient along bench to collimator produces defocus of ~8 microns/K maximum; defocus due to 2% CTE variation (6061) may be 120 microns (i.e. equivalent to 15K gradient). Some warm to cold adjustment (shim adjustment) will probably be needed.

• Active shield decoupled from bench structure. Most heat inputs go into active shield (radiation, cold-station wires, bench supports), then to coolers, and bypass bench. Gradients in shield not a concern. Forward baffle tied to shield, not bench to minimize heat input into bench through window.

• Motors potentially major heat input (instantaneous power = radiation load), so are isolated from bench and coupled to cryocoolers. Requires motors be external to bench (radiation from motors an issue as well).
Thermal Analysis

Gradients negligible
• Active shield
• Motors decoupled from structure
Thermal Analysis

Facing Page
Temperature variations are limited by design, limited analysis needed to demonstrate this. Note that requirement to limit gradient variations is main concern.

• Variations in collimator temperature relative to bench produce defocus of ~8 microns/K of temperature change.
• Variations in temperature gradients across turret supports may produce tilts of several microrad/degree of temperature difference; may be less depending on geometry.
• Active shield decoupled from bench structure. Most heat inputs go into active shield (radiation, cold-station wires, bench supports), then to coolers, and bypass bench. Gradients in shield not a concern. Radiation inputs vary by ~40% so must minimize gradients they produce in the bench.
• Motors potentially major variable heat input (instantaneous power= radiation load, while average power very small), so are isolated from bench and coupled to cryocoolers. Requires motors be external to bench (radiation issues as well). Motors not tied to mechanism supports so these don’t become heat paths and develop gradients.
• Bench temperature control allows stabilization of bench temperature at nominal value, allows heat input from active shield into coolers to vary without pulling bench along.
Thermal Analysis

Thermal variations minimal
• Active shield
• Isolate motors
• Bench thermal control
Optics Risk Reduction

- Optics mount prototype (BK7 lens)
- Early procurement
- Acceptance testing
- Light leak/ baffling analysis
- Cross-check ray trace with bench design
Optics Mount Design

- Three axial seats (conic)
- Spring-loaded axial preload
- Two fixed, one compliant radial seat
  - Provide radial preload
  - Allow for differential thermal contraction of lens, mount
Optics Mount Requirements

• The camera elements must be held to tolerances of ~20 µm (axial), 20 µm (radial), and ZZ mrad in tilt. The radial and axial seats may be final machined after the optics are received and tested.

• CTE of 6061 Al lens mount is greater than that of lens, and it will cool first. As the lens cools, the radial preload must keep the lens against the seats.

• The optics must attain ~ 60 K within the four-day cooldown requirement

• Contact between the lens and its mount must minimize risk of damage to the lens resulting from physical stress or large thermal gradients
Optics Mount Requirements

• Secure optics in proper location
• Maintain location when cold
• Ensure timely cooling
• Minimize risk of damage
Prototype Test Plan

• A number of tests are initially done at room temperature
  – Assembly and fit check
  – Adjustment of preloads to design values
  – Measurement of friction, preload operation in different orientations with respect to gravity
  – Repeat tests after thorough cleaning of components

• Initial cooling tests to measure preload operation
  – Temperature sensors installed on lens
  – Observe fiducial marks on lens and mount for differential motion as lens is cooled

• Second tests to measure lens cooling
  – Lens covered to eliminate ambient IR radiation
  – 1 W heaters on mount & lens for measuring properties
Prototype Tests

• Ambient Temperature

• Cold Tests - 1
  – Positional repeatability

• Cold Tests - 2
  – Cooling time
  – Thermodynamic properties
  – Model thermal behavior
Ambient Temperature Tests

• Proper preload achieved using stock springs, tailored shims, adjustments (interchangable)

• Thorough cleaning of components resulted in dramatic increase in friction between lens and mount
  – Preload force insufficient to return lens against radial or axial seats after a small displacement
  – Apparent abrasion of Al mount by lens

• Results
  – Polish axial, radial seats to remove machining marks, burrs
  – Install Kapton tape on axial, radial seats to reduce friction
  – Friction now reduced so lens returns to initial position after small displacement, even against gravity
  – Continue to cold test phase
Ambient Tests

- Axial, radial spring forces
- Coefficient of friction before/after cleaning
- Restoring against displacements
- Kapton tape reduces friction at seats
Cold Tests (1)

