GYRO READOUT

CRITICAL DESIGN REVIEW

JANUARY 18, 1996
AGENDA - GYROSCOPE READOUT CRITICAL DESIGN REVIEW  
THURSDAY, JANUARY 18, 1996 - GP-B CONFERENCE ROOM

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<th>Session</th>
<th>Presenter</th>
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<td>9:30</td>
<td>1. Overview and Requirements</td>
<td>J. Lockhart</td>
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<td>9:50</td>
<td>2. PDR Action Item Status</td>
<td>J. Lockhart</td>
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<td>3. Baseline Design</td>
<td>B. Muhlfelder</td>
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<td>4. Science Data Requirements / Loop Sym.</td>
<td>M. Keiser</td>
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<td>5. Specification Documents</td>
<td>M. Tapley</td>
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<td>10:50</td>
<td>6. Design Status</td>
<td>J. Anastas</td>
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<td>11:00</td>
<td>7. Manufacturing Plan</td>
<td>M. Luo</td>
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<td>11:15</td>
<td><strong>Test and Verification</strong></td>
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<td>11:30</td>
<td>8. Overview; Pickup Loop &amp; Cables</td>
<td>B. Muhlfelder</td>
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<td>11:30</td>
<td>SQUID Bracket</td>
<td>B. Muhlfelder</td>
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<tr>
<td>11:35</td>
<td>9. SQUID Die, Carrier and Package</td>
<td>G. Gutt</td>
</tr>
<tr>
<td>11:50</td>
<td>10. SQUID System</td>
<td>J. Lockhart</td>
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<tr>
<td>12:00</td>
<td><strong>LUNCH BREAK</strong></td>
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<td>1:00</td>
<td><strong>Development Testing</strong></td>
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<td>1:00</td>
<td>11. System Performance/GTU-1</td>
<td>J. Lockhart</td>
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<tr>
<td>1:00</td>
<td>12. SQUID Temperature Control</td>
<td>B. Muhlfelder</td>
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<tr>
<td>1:25</td>
<td>13. Outstanding Issues</td>
<td>B. Muhlfelder</td>
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<tr>
<td>1:30</td>
<td><strong>Systems Issues</strong></td>
<td></td>
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<tr>
<td>1:30</td>
<td>14. Magnetics and Trapped Flux</td>
<td>J. Mester</td>
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<tr>
<td>1:45</td>
<td>15. Electronics Interfaces; Constraints</td>
<td>J. Lockhart</td>
</tr>
<tr>
<td>1:50</td>
<td>16. EMI, Grounding, Shielding</td>
<td>J. Lockhart</td>
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<tr>
<td>2:00</td>
<td>17. Vibration Compatibility</td>
<td>L. Sokolsky</td>
</tr>
<tr>
<td>2:05</td>
<td>18. Thermal &amp; Proton Compatibility</td>
<td>B. Muhlfelder</td>
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<tr>
<td>2:15</td>
<td>19. Reliability / Quality</td>
<td>F. Berkowitz</td>
</tr>
<tr>
<td>2:20</td>
<td>20. Schedule &amp; Resources</td>
<td>J. Burns</td>
</tr>
</tbody>
</table>
GYRO READOUT

CRITICAL DESIGN REVIEW

OVERVIEW AND GENERAL REQUIREMENTS

James M. Lockhart
SCOPE OF REVIEW

- Critical Design Review for cryogenic gyro readout hardware
  
  → SQUID sensor (die), carrier, package
  → SQUID thermal mount bracket, GRT thermometers, and heaters
  → SQUID Jumper Cables (output connection from SQUID package to probe)
  → Pickup loop and superconductive input cable (with heater)

- SQUID Readout Electronics covered in SQUID Readout Electronics (SRE) PDR/CDR

- Rotor covered in Gyro PDR/CDR

- Probe Cables for readout covered in Probe-C PDR/CDR

- Cryoperm Magnetic and Lead Bag Shield Shield Covered in Science Mission Dewar PDR/CDR

- Local Superconductive Magnetic Shield covered in SIA Reviews

- Science Fluxgate Magnetometer electronics covered in ECU PDR/CDR
GYRO READOUT SYSTEM SCHEMATIC - KEY

A. Rotor with Superconductive Coating
B. Primary Pickup Loop
C. Secondary Pickup Loop (Spare)
D. Local Superconductive Magnetic Shield
E. SQUID Superconductive Input Cable
F. SQUID Input EMI Filter
H. Input Loop Deflux Heater
J. Superconductive Flux Feedback Transformer
K. SQUID Resonance Damping Network
L. Low Noise DC SQUID Sensor
M. SQUID Buffer Resistors
N. Bias Current Steering Resistors
O. SQUID Output Transformer
P.,Q.,R.,S. SQUID Jumper Cables
T. SQUID Package
U. SQUID GRT Thermometers
V. SQUID Mounting Bracket
W. SQUID Heaters
X. SQUID Mounting Bracket Thermal Link

January 18, 1996 • Stanford University
Gyro Readout Operating Modes and Parameters  
(Signal Amplitudes at SQUID)

<table>
<thead>
<tr>
<th>Mode</th>
<th>London Moment Ampl. ($\Phi_0$)</th>
<th>Trapped Flux Ampl. ($\Phi_0$ Specs.)</th>
<th>Trapped Flux Ampl. ($\Phi_0$ Goal)</th>
<th>FLL Range ($\Phi_0$)</th>
<th>FLL Output ($\mu$V/marcs)</th>
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</thead>
<tbody>
<tr>
<td>Ground Test (360°; 150 Hz spin)</td>
<td>61</td>
<td>0.57</td>
<td>0.11</td>
<td>100</td>
<td>0.03</td>
</tr>
<tr>
<td>Spin Align (2°)</td>
<td>2.1</td>
<td>0.57</td>
<td>0.11</td>
<td>5</td>
<td>0.6</td>
</tr>
<tr>
<td>Science - Low Sens. (100 arcs)</td>
<td>0.03</td>
<td>0.57</td>
<td>0.11</td>
<td>1</td>
<td>3.0</td>
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<tr>
<td>Science - High Sens. (100 arcs)</td>
<td>0.03</td>
<td>0.57</td>
<td>0.11</td>
<td>0.2</td>
<td>15</td>
</tr>
</tbody>
</table>
GENERAL PERFORMANCE REQUIREMENTS:

* Readout System Noise
  - Total Readout System Noise at Roll Freq. →<190 marcs/√Hz
  - Magnetic Field Noise at Pickup →<5 x 10⁻¹¹ G/√Hz

* Readout System Dynamic Range
  → As per "Readout Operating Modes and Parameters" Table

* Readout System Stability
  - Mechanically-Induced Drift →Consistent with Science Data Requirements
  - Thermally-Induced Drift →Consistent with Science Data Requirements
  - Cosmic Radiation-Induced Drift →Acceptable in 650-km Polar Orbit
    (Data loss during SAA permitted)

* Constraints on Other Systems
  - GSU Voltages as per "Acceptable Suspension Levels" Chart
  - EMI Faraday cage provided by probe; all wiring emi filtered
GENERAL REQUIREMENTS - 2

* Readout System Linearity
  - Linearity Requirements Compatible with Science Data Requirements at
    → Roll Frequency (0.3 marcs after in-flight calibration)
    → Gyro Spin Frequency and Harmonics 2-5 (0.01%)
    → Calibration Frequencies

* Readout System Operating Conditions
  - Rotor & Loop Temperature → < 8K
  - SQUID Temperature → > 1.8K; < 6.5K
  - Magnetic Environment → 0.2 μG DC; 10^-12 AC Attenuation

* Fluxgate Magnetometer Requirements
  → Provide Data Needed to Model Magnetic Leakage Fields

* Earth-Based Test and Spacecraft Launch
  - 1g Operational Capability (1g Suspension Effort Compatibility) for test
  - 15 g Vibration Loading Survivability (See "Vibration Compatibility section")
READOUT SYSTEM AND PERTURBING INFLUENCES
GYRO READOUT
CRITICAL DESIGN REVIEW

STATUS - ACTION ITEMS

J. M. Lockhart
Relativity Mission  Gyro Readout Critical Design Review

Action Items Status (from Readout Preliminary Design Review)

- Open Action Items

(13) - Work out details of dithering dewar in GTU horizontal configuration for SQUID tests. (M. Taber)

(14) Make sure spinup process in GTU orientation (possibly augmented by spin axis alignment using suspension) produces spin axis sufficiently close to horizontal for SQUID testing (dither, etc.). (B. Muhlfelder, S. Buchman, B. Bencze)

(20) [Timeline effects of SQUID defluxing operations]. (J. Lockhart, J. Grady)

- The following items have been or are being closed as follows:

Closed:  6

Closure recommended:  1,2,3,5,8,9,10,11,12,15,16,17,19

- The following items are to be re-assigned to the SRE PDR Action Item List

4, 7, 18
GYRO READOUT
CRITICAL DESIGN REVIEW

Baseline Design

Barry Muhlfelder
GYRO READOUT SYSTEM SCHEMATIC - KEY

A. Rotor with Superconductive Coating
B. Primary Pickup Loop
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K. SQUID Resonance Damping Network
L. Low Noise DC SQUID Sensor
M. SQUID Buffer Resistors
N. Bias Current Steering Resistors
O. SQUID Output Transformer
P.,Q.,R.,S. SQUID Jumper Cables
T. SQUID Package
U. SQUID GRT Thermometers
V. SQUID Mounting Bracket
W. SQUID Heaters
X. SQUID Mounting Bracket Thermal Link
SQUID Carrier Design

Carrier Schematic

To SC Cable (Pickup Loop) — Cd — Input Coil — Rs — T-Output — Rs

T-FB — Rb — Mod Coil — Rs — Rst

Bias — Rb

Signal — Rb

Mod — Rb

Feedback — Rb

To Output Connector
BASELINE HARDWARE DESIGN

A. Gyroscope
   - London Moment Readout; Trapped Flux Supplementary Readout
   - Nb Coating (NbN alternative)
   - Trapped Flux < 2 x 10^{-6} G-cm^2
   - Spin Speed 130 Hz +50/-30 Hz
   - Ambient DC Field at Gyro < 2 x 10^{-7} G
   - Roll Frequency AC Magnetic Field at Gyro < 5 x 10^{-13} G
   - Magnetic Field Noise at 5 mHz at Gyro < 5 X 10^{-11} G/\sqrt{Hz}