• Different CTE of lens, mount results in differential motion during cooldown
• Measure relative positions of lens and mount over a thermal cycle
  – Optical fiducials on lens and mount
  – $T_{\text{LENS}} \sim 150$ K
• Measurements consistent with proper preload function
Cold Tests (2)

• $T_{\text{LENS}}$ vs time
  – Lens shielded from ambient radiation
  – Continuous evacuation of cryostat

• Heater tests
  – Thermodynamic properties at ~ 80 K

• Model calculations
  – Radiative coupling
  – Conduction (direct, sensor wires)
Prototype Test Conclusions

- Kapton tape on lens seats is required to reduce friction
- Differential motion of lens and mount during cooling is consistent with proper operation of radial preload
- When shielded from ambient radiation and conduction, lens cools to mount temperature in ~ 30 hours
  - Both radiative and conductive cooling are important
  - Kapton probably increases cooling time, but it is still acceptable
  - Similar mount scheme for prisms should yield acceptable cooling
- Risk of damage should be small
  - Overaggressive cooling can induce stress fracture (cooling plugs in prisms may pose a danger in this respect)
  - Kapton tape may act as thermal buffer
  - Anticipated cooling rate of GNIRS camera should not impose large thermal gradients in lenses
Prototype Test Conclusions

- Preloads function properly at low temperature
- Cooling of lens acceptable
- Cross-disperser elements
- Risk of damage minimal
Optics Procurement and Testing

• Optical elements can be long lead-time items. We have initiated procurement to permit delivery well ahead of needs, with significant allowance for contingency.
  – RMI (camera lenses)
  – II-VI (powered mirrors)
  – Spectronics (gratings)
  – Filters (NDC/IR Engineering)

• NOAO has skilled in-house opticians to ensure quality control of vendor products
  – In-process inspection of optical material at vendor site
  – Witness acceptance testing of optics at vendor site
  – Perform in-house inspection at NOAO prior to acceptance
Optics Procurement & Testing

• Early procurement of optics components
• In-process inspections of optics
• Acceptance testing
  – Vendor site
  – In-house
Baffling and Light Leaks

- Bench will be light-tight structure (excepting entrance aperture)
  - Step / labyrinth seals on cover plates and interface joints
  - Cryomotor feedthrough designed to be light-tight
- 3-dimensional design yields optics footprint throughout bench
  - Design baffles to fit footprint
  - Some optical analysis required for critical locations (Offner)
  - Investigate appropriate materials for baffles
- Some vignetting in cross-dispersed mode (short blue camera)
  - Occurs only at extremal wavelengths (short end of m=6 @ 0.95 \( \mu \text{m} \) [1.5%]; long end of m=3 @ 2.53 \( \mu \text{m} \) [0.5%])
  - Mitigating factors: higher blaze efficiency at 0.95 \( \mu \text{m} \) in 7th order; low transmission of SF57 cross-dispersion prism at 2.53 \( \mu \text{m} \)
Baffling & Light Leaks

- Labyrinth, angle seals at joints
- Motor interface
- Baffles at appropriate locations
- 3-d design provides optics footprint
Risk Reduction - Prototypes

• Cold Motor Testing
• Rotary Prototype Mechanism
• Linear Prototype Mechanism
• Optics Mount Prototype
Mechanism Risk Reduction

Cold Motors
• Identify suitable motor
• Specify operating parameters
Mechanism Risk Reduction

Facing Page
Cold Motors - Objectives and results
• Identify suitable motor. Phytron series 52 identified (same as NIRI). Examined API, smaller Phytron (series 42) motors, but these did not appear able to run for long periods at required speeds (600 rpm+)
• Specify operating parameters. Require that motors be operable continuously without control of cuty cycle. Motors cannot be run at full power at higher speeds for extended periods (minutes). Power must be limited to 10W or less for continuous operation, which limits torque available (roughly 7 oz-in at 600 rpm). Can run faster at lower torque, slower with higher torque. Implies mechanism drive torques <7 oz-in, ideally <3 oz-in.
Mechanism Risk Reduction

Rotary Prototype Mechanism

• Model for 3 turrets
• Addresses flexure (tilt most critical), drive performance, thermal performance
• Additional prototyping
Mechanism Risk Reduction

Rotary Prototype Objectives

• Repeatability
• Flexure
• Torque
• Cooling time
• Motor Heating
Mechanism Risk Reduction

Facing Page
Rotary Prototype Objectives
• Mechanism to be repeatable to 0.035 mrad (drive reduction set to make this 1/2 motor step)
• Mechanism flexure to be <1 microrad tilt under 1g. Displacements can be much larger, not an issue.
• Torque <7 oz-in, ideally <<7 oz-in due to motor properties
• Cooling time needs to be a few hours so mechanism will track bench
• Motor heating. Motor deliberately not isolated in order to compare heating effects with models.
**Mechanism Risk Reduction**

**Facing Page**
**Rotary Prototype Description**
- Rotating barrel similar in mass, size to prism and grating turrets
- 540:1 reduction same as that for prism and grating turrets
- Backlash allowed (expected)
- Temperature sensors, including one on barrel (won’t do this in GNIRS)
- 22-bit encoder on barrel
- Motor mounted directly on base-plate
- Provisions for manual operation (external feed-through on dewar)
- Tests in 2 orientations possible
Mechanism Risk Reduction

Rotary Prototype Results
• Repeatability 0.2 motor steps
• Flexure >10 microrad (more work)
• Torque <2 oz-in
• Cooling time
• Motor Heating
Mechanism Risk Reduction

Facing Page
Rotary Prototype Results
• Observed repeatability (measured at encoder) is ~0.2 motor steps rms (>2x better than requirements)
• Mechanism flexure is >10 microrad - *need further work* (discussed below).
• Torque <2 oz-in, well within requirements - may be able to run faster (900 rpm).
• Cooling time
• Motor heating. Temperature gradient across baseplate, compare with model prediction.
Mechanism Risk Reduction

Rotary Prototype Additional Work

• Flexure >10 microrad (more work)
• Prototype improved bearing/pre-load designs
Bearing Test Prototype #1

• Section view

• Timken tapered rollers against aluminum races.

• Preload flexure removes endplay and radial clearance.
Bearing Test Prototype #1

Rotary Prototype Bearing Prototype #1 Description

• Tapered roller bearings to maximize contact for thermal conduction, wear, deflection
• Spring-loaded with flexure to provide pre-load
• Bearing locations design to produce equal deflections (zero tilt) under gravity
• Aluminum races (contact surfaces) provide essentially athermal design; large contact area should minimize wear; rollers are chrome-plated steel
• Test flexure and torque
• *If performance satisfactory, stop here*
Bearing Test Prototype #2

- Section view

- Precision angular contact bearings on 440C races.

- Preload flexure removes endplay and radial clearance.
Bearing Test Prototype #2

Facing Page
Rotary Prototype Bearing Prototype #2 Description
• Stainless steel angular contact bearings to provide good performance in terms of wear, corrosion, repeatability.
• Spring-loaded with flexure to provide pre-load
• Bearing locations design to produce equal deflections (zero tilt) under gravity
• Bearing interface uses Invar plug, flexures to match average contraction of bearing seat and shaft to bearing
• Test flexure and torque
Mechanism Risk Reduction

Linear Prototype Mechanism

• Model for Slit/IFU slide
• Addresses flexure (displacements most critical), drive performance, thermal performance
Mechanism Risk Reduction

Linear Prototype Objectives

• Repeatability
• Flexure
• Torque
• Cooling time
• Motor Heating
Mechanism Risk Reduction

Facing Page
Linear Prototype Objectives
• Mechanism to be repeatable to 1 micron in direction of motion (drive reduction set to make this 1/2 motor step)
• Mechanism flexure to be <4 microns in direction of motion under 1 g. Tilts must keep displacements at different slit locations under this value - typically <1 mrad.
• Torque <7 oz-in, ideally <<7 oz-in due to motor properties
• Cooling time needs to be a few hours so mechanism will track bench
• Motor heating. Motor isolated in order to test isolation calculations/design.
Mechanism Risk Reduction

Facing Page
Linear Prototype Description
• Slide similar in mass, size to slit/IFU slide
• Slide moves on 4 rollers with top pre-load roller & spring arm
• Counterweight with idler
• Spring-loaded split screw drives half-nut on slide (zero backlash)
• Reduction same as that for slide
• Backlash allowed (expected) ahead of split screw (30:1 reduction)
• Temperature sensors, including one on slide (won’t do this in GNIRS)
• 22-bit encoder on slide
• Motor mounted with thermal isolation; thermal sensors on either side of isolation
• Provisions for manual operation (external feed-through on dewar)
• Tests in 2 orientations possible
Pre-Fab Review

Mechanism Risk Reduction

Linear Prototype Results

• Repeatability
• Flexure
• Torque 4-5 oz-in - design change
• Cooling time
• Motor isolation
Mechanism Risk Reduction
Risk Reduction - Procurement