B. Pickup Loops and Superconductive Input Cables
   - Two coaxial thin-film pickup loops per gyro
   - Loops with 4 closely-spaced turns each
   - Low inductance stripline superconductive input cables
   - Superconductive connection to loop via demountable pressure contact
   - Loop heater (1300 \Omega nominal) mounted on superconductive cable to deflux pickup circuit
   - Low stray area to minimize parasitic effects

C. SQUID Sensors (SQUID Die)
   - 4 Quantum Design well-coupled DC SQUID sensors
   - Sensor die pre-tested at Quantum Design; cycled and retested at Stanford
   - Sensor die wire-bonded and mounted to carrier at Stanford
BASELINE HARDWARE DESIGN - 2

D. SQUID CARRIER
   • SQUID sensor mounted on sapphire carrier
   • Torroidal core output transformer
   • Flux feedback and calibration to SQUID input via superconductive thinfilm transformer
   • Detachable connection of readout cable to thinfilm input circuit
   • Copper strap to thermally anchor carrier to package

E. SQUID Package
   • Solid (light tight) Nb SQUID package, one per SQUID sensor
   • Capacitive EMI filter at SQUID package input (no damping cylinder)
   • High thermal conductivity niobium (RRR) to allow temp. control
   • Lead/tin foil and thick lid to allow adequate ac shielding factor

F. SQUID Jumper Cables (SQUID connections to probe cables)
   • Twisted pair cables with 10-pin Lemo connector at SQUID end
   • 4-pin Lemo connectors (3 ea) to mate with probe readout cables
   • Unique length cable to each SQUID position

G. SQUID Thermal Bracket
   • Two SQUID Packages mounted on each of two thermal brackets
   • Bracket provides two GRTs (5000 Ω nominal resistance at 2.5 K) & two heaters (1300 Ω at 2.5 K)
   • Allows SQUID sensor temp. control to 5 μK in a 3mHz band around roll freq. 250 μW nominal power dissipation
   • High conductivity mounting plate allows 200-to-1 disturbance rejection at roll freq.
GYROSCOPE READOUT
CRITICAL DESIGN REVIEW

SCIENCE DATA REQUIREMENTS
AND
PICKUP LOOP SYMMETRY

Mac Keiser
January 18, 1996
UNMODELED ERRORS DUE TO VARIATIONS IN BIAS, SCALE FACTOR, AND PHASE SHIFT

EXPECTED SQUID OUTPUT DUE TO MISALIGNMENT, RELATIVISTIC DRIFT, ABERRATION, PARALLAX, DEFLECTION OF STARLIGHT, AND BIAS

\[ z = C_g \left[ (NS + R_Gt + A_{NS})\cos(\phi_R + \delta\phi) + (EW + R_Ft + A_{EW})\sin(\phi_R + \delta\phi) + b + \nu \right] \]

where
- \( C_g \) is the SQUID and gyroscope scale factor
- \( \phi_R \) is the roll phase measured by the star tracker
- \( \delta\phi \) is the roll phase error due to misalignment of the gyroscope and phase shift in the electronics
- NS and EW are the initial (or average) misalignments in NS and EW directions
- \( R_G \) and \( R_F \) are the geodetic and frame-dragging relativistic drift rates
- \( A_{NS} \) and \( A_{EW} \) are the deflection of the starlight in the NS and EW directions due to aberration, parallax, and gravitational deflection of light
- \( b \) is the bias measured by the SQUID electronics
- \( \nu \) is the noise in the SQUID output

VARIATIONS IN BIAS, SCALE FACTOR, OR PHASE SHIFT MAY CAUSE UNMODELED ERRORS IN MEASUREMENTS OF RELATIVISTIC DRIFT RATE
PRINCIPAL CHANGES SINCE GYROSCOPE READOUT PDR

Modifications to T003 - System Design and Performance Requirements
Section 3.5 Signal Processing - Low Frequency SQUID Readout Signal

3.5 Signal Processing - Low Frequency SQUID Readout Signal

3.5.1 Definition

3.5.2 Bias Variation

(1) The amplitude of any linear variation in the body-fixed bias signal at roll frequency (linear variation in the inertially-fixed bias), the body-fixed calibration signal frequency, and the body-fixed satellite dither frequency shall be less than 0.1 marcsec for data taken over the course of one year during the time the guide star is valid.

(2) The amplitude of any variation at annual rate in the body-fixed bias signal at roll, calibration, or dither frequencies shall be less than 0.4 marcsec for data taken over the course of one year during the time the guide star is valid.

(3) The amplitude of any variation at orbital rate in the body-fixed bias signal at roll, calibration, or dither frequencies shall be less than 0.1 marcsec for data taken over the course of one year during the time the guide star is valid.

3.5.3 Low Frequency Calibration Signal

(3) The stability of the amplitude and phase of the calibration signal at the annual period and at the orbital period shall be better than 1 part in $10^5$, and

(4) the linear drift of the amplitude and phase of the calibration signal shall be less than $10^{-5}$/year.
REQUIREMENTS ON SQUID BIAS VARIATION (cont.)
(T003 - SYSTEM DESIGN AND PERFORMANCE REQUIREMENTS)

3.5 Signal Processing - Low Frequency SQUID Readout Signal (cont.)

3.5.4 Scale Factor Variation
(1) Over any 15 day period, the variation in the SQUID scale factor at orbital frequency shall be less than $2 \times 10^{-5}$.
(2) Over any 15 day period, the linear drift in scale factor shall be less than $2 \times 10^{-5}$.
(3) For those parts of the overall readout system, where the variation of the scale factor can not be measured by the calibration signal, the stability of the scale factor shall be equal to or better than the above requirements (Section 3.5.3) on the relative stability of the amplitude of the calibration signal.

3.5.5 Phase Shift Variation
a) Over any 15 day period, the variation in the phase shift at orbital frequency shall be less than $2 \times 10^{-5}$ radians.
b) Over any 15 day period, the linear drift in phase shift shall be less than $2 \times 10^{-5}$ radians.
c) For those parts of the overall readout system, where the variation of the body-fixed phase shift at the roll frequency and the calibration signal frequency can not be measured by the calibration signal, the stability of the phase shift shall be equal to or better than the above requirements (Section 3.5.3) on the relative stability of the phase of the calibration signal.
UNMODELED ERRORS DUE TO SQUID BIAS VARIATIONS

SQUID Bias Variations
Linear Variation at Roll < 0.1 marcs/sec/yr
Annual Variation at Roll < 0.4 marcs/sec
Orbital Modulation of Roll < 0.1 marcs/sec

- Bias Thermal Variation
- Readout Nonlinearity
- Rotor Miscentering
- Modulation of D.C. Flux Bias
- Magnetic Field Leakage
- Flux Jumps

- SQUID Thermal Variation
- SQUID Electronics Thermal Variation
- Sensitivity to Rotor Miscentering
  - Pickup Loop Alignment
  - Pickup Loop Asymmetry
  - Trapped Flux Mag. and Dist.

- Sensitivity to D.C. Bias
  - Pickup Loop Misalignment
  - Pickup Loop Asymmetry
  - Miscentering of Readout Loop

- Variation in D.C. Bias
  - Trapped Flux Modulation
  - Change in L.M. with Spin Speed

GMK 6
VARIATION IN BIAS DUE TO MISCENTERING

SENSITIVITY TO ROTOR MISCENTERING

Alignment of Center of Pickup Loop with center of Rotor:
A miscentering of the pick-up loop along the direction of the spin axis of 10-3 cm (0.4 milli-inches) produces a bias shift of 0.1 marcsec for a miscentering of 11.8 nm perpendicular to the readout loop plane.

In-Plane Asymmetry of the Pickup Loop:
An in-plane asymmetry (asymmetric area to total loop area) of the pickup loop is less than 0.03 (outer loop) at an angle greater than 70° from the direction of the spin axis produces shift of 0.1 marcsec for a miscentering of 0.6 nm perpendicular to the readout loop plane.

Trapped Flux Distribution and Magnitude
Sensitivity to Miscentering depends on the magnitude and distribution of the trapped magnetic flux. For 100 fluxons in a reasonable distribution, a shift of greater than 8 nm is expected to be required to produce a bias shift of 0.1 marcsec.

MAGNITUDE OF ROTOR MISCENTERING
Roll Frequency Miscentering due to thermal (or other) variations in GSU capacitance bridge < 0.3 nm
Gravity Gradient Miscentering < 10 nm (0.4 microinch)

The combination of the gravity gradient miscentering and inplane asymmetry of the pickup loop will produce an error in the roll frequency component modulated by orbital of 1.7 marcsec.
UNMODELED ERRORS DUE TO SCALE FACTOR VARIATION

A. SCALE FACTOR VARIATIONS NOT MEASURABLE WITH CALibrATIONS SIGNAL

Unmeasurable Scale Factor Variations
  Linear < 1e-5
  Annual < 1e-5
  Orbital < 1e-5

Gyroscope Scale Factor
  Uncertainty in Measurement of Gyroscope Spin Speed
  Variation in Trapped Flux Level or Distribution
  Change in Polhode Path and Trapped Flux

Change in Coupling of Calibration Signal
  Mutual Inductance between Pickup Loop and Input Coil
  Change in Pickup Loop Inductance due to Change in Rotor Position

Stability of Calibration Signal
  Variations in Voltage Reference
UNMODELED ERRORS DUE TO SCALE FACTOR VARIATION (cont.)

B. SCALE FACTOR VARIATIONS MEASURABLE WITH CALIBRATIONS SIGNAL

- Measurable Scale Factor Variations
  - Drift < 1e-5 in 15 days
  - Orbital Variation < 1e-5

  - Coupling between pickup loop and SQUID
  - Mutual Inductance between Pickup loop and SQUID

  - SQUID scale factor Variation
    - SQUID Scale Factor Temperature Dependence

  - SQUID Electronics Scale Factor Variation
    - Amplifier and Low Pass Filter Temperature Sensitivity
    - A/D Scale Factor Temperature Sensitivity
UNMODELED ERRORS DUE TO PHASE SHIFT VARIATION

A. PHASE SHIFT VARIATIONS NOT MEASURABLE WITH CALIBRATIONS SIGNAL

<table>
<thead>
<tr>
<th>Unmeasurable Phase Shift Variations</th>
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<tbody>
<tr>
<td>Linear $&lt; 1e^{-5}$ radians</td>
</tr>
<tr>
<td>Annual $&lt; 4e^{-5}$ radians</td>
</tr>
<tr>
<td>Orbital $&lt; 1e^{-5}$ radians</td>
</tr>
</tbody>
</table>

- Variations in Pickup Roll Phase
- Stability of Phase of Calibration Signal
UNMODELED ERRORS DUE TO PHASE SHIFT VARIATION

B. PHASE SHIFT VARIATIONS MEASURABLE WITH CALIBRATIONS SIGNAL

Measurable Phase Shift Variations
Drift < 1e-5 radians in 15 days
Orbital Variation < 1e-5 radians

SQUID Electronics
Phase Shift Variation

Amplifier and Low Pass Filter
Temperature Sensitivity

A/D Phase Shift
Stability
CONTRIBUTIONS TO DIFFERENCES IN GyRO-TO-GYRO ROLL PHASE ERRORS

Gyro-to-gyro
Roll Phase Error Comparison
No requirement
Science Mission Measurement to Accuracy of 4 arc sec

- Misalignment of Gyro Parting Plane
  10 arc sec
  measured to 5 arcsec

- Effects of Stray Loop Area of 5e-4
  100 arc sec
GYRO READOUT
CRITICAL DESIGN REVIEW

Specification Documents

Mark Tapley
Science Instrument Assembly Specification

- Contains Complete Performance Specifications for Readout Cryogenic Hardware Performance numbers and allocations flowed down from T003

- Substantially Complete, in final review before going under configuration control

- Total Number of Performance Specifications applying to Readout System: 36

- Readout System Section Specs Which Have been Met in Tests: 25

- Readout System Section Specs Which Have been Partially Met in Tests: 5

- Readout System Section Specs Which Have Not Been Tested in System Tests: 6

- Only 3 specs have been tested fully but not met requirements in system-level tests:
  - Thermal Control
    - Spec met in component tests after GTU-1
  - SQUID Operating Temperature Range
    - Operating Temperature Range exceeds that needed for science data collection
    - Requirement for extended range (1.8-6.5K) under review
  - Magnetics
    - SQUID Package for GTU-1 did not meet specs
    - Components not meeting specs have been identified
    - New components which meet specs in component tests have been obtained
The SQUID sensor shall have a linearity better than 1% with 100 arcsecond noncompensated error.
Relativity Mission Gyro Readout Critical Design Review

Test Plan Screen in Database

Test No: 1.6  Activity: SQUID Package C  Engineer: Muhlfelder
Title: Linearity
Duration: 0.00  Setup Duration: 0.00  Sign-Off List
Rev No: Rev Date:  / /  Revise  Navigate  Print  Type:

Specifications Associated with this Test Plan:

Hardware to be Tested:

Add Spec  Del Spec
Details  Edit Test Summary
Add Part  Del Part

Loc: All  One  None

Filter = TESTCAT=CTESTCAT

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Verification Matrix

- Integrated with SIA Spec in Database
  For Specs which are tested, Verification Test Plan record is linked to Spec
  For Specs supported by analysis, Analyses will be entered as S-documents and linked to Specs
  For Specs supported by Inspection, Verification Test Plan record is linked to Spec

- Verification Plan Discussed in Test and Verification Section

Procedures

- Procedures will be Signed off and Controlled

- Some Procedures Supply verification of Specifications
  These Will be Entered into System Engineering Database and Linked from Specification

- Discussed in greater detail in Manufacturing Plan Section of presentation
Failure Modes, Effects and Control Analysis

- FMECA completed by Sharad Sinkar, closing action issued at PDR
  Appears in Engineering Package

- Total 31 Failure Modes Identified

- Quadruple-Redundant Gyro and Readout System Mitigates Effects of All Failure Modes

- 8 FMs acceptable without review

- 19 FMs Acceptable with review

- 4 FMs Undesirable

- No Failure Modes in Unacceptable Risk Category
Relativity Mission Gyro Readout Critical Design Review

Deliverables

- FMECA
- SIA Specification
- Test Plan Matrix
- Drawing Tree
GYRO READOUT CRITICAL DESIGN REVIEW

Design Status

Jay Anastas
**Design Status**

- Parts 90%
- Assy's 60%
- % Completed by Assy's

<table>
<thead>
<tr>
<th>Completed</th>
<th>Description</th>
<th># of parts</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>FASTENERS AND SPACERS</td>
<td></td>
</tr>
<tr>
<td>90%</td>
<td>SQUID BRACKET KIT</td>
<td>25475-101</td>
</tr>
<tr>
<td>80%</td>
<td>CABLE KIT, OUTPUT</td>
<td>25042-10g</td>
</tr>
<tr>
<td>90%</td>
<td>CLIP KIT, R/O CABLE HEATER</td>
<td>25326-101</td>
</tr>
<tr>
<td>90%</td>
<td>CLIP KIT, THERMAL GROUND</td>
<td>25236-101</td>
</tr>
<tr>
<td>80%</td>
<td>SQUID PACKAGE ASSY</td>
<td>25017-101</td>
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<tr>
<td>100%</td>
<td>CABLE KIT, READOUT</td>
<td>25000-102</td>
</tr>
</tbody>
</table>

⇒ Total of 99 drawings
⇒ 2 Drawing trees (SM and GTU2) released
GYRO READOUT
CRITICAL DESIGN REVIEW

Manufacturing Plan

Ming Luo
Readout Hardware Structure

- Pickup Loop
- Heater to Cable
- SC Input Cable
- SQUID Carrier
- SQUID Package
- Bracket
- Output Jumper Cable
- Heater & Sensor to Bracket
Readout Hardware Composition

**SC Input Cable**
- Req Assemblies: 4
- Spare Assemblies: 8
- SU Man Hour: 220

- Nb Conductor
- Nb Shield
- Nb Flange
- Ti Clamps
- Hex Nut
- Flat Washer
- Cured Washer
- Contact Pin
- Kapton Washer
- Contact Sleeve
- Contact Spring
- Retaining Ring
- Polyester Tubing
- Accessories
  - Req Parts: 20 x 4 = 80
  - Spare Parts: 20 x 8 = 160
  - SU Man Hrs: 140

**Output Jumper Cable**
- Req Assemblies: 4
- Spare Assemblies: 4
- SU Man Hour: 200

- Shield Tubing
  - Twisted pairs
  - Output Flange
  - Output Frame
  - Output Cover
  - 10 Pin Connector
  - Plug Cable Adapter
  - Collect back Nut
  - Connect Sleeve
  - Screws
  - Req Parts: 21 x 4 = 84
  - Spare Parts: 21 x 4 = 84
  - SU Man Hrs: 40

**Bracket and Heater**
- Req Assem.: 2
- Spare: 1
- Man Hour: 20

- Package Bracket
- Shoulder Washer
- Insulation Shim
- Heater
- Thermometer
- Fastening Clips
- Screws
  - Req Parts: 20 x 2 = 40
  - Spare: 20 x 1 = 20
  - SU Man Hrs: 50
Readout Hardware Composition (Continued)

**SQUID Carrier**
- Req Assemblies: 4
- Spare: 8
- SU Man Hour: 200

- Sapphire Substrate
- SQUID Die
- FB Transformer
- Output Transformer
- Transformer Post
- Lemo Connector
- Damping Network
- Buffer Resisters
- Accessories

- Req Parts: \(14 \times 4 = 56\)
- Spare Parts: \(14 \times 8 = 112\)
- SU Man Hrs: 400

**SQUID Package**
- Req Assemblies: 4
- Spare: 2
- SU Man Hour: 50

- Package Body
- Package Lid
- Centering Ring
- Lead Gasket
- Protective Cover
- Contact Clamps
- Square Washer
- Capacitor Bracket
- Capacitor Washer
- Capacitor Flange
- Connector Block
- Capacitor Wedge
- Capacitor Ring
- Screws

- Req Parts: \(37 \times 4 = 148\)
- Spare Parts: \(37 \times 2 = 74\)
- SU Man Hrs: 90

* Total Parts for Total Assemblies: 838
* SU Man Hours for Total Assemblies: 1410
Readout Hardware Resource and GP-B Facilities

Resource:
DG= Dale Gill
RS= Roger Shile
MB= Margaret Bogan
ML= Ming Luo
GG= Gregory Gutt
BM= Barry Muhlfelder
JM= John Mester
GB= Grace Brauer
LN= Larry Novak
*PB= Paul Bayer

Facility:
F01= Clean Room 130, 132
F02= Readout Clean Area
F03= Readout EMI Screen Room
F04= Readout General Assembly Area
F05= Other GP-B Area

* Not a member of readout group.
SQUID Carrier Hardware Flow Chart

Carrier Substrate
(P0152, RE: GG)

Clean Wafer → F01 DG
Depository Niobium → F01 DG
Deposit Gold → F01 DG
Deposit Copper → F01 LN
Photolithography → F01 RS
Etch Copper → F01 RS
Etch Gold → F01 RS
Etch Niobium → F01 RS
Dice Wafer → F01 RS

SQUID Die
(P0164, RE: GG)

Pre-Screening → F03 ML
Attach to Substrate → F02 RS
Wire Bonding → F02 RS

FB Transformer
(P0156, RE: GG)

Fabricate X-former → F01 RS
Test Transformer → F04 RS
Epoxy to Substrate → F02 RS
Wire Bonding → F02 RS

Output Transformer
(P0155, RE: GG)

Solder Post to Pad → F02 RS
Wind Transformer → F04 MB
Solder Resister Wire → F04 MB
Solder Leads to Pads → F02 RS
Epoxy to Post → F02 RS

Sapphire Carrier Assembly → F02 RS, P0153

Test & Verification → F03 ML, P0154
SQUID Package Hardware Flow Chart

Capacitor Assembly  
(P0161, RE: GG)

- Pre-tin Parts  F04 MB
- Solder Capacitor to Blocks  F04 MB
- Install Capacitor in Bracket  F04 MB
- Reflow Solder  F04 MB
- Test Capacitor Assembly  F04 ML

SQUID Package  
(P0159, RE: GG)

- Place SQUID Carrier  F04 ML
- Install Centering Ring  F04 ML
- Secure Carrier  F04 ML
- Secure Centering Ring  F04 ML
- Install Thermal Strip  F04 ML

SC Cable Connection  
(P0162, RE: GG)

- Epoxy Ball to Clamp  F02 MB
- Install Clamps  F04 ML
- Insert Conductors  F04 ML
- Tight Up Wedge  F04 ML
- Tight Clamps Down  F04 ML

Package Assembly  F04 ML, P0159

Test and Verification  F03 ML, P0160

Final Integration
SC Cable Hardware Flow Chart

(P0102, RE: BM)

Etch Nb Shield → F01 MB
Pre-crush Tubing → F04 MB
EDM Cut Slot → Vendor
Weld Flange On → Vendor
EDM Conductors → Vendor
Deburr Conductors → F04 GB
Insert Conductors → F04 MB
Crush Shield → F04 MB

Form Cones → F04 MB
Install Ti Clamp → F04 MB
Install Washer & Nut → F04 MB
Electronic Check → F04 ML
Stray Area Check → F01 PB
Thermal Cycle → F04 ML
Magnetic Test → F05 JM
Final Integration → P0166
Jumper Cable Hardware Flow Chart

(P0163, RE: BM)

- Figure Length for Each Cable F05 ML
  - Cut Shield to Length F04 MB
  - Pre-tin Parts F02 MB
  - Solder Shield to Plug Adapter F02 MB
  - Solder Flange to Shield F02 MB
  - Make Twisted Pairs F02 MB
  - Solder Wire to Connector F02 MB
  - Integrate Wire with Shield F02 MB
  - Assembly Connector Parts F02 MB
  - Attach Resistors to Wire F02 MB

- Install Output Sleeve F02 MB
  - Assembly Output Cover F02 MB
  - Functional Test F03 ML
  - Thermal Cycle F03 ML
  - Mechanical Fitting Check F05 ML
  - Magnetic Test F05 JM
  - Final Integration P0166
Bracket and Heater Hardware Flow Chart

Bracket (P0117, RE: BM)
- Fabricate Part
- Etch Bracket
- Pb/ Sn Coat Part
- Install Helicoils
- Magnetic Test
- Test & Verification
- Final Integration

Heater (P0120, RE: BM)
- Vendor
- Make Twisted Wire
- Solder Chip Resister
- Put and Shape Epoxy
- Add Connector
- Magnetic Test
- Test & Verification

Thermometer (P0116, RE: BM)
- Install Connector
- Magnetic Screen
- Cryogenic Test
- Test & Verification

P0165
P0166
Pickup loop Fabrication

(P0114, RE: BM)

Gyro House Cleaning  F01, DG

Loop Deposition  F01, DG

Loop Patterning  F01, RS

Centering Measurement  F01, RS

Superconductivity Test  F01, RS

* See Gyro CDR for Housing Fabrication Procedure
## Hardware Storage and Documentation

<table>
<thead>
<tr>
<th>Hardware</th>
<th>Intermediate Storage</th>
<th>Trace Method</th>
<th>Document</th>
<th>Storage</th>
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</thead>
<tbody>
<tr>
<td>SQUID Carrier</td>
<td>Readout Clean Area</td>
<td>Serial Number</td>
<td>Raw Materials Request</td>
<td>Cabinet #7</td>
</tr>
<tr>
<td>SQUID Package</td>
<td>Readout Clean Area</td>
<td>Serial Number</td>
<td>Conformance Certificate</td>
<td>Cabinet #7</td>
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<tr>
<td>SC Cable</td>
<td>Readout Cabinet #3</td>
<td>Serial Number</td>
<td>Travelers</td>
<td>Cabinet #7</td>
</tr>
<tr>
<td>Jumper Cable</td>
<td>Readout Cabinet #3</td>
<td>Serial Number</td>
<td>Procedures</td>
<td>Cabinet #7</td>
</tr>
<tr>
<td>Bracket</td>
<td>Readout Cabinet #3</td>
<td>Serial Number</td>
<td>Test Reports</td>
<td>Cabinet #7</td>
</tr>
<tr>
<td>Parts</td>
<td>Readout Cabinet #4</td>
<td>Lot Number</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Material</td>
<td>John Stamets</td>
<td>Lot/ Heat Number</td>
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<td></td>
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</tbody>
</table>

* Final parts go to John Stamets / Bonded Storage.
Readout Procedures

<table>
<thead>
<tr>
<th>Procedure Number and Name</th>
<th>Percent Complete</th>
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<tbody>
<tr>
<td>Fabrication &amp; Assembly (Total 16):</td>
<td>40%</td>
</tr>
<tr>
<td>P0102 SC Input Cable Assembly</td>
<td>90%</td>
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<tr>
<td>P0110 Output Jumper Cable Assembly</td>
<td>50%</td>
</tr>
<tr>
<td>P0114 Pickup Loop Nb Deposition Procedure</td>
<td>100%</td>
</tr>
<tr>
<td>P0116 Temperature Sensor Assembly</td>
<td>25%</td>
</tr>
<tr>
<td>P0117 SQUID Bracket Assembly</td>
<td>25%</td>
</tr>
<tr>
<td>P0120 Heater Assembly Procedure</td>
<td>25%</td>
</tr>
<tr>
<td>P0152 SQUID Carrier Substrate Fabrication</td>
<td>90%</td>
</tr>
<tr>
<td>P0153 SQUID Carrier Assembly</td>
<td>90%</td>
</tr>
<tr>
<td>P0155 Output Transformer Fabrication</td>
<td>50%</td>
</tr>
<tr>
<td>P0157 Stycast 1266 Epoxy Mix</td>
<td>75%</td>
</tr>
<tr>
<td>P0158 Lead Gasket Fabrication</td>
<td>0%</td>
</tr>
<tr>
<td>P0159 SQUID Package Assembly</td>
<td>25%</td>
</tr>
<tr>
<td>P0161 SQUID Capacitor Kit Assembly</td>
<td>25%</td>
</tr>
<tr>
<td>P0162 SC Cable Installation</td>
<td>0%</td>
</tr>
<tr>
<td>P0166 System Integration</td>
<td>0%</td>
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<tr>
<td>P0169 Thermal Ground Kit</td>
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## Readout Procedures (Continued)

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<thead>
<tr>
<th>Procedure Number &amp; Name</th>
<th>Percentage Completed</th>
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<tbody>
<tr>
<td><strong>Test &amp; verification (Total 7):</strong></td>
<td></td>
</tr>
<tr>
<td>P0154 SQUID Carrier Testing and Verification</td>
<td>0%</td>
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<tr>
<td>P0156 FB Transformer Verification</td>
<td>0%</td>
</tr>
<tr>
<td>P0160 SQUID Package Testing and Verification</td>
<td>0%</td>
</tr>
<tr>
<td>P0164 SQUID Die Pre-screening Procedure</td>
<td>75%</td>
</tr>
<tr>
<td>P0165 Bracket and Heater Verification</td>
<td>0%</td>
</tr>
<tr>
<td>P0167 Loop and SC Cable Verification</td>
<td>0%</td>
</tr>
<tr>
<td>P0168 FB Transformer Specification</td>
<td>90%</td>
</tr>
<tr>
<td><strong>Other Related Procedures (Total 4):</strong></td>
<td>100%</td>
</tr>
<tr>
<td>P0057 GP-B Magnetic Control Plan</td>
<td>100%</td>
</tr>
<tr>
<td>P0080 Cryogenic Magnetic Screening</td>
<td>100%</td>
</tr>
<tr>
<td>P0147 Relativity Mission Contamination Control Plan</td>
<td>100%</td>
</tr>
<tr>
<td>P0145 Stanford Material Process Control Plan</td>
<td>100%</td>
</tr>
</tbody>
</table>
GYRO READOUT
CRITICAL DESIGN REVIEW

Test and Verification

Barry Muhlfelder
Specification and Verification Flow

T001, T002, T003

SIA Specification

Verifies & Supports System Performance

System Perf. Specs

Verifies System Performance

Component Specifications

Analysis
Includes physical part data, vendor specs, etc.

Verification of Readout Components
SQUID Package
SQUID Carrier
SQUID Sensor
Pickup/Cal Loop
Rotors
Readout Cables
SQUID Bracket

Component Performance Data

System Tests
GTU-1, GTU-2,
Science Payload Tests
Fist Ops Area
EDD, SMD
Probe-B, Probe-C
DDC Suspension,
Flight Prototype
Development, Flight
Prototype Readout Units
Prototype, Flight Gyros
Test Plans And Test Run Summaries

**TEST PLAN**

- SQUID Package
  - Thermal Cycling
  - Linearity

**TEST SUMMARIES**

- Run 1 Development
  - Defining Requirements
  - Allocating Error Budgets
  - Verifies Design

- Run 2 Prototype
- Run 3 Qualification
  - Verify Design Performance Specifications
  - Accept Flight Hardware

- Run 4 Flight
# TEST PLAN MATRIX FOR READOUT COMPONENTS

(1ST PAGE ONLY)

<table>
<thead>
<tr>
<th>TEST PLAN #</th>
<th>TEST NAME</th>
<th>REQUIREMENT</th>
<th>SPEC</th>
<th>VERIFICATION METHOD &amp; FACILITY</th>
<th>STATUS (does not refer to flight hardware)</th>
<th>DESIGN OR COMP.</th>
<th>P Doc Number</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>SQUID PACKAGE</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1.1</td>
<td>Thermal Cycling</td>
<td>20 Cycles Between 77K and Room Temp.</td>
<td>28</td>
<td>T, SQUID Package Accept. Facility</td>
<td>DONE</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>1.2</td>
<td>Vibration</td>
<td>Sin Sweep 0-100 Hz, 10g’s</td>
<td>22.1</td>
<td>T, Ames</td>
<td>NOT DONE</td>
<td>D</td>
<td></td>
</tr>
<tr>
<td>1.3</td>
<td>EMI</td>
<td>TBD</td>
<td>14.8, 12.5</td>
<td>T, A, SQUID Package Acceptance Fac.</td>
<td>PARTIAL</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>1.4</td>
<td>Thermal Cycling</td>
<td>300-4 K quant:3x</td>
<td>28</td>
<td>T,SQUID Package Accept. Facility</td>
<td>DONE, Achieved in GTU-1 testing</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>1.5</td>
<td>Magnetic Shielding</td>
<td>&lt;2x10^{-23} Webers</td>
<td>8</td>
<td>T,SQUID Package Accept. Facility</td>
<td>DONE, Achieved 1x10^{-23} Wb (margin of 2)</td>
<td>C</td>
<td></td>
</tr>
<tr>
<td>1.6</td>
<td>Linearity</td>
<td>0.01% for science level signals/ 1% for 100 arcsec error</td>
<td>3.2</td>
<td>T,SQUID Package Accept. Facility</td>
<td>PARTIAL</td>
<td>C</td>
<td></td>
</tr>
</tbody>
</table>
Relativity Mission Gyro Readout Critical Design Review

Verification Test Plan 1

• SQUID Sensor
  Tests:
    2.6)  2.8)  2.9)  2.10)  2.11)  2.12)

  Tests Supporting Analysis:
    2.1) White Noise at 4.2K
    2.2) Low Frequency Noise at 4.2K

• SQUID Carrier
  Tests:
    7.1)  7.2)  7.3)  7.4)

  Inspection:
    7.5) Visual Inspection

  By Procedure:
    7.6) Cleanliness

(NOTE: Test numbers refer to Verification of Readout Components Test Plan in Engineering Package)
Relativity Mission Gyro Readout Critical Design Review

Verification Test Plan 2

- SQUID Package
  Tests:
  1.2) 1.4) 1.5) 1.6) 1.8) 1.9) 1.10) 1.11) 1.19) 1.21) 1.22) 1.23) 1.24) 1.25) 1.27)

Tests Supporting Analysis:
  1.3) EMI
  1.13) SQUID Package Noise at 4.2K at 5.5 mHz (shorted input)
  1.15) SQUID Bias Temperature Coefficient at 2.5K
  1.16) SQUID Scale Factor Temperature Coefficient at 2.5K

Analysis:
  1.18) Input Coil Mutual Inductance Stability
  1.26) Feedback Coil Coupling Stability

Inspection:
  1.14) Cleanliness
Verification Test Plan 3

- Pickup/Calibration Loop
  Tests:
  3.3) 3.5) 3.6) 3.7) 3.8) 3.10) 3.11)

  Tests Supporting Analysis:
  3.1) London Moment Coupling Eff.
  3.2) Residual Resistance (Decay Time, Noise)

By Design:
  3.8) Geometry (number of turns)
  3.12) Maximum Radius

By Procedure:
  3.9) Material
Verification Test Plan 4

• Readout Cable
  Tests:
    5.2)  5.3)  5.7)  5.9)

Tests Supporting Analysis
  5.1) Residual Resistance (Decay Time, Noise)

Analysis
  5.8) Inductance Stability

Inspection:
  5.4) Cleanliness
  5.5) Out of Plane Stray Area
  5.6) Angle Between Spin Axis and Out of Plane Asymmetry

• SQUID Bracket
  Tests:
    6.1)  6.2)  6.3)  6.4)  6.5)  6.6)  6.8)

Tests Supporting Analysis
  6.9) Temperature Drift
  6.10) Nominal Power Dissipation

Inspection:
  6.7) Cleanliness
VERIFICATION FACILITIES

HARDWARE VERIFICATION
SQUID Bracket- Cryogenic Acceptance Probe (Old Gyro Acceptance Probe)
Shake Test Facility- Viking Labs

Readout Loop and Superconductive Cable- New Gyro Acceptance Probe

SQUID Package- SQUID Package Acceptance Probe

SQUID Chip- Dip Probe and Vendor Facilities

SYSTEM VERIFICATION
Overall System- GTU-2 and Payload Tests

Streamlined System- New Gyro Acceptance Probe

EMI Testing- Upgraded Probe B Cable Test Facility, Sunshade/Window Testing
BRACKET VERIFICATIONS

BRACKET ASSEMBLY TESTS (PERFORMED IN OLD GYRO ACCEPTANCE FACILITY)
   Thermal Control/Noise- 5 \mu K in a 3 mHz BW about roll freq.
   Thermal Drift- Less than 30 mK/yr
   GRT Resistance- 5000 (+/-1000) ohms at 2.5 K
   Heater Resistance- 1320 (+/-50) ohms at 2.5 K Thermal Impedance- 2 to 3 mW/K
   Vibration- 18g lateral, 31 g axial (performed at Viking Labs at room temperature)

SUBASSEMBLY TESTS
   GRT Resistance at 4.2 K- 1500 ohms nominal (dip probe)
   Heater Resistance at 4.2 K- 1320 ohms nominal (dip probe)
   Fit Check of Parts (Probe C)
   Magnetic Testing- All parts Consistent With Zone 2A (magnetic test probe)
   Lemo Connector Fit Check- Verify Fit Onto Probe (probe C)
   Superconductivity Check of Pb/Sn Plating (magnetics test probe)
READOUT CABLE AND LOOP VERIFICATIONS

ASSEMBLY TESTS (PERFORMED IN NEW GYRO ACCEPTANCE PROBE)

- Decay Time- Less than 1% decay in 10 minutes
- Noise- Less than 190 marcsec/Hz^{0.5} at 5.5 mHz
- London Moment Coupling- Greater than 20 fA per milliarcsecond (assumes spinup to 70 Hz)
- Transition Temperature- Greater than 8 K

SUBASSEMBLY TESTS

READOUT CABLE

- Magnetics- Zone 1
- Asymmetry- 0.03 in-plane, 0.05% out-of-plane
- Room Temperature Electrical- Greater than 20 Mohms to Shield
- Inductance Stability- 50 PPM/yr for cable,

LOOP

- Inductance Stability- 5 PPM/yr for loop
- Room Temperature Electrical- 6000 (+/- 1000) ohms
- Transition Temperature - Greater than 8 K
- Centering- better than 10 micrometers
OUTPUT CABLES

ASSEMBLY TESTS
Room Temperature Electrical Continuity
Connector (4 pin) Fit Check to Lemo Connectors on Probe C
Connector Fit Check to SQUID Package Lemo Connector
Magnetics- Consistent with Zone 2b
GYRO READOUT
CRITICAL DESIGN REVIEW

SQUID Package Test & Verification

Gregory Gutt
## SQUID Chip/Carrier/Package Tests
### (Component Verification on 100% of Delivered Parts)

<table>
<thead>
<tr>
<th>Test Plan Number</th>
<th>Reference Specification</th>
<th>Test Name</th>
<th>Requirement</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.3</td>
<td>14, 8, 12.5</td>
<td>EMI</td>
<td>TBD</td>
<td>Expose package to EMI Source &amp; measure FLL output</td>
</tr>
<tr>
<td>1.4</td>
<td>28</td>
<td>Thermal Cycle (Package)</td>
<td>300-4 K 3 times</td>
<td>Dip test in liquid Helium bath</td>
</tr>
<tr>
<td>1.5</td>
<td>8</td>
<td>Magnetic Shielding</td>
<td>&lt; 2x10^{-23} Webers</td>
<td>Expose package to varying external magnetic field, measure FLL output</td>
</tr>
<tr>
<td>1.6</td>
<td>3.2</td>
<td>Linearity</td>
<td>1% for 100 arc-sec error</td>
<td>Calibrate V-Φ curve using dither signal and open loop FLL output</td>
</tr>
<tr>
<td>1.8</td>
<td>8.2, 12.3</td>
<td>Magnetics</td>
<td>Zone 2A</td>
<td>Measure piece parts and final assembly using appropriate magnetic test facility (RT Gradiometer, Susceptometer, LFF)</td>
</tr>
<tr>
<td>1.10</td>
<td>3.2, 3.3, 3.5</td>
<td>Output Transformer Coupling</td>
<td>k&gt;0.85, Lp=8μH, Ls=285μH</td>
<td>Measure at room temperature using LCR meter</td>
</tr>
<tr>
<td>1.11</td>
<td>3.2, 3.5</td>
<td>Electrical Isolation</td>
<td>&gt; 20 Mohms</td>
<td>Measure at room temperature using Ohm meter</td>
</tr>
<tr>
<td>1.13</td>
<td>3.2</td>
<td>SQUID Package Noise</td>
<td>&lt;140marc-sec/rt Hz @ 5.5 mHz</td>
<td>Measure flux locked output of SQUID, @4.2K, in liquid Helium, input shorted</td>
</tr>
<tr>
<td>1.15</td>
<td>12.8, 3.4</td>
<td>SQUID Bias Temp Coef</td>
<td>&lt; 40 arcsec/K</td>
<td>Measure flux locked output while varying temperature between 2.5 and 4.2 K</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td>Value/Details</td>
<td>Notes</td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>--------------------------------------------------</td>
<td>------------------------------------------------------------------------------</td>
<td>----------------------------------------------------------------------</td>
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<tr>
<td>1.16</td>
<td>SQUID Scale Factor Temp Co.</td>
<td>(&lt; 3 \times 10^{-4}) @ f=.1 Hz</td>
<td>Inject sinusoidal signal into SQUID while varying the temperature between 2.5 and 4.2K, measure FLL output</td>
<td></td>
</tr>
<tr>
<td>1.19</td>
<td>SQUID Carrier Critical Current</td>
<td>10(\mu)A - 30(\mu)A</td>
<td>Tune up SQUID, measure bias current using calibrated SQUID electronics</td>
<td></td>
</tr>
<tr>
<td>1.21</td>
<td>Input Filter Capacitance</td>
<td>1 to 10nF</td>
<td>Measure at RT using LCR meter</td>
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</tr>
<tr>
<td>1.22</td>
<td>SQUID Package White Noise</td>
<td>(&lt; 60) marc-sec/rt Hz @ f=130Hz</td>
<td>Measure FLL output of SQUID package @ 4.2K, input shorted</td>
<td></td>
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<tr>
<td>1.25</td>
<td>Decay Time of Input (SC test)</td>
<td>Less than 1% change in 10min</td>
<td>Measure FLL output with a dc test field coupled to the input circuit, calculate worst case decay time.</td>
<td></td>
</tr>
<tr>
<td>1.27</td>
<td>Electrical Isolation to SM Probe</td>
<td>&gt; 20 Mohms</td>
<td>Measure at RT using Ohm meter</td>
<td></td>
</tr>
<tr>
<td>2.1</td>
<td>SQUID Sensor White Noise</td>
<td>60 marc-sec/rt Hz @ 130Hz</td>
<td>Pre-test in quick dip probe, before integration. Measure FLL output of SQUID @4.2K in liquid Helium.</td>
<td></td>
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<tr>
<td>2.2</td>
<td>SQUID Sensor Low Freq Noise</td>
<td>(&lt; 200) marc-sec/rt Hz @ 5.5mHz</td>
<td>See 2.1</td>
<td></td>
</tr>
<tr>
<td>2.6</td>
<td>Input Coil Inductance</td>
<td>(&lt; 2.0\mu)H</td>
<td>Tested at QD</td>
<td></td>
</tr>
<tr>
<td>2.8</td>
<td>Modulation Coi Coupling</td>
<td></td>
<td>Tested at QD</td>
<td></td>
</tr>
<tr>
<td>2.9</td>
<td>Input Coil Inductance</td>
<td></td>
<td>Tested at QD</td>
<td></td>
</tr>
<tr>
<td>2.10</td>
<td>Input Coil Coupling</td>
<td>Tested at QD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>------</td>
<td>---------------------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.11</td>
<td>Input Coil Critical Current</td>
<td>Tested at QD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.12</td>
<td>Bias Current</td>
<td>Tested at QD</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.1</td>
<td>SQUID Carrier Electrical Cont.</td>
<td>Internal Spec</td>
<td>Measured at RT using Ohm Meter</td>
<td></td>
</tr>
<tr>
<td>7.2</td>
<td>SQUID Carrier Therm Cycle</td>
<td>300K-77K 20 Times</td>
<td>Dip test in liquid Nitrogen</td>
<td></td>
</tr>
<tr>
<td>7.4</td>
<td>SQUID Carrier Bake</td>
<td>300-360K for 1 week</td>
<td>Bake at 60 C for one week</td>
<td></td>
</tr>
<tr>
<td>7.5</td>
<td>TBD</td>
<td>Visual Check</td>
<td>Internal Spec</td>
<td>Inspect at 30X-100X per MIL-STD 883 Method 207</td>
</tr>
</tbody>
</table>

### Comparison of Testing Between GTU-1 and Science Mission

<table>
<thead>
<tr>
<th></th>
<th>Number of Tests</th>
<th>Number of Cryogenic Tests at Stanford</th>
</tr>
</thead>
<tbody>
<tr>
<td>GTU-1</td>
<td>14</td>
<td>5</td>
</tr>
<tr>
<td>GTU-2 / SM</td>
<td>27</td>
<td>13</td>
</tr>
<tr>
<td>Percent Increase in Testing</td>
<td>92%</td>
<td>160%</td>
</tr>
</tbody>
</table>
# SQUID Package Verification Flow Diagram

<table>
<thead>
<tr>
<th>Part Categories</th>
<th>Pre-Assembly Testing</th>
<th>Test #</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>A) Bulk Machined Parts</strong></td>
<td>1) Magnetically prescreen raw materials</td>
<td>1.8</td>
</tr>
<tr>
<td>Package Body</td>
<td>2) Magnetically screen machined parts using RT Gradiometer</td>
<td>1.8</td>
</tr>
<tr>
<td>Lid</td>
<td>3) Fit check</td>
<td>-</td>
</tr>
<tr>
<td>Fasteners</td>
<td></td>
<td></td>
</tr>
<tr>
<td>...</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>B) Vendor Supplied Electrical Parts</strong></td>
<td>1) Magnetically screen piece parts using RT Gradiometer</td>
<td>1.8</td>
</tr>
<tr>
<td>Resistors</td>
<td>2) RT electrical checks</td>
<td>7.1</td>
</tr>
<tr>
<td>Capacitors</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Feedback Transformer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Carrier</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wire</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C) Magnetically Sensitive Parts</strong></td>
<td>1) Magnetically screen parts in the Low Field Facility</td>
<td>1.8</td>
</tr>
<tr>
<td>Output Transformer</td>
<td>2) RT electrical tests</td>
<td>1.10, 1.21</td>
</tr>
<tr>
<td>Feedthrough Capacitor</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>D) Sensor</strong></td>
<td>1) Vendor Checks</td>
<td>2.6-2.12</td>
</tr>
<tr>
<td>SQUID</td>
<td>2) RT Electrical Tests at Stanford</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>3) Cryogenic Noise Test</td>
<td>2.1, 2.2</td>
</tr>
</tbody>
</table>
SQUID Package Assembly Verification Flow

Type A Parts
Type B Parts
Type C Parts
Type D Parts

SQUID Carrier Assembly
SQUID Body Assembly

RT Electrical Tests
Thermal Cycle
7.1, 7.2, 7.4 7.5

SQUID Package Assembly
Assembly Fit Tests

Cryo Testing -
..Thermal Cycle
..Tune up
..Noise
..Linearity
1.3, 1.4, 1.5, 1.6,
1.13, 1.15, 1.16,
1.19, 1.22 1.25

Magnetic Test of Assembly (LFF) 1.8

Cryogenic Survival Test
..SQUID Tuneup
..Noise

Final Integration 1.11, 1.27
## SQUID Chip/CARRIER/Package Tests

(One Time Verifications)

<table>
<thead>
<tr>
<th>Test Plan Number</th>
<th>Reference Specification</th>
<th>Test Name</th>
<th>Requirement</th>
<th>Status</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2</td>
<td>22.1</td>
<td>Vibration</td>
<td>Sin Sweep 0-100Hz, 10g's</td>
<td>Open</td>
</tr>
<tr>
<td>1.9</td>
<td>3.2, 3.5</td>
<td>Feedback Transformer Coupling</td>
<td>0.35-0.45\mu H</td>
<td>Done</td>
</tr>
<tr>
<td>1.14</td>
<td>12.4</td>
<td>Visual Inspection</td>
<td>Zone IV</td>
<td>Done</td>
</tr>
<tr>
<td>1.18</td>
<td></td>
<td>Input Coil Mutual Inductance Stability</td>
<td>$&lt; 5 \times 10^{-6}$ / year</td>
<td>Open</td>
</tr>
<tr>
<td>1.24</td>
<td></td>
<td>Flux Jump Spec</td>
<td>TBD</td>
<td>Open</td>
</tr>
<tr>
<td>1.26</td>
<td></td>
<td>Feedback Coil Coupling Stability</td>
<td>5 parts per million / year</td>
<td>Done (Analysis)</td>
</tr>
<tr>
<td>7.6</td>
<td>12.4</td>
<td>SQUID Carrier Cleanliness</td>
<td>Zone IV</td>
<td>Done</td>
</tr>
</tbody>
</table>

SQUID Package Verifications - 57% Complete
GYRO READOUT
CRITICAL DESIGN REVIEW

Readout System Verification

J.M. Lockhart
READOUT SYSTEM VERIFICATION

- Verification of SQUID Package with pickup circuit in Low Field Gyro Acceptance Probe

  Partial verification of coupling and noise of SQUID package with pickup circuit and gyro

- Full verification of readout system in GTU-2 (design verification) and Payload Test
  (final system verification)

  → SQUID cable tests

  → SQUID tuneup performance

  → SQUID input circuit coupling

  → Readout System noise (roll frequency and spin frequency)

  → ac magnetic shielding factor

  → emi resistance

  → SQUID temperature control performance (stability and disturbance rejection)
• Readout Science Data Validation will be proofed in GTU-2 and performed during Payload Test

→ Output resulting from low and high frequency signals from calibration source

→ Frequency response of readout system (roll frequency to 1 kHz)

→ Readout system phase shift versus frequency

→ Precision readout scale factor determination

→ SQUID thermometer inter-calibration

→ Readout system noise (roll frequency and spin frequency)

→ Temperature dependence of SQUID bias and scale factor
GYRO READOUT
CRITICAL DESIGN REVIEW

Readout System Performance / GTU-1

J.M. Lockhart
READOUT SYSTEM PERFORMANCE / GTU - 1

- GTU - 1 provided design verification for many components of the Science Mission readout:
  
  → Quantum Design SQUID die
  
  → Multi-turn pickup loop
  
  → Superconductive stripline cable with loop heater
  
  → Pressure contact superconductive connections to gyro housing and SQUID carrier
  
  → SQUID output transformer
  
  → Prototype SQUID package
  
  → SQUID thermal bracket with GRT thermometers and heaters
  
  → SQUID jumper cables
The following components will be new or significantly changed for GTU-2

- Sapphire SQUID carrier
- Capacitive emi filters at SQUID package input
- Thin film SQUID feedback transformer

Readout performance in GTU-1 showed that the following requirements have been met:

<table>
<thead>
<tr>
<th>Quantity</th>
<th>Requirement</th>
<th>Observed Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>→ Readout System Noise</td>
<td>&lt;190 marcs/√Hz</td>
<td>188 marcs/√Hz</td>
</tr>
<tr>
<td>→ ac magnetic shielding factor</td>
<td>&lt;10^-12</td>
<td>&lt;10^-13</td>
</tr>
<tr>
<td>→ Science Data Validation (Nb Bird)</td>
<td>Consistent with noise</td>
<td>Consistent with noise</td>
</tr>
<tr>
<td>→ SQUID Input Circuit Coupling (multi-turn pickup loop)</td>
<td>&gt;40 fA/marscs</td>
<td>&gt;40 fA/marscs</td>
</tr>
</tbody>
</table>
GYRO READOUT
CRITICAL DESIGN REVIEW

SQUID Temperature Control

Barry Muhlfelder
SQUID TEMPERATURE CONTROL

TEST REQUIREMENTS
- With no applied disturbances, show 5 μK (peak) control of SQUID packages in a 3 mHz band about 5.5 mHz
- Show a 200-to-1 disturbance rejection at roll freq.
  - Consistent with adequate rejection of a 1 mK thermal variation at the SQUID attachment point

TEST CONFIGURATION
- Electronics
  - SM pre-prototype temperature control electronics
  - Digital acquisition system and digital control- laboratory system
  - These electronics are not the main focus of this presentation

- GTU-1 Vintage Readout (Cryogenic Hardware)
  - Bracket with heaters and thermometers on SQUID mounting plate
  - 2 SQUID Packages with jumper cables (thermometer on 1 SQUID carrier)
  - Heater and thermometer on simulated spider
  - Thermal impedance from simulated spider to ground not representative of SM

CONCLUSIONS
- Achieved better than 2 μK (peak) control of SQUID packages in a 3 mHz band about 5.5 mHz
- Showed a 195-to-1 disturbance rejection at roll freq.

- Bracket Characteristics- Single pole at 15 mHz, 160 K/W at DC; 0.2-0.4 second propagation delay due to heater
SQUID BRACKET THERMAL CHARACTERIZATION

Blue dewar SQUID bracket thermal characterization J3 P2

GAIN (K/W)

10^3
10^2
10^1
10^0

10^{-3} 10^{-2} 10^{-1} 10^0 10^1

FREQUENCY (rad/sec)

PHASE vs FREQUENCY

PHASE (degrees)

0
200
300

-300

10^{-3} 10^{-2} 10^{-1} 10^0 10^1

FREQUENCY (rad/sec)
Temperature

Error Signal

Low pass Error Signal

FFT of Error Signal
GYRO READOUT
CRITICAL DESIGN REVIEW

Outstanding Issues

Barry Muhlfelder
OUTSTANDING ISSUES

- EMI Sensitivity (Input Cable Filter)
  - Readout System in GTU-1 showed EMI sensitivity
  - On-going set of tests with input cable filter, SM-like configuration (electronics, etc.)
  - off-line tests to reduce magnitude of sensitivity

- Damping Network Optimization (SQUID Package)
  - Damping network controls SQUID linearity
  - damping network coupled to input cable filter
  - Set of on-going tests to understand and optimize design

- Mutual Inductance Stability
  - Changes in SQUID input circuit mutual and self inductances cause changes in readout scale factor
  - Such changes could increase uncertainty of readout scale factor and experiment error
  - Calculations (and if needed tests) are underway to evaluate baseline design

- SQUID Package Connector Robustness
  - Mechanical interface of SQUID package connector to package and output cable is overconstrained
  - Evaluation (and if need be redesign) of baseline design is underway
GYRO READOUT
CRITICAL DESIGN REVIEW

Magnetics and Trapped Flux

John Mester
Readout System Magnetics Compatibility Objectives

- Ensure Readout System Components Meet GP-B Magnetics Requirements.

- Ensure Fabrication, Cleaning, And Assembly Follow Magnetics Guidelines.

- Consider Special Readout System Material Applications In Order To Execute Appropriate Verification Procedures.

- Determine Magnetic Field Noise Sources; Minimize Impact.

- Achieve Trapped Flux Level Requirements
Magnetics Requirements

GP-B Requirement: Rotor Trapped Flux < 10^{-6} Gauss

GP-B Goal: Rotor Trapped Flux < 2 \times 10^{-7} Gauss

⇒ Readout Hardware Contribution to Field at Gyros
  Goal: \leq 6 \times 10^{-8} Gauss
  Requirement: \leq 1 \times 10^{-7} Gauss

Magnetics Requirements And Verification Procedures Follow

Stanford GP-B Procedure P0057: Magnetic Control Plan
### Magnetic Control Issues Guide All Phases
Of Readout Hardware Construction

<table>
<thead>
<tr>
<th>Design</th>
<th>Material Selection</th>
<th>Fabrication</th>
<th>Assembly</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPB Document</td>
<td>GPB Document</td>
<td>GPB Document</td>
<td>GPB Document</td>
</tr>
<tr>
<td><em>Drawing Notes For Magnetic Control of Parts</em></td>
<td><em>Candidate Materials List</em></td>
<td><em>Guidelines for Non-magnetic Fabrication Practices</em></td>
<td><em>Procedure for Magnetic Control of Tools, Fixtures,</em></td>
</tr>
<tr>
<td>Magnetics zones specified in drawing notes</td>
<td>Material Coupons</td>
<td>Faced Parts</td>
<td><em>Sets maintained by magnetics group</em></td>
</tr>
<tr>
<td>Dimension Specs should account for Chem Etch Cleaning</td>
<td>submitted for mag approval as outlined in Control Plan</td>
<td>submitted for mag approval as outlined in Control Plan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Inventory control of approved materials</td>
<td>Inventory control of approved parts</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Critical Assemblies submitted for magnetics approval</td>
</tr>
</tbody>
</table>

*January 18, 1996 • Stanford University*
Magnetics Requirements And Verification

Magnetics Control Zones Most Relevant To Readout System

Zone 1: Regions inside each local superconducting shield.

Zone 2: Region inside lead bag shield (not already including zone 1) extending from the bottom of the lead bag to 25 cm above the uppermost gyro.

Zone 2A: Portion of zone 2 within 9 cm distance from the center of any gyro.

Zone 2B: Remaining portion of zone 2.
Material Qualification

Material Characteristics Considered:

A. Remanent Moment ⇒ DC field at gyro. Minimize.

B. Susceptibility ⇒ Allows sensitive test for magnetic contamination. Minimize.

C. Superconductivity ⇒ Can flux trap or distort fields. Use only as required.

D. Electrical Resistivity ⇒ Low resistivity materials generate Johnson noise currents which can interfere with readout. Minimize use of high conductivity materials.
Material Magnetics Standards By Zone

<table>
<thead>
<tr>
<th>Magnetic Zone</th>
<th>Rem. Moment</th>
<th>Susceptibility</th>
<th>Superconductivity</th>
<th>Resistivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$&lt;1 \times 10^{-7}$ d$^3$ emu</td>
<td>$&lt;5 \times 10^{-6}$ emu/G/g</td>
<td>Only as required</td>
<td>$&gt;1.0 , \mu\Omega\cdot$cm @ 2K</td>
</tr>
<tr>
<td>2A</td>
<td>$&lt; 2 \times 10^{-6}$ emu</td>
<td>$&lt;5 \times 10^{-6}$ emu/G/g</td>
<td>Only as required</td>
<td>$&gt;0.2 , \mu\Omega\cdot$cm @ 2K</td>
</tr>
<tr>
<td>2B</td>
<td>$&lt; 4 \times 10^{-6}$ emu</td>
<td>$&lt;1 \times 10^{-5}$ emu/G/g</td>
<td>Only as required</td>
<td>$&gt;0.1 , \mu\Omega\cdot$cm @ 2K</td>
</tr>
</tbody>
</table>

$d = \text{distance from rotor surface in cm}$
Finished Part Magnetics Standards By Zone

<table>
<thead>
<tr>
<th>Magnetic Zone</th>
<th>Rem. Moment</th>
<th>Verification Method</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$&lt; 1 \times 10^{-7} d^3 \text{ emu}$</td>
<td>Cryogenic</td>
</tr>
<tr>
<td>2A</td>
<td>$&lt; 2 \times 10^{-6} \text{ emu}$</td>
<td>Cryogenic</td>
</tr>
<tr>
<td>2B</td>
<td>$&lt; 4 \times 10^{-6} \text{ emu}$</td>
<td>Cryogenic or Gradiometer</td>
</tr>
</tbody>
</table>

$d = \text{distance from rotor surface in cm.}$

Application for Waiver may be submitted to GP-B Magnetics Committee for Parts not meeting standards. Approval decision based on fundamental magnetics requirements.
Special Readout System Material Applications

- Permalloy SQUID Output Transformer Cores (10 cm from closest gyro center):

  High Material Susceptibility ⇒ Remanent Moment Verification Must Be Conducted At Low Background Field. Two Methods Are Available.

  1) Quantum Design MPMS

  Employ low field option to reduce background field to milligauss level. Then use in-situ Fluxgate to map field vs. position, and fit data to extract remanent moment from combined remanent/susceptibility signal. Yields approximate remanent moment value.

  2) Large Cryosceening Apparatus in Varian Ultralow Field Facility

  Yields direct measurement of remanent moment.

  To date: Five cores tested after demagnetization; all passed zone 2B requirements. Care should be taken not to expose to high fields (>10 Gauss). Procedure has been developed for remote demagnetization of core after integration into SQUID package.
Special Readout System Material Applications

- SQUID readout cables

Procedures established to minimize interference of flux trapping on remanent moment measurements of Nb readout cables and other superconducting readout parts and assemblies.

Magnetic moment measurements determined the need for precisely controlled chemical etching of fabricated parts, in particular the extruded Nb cable shields.

To date: Six GTU2 readout cable assemblies have been tested in the Large Cryoscreening Apparatus. All have passed zone 1 and 2A magnetics requirements indicating present fabrication procedure is effective.
Magnetic Field Noise

Requirement is Based On Total SQUID Noise Referenced To Input

Consider:

- Flux Coupling To SQUID Through Pickup Loop Gap Area
- Rotor Self Shielding
- Rotor Demagnetization Factor

⇒ Magnetic Field Noise Requirement

\[
< 5 \times 10^{-11} \text{ Gauss/\sqrt{Hz}} \quad \text{at 5.5 mHz}
\]
\[
< 1 \times 10^{-11} \text{ Gauss/\sqrt{Hz}} \quad \text{above 1/f Knee}
\]
Magnetic Field Noise Sources

- Thermoelectric Currents
  Avoid Contacts Of Dissimilar Metals In Temperature Gradients

- Sensor And Heater Current Fluctuations
  Avoid Unbalanced Currents

- Johnson Currents In Normal Metals
  Field Noise Is Proportional To: $\sqrt{\sigma}$ ($\sigma =$ conductivity)
  Falls Off With Source Distance As $1/d$ in Near Field
  Transitioning To $1/d^3$ In Far Field
  Noise Spectrum Is White At Low Frequency, Falls Off At High Frequency
  Due To Inductive Effects In The Source.
Magnetic Field Noise Due To Johnson Currents

Calculated Noise For A 1 cm³ Metallic Source 2 cm From Gyro

<table>
<thead>
<tr>
<th>Material</th>
<th>Resistivity at 2K</th>
<th>Calculated Field Noise</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ti</td>
<td>11.3 µΩ-cm</td>
<td>4.7 x 10⁻¹³ Gauss/√Hz</td>
</tr>
<tr>
<td>Cu</td>
<td>0.002 µΩ-cm</td>
<td>3.4 x 10⁻¹¹ Gauss/√Hz</td>
</tr>
</tbody>
</table>

⇒ Minimize Use Of High Conductivity Metals Near Gyro

For Sources Outside Magnetic Zone 1, The Local Nb Shield Provides AC Shielding Factor Of 7 x 10⁻³ Axial, 4 x 10⁻⁵ Transverse, Easing Field Noise Concerns.
GTU1 Magnetics Testing

Finished part acceptance rate ~60%

Magnetics failures can have large impact on schedule due to:

- Alternative material selection
- Re-fab or re-processing (e.g. etching, plating) of parts
- Additional magnetics testing procedures

Special efforts such as developing new plating procedures with Hammon Plating and new etch procedures for readout cables are yielding positive impact on GTU2 testing.
Trapped Flux

GTU1 closely followed GP-B magnetics control plan. Achieved trapped flux level of $7 \times 10^{-7}$ Gauss, meeting requirement.

Working group has been established to review Flux Flushing Procedure. Will exploit data from GTU1, Varian Low Field Gyro Probe, Large Cryosceening Apparatus and the new Gyro Acceptance Facility to determine optimal thermal transfer rates. Will investigate effects of Gyro Rotor coatings (N, NbN) and Local Shield material (N, NSn) on trapped flux levels.
GYRO READOUT
CRITICAL DESIGN REVIEW

Interfaces & Constraints
SQUID Electronics, ECU, GSU

J.M. Lockhart
Interface to SQUID Electronics

- Outputs from Gyro Readout System to SQUID Electronics (w/o Probe Cable, emi filter, and Tophat cable impedances)

  SQUID Error Signal (6 pV RMS nominal level at 420 kHz; 100 µV RMS max. unlocked level; one per SQUID)
  Source Impedance: 130 Ω resistive
  SQUID GRT Voltage Signal (10 mV nominal level; two per SQUID bracket); Source Impedance: 10 kΩ resistive

- Inputs from SQUID Electronics (w/o Probe Cable, emi filter, and Tophat cable impedances)

  SQUID dc bias current (30 µA nominal; one per SQUID); Load impedance 100 Ω resistive
  SQUID flux modulation current (0.75 µA nominal; one per SQUID); Load impedance 100 Ω resistive
  SQUID feedback current (1 µA nominal in science data mode, 1.5 µA per flux quantum of range; one per SQUID);
    Load impedance 100 Ω resistive
  SQUID GRT Drive Current (1 µA RMS nominal; two per SQUID bracket); Load impedance 10 kΩ resistive
  SQUID Heater current (1.0 mA nominal P-P low freq. ac; 2 circuits/bracket, 1 powered); Load imped. 1300 Ω res.
  SQUID Loop Defluxing Heater current (5 mA nominal dc current, initialization use only; one per SQUID);
    Load impedance 1300 Ω resistive

- Outputs to ECU Electronics

  Payload Fluxgate Magnetometer Signals (2 V nominal level; 12 channels)

- Inputs from ECU

  Payload Magnetometer Power (4 channels; +5V @ 20 mA & -5V @ 20 mA)

- SQUID System Power: 0.2 µW per SQUID plus 0.25 mW per SQUID Bracket
CONSTRAINTS

• Constraints on SQUID Electronics
  • No active high speed digital circuitry directly coupled to SQUID
  • EMI filters on all connections to SQUID

• CONSTRAINTS ON GYRO SUSPENSION UNIT
  • GSU sense and forcing signal amplitudes must be consistent with "Allowable Suspension Voltages"
  • No GSU signals should be present near roll frequency, spin frequency, spin frequency harmonics, or cal. freqs.
  • GSU sense frequency 70 kHz baseline assumed for peaking SQUID controller

• CONSTRAINTS ON PROOF MASS
  • Trapped flux dipole (term) on proof mass < 10^-4 G-cm^2 ; spin speed > 0.1 RPM

• CONSTRAINTS ON ROTOR SPIN AND SPACECRAFT ROLL
  Readout noise estimates are based on 150 Hz spin and 3 min roll period
Constraint on Gyro Suspension Bridge and Forcing Signal Levels

ALLOWABLE SUSPENSION P-P VOLTAGE VS. FREQ.
SCIENCE MISSION READOUT CONFIG. - 420 kHz FLUX MOD

MAXIMUM SUSPENSION VOLTAGE (mV p-p)

SUSPENSION FREQUENCY (kHz)
GYRO READOUT
CRITICAL DESIGN REVIEW

EMI Compatibility
Grounding & Shielding

J.M. Lockhart
Design EMI Environment

250 nmi altitude
90° orbital inclination
2nd level database

Figure F-18. Electric field intensity versus frequency for orbital parameters of 250 nmi & 90° inclination. (Logarithmic Ordinate Scale)
Features of emi Design

- Well-shielded SQUID package with emi gasket on access panel
- Capacitive emi filter at SQUID package input
- Balanced circuits used for all wiring to SQUID
- Superconductive input cable is shielded with shield connection to SQUID package
- Constraints on other payload components:
  → Faraday cage to be formed by probe vacuum shell and metallization of Window 4
  → Additional emi attenuation to be provided by sunshade
  → Probe cables with continuous metal shields
  → emi filters on all wires entering the probe Faraday cage
  → Tophat-to-forward electronics cables with continuous metal shields
  → Additional cable and connector shielding provided by Forward Equipment Enclosure
  → Control of spurious emissions from suspension, instrumentation, etc.
EMI Development and Qualification Testing

- Component level tests
  
  → EMI test of each SQUID package in SQUID Package Acceptance Facility
  
  → EMI attenuation test of sunshade/window-4 assembly at LMMS

- Sub-system development test of cables, emi filters, and SQUID package (proposed)
  
  → Operate one SQUID package in dewar with gyro suspension and instrumentation connections and emi filters in place; evaluate emi resistance

- System level tests
  
  → GTU-1 tests completed; showed need for improvement in
    
    * Tophat-to-electronics cables
    
    * emi filters (suspension and instrumentation)
    
    * Reduction of emi entering telescope aperature (window 4 & sunshade)
  
  → GTU -2 full system tests scheduled
SQUID Package Grounding Scheme

$\bullet =$Ground Connection

$2K$
Probe Shielding Scheme with Faraday Cage Around Pickup Loops & SQUIDs

- Suspension & Inst. EMI Filt.
- Silver-Coated Window
- Top Hat - GROUND REFERENCE
- SQUID EMI Filters
- Dewar Necktube - Insulating
- Probe Neck; Ti Foil, <0.5 Ohm
- Station 200 Ring
- QBA Support; <0.1 Ohm
- SQUID Shielded Tw. Pair
- Probe Vacuum Shell - FC 1
- SQUID Package - Shield + Filt.
- SQUID Input; Shielded Tw. Pr.
- Local Mag. Shield; Grounded
- Dewar Inner Shell - FC 2
- Dewar Outer Shell - FC 3
GYRO READOUT
CRITICAL DESIGN REVIEW

Vibration Compatibility

Larry Sokolsky
Squid Load Factors and Test Levels

- Load factors for squids based on SSD secondary structure loads curve for shuttle and ELV payloads
  - 18 g lateral
  - 31 g axial
- Protoqual vibration spectrum from ‘Gravity Probe-B Payload Component Vibroacoustics Specifications’ (EM 400/GPB-100169) and modified by ‘Vibration Levels for SMD Components’ (GPB-100362)

<table>
<thead>
<tr>
<th>Frequency (hz)</th>
<th>Protoqual level (g²/hz)</th>
<th>Qual Level (g²/hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>0.005</td>
<td>0.010</td>
</tr>
<tr>
<td>20</td>
<td>0.005</td>
<td>0.010</td>
</tr>
<tr>
<td>50</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>300</td>
<td>0.05</td>
<td>0.10</td>
</tr>
<tr>
<td>2000</td>
<td>0.001</td>
<td>0.002</td>
</tr>
<tr>
<td>Composite (grms)</td>
<td>5.05</td>
<td>7.14</td>
</tr>
</tbody>
</table>

- Frequency requirement - keep all squid assy primary vibration modes above 100 hz
Squid Bracket Stress Analysis

- Finite element model of bracket was built
  - Model included weight for 4 squids per bracket
  - Squid weight was 20% less than current

- Factors of safety
  - 1.25 Yield
  - 1.5 Ultimate

- Modal frequency - all modes above 122 hz
  - Weight increase would drop this to ~110 hz

- Stress analysis
  - Margins of safety were all high or very high (>3.0)

- Mounting only two squids per bracket would beneficially lower stresses and raise frequencies
Testing

READOUT CRITICAL DESIGN REVIEW

- Mock probe test achieved levels of about 7 grms at the spider from 10 to 150 hz (modified protoqual vibration)
- 3.5 grms levels expected on Probe-B and Probe-C protoqual vibration testing. About 5 grms expected for GTU-2 vibration tests (protoqual vibration).
- 5.05 grms (protoqual) or 7.14 grms (qual level) random vibration testing suggested for squid package subassembly
GYRO READOUT
CRITICAL DESIGN REVIEW

Proton & Thermal Compatibility

Barry Muhlfelder
ENERGETIC PARTICLES

Requirement: Readout System shall recover from SAA and polar radiation exposure within 30 seconds.

Goal: Readout System shall remain functional during SAA and polar radiation exposure.

Results from proton bombardment experiments:

Tested both QD (and NIST Devices); 50-280 MeV protons; 100-60000X SAA rate; total dose: 10 yrs.

Both devices meet the requirement: Survivability and no need to thermally cycle the device

Expected bias shifts due to proton bombardment: 10's of arcseconds

Both devices meet the goal assuming event rate scales with both proton flux rate and amb. magnetic field

NIST Device meets goal without a need to scale proton flux rate or magnetic field
THERMAL COMPATIBILITY

Spec: Total heat load into SIA during science gathering = 0.25 mW/bracket
    Design Conforms to Spec

Spec: Total heat load into SIA during flux flushing < 100 mW/bracket
    Design Conforms to Spec

Maximum expected temperature variation at bracket interface to SIA during science < 1 mK (amplitude at roll)

Overall design compatible with 1.8-6.5 K operation i.e. transition temperature of input circuit > 6.5 K
    (significant loss in noise performance above approx. 3K)

Negligible thermal impact during SAA (power absorbed < 20 nW)
GYRO READOUT CRITICAL DESIGN REVIEW

Quality Assurance and Reliability

- Fred Berkowitz
• Quality Provisions per SU's "Science Mission Quality Plan" P0108

• Configuration Control per “Science Mission Configuration Management Plan” P0098
  • Drawings Release through Drawing Release Review and Change Control (ECB)
  • Drawing tree updated as required; controlled trough drawing release process
  • Changes of requirements through Program Change Board (PCB)
  • Changes of Drawings through Engineering Change Board (ECB)

• Fabrication Control:
  • Identification, Traveler, As-Built Configuration
  • Workmanship
  • Special Processes: Per written procedures
  • ESD Control per MIL-STD-1686A
  • Authorized fabricators complete specialized training (e.g. soldering course)
Relativity Mission Gyro Readout Critical Design Review

- **Inspection and Tests:**
  - Incoming inspection for workmanship and functional
  - Dimensional Inspection: 100% per the approved DWG’s exceptions by RE (e.g. SQUID chip).
  - Tests: Per written and approved procedures
  - Periodic calibrated equipment for RE defined final/specs tests

- **Configuration and Test Database**
  - Database includes:
    - Requirements, Specs and other documents, Reviews and Action Items, PCBs
  - Test-case dry-run inclusion in process:
    - ECOs, DR’s, DWG’s/Parts Tree, As-Built Configuration, Tests Plans and Tests Results and more.

- **Nonconformance Control:**
  - Discrepancy Reports including Analysis and Corrective Action.
  - Disposition by Material Review Board (MRB).
• **Procurement Control**
  - Vendors selection from SU Approved Vendors List
  - Vendors Quality System meets the requirements of MIL-I-45208A
  - Procurement document reviewed by the Quality Engineer

• **Reliability:**
  - FMECA to be completed by CDR.

• **Reports:**
  - All Discrepancy Reports (DRs) and Engineering Changes ECOs are reported to NASA in the Monthly Reviews
GYRO READOUT
CRITICAL DESIGN REVIEW

Schedule and Resources

Jim Burns
GYRO READOUT CRITICAL DESIGN REVIEW

Wrap-Up

J.M. Lockhart
Wrap-Up

- Action Item List by January 25, 1996

- FMECA is part of Engineering Package

- Other Actions ..