Early procurement (not “just in time”) for critical items:

• Powered Mirrors (II-VI)
• Lenses (RMI)
• Filters (NDC/IR Engineering)
• Gratings (master rulings: Spectronics)
• Large Al 6061 Billet (for bench: Bechdon)
Risk Reduction - Isolate Sub-Systems

Integral Field Unit
  • Each IFU is single module
  • Installs via access port
  • Interfaces controlled by ICD
Pre-Fab Review
Risk Reduction - Isolate Sub-Systems

On-Instrument WFS
• Installs on its own bench structure
• Separate electronics
• Interfases controlled by ICD
Risk Reduction - Isolate Sub-Systems

On-Instrument WFS

Separate bench and electronics allow functionality and internal alignment of OIWFS to be verified independent of spectrograph functions. Interactions required are alignment of OIWFS to spectrograph slit (mainly focus) and communications interface (software).
GNIRS Software

• Requirements

• Software Development Plan

• Schedule and Status
### Software Requirements

<table>
<thead>
<tr>
<th>Area</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICD</td>
<td>1.9.b/3.1</td>
</tr>
<tr>
<td>Instrument Sequencer interface software</td>
<td>Integrates OIWFS, detector controller and CC, using EPICS and ‘C’.</td>
</tr>
<tr>
<td>Engineering interface (screens)</td>
<td>Use DM (display manager)</td>
</tr>
<tr>
<td></td>
<td>Allow for verification of compliance with Gemini OCS interface</td>
</tr>
<tr>
<td></td>
<td>Jog motors (command line, during engineering/test phase)</td>
</tr>
<tr>
<td>Simulation mode(s)</td>
<td>Simulate instrument functions – 3 modes</td>
</tr>
<tr>
<td>Control mechanism motors</td>
<td>Datum at home position</td>
</tr>
<tr>
<td></td>
<td>Move motors simultaneously</td>
</tr>
<tr>
<td></td>
<td>Backlash compensation</td>
</tr>
<tr>
<td>Control instrument functions</td>
<td>On-off cyrocooler control</td>
</tr>
<tr>
<td></td>
<td>Control dewar heaters</td>
</tr>
<tr>
<td>Monitor instrument functions</td>
<td>Sense limit switch activations</td>
</tr>
<tr>
<td></td>
<td>Read/report temperature and pressure</td>
</tr>
<tr>
<td></td>
<td>Read/report dewar internal pressure</td>
</tr>
<tr>
<td>Configuration</td>
<td>Allow user to specify filter combinations by names</td>
</tr>
<tr>
<td></td>
<td>Motor motion parameters not compiled into code</td>
</tr>
<tr>
<td>Hardware</td>
<td>No encoders</td>
</tr>
<tr>
<td></td>
<td>Digital I/O required for some motor control</td>
</tr>
<tr>
<td></td>
<td>Test/use backup switches</td>
</tr>
</tbody>
</table>
Software Requirements

Multiple Sources:

• ICD’s
  – Gemini
  – User (1.9.b/3.1)
  – OIWFS, GNAAC

• Engineering Interface

• Hardware
# Software Derived Requirements

<table>
<thead>
<tr>
<th>Area</th>
<th>Example</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motor drive</td>
<td>Ability to boost motors to overcome starting friction</td>
</tr>
<tr>
<td></td>
<td>Ability to vary motor speeds (rates)</td>
</tr>
<tr>
<td></td>
<td>How to approach HOME position</td>
</tr>
<tr>
<td></td>
<td>Backlash-removal “dance”</td>
</tr>
<tr>
<td>Position labels</td>
<td>Linked lists</td>
</tr>
<tr>
<td></td>
<td>Configuration file format</td>
</tr>
<tr>
<td>Unit Transformations</td>
<td>Convert desired positions to motor steps</td>
</tr>
<tr>
<td></td>
<td>Illegal positions imply CAR placed in ERROR state</td>
</tr>
<tr>
<td></td>
<td>Convert volts to degrees K, C</td>
</tr>
<tr>
<td>Testing</td>
<td>Log data, and in format suitable for trend analysis</td>
</tr>
<tr>
<td></td>
<td>Integrate CA with scripting to control full instrument</td>
</tr>
<tr>
<td>DHS WCS</td>
<td>A/V pairs for headers</td>
</tr>
<tr>
<td></td>
<td>Modify/pass WCS information</td>
</tr>
<tr>
<td>Thin layer EPICS</td>
<td>Provide command line control as well as DM and OCS interfaces</td>
</tr>
<tr>
<td></td>
<td>Semaphores for control of CAD states</td>
</tr>
</tbody>
</table>
Software Derived Requirements

These, in turn, come from

• Software Requirements
• Internal Hardware Details
• Software Design Decisions
• …
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Software Development Phases

• Component controller software
• Lab support software
• Detector interface software
• Test and debug
• EPICS software
Component Controller

**ICD’s:** One major ICD: 1.9.b/3.1, On-WFS ICD, Detector Controller ICD

**Infrastructure:** System code module. System initialization, allocation of structures, interrupt, logging, etc.

**Motor control:** Code for operation of mechanisms. Interrupt driven, funnels commands to VME controllers, records status: motion complete, current position, home position, etc.

**Digital I/O board:** Code for I/O control of motor power, cryohead operation, etc.

**Temperature board:** Code for monitoring of temperature sensors throughout the instrument. Detects out of range conditions. Provides input to status/health module.

**Status and Health:** Checks status of motor position, limit and home switches, motor state, I/O bit states, temperatures, etc.

**Simulation:** Both full and fast modes can be accommodated.
Component Controller Software

- Infrastructure
- Motor control
- Low-level
- High-level
- Digital I/O
- Temperature board
- Status/health/simulation
- Schedule time 3 months

Baseline data: Allows detection of degraded performance.

Detector Interface: Channel access code to provide needed message stream to operate the NIRS Array Controller.
Lab Support and Detector Interface Software

• Lab support software
  – Scripts
  – Script language
  – Logging
  – GUI

• Detector interface software
  – Channel access
  – Instrument coordination

• Schedule time 4 months
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Test and Debug Requires Electronics

- Includes testing of components controller software
- Goal is to eliminate problems during instrument integration
- A software test fixture will be provided
- Phased to coincide with completion of thermal enclosure electronics
- Schedule time is approximately 5 months
EPICS Software

**EPICS:** Intended to make minimal use of CAPFAST diagrams and containing no SNL code.

Thin layer works well with components controller.

Instrument sequencer talks to OIWFS, GNAAC, OCS and CC and so may require more elaborate use of standard EPICS.
EPICS Software

- Study/design
- Using DM, CAPFAST
- Instrument Sequencer
  - OIWFS
  - Detector Controller
- Components controller
- SAD
- Schedule time 7 months
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Software Organization and Data Flow

- Top level graphic
- Functional Flow
- Command sequences and interfaces
Pre-Fab Review

- Uncertain portion
  - Instrument Sequencer
  - OIWFS
- Thin EPICS and Detector
- Straightforward part
Pre-Fab Review

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Pre-Fab Review

Functional Flow Diagram

- Gemini Interface
  - OCS
  - Eng Interface

- Thin EPICS Layer
  - No SNL
  - Minimal CAPFAST

- UNITS/Position - Conversion
  - Validate parameters from OCS
  - Determine detector position
  - Configuration file for parameters

- Instrument Sequencer

- IR Controller

- OIWS

- System Health
  - System State

- User Input via Command Line
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Functional Flow Diagram

Scripts/Logging
- Support testing
- Data Storage
- Temps
- Motor Positions

Digital I/O and Motor Commands
- CryoHead Enable
- Mechanism control
- Motor on/off
- Move to position
- Backlash removal
- Temperature Diode readback

Send commands to Motor Controller
- Control Access
- Handle Responses
- Fetch Status
- Timeout on Error/limit

Operate Mechanism
- Command Routing
- Interrupt Handling
- Signals/Semaphores
- Flags
  - Illegal command
  - Limit overtravel
  - Done

Status
Motor Position
Home Switch
Limit Switch
Command OK
I/O bits
Temperatures

Health
- Good
- Warning
- Bad

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Low Level Motor Control

- Interrupt driven communication
- Four motors on one card
- No encoders!
- Handles commands that have immediate response
- Timeout marks motion failure
Pre-Fab Review

Commands that request immediate response

SendToMotorDriver

Position Command

motorPos

WaitFor (1 motor)

VME board

Four Motors

Sent Ring Buffer

Interrupt Service Routine

Out Ring Buffer

Message structure

responses (char by char)

SemDone (one per motor)

status (Fetched)

commands

commands

commands/status

response

Ok or Timeout

Controller for 4 Motors

Per Motor

commands

semResponse

semaphore

cmd/resp
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Motor Motion
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Motion -- up